CIVIL ENGINEERING DEPARTMENT
SCHOOL OF INFRASTRUCTURE, PROCESS ENGINEERING AND TECHNOLOGY
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BOOK OF PROCEEDINGS



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ADVANCING THE FRONTIERS OF INFRASTRUCTURE DEVELOPMENT THROUGH ARTIFICIAL INTELLIGENCE

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PREFACE

It is with great pleasure that we present the Book of Proceedings for the 3rd International Civil Engineering Conference (ICEC 2024), organized by the Department of Civil Engineering, School of Infrastructure, Process Engineering, and Technology, Federal University of Technology, Minna. This prestigious conference, held from February 23rd to 25th, 2025, at NITDA Hall, Gidan Kwano Campus, Minna, Nigeria, brought together leading academics, researchers, industry professionals, and policymakers to engage in insightful discussions on the theme:

"Advancing the Frontiers of Infrastructure Development Through Artificial Intelligence."

The rapid advancement of artificial intelligence (AI) is transforming infrastructure development, offering innovative solutions to enhance efficiency, sustainability, and resilience. The papers compiled in this volume represent cutting-edge research and practical advancements in this field. Each contribution has undergone a rigorous peer-review process, ensuring the highest standards of academic excellence and relevance.

We extend our profound appreciation to Prof. Faruk Adamu Kuta, Vice Chancellor of the Federal University of Technology, Minna, for his unwavering support and commitment to academic excellence. We also express our sincere gratitude to the principal officers of the university, whose leadership and dedication have created an enabling environment for impactful research and intellectual exchange.

Special appreciation goes to the Chief Host, Engr. Prof. (Mrs.) Z. D. Osunde, Dean of SIPET, and the Host, Engr. Prof. M. Saidu, Head of the Civil Engineering Department, for their tireless efforts in ensuring the success of this conference.

We are particularly grateful to our Keynote Speaker and Lead Paper Presenter, whose insightful contributions provided invaluable perspectives on the role of AI in infrastructure development. Their expertise and thought leadership have greatly enriched the discussions and outcomes of this event.

Finally, we acknowledge the hard work and dedication of the conference organizing committee, peer reviewers, sponsors, and all participants. Their collective contributions have made this event a resounding success and a vital platform for knowledge dissemination and collaboration.

It is our hope that this book of proceedings will serve as a valuable resource for researchers, practitioners, and students, inspiring further exploration and innovation in the integration of artificial intelligence and civil engineering. We look forward to seeing the impact of these contributions in shaping the future of infrastructure development.

Engr. Prof. M. M. Alhaji
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3rd International Civil Engineering Conference (ICEC 2024)
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CHARACTERIZATION OF MUNICIPAL SOLID WASTE FOR SUSTAINABLE SOLID WASTE MANAGEMENT IN BWARI AREA COUNCIL OF ABUJA FCT

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ABSTRACT
Effective management of municipal solid waste is a significant environmental challenge in developing countries. This study examines the characteristics of municipal solid waste in Bwari township of Bwari Area Council, Abuja, Nigeria, in terms of composition, mass, and percentage generated per district. The results show that According to the study, biodegradable matter accounted for 41.98% of the total solid waste created in the Bwari township of Bwari area council of FCT, while non-biodegradable matter accounted for the remainder which is 58.02%. The study area's range of per capita waste generation ranged between 0.38 and 0.95 kg/capita/day. Using the results of this characterization study as a guide, the results clearly indicate the necessity to create formal composting (for 41.98% of the waste) and recycling facilities (for 58.02% of the waste) facilities within the Bwari township. The waste generation rate ranges from 0.38 to 0.95 kg/capita/day. However, the Abuja Environmental Protection Board (AEPB) faces challenges such as inadequate funding, lack of institutional framework, and insufficient data on waste quantity and composition. To address these issues, the study recommends adequate funding, proper legislation, staff training, community involvement, and establishment of formal composting and recycling facilities.

Keywords: *Abuja, Characterization, Composting, Municipal Solid Waste, Recycling.*

1 INTRODUCTION

Waste (also known as rubbish, trash, refuse, garbage, junk, litter) is unwanted or useless materials. In biology, waste is any of the many unwanted substances or toxins that are expelled from living organisms; such as urea, sweat or feces. Litter is waste which has been disposed of improperly. Waste is directly linked to human development, both technologically and socially. The compositions of different wastes have varied over time and location, with industrial development and innovation being directly linked to waste materials. An Example of this include plastics and nuclear technology. Some components of waste have economic value and can be recycled once correctly recovered. Waste is sometimes a subjective concept, because items that some people discard may have value to others. It is widely recognized that waste materials are a valuable resource, whilst there is debate as to how this value is best realized. Such concepts are colloquially expressed in western culture by such idioms as "One man's trash is another man's treasure."

Solid waste can be defined as garbage, refuse and other discarded materials including waste resulting from industrial, commercial and agriculture operations and from community activities or waste that are normally solid and that are discarded as useless or unwanted (Muthuraman & Ramaswamy 2019). The solid content is technically known as refuse while the liquid substances are called effluent (Zhu *et al*., 2023). According to Environmental Protection Department Air Management Group, EPDA (2001), waste involves categories of household, municipal, commercial and industrial wastes, some hazardous and toxic. Municipal solid waste includes wastes generated from residential, commercial, industrial, institutional, construction, demolition, process, and Residential Single and multifamily dwellings generate food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, metals, ashes, special wastes (e.g., bulky items, consumer electronics, white goods, batteries, oil, tires), and household hazardous wastes.

The composition and characteristics of municipal solid waste is influenced by certain factors, which include the area (residential, commercial, etc.), (Nanda and Berruti 2021). the economic level (differences between high and low-income areas) (Sharma and Jain 2020), the season and weather (differences in the amount of population during the year, tourist places) (Cheela *et al*., 2021) and culture of people living or doing business in the area (Nguyen *et al*., 2020). High-income areas usually produce more inorganic materials such as plastics and

paper, while low-income areas produce relatively more of organic waste. Uncontrolled or improperly sited open solid waste dumpsites constitute health hazards and damage the aesthetic beauty of many cities in Nigeria (Osuji *et al* 2023).

Municipal solid waste characterization identifies the quantity and quality of waste constituents, including paper, glass, and food waste, considering location, season, and generation trends. This helps determine waste management needs, plan resources, and mitigate environmental impacts. Characterization informs waste management decisions, such as treatment methods like recycling, composting, and incineration. According to Ihsanullah *et al*. (2021), accurate data, measured in volume (m^3/capita/day) and weight (kg/capita/day), is crucial for effective waste management. The study further posited that understanding waste composition and generation trends enables proper planning, resource allocation, and environmental protection. This information is essential for developing effective waste management strategies and minimizing waste's environmental and health impacts.

To determine the composition of municipal waste, two approaches can be used: physical observation or laboratory analysis. This research employs the physical approach to assess the waste's characteristics at the disposal site. Landfills have been widely used for decades as a final disposal solution for various types of waste, as highlighted by Mondal *et al*., 2023 despite other available waste management methods.

2 METHODOLOGY

Abuja, Nigeria's capital since 1991, is centrally located at 9° 12' N and 7° 11' E. With a population of 1.4 million, including 405,000 in the municipality, Abuja covers 713 km² and is divided into six area councils and twenty waste evacuation districts. The city has a tropical climate with savannah vegetation, except for southern rainforest areas. It receives 1,100mm of rainfall annually, making it a unique urban environment in the heart of Nigeria.

Bwari is one of the six local government area councils that make up the Federal Capital Territory (FCT). Coined from Bwaya, the local government area was created in 1991 and is the predominant ancestral home of the Gbagyi ethnic group of Nigeria. Temperatures in the climate range from 59°F to 93°F, rarely falling below or above 100°F, and there are two hot, humid seasons that alternate with hot, partly overcast ones. It is located at an elevation of 584 meters above sea level and its population amounts to 171,672. Its coordinates are 9°16' 60" N and 7°22'60" E in DMS (Degrees Minutes Seconds) or 9.28333 and 7.38333 (in decimal degrees) (Figure 1). Its UTM position is LR22 and its Joint Operation Graphics reference is NC32-09.

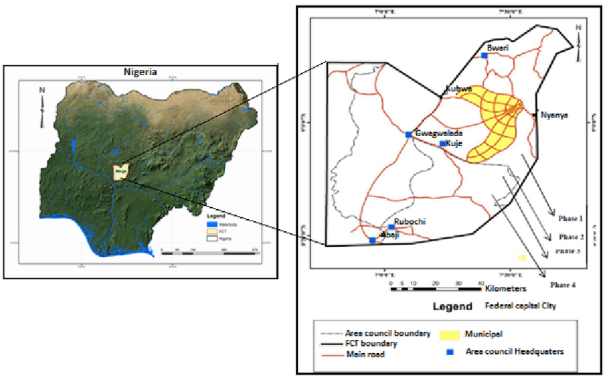


Figure 1: Map of Nigeria showing the study area, Bwari Area Council in Abuja

2.1 DATA COLLECTION: WASTE COMPOSITIONAL STUDY

Two primary methodologies exist for characterizing solid waste: material-based and potential use-based approaches. This study employs the material-based approach, where household solid waste samples are collected, labelled, and transported to a sorting facility. Samples are weighed, segregated into components (e.g., paper, plastic, glass), and their weights determined as a percentage of the total sample weight. Approximately 1kg of each material was sent to the Abuja Environmental Protection Board laboratory for moisture content analysis, which must be completed within a day to minimize errors. This methodology provides a detailed characterization of solid waste composition.

2.2 MOISTURE CONTENT DETERMINATION

Air oven method was used for waste moisture content determination. This method is based on moisture loss on drying at oven temperature of 1050C. Besides water, the loss will include other matters volatile at 105oC. Materials used in the waste moisture content determination include:

1. Flat bottom silica dish
2. Thermostatically Controlled Hot Air Oven with Fan
3. Analytical Weighing Balance
4. Desiccator

Three samples were collected at random from the three categories used from the study area. All the samples were analyzed in duplicates and the results obtained using equation 1.

$$Moisture\ Content\ \% = \frac{Wet\ Sample - Dry\ Sample}{Wet\ Sample}\ x\ 100 \qquad 1$$

2.3 DESIGN OF SURVEY QUESTIONNAIRE

This study conducted three questionnaire surveys among households, businesses, and waste policymakers in Bwari, including the Abuja Environmental Protection Board (AEPB). The questionnaires will be designed to collect data on municipal solid waste (MSW) management, with a focus on economic-demographic variables (Kineber *et al*. 2020). Participants received numbered questionnaires and garbage bags, and their household wastes were collected and analyzed over 10 days. The wastes were sorted, weighed, and compacted, and the data were logged and analyzed. The study collected data from 30 consistent participants, representing low, middle, and high-income earners. The study follows best practices in questionnaire design and administration, ensuring quick, easy, and unbiased responses. The goal was to gather critical data on MSW management in Bwari town, where none currently exists.

2.4 DATA ANALYSIS METHOD

Questionnaires were administered to households, businesses, and policymakers in Bwari Area Council Metropolis, specifically in the Bwari Township. A sample size calculator was used to determine the suitable sample size, using a population of 171,672 and a 95% confidence level. Data will be collected through waste compositional analysis and questionnaire surveys. Microsoft Excel and SPSS was used for data analysis. Normality tests was conducted using descriptive and inferential statistics. This will help identify trends and patterns in waste management practices.

2.5 DESCRIPTIVE STATISTICAL ANALYSIS

Descriptive statistical analysis therefore involved the use of frequencies, percentages, means, and standard deviation to describe various variables encountered during the study. These techniques were employed for analyzing data relating to the characteristics of the respondents or organizations they represent. Graphical was also utilized to present the results from these analyses and this will include pie charts, bar charts, and tables.

3 RESULTS AND DISCUSSION

Bwari township in Abuja was selected as the study area due to its diverse socio-demographic characteristics. The area was divided into three sampling zones: Quarters extension/Child care Trust, Law School/Jamb quarters, and Bwari Area-1/Tudun-fulani. A questionnaire was administered to capture the characteristics of the area, shown in Table 1.

TABLE 1: OVERVIEW OF SOCIO DEMOGRAPHIC CHARACTERISTICS OF SAMPLING AREA

Sample Area	No of household sampled	Geographical Description	Demographical Classification	Average Household Size	Income Classification
1	10	Bwari Area-1/ Tudun-fulani.	High-Density	11-12	Low-Income
2	10	Law School/Jamb quarters	Middle-Density	9– 10	Middle-Income
3	10	Quarters extension/Child care Trust	Low-Density	6 – 7	High-Income

3.1 POPULATION DISTRIBUTION OF THE STUDY AREA

Three specific study areas considered in this study are all within Bwari township, in Abuja, FCT, with a combined population of 171,672 according to the 2006 National Population Census (Table 2).

TABLE 2: POPULATION DISTRIBUTION OF THE STUDY AREA

Location	No of Male	%	No of Female	%	Total	%
Low-Income	25,315	38.44226	42,200	39.87904	67,515	39.3279
Mid-Income	22,317	33.88963	34,200	32.31903	56,517	32.9215
High-Income	18,220	27.6681	29,420	27.80193	47,640	27.75059
Total	65,852	100	105,820	100	171,672	100

3.2 MOISTURE CONTENT ANALYSIS

Municipal Solid Waste samples were randomly selected from the households used in the study: 10 households in low-income area, another 10 households in middle-income areas and also 10 households in high-income areas. The approximate moisture content of waste samples from the study area was determined as detailed in the previous chapter. 15 grammes of wet samples (Ww) were weighed and oven dried at 105^{o}C for 24 hours. Final weights (W_f) of samples were noted at the end of drying. Dry weights (W_d) were obtained as the difference between final weight and weight of container (W_c). Moisture content was calculated as the difference between wet weight and dry weights (Xie and Xue 2023).

TABLE 3: PERCENTAGE (%) MOISTURE CONTENT OF WASTE SAMPLES

SAMPLE	METHOD	RESULT (%)
SAMPLE A	Air Oven Method	29.58
SAMPLE B	Air Oven Method	23.16
SAMPLE C	Air Oven Method	35.48
SAMPLE D	Air Oven Method	50.43
SAMPLE E	Air Oven Method	21.73

3.3 Results of MSW Composition Analysis for Low-Income, Mid-Income and Low-Income households

The MSW composition analysis of dry samples collected from the sampling area is shown in Figure 2. from this graph, the main components of waste stream during the period of sampling were food (7%), plastic film (11%), paper (4%), metal (0.4%), rubber (3%), glass/ceramics (1%) and others (74%).

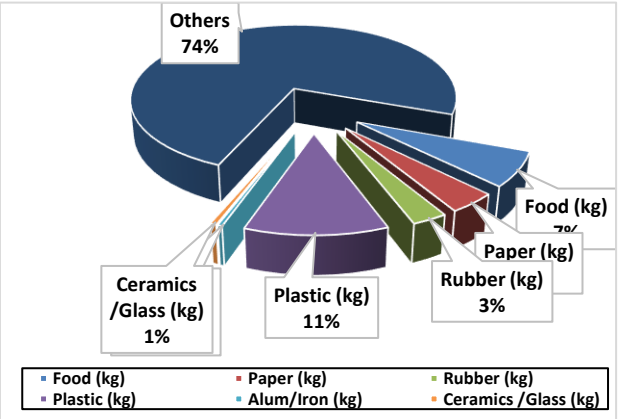


Figure 2 : MSW Composition Analysis for Low-Income household

3.4 Results of MSW Composition Analysis for Mid-Income households

Samples for this sampling area were collected mainly from Law school/Jamb quarters in Bwari Metropolis of Abuja, a middle-density neighborhood. The socio-economic classification of households in this sampling area is medium income, as described in Table 4.1. The MSW composition analysis of samples collected from the sampling area is shown in Figure 4.4. From this graph, the main components of waste stream during the period of sampling were food (10%), plastic film (24%), paper (6%), metal (2%), rubber (0%), ceramics/glass (4%) and others (54%). The plastic waste, food, paper and metal of the samples here is observed to be higher than that of low-income household same as the percentage composition of others which include E-waste, polythene and organic matters were observed to be higher in the low-income household area.

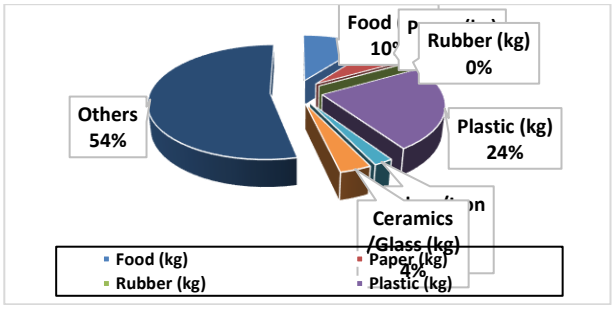


Figure 3: MSW Composition Analysis for Medium-Income household

3.5 Results of MSW Composition Analysis for HIGH-INCOME households

Samples for this sampling area were collected mainly at Quarters Extension/Child Care Trust, a low-density neighborhood within the metropolis. The socio-economic classification of households in this sampling area is high income, as previously described. The MSW composition analysis of samples collected from the sampling area is shown in Figure 4.5. From Figure 4.5, the main components of waste stream were: food (23%), plastic (22%), paper (7%), metal (2%), rubber (0 %), glass (2%) and others (44%).

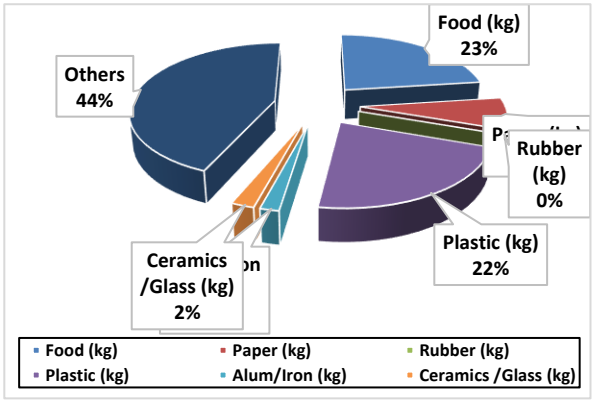


Figure 4: MSW Composition Analysis for High-Income household

3.6 Discussion of Results

The study analyzed questionnaire results and solid waste composition in Bwari metropolis of Abuja, FCT. It found that solid waste management methods are ineffective, leading to environmental degradation. Factors contributing to this include open dumping, inadequate enforcement, rapid urbanization, poor collection routes, and lack of funding, according to Golzary *et al.* (2024) . The waste composition analysis showed that a significant portion of waste (43.9%-44.8%) is biodegradable and can be composted, producing fertilizer. High-income

households generate more organic waste. However, there are no formal recycling and composting sites in Bwari, and scavengers, mostly young people, collect recyclables without protective gear, risking their health. The study recommends recycling and composting as a sustainable and cost-effective approach to solid waste management, reducing environmental harm and health risks. Implementing effective waste management strategies is crucial for urban development and sustainability.

For the generation of per capita waste generation in the study area, Table 4 presented the weekly and daily per capita waste generation for Bwari metropolis. High-Income households were observed to generate more waste than the rest with 0.95 kg/capita/day, followed closely by Mid-Income with 0.59 kg/capita/day. Low-income households have the lowest waste generaion of 0.38 kg/capita/day (Table 4.13). Dauda and Osita (2003) found 0.25kg/capita/day in Maiduguri, Aluko (2012) found 0.56kg/capita/day in Mushin, Lagos, and Salisu *et al*. (2020) found 0.49kg/capita/day in average Nigeria villages with home and commercial centers. The average of 0.64kg/capital/day was determined by the people's socioeconomic position and consequently the location.

TABLE 4: TOTAL WASTE GENERATED PER CAPITAL/DAY

Location	No of Male	No of Female	Total	Total Waste Generated	Per Capita Waste Generation (PCWG) kg/Person/Day
Low-Income	52	59	111	295.8	0.38
Mid-Income	41	48	89	369.74	0.59
High-Income	22	28	50	333.39	0.95
Total	115	135	250	998.93	

4 CONCLUSION

The characterization of solid waste in the Bwari metropolis of Abuja has now been researched. This is the primary step required for any community to achieve sustainable solid waste management. The first stage in solid waste management is to understand the waste kinds that are generated in order to establish appropriate collection and disposal methods, which can be accomplished through solid waste characterization. The majority of waste generated in Bwari metropolis of Abuja can be composted rather than disposed away. Food/organic matter, glass/ceramics, metals (alum/iron), paper, plastics, rubber and others make up the majority of the solid waste produced. According to the study, biodegradable matter accounted for 41.98% of the total solid waste created in the Bwari area council of FCT, while non-biodegradable matter accounted for the remainder which is 58.02%. The study area's range of per capita waste generation ranged between 0.38 and 0.95 kg/capita/day. Using the results of this characterization study as a guide, the results clearly indicate the necessity to create formal composting (for 41.98% of the waste) and recycling facilities (for 58.02% of the waste) facilities within the FCT Abuja urban region.

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Systematic Review on Risk Mitigation Strategies for Enhancing Operational Efficiency in Inland Waterways Transportation: The Nigerian Context

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ABSTRACT
This paper presents a systematic review of risk mitigation strategies to improve the operational efficiency of inland waterways transportation (IWWT) in Nigeria. It focuses on challenges specific to Nigeria's inland waterways and examines global strategies for operational efficiency**.** By comparing practices from Europe, Southeast Asia, and Africa, the study highlights solutions to funding constraints, piracy, human error and environmental risks. Strategies include GPS integration, port upgrades, infrastructure development, regulatory reforms**,** adoption of sustainable technologies and fostering public-private partnerships to address these challenges. The findings provide actionable recommendations and future research directions for enhancing the efficiency and safety of Nigeria's inland waterways system.

Keywords: *Infrastructure Development, Inland Waterways Transportation (IWWT), Operational Efficiency, Regulatory Frameworks, Risk Mitigation.*

1.0 INTRODUCTION

The economic and social progress of any country depends heavily on its transportation system, which facilitates the movement of people, commodities, and services (Cheng, Jiang, & Nielsen, 2023). As a more economical and environmentally friendly alternative to road and rail transportation, inland waterways transportation—a subset of the larger transportation network—is especially important in areas with vast river systems (Browne, Dubois, & Hulthén, 2023). Despite abundant waterways, Nigeria lags in exploiting this mode of transport due to systemic inefficiencies, including poor infrastructure and weak regulatory enforcement. Inland waterways, such as rivers, creeks, and lagoons, present significant opportunities to improve transportation efficiency, reduce road congestion, and foster economic growth in nations such as Nigeria (Afolabi, 2023).

However, Nigeria's inland waterways transportation (IWT) is confronted with numerous operational issues despite its great promise. These include environmental hazards, such as flooding and sedimentary flows, inadequate infrastructure, navigational challenges, and weak regulatory oversight (Adewumi et al., 2023; Akpudo, 2021). Furthermore, the sector's expansion has been hindered by safety concerns resulting from outdated navigation equipment, inadequate safety measures, and vessel overloading (Badejo, 2014). Unlocking the full potential of Nigeria's inland waterways and advancing effective transportation networks depend on addressing these systemic issues.

To ensure operational efficiency and minimize vulnerabilities in Nigeria's IWT system, risk mitigation strategies are crucial. Globally, several tactics have proven successful in enhancing operational efficiency and reducing risks, including the adoption of modern navigation systems, strict enforcement of safety regulations, and infrastructure improvements (Syaiful, Pratikso, & Mudjanarko, 2023). However, implementing these strategies in the Nigerian context requires a deep understanding of the sector's unique risks and challenges.

The objective of this systematic review is to identify and synthesize existing literature on risk mitigation strategies with the aim of improving the operational efficiency of inland waterways transportation in Nigeria. This analysis evaluates global best practices and their applicability to Nigeria, providing a comprehensive understanding of the risks and mitigation strategies necessary to enhance the effectiveness and safety of Nigeria's inland waterways system. By assessing the relevance of global risk mitigation models to the Nigerian context, this review aims to bridge a critical gap in the literature.

2.0 METHODOLOGY

2.1 SEARCH STRATEGY

An organized method was used in this systematic review to find and compile pertinent material. Several electronic databases, including Google Scholar, IEEE Xplore, Scopus, and ScienceDirect, were used in the search. Combinations of keywords associated with the study's scope were used as the main search phrases, which included "inland waterways," "risk mitigation," "transportation efficiency," "Nigeria," and "operational risks." Boolean operators (AND, OR) were applied to refine the search results, focusing on studies that specifically addressed risk management in inland waterways. For instance, phrases like "risk mitigation AND inland waterways" were combined.

Studies focusing on air or land transportation were excluded unless they presented risk mitigation models that could be applied to waterways. This is because air and land transport differ significantly from inland waterways in terms of operational challenges and mitigation strategies, such as the nature of navigation, environmental risks, and infrastructure requirements.

The search was restricted to studies published between 2010 and 2024 to ensure the inclusion of the most up-to-date research on the subject. Only peer-reviewed articles, technical reports, and case studies were included to ensure quality and academic rigor, as illustrated in the PRISMA flow diagram (Figure 1).

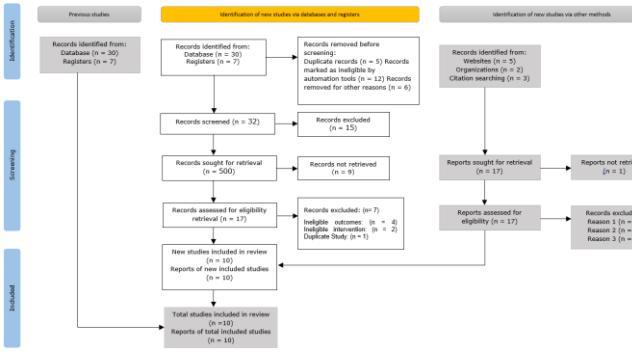


Figure 1: PRISMA Flow Diagram

2.2 INCLUSION AND EXCLUSION CRITERIA

To ensure relevance and quality, the following inclusion and exclusion criteria were applied:

2.2.1 INCLUSION CRITERIA

i. Studies that directly addressed risk mitigation in inland waterways.
ii. Research focused on improving operational efficiency through risk management.
iii. Articles and reports published in peer-reviewed journals or as official reports.
iv. Research that evaluated risk mitigation strategies in developing countries or regions with similar transportation infrastructure to Nigeria.
v. Studies were published between 2010 and 2024.

2.2.2 EXCLUSION CRITERIA

i. Studies focusing solely on land or air transportation without mentioning inland waterways. These modes were excluded as they differ significantly in operational challenges, including navigation, environmental risks, and infrastructure requirements.
ii. Research outside the scope of operational efficiency or risk mitigation.
iii. Non-peer-reviewed literature, such as opinion pieces or conference abstracts without empirical data.
iv. Studies written in languages other than English.

2.3 DATA EXTRACTION PROCESS

The data extraction process involved systematically identifying and organizing key information from the selected studies. A data extraction form was used to capture relevant details from each study, including:

i. Study details (e.g., author, year, country).
ii. Types of risks identified in inland waterways transportation.
iii. Risk mitigation strategies discussed.
iv. Outcomes of the risk mitigation measures on operational efficiency.
v. Applicability of strategies to the Nigerian context.

2.4 QUALITY ASSESSMENT

To ensure the reliability and validity of the findings, the quality of the selected articles was assessed using a modified version of the Cochrane Risk of Bias tool. This tool evaluates factors such as:

i. Methodological rigor (e.g., study design, sample size, data collection methods).
ii. Potential biases (e.g., selection bias, reporting bias).
iii. Relevance to the research questions (i.e., the extent to which the study focused on risk mitigation and operational efficiency in inland waterways).

Studies that scored poorly on these quality indicators were excluded from the final review to maintain the integrity of the systematic review process.

3.0 RESULTS

3.1 OVERVIEW OF INCLUDED STUDIES

A total of ten significant papers that examined operational difficulties and risk mitigation techniques in inland waterways transportation across different geographies were included in this systematic review. These studies emphasize critical elements such as inadequate infrastructure, navigational risks, safety infractions, and environmental hazards that influence the effectiveness of inland waterways systems. The findings underscore the necessity of comprehensive approaches, including infrastructure investments, regulatory frameworks, and technological advancements, to enhance the operational efficiency of inland waterways, particularly in developing countries like Nigeria. Table 1 provides a concise summary of the studies reviewed, highlighting their geographic focus, key findings, and relevance to Nigeria's inland waterways system.

TABLE 1: KEY STUDIES ON RISK MITIGATION AND OPERATIONAL CHALLENGES IN INLAND WATERWAYS

Study Reference	Year	Country/Region	Key Findings	Relevance to Nigeria
Gast et al.	2020	Global	Notification time significantly impacts risk mitigation in supply chain logistics	High
Nwaogbe & Ogorode	2024	Nigeria	Operational performance and service quality in inland waterways are influenced by infrastructure quality and staff performance	High
Akpudo	2021	Nigeria	Human errors, natural factors, and mechanical failures are key causes of boat accidents in Nigeria	High
Nwankwo & Ukoji	2015	Nigeria	Overloading, piracy, and poor weather are major causes of boat accidents in the Niger Delta	High
Idiapho & Awwal	2020	Nigeria	Human errors and technical failures are the primary causes of tugboat accidents	High
Portman	2018	Israel/Mediterranean	Integration of inland water and coastal management improves resilience to coastal erosion	Moderate
Pratas, Garrido, & Pimentel	2023	Brazil	A framework for sustainable inland waterways systems, focusing on multimodal	Moderate

			integration and government support	
Hassan & Xuefeng	2022	Bangladesh	Infrastructure deficiencies, such as low-depth channels and poor port facilities, hinder inland waterways transport	High
David	2023	Europe	Sustainable goods transport via inland waterways requires investment in fuel-efficient vessels and green technologies	Moderate
Roso et al.	2020	Netherlands, Sweden	Drivers for IWT include congestion relief and environmental benefits, but barriers such as poor hinterland connectivity remain	Moderate

3.2 IDENTIFIED RISKS IN INLAND WATERWAYS

Various hazards affecting inland waterways transportation systems were identified in the reviewed studies. These risks include environmental hazards, navigational challenges, human errors, and infrastructural deficiencies. Table 2 presents the key risks along with their relevance to Nigeria.

TABLE 2: CATEGORIZATION OF RISK FACTORS IN INLAND WATERWAYS TRANSPORTATION

Risk Factor	Study Reference	Description	Relevance to Nigeria
Navigational Hazards	Akpudo (2021)	Poor navigation tools and unmarked channels lead to frequent accidents.	High
Human Errors	Idiapho & Awwal (2020)	Overloading and improper operation of vessels contribute to accidents.	High
Environmental Risks	Nwaogbe & Ogorode (2024)	Flooding and sedimentation disrupt inland waterways transport	High
Infrastructure Deficiency	Hassan & Xuefeng (2022)	Poor port facilities and low-depth channels limit the efficiency of transport	High
Regulatory Deficiencies	Roso et al. (2020)	Lack of regulatory support for inland waterways hinders operational efficiency	Moderate
Technical Failures	Idiapho & Awwal (2020)	Mechanical failures, such as engine breakdowns, are common in tugboat accidents	High
Natural Disasters	Portman (2018)	Coastal erosion and inland flooding threaten transportatio	Moderate

		n infrastructure	
Logistical Challenges	Gast et al. (2020)	Inadequate notification times affect the ability to mitigate logistical risks	Moderate

3.3 RISK MITIGATION STRATEGIES

The studies reviewed propose several risk mitigation strategies that can enhance the operational efficiency of inland waterways transportation systems.

TABLE 3: RISK MITIGATION STRATEGIES FOR INLAND WATERWAYS TRANSPORTATION

Mitigation Strategy	Study Reference	Description	Effectiveness	Applicability to Nigeria
Improved Navigational Tools	Akpudo (2021)	Use of GPS and radar systems to improve navigation and avoid hazards	High	High
Dredging and Port Upgrades	Hassan & Xuefeng (2022)	Regular dredging and upgrading port facilities for better throughput	High	High
Safety Regulation Enforcement	Idiapho & Awwal (2020)	Enforcement of safety protocols, including life jacket use and vessel inspections	High	High
Environmental Risk Management	Portman (2018)	Implement flood monitoring and water management practice	Moderate	Moderate
Public-Private Partnerships	Pratas et al. (2023)	Collaboration between government and private sector for infrastructure investment	High	High
Use of Sustainable Technologies	David (2023)	Adoption of green technologies like fuel-efficient vessels and route optimization software	Moderate	High
Training and Capacity Building	Nwaogbe & Ogorode (2024)	Operator training and education programs on safety and risk mitigation	Moderate	High
Regulatory Reforms	Roso et al. (2020)	Reforming regulatory frameworks to improve governance and oversight	Moderate	High

Hydrographic Surveys	Gast et al. (2020)	Conducting regular hydrographic surveys to ensure navigability	Moderate	Moderate
Community Engagement	Nwankwo & Ukoji (2015)	Engaging local communities to reduce piracy and improve compliance	Moderate	High

A thorough overview of the risk mitigation techniques considered in the study is given in Table 3, which also includes information on how they were implemented, how effective they were judged to be, and how applicable they were in the Nigerian setting. It highlights how these tactics may be used to tackle important issues in inland waterways transportation and provides information on how international best practices can be modified to improve operational effectiveness and safety in Nigeria.

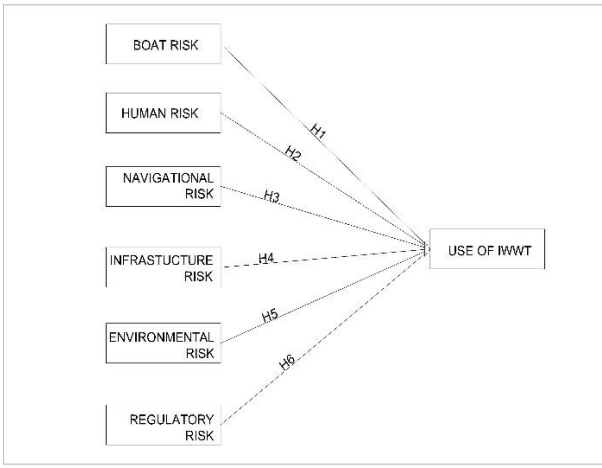


Figure 2: Conceptual Model Highlighting Key Risks in Nigerian's Inland Waterways

Figure 2 illustrates a conceptual model of key risks impacting the use of Inland Waterways Transportation (IWWT), categorized into six factors: Boat Risk (H1), which pertains to vessel conditions and maintenance; Human Risk (H2), arising from errors such as inadequate training or improper operation; Navigational Risk (H3), related to challenges with water hyacinth infestation and unmarked channels; Infrastructure Risk (H4), encompassing inadequate or poorly maintained jetties and waterways; Environmental Risk (H5), involving natural hazards like flooding and sedimentation; and Regulatory Risk (H6), stemming from weak enforcement and governance. These risks collectively influence the safety, efficiency, and operational effectiveness of IWWT, highlighting the importance of targeted mitigation strategies to optimize this critical transportation mode.

3.4 APPLICATION TO NIGERIA

The global risk mitigation strategies identified in the review provide valuable insights for improving Nigeria's inland waterways transportation system. However, some of these strategies need to be adapted to the local context, considering Nigeria's unique challenges such as piracy, militancy, and infrastructural limitations.

TABLE 4: APPLICATION OF GLOBAL STRATEGIES TO NIGERIA

Global Strategy	Region Applied	Effectiveness (Based on Studies)	Adaptability to Nigeria	Barriers to Implementation
Improved Navigational Tools	Global (Akpudo, 2021)	High	High	Cost, lack of technical expertise
Dredging and Port Upgrades	Bangladesh (Hassan & Xuefeng, 2022)	High	High	Funding constraints, bureaucratic delays
Safety Regulation Enforcement	Nigeria (Idiapho & Awwal, 2020)	High	High	Weak enforcement, corruption
Sustainable Technologies	Europe (David, 2023)	Moderate	High	High cost of fuel-efficient vessels
Public-Private Partnerships	Brazil (Pratas et al., 2023)	High	High	Limited private investment
Hydrographic Surveys	Global (Gast et al., 2020)	Moderate	Moderate	Insufficient funding, expertise

Regulatory Reforms	Netherlands (Roso et al., 2020)	Moderate	High	Political instability, outdated laws
Training and Capacity Building	Nigeria (Nwaogbe & Ogorode, 2024)	Moderate	High	Limited access to resources

Table 4 outlines the global strategies and their potential application in Nigeria, highlighting key barriers such as funding constraints, weak regulatory enforcement, and limited technical expertise.

4.0 DISCUSSION

4.1 GLOBAL PRACTICES VS. NIGERIAN CONTEXT

Global best practices in inland waterways transportation, particularly from regions like Europe, Southeast Asia, and Africa, demonstrate effective risk mitigation strategies focused on enhancing infrastructure, implementing safety regulations, and leveraging advanced technologies to improve operational efficiency. For example, Europe has significantly enhanced the sustainability and efficiency of inland waterways through the adoption of fuel-efficient vessels, GPS navigation systems, and route optimization software (David, 2023; Roso et al., 2020). However, while these technologies are highly effective, their adoption in Nigeria is hindered by prohibitive costs and limited technical expertise, which restrict the capacity to operate and maintain such systems effectively.

In Southeast Asia, substantial investments in dredging and inland port construction have successfully addressed challenges such as siltation and inadequate port infrastructure (Hassan & Xuefeng, 2022). These strategies could greatly benefit Nigeria, where similar challenges persist. However, the implementation of such large-scale projects in Nigeria is impeded by funding constraints and bureaucratic inefficiencies.

Africa's inland waterways systems, though less advanced, share similar challenges with Nigeria, including weak regulatory enforcement and limited funding for infrastructure improvements. Initial attempts at regulatory reform in African nations have shown some promise, but Nigeria struggles with underfunded agencies like NIWA and NIMASA, which lack the resources and authority to enforce safety standards effectively (Idiapho & Awwal, 2020).

While advanced technological solutions, such as radar systems and GPS navigation, have the potential to mitigate navigational hazards, their implementation in Nigeria is further hampered by a shortage of skilled professionals to operate and maintain these technologies. Thus, tailoring these global strategies to Nigeria's context requires addressing its unique challenges, including funding deficits, governance gaps, and environmental vulnerabilities.

TABLE 5: COMPARATIVE ANALYSIS OF RISK MITIGATION STRATEGIES BY REGION

Region	Key Risk Mitigation Strategies	Effectiveness	Challenges	Applicability to Nigeria
Europe	- Adoption of sustainable technologies (e.g., fuel-efficient vessels, GPS navigation) - Route optimization software	High	High costs of green technologies Infrastructure upgrades required	Partially applicable, but requires significant investment in technology and infrastructure
Southeast Asia	- Dredging and port upgrades - Infrastructure development and siltation control	High	Maintaining infrastructure Environmental challenges like siltation	Highly applicable, especially for addressing infrastructure challenges in Nigeria
Africa	- Basic infrastructure improvements - Initial attempts at regulatory reform	Moderate	Weak regulatory enforcement Limited funding for large-scale projects	Similar challenges to Nigeria, particularly in regulatory enforcement

				and funding
Nigeria	- Limited infrastructure development (dredging, port upgrades) - Regulatory improvements (but weak enforcement)	Low to Moderate	Weak enforcement Limited technological adoption Funding constraints	Requires tailored strategies focused on infrastructure development and regulatory reform

A thorough comparative study of risk reduction techniques used in Nigeria, Europe, Southeast Asia, and Africa is given in Table 5. It draws attention to the tactics' efficacy, the difficulties that each region encounters, and how these strategies might be applied to Nigeria's inland waterway system.

4.2 CHALLENGES IN IMPLEMENTATION

Several challenges restrict the successful adoption of global best practices in Nigeria's inland waterways transportation system:

i. **Funding Constraints:** Advanced technologies like GPS navigation systems and fuel-efficient vessels require significant investment, which is often unattainable due to Nigeria's limited public and private funding (Nwankwo & Ukoji, 2015).

ii. **Weak Regulatory Frameworks:** Unlike Europe or Southeast Asia, where regulations are stringently enforced. Nigeria's regulatory bodies face challenges like inadequate funding and corruption, limiting their ability to implement and monitor safety standards effectively (Idiapho & Awwal, 2020).

iii. **Technical Expertise Gaps:** Many of the global practices rely on skilled personnel to implement and sustain them. In Nigeria, a lack of trained professionals hinders the adoption of advanced systems like route optimization software and sustainable technologies (David, 2023).

iv. **Environmental Challenges:** Frequent flooding, sedimentation, and other natural hazards disrupt inland waterways operations. These challenges are exacerbated by a lack of comprehensive hydrographic surveys and flood monitoring systems (Nwaogbe & Ogorode, 2024).

4.3 POLICY AND PRACTICE IMPLICATIONS

Addressing the challenges and aligning global practices with Nigeria's context requires targeted policy and practical interventions:

i. **Infrastructure Investments:** Large-scale investment in dredging, port upgrades, and channel maintenance is essential. Public-private partnerships (Pratas et al., 2023) can play a pivotal role in mobilizing resources and technical expertise for these projects.

ii. **Strengthening Regulatory Frameworks:** Regulatory bodies like NIWA and NIMASA must be empowered with adequate funding, resources, and authority to enforce safety standards. Introducing incentive-based compliance programs could also encourage adherence to regulations (Idiapho & Awwal, 2020).

iii. **Capacity Building and Training:** Investing in operator training programs is critical for addressing skill shortages. Such programs should focus on advanced navigation tools, safety protocols, and green technologies to ensure operators are equipped to manage risks effectively (Nwaogbe & Ogorode, 2024).

iv. **Adopting Technological Solutions:** Although the high cost of GPS navigation systems, fuel-efficient vessels, and route optimization software poses a challenge, these technologies offer long-term benefits in reducing accidents and improving efficiency (Rafalias, 2024). Funding mechanisms like government subsidies or international aid could offset initial costs.

v. **Environmental Risk Management:** Comprehensive hydrographic surveys and flood monitoring systems are crucial for predicting and mitigating the impacts of natural disasters. Adopting water management practices, such as sediment control, could enhance resilience against environmental disruptions (Portman, 2018).

CONCLUSION

This systematic review highlights the critical risks affecting Nigeria's inland waterways transportation system, including inadequate infrastructure, weak regulatory enforcement, and navigational hazards. While global best practices, such as the use of advanced technologies, infrastructure upgrades, and strict enforcement of safety regulations, have proven

successful elsewhere, their implementation in Nigeria faces significant challenges due to funding limitations and a lack of technical expertise.

To address these challenges, immediate efforts should focus on cost-effective, context-specific solutions. For example, future studies should prioritize the development and deployment of low-cost GPS navigation systems tailored to Nigeria's waterways. Public-private partnerships must be actively pursued to mobilize resources for dredging projects and port upgrades, while capacity-building programs should focus on equipping operators with the necessary skills to adopt and maintain advanced technologies.

Additionally, targeted regulatory reforms are essential to empower agencies like NIWA and NIMASA with adequate funding and authority to enforce safety standards. To mitigate environmental risks such as flooding and sedimentation, comprehensive hydrographic surveys and flood monitoring systems should be prioritized. Addressing piracy and militancy will require engaging local communities and introducing incentive-based compliance programs to foster cooperation. By aligning global best practices with Nigeria's unique challenges and leveraging tailored implementation pathways, the operational efficiency and safety of the country's inland waterways system can be significantly enhanced.

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Artificial Intelligence's (AI) Role in Civil Engineering: A Brief Overview

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ABSTRACT
AI-driven technologies, including machine learning, deep learning, and data-driven decision-making systems, are reshaping traditional practices in civil engineering. These advancements enable more effective structural health monitoring, precise cost estimation, efficient resource allocation, and optimized traffic management. AI's potential to enhance accuracy, reduce costs, and promote sustainable infrastructure development is substantial. Despite its numerous benefits, the adoption of AI in civil engineering faces challenges, including data limitations and the need for interdisciplinary expertise. However, recent case studies demonstrate AI's significant impact on project efficiency and sustainability. Looking ahead, the continued development of AI, coupled with emerging technologies like the Internet of Things (IoT) and big data analytics, promises to further revolutionize civil engineering practices. This synergy will contribute to the creation of more sustainable, safe, and efficient infrastructure. As AI continues to evolve, its application in civil engineering is expected to expand, offering even more sophisticated solutions for complex problems. The integration of AI with other cutting-edge technologies will undoubtedly shape the future of civil engineering, leading to smarter, more resilient, and environmentally friendly infrastructure development.

Keywords: *Application; Artificial Intelligence; Civil Engineering; Machine Learning.*

1 INTRODUCTION

Artificial intelligence (AI) has dramatically reshaped civil engineering, offering cutting-edge solutions to long-standing challenges. Since its introduction in 1956, AI has evolved to include various techniques that mimic human thought processes, enabling engineers to tackle complex problems with remarkable accuracy and efficiency.

Civil engineering projects, from roads and bridges to tunnels and dams, are the foundation of modern infrastructure. Managing and maintaining these structures has always been a daunting task due to their complexity and the many factors involved. In the past, traditional methods relied heavily on human expertise, but AI is ushering in a new era of advanced tools that provide greater precision, efficiency, and sustainability (Dauvergne, 2020).

Several AI techniques have been integrated into different areas of civil engineering:

- Machine Learning (ML) has become a go-to tool for analyzing data and predicting outcomes. It's particularly useful in structural health monitoring, where it can detect damage, forecast material behavior, and optimize structural performance (Malekloo et al., 2022). ML also excels at tasks like estimating concrete strength and classifying materials.
- Deep Learning (DL), which uses multi-layered neural networks, is perfect for handling large datasets and uncovering complex patterns. Its ability to learn directly from raw data without human guidance makes it invaluable for tasks such as visual inspections, damage detection, and earthquake engineering (Srinivas et al., 2022).
- Evolutionary Computation (EC) draws inspiration from natural selection to solve optimization problems. In civil engineering, EC helps optimize designs, streamline construction processes, and improve infrastructure management (Rahimian et al., 2021). By mimicking biological evolution, EC uncovers innovative solutions that engineers might otherwise overlook.
- Artificial Neural Networks (ANNs) excel in pattern recognition and data classification. They are particularly effective in structural health monitoring, where they process real-time sensor data to detect anomalies in bridges, buildings, and other infrastructure (Navabian, 2020). This capability allows for timely preventive maintenance, reducing the risk of failures.
- Fuzzy Systems (FS) are ideal for managing uncertainty and imprecision, which makes them highly valuable in risk assessment and predicting delays in construction projects (Al-Nahhas et al., 2024). Their ability to work with approximate reasoning helps engineers make

informed decisions, even when conditions are uncertain.

- Computer Vision (CV), when combined with AI, has revolutionized visual inspections of construction sites. AI-powered drones can now scan large areas for defects, monitor project progress, and ensure safety compliance, drastically cutting down the need for manual inspections and speeding up timelines (Ali, 2023).
- Expert Systems use specialized knowledge from human experts to assist in tasks ranging from structural analysis to geotechnical engineering (Krishnamoorthy & Rajeev, 2018). These AI systems offer consistent advice and enable quick decision-making in complex scenarios.
- Hybrid AI models, which combine various AI techniques, are pushing the boundaries of what's possible in civil engineering (Tapeh & Naser, 2023). By integrating different AI methods, these models provide more accurate results in areas like concrete mix design, energy efficiency modeling, and labor productivity forecasting. They are also playing a critical role in sustainability assessments, helping engineers design eco-friendly structures.

Looking ahead, AI's role in civil engineering will only continue to expand. From more accurate predictions to better decision-making and optimized systems, AI is transforming how we design, build, and maintain infrastructure (Baduge et al., 2022). While challenges remain, the potential benefits of AI in civil engineering are vast, promising a future with safer, more efficient, and more sustainable infrastructure. This mini review highlights the advancements, challenges, and future directions of AI applications in civil engineering, underscoring its growing impact on the industry.

2 METHODOLOGY

This systematic investigation explores the intersection of Artificial Intelligence and civil engineering, encompassing a broad spectrum of applications ranging from structural analysis and construction management to geotechnical engineering, transportation systems, and environmental sustainability initiatives. Our methodological framework provides a structured approach to examining AI's evolving role within these domains.

2.1 LITERATURE REVIEW AND DATA SELECTION

Our literature acquisition process employed a systematic strategy, leveraging prominent academic databases including Web of Science and Scopus, supplemented by additional online repositories. The search protocol utilized carefully selected keywords—"artificial intelligence," "civil engineering," and "applications"—to identify relevant scholarly contributions. We prioritized recent English-language publications demonstrating robust methodological frameworks, focusing particularly on peer-reviewed journals and conference proceedings that presented original research with clear objectives and empirical foundations.

The initial database queries yielded 70 and 89 potentially relevant studies from Web of Science and Scopus, respectively. Following preliminary screening, we retrieved and evaluated 47 and 72 full-text articles. Of these, 53 studies met our inclusion criteria, with an additional seven relevant documents identified through manual searching, culminating in a final corpus of 60 studies. We adhered to the PRISMA 2020 guidelines throughout our reporting process, selected for their emphasis on transparency and methodological clarity.

2.2 STUDY SELECTION PROCESS

Our selection methodology followed a rigorous three-stage process designed to maximize precision and reliability. The initial phase involved comprehensive deduplication to ensure the uniqueness of each entry. The second stage comprised a careful review of titles and abstracts to align selected studies with our research objectives. The final phase involved independent full-text evaluation by two reviewers, with a third reviewer providing arbitration in cases where consensus proved elusive.

2.3 SYNTHESIS AND INTERPRETATION

The analytical approach extended beyond mere aggregation of findings, aiming to construct a coherent narrative that illuminated connections across diverse studies. Our synthesis mapped emerging patterns and trends, offering a comprehensive perspective that transcended the limitations of individual investigations. This interpretative process maintained unwavering commitment to objectivity while acknowledging the human dimensions underlying the data.

2.4 PURPOSE AND SIGNIFICANCE

This review represents more than an academic exercise—it constitutes a purposeful investigation aimed at identifying AI applications in civil engineering domain. By identifying critical research gaps and synthesizing diverse perspectives, our work seeks to catalyze innovations that could prevent workplace accidents and protect human life. Our adherence to PRISMA guidelines ensures methodological rigor throughout the investigation.

3 USES OF AI IN CIVIL ENGINEERING

3.1 AI IN STRUCTURAL ENGINEERING

Artificial Intelligence (AI) is bringing remarkable changes to structural engineering, reshaping how we monitor, analyze, and maintain our infrastructure.

3.1.1 STRUCTURAL HEALTH MONITORING (SHM) AND DAMAGE DETECTION

Artificial Intelligence (AI) is bringing remarkable changes to structural engineering, reshaping how we monitor, analyze, and maintain our infrastructure.

AI-powered Structural Health Monitoring (SHM) systems act like ever-watchful inspectors. Utilizing advanced technologies like neural networks and genetic algorithms, these systems can detect flaws in bridges and buildings that human eyes might miss (Malekloo et al., 2022). By constantly analyzing data from embedded sensors, AI can identify issues such as cracks or corrosion early, reducing the need for frequent manual inspections, saving time and resources, and improving safety.

3.1.2 PREDICTIVE MODELING AND DESIGN OPTIMIZATION

Artificial Intelligence (AI) is bringing remarkable changes to structural engineering, reshaping how we monitor, analyze, and maintain our infrastructure.

AI offers structural engineers a powerful tool for predicting how structures will behave under various conditions, whether everyday stress or extreme events like earthquakes or hurricanes (Guha et al., 2022). Using machine learning and deep learning, engineers can design more resilient structures optimized for safety, durability, and cost-effectiveness. AI's ability to explore numerous design variations allows engineers to achieve the best balance between strength and sustainability.

3.1.3 CONCRETE STRENGTH PREDICTION

With AI, concrete mixing becomes more precise. Machine learning models, particularly artificial neural networks, can predict the compressive strength of concrete based on specific factors such as the water-cement ratio and aggregate properties (Moein et al., 2023). This ensures higher quality control, reduces material waste, and extends the lifespan of structures.

3.1.4 ADVANCED DAMAGE DETECTION

AI is pushing damage detection to new levels. Systems like CrackNet and CrackNet II, which use convolutional neural networks, can identify surface cracks with exceptional accuracy (Arafin, 2022). Other technologies, such as the Faster Region-based Convolutional Neural Network (Faster R-CNN), can diagnose multiple types of surface damage simultaneously, essential for maintaining aging infrastructure (Kim & Cho, 2020).

3.1.5 DESIGN OPTIMIZATION

AI algorithms are becoming critical in optimizing structural design (Salehi & Burgueño, 2018). These systems can quickly evaluate various design options based on factors such as strength, weight, cost, and environmental impact, helping engineers explore innovative solutions that may not be apparent through traditional methods.

3.2 AI IN CONSTRUCTION MANAGEMENT

AI is revolutionizing construction management, enhancing efficiency, precision, and safety in an industry traditionally guided by human expertise and intuition.

3.2.1 PROJECT PLANNING AND SCHEDULING

AI can act as a highly skilled project manager, sifting through vast historical data to create more accurate project timelines and predict potential challenges (Goldberg, 2019). Machine learning algorithms allow project managers to allocate resources more effectively, improving decision-making and keeping timelines on track (Williams, 2024).

3.2.2 PROJECT PLANNING AND SCHEDULING

AI is transforming cost estimation and budget management. By analyzing historical data, market trends, and project specifics, AI models provide highly accurate cost estimates (Elmousalami, 2020). They also continuously monitor expenses, alerting managers to potential cost overruns before they escalate into major issues, reducing financial risks.

3.2.3 RISK MANAGEMENT AND SAFETY

AI is becoming a key player in enhancing construction site safety. Using sensors and cameras, advanced AI systems can monitor real-time conditions and identify hazards like structural weaknesses in scaffolding before they lead to accidents (Khan et al., 2022). By predicting potential risks, AI helps managers take preventive actions, reducing workplace injuries and saving lives.

3.2.4 RESOURCE ALLOCATION AND PRODUCTIVITY MONITORING

AI excels at optimizing the use of resources, whether materials, equipment, or labor. Machine learning algorithms can analyze productivity data, identify inefficiencies, and suggest improvements. For instance, AI can predict labor productivity based on factors like weather, work methods, and crew size, helping managers make informed staffing decisions (Orlova, 2021).

3.2.5 SITE LAYOUT OPTIMIZATION

AI is reshaping how construction sites are organized. AI-powered systems can quickly analyze potential sites and generate 3D models, optimizing layouts for efficiency, safety, and cost-effectiveness (Rane, 2023). These systems consider factors that may not be immediately apparent to human planners.

3.2.6 AUTOMATED EQUIPMENT MANAGEMENT

AI is making construction equipment smarter. Innovations like automated bricklayers and AI-managed robot teams are helping speed up construction while reducing risks to human workers (Zheng et al., 2024). These AI-controlled machines can work in challenging conditions, making construction processes more efficient.

3.2.7 MODULAR CONSTRUCTION DECISION-MAKING

AI is becoming an essential tool in modular construction, where prefabricated modules are assembled on-site (M. Pan et al., 2022). By analyzing project requirements, AI systems can help determine whether traditional construction methods or modular approaches are more suitable, aiding the industry's shift toward prefabricated solutions.

3.2.8 SUPPLY CHAIN MANAGEMENT

AI is also helping construction managers streamline supply chain management. By analyzing market trends and supplier performance, AI optimizes procurement, minimizes delays, and manages inventory more effectively, ensuring smoother project execution (Ogundipe et al., 2024).

3.3 AI IN GEOTECHNICAL ENGINEERING

AI is making significant strides in geotechnical engineering, providing new insights and precision in dealing with complex tasks. While AI enhances engineers' capabilities, it complements, rather than replaces, human expertise.

3.3.1 SOIL ANALYSIS AND BEHAVIOR PREDICTION

Soil Behavior Prediction: AI models, especially adaptive neuro-fuzzy inference systems, are improving predictions of soil behavior (Besalatpour et al., 2012). These systems analyze intricate interactions between soil particles, water, and environmental factors to offer more precise assessments, helping engineers with tasks such as foundation design and slope stability evaluations.

Soil Classification: AI is streamlining the soil classification process, a fundamental task in geotechnical engineering. Machine learning algorithms can quickly classify soils based on their properties, often more quickly and accurately than manual methods, speeding up site investigations and improving design reliability (Srivastava et al., 2021).

Material Property Prediction: AI is also helping predict the properties of geotechnical materials like soil and rock. Machine learning models estimate characteristics such as shear strength and compressibility, reducing the need for extensive laboratory testing and providing faster, reliable data for design (Zhu et al., 2022).

3.3.2 DESIGN AND ENGINEERING APPLICATIONS

AI is reshaping how construction sites are organized. AI-powered systems can quickly analyze potential sites and generate 3D models

Foundation Design Optimization: AI is transforming foundation design. By simulating complex interactions between soil and structures, AI can account for variables like soil type, groundwater conditions, and dynamic loads, leading to more reliable and efficient designs, particularly in challenging terrains (Alam et al., 2024).

Settlement and Bearing Capacity Prediction: AI models offer more accurate predictions for soil settlement and bearing capacity, analyzing a wide range of factors and learning from historical data to provide engineers with reliable estimates for designing foundations and other structures (Moayedi et al., 2020).

3.4 AI IN TRANSPORTATION ENGINEERING

AI is transforming transportation engineering, paving the way for smarter, safer, and more efficient mobility systems. From managing traffic to optimizing logistics, AI's role in transportation is creating a future that's not only more efficient but also safer and sustainable.

3.4.1 SUPPLY CHAIN MANAGEMENT

Traffic Management and Congestion Reduction: AI is revolutionizing how we manage traffic flow. By analyzing real-time data from sensors, cameras, and connected vehicles, AI systems can adjust traffic lights, predict bottlenecks, and recommend alternate routes to ease congestion (Akhtar & Moridpour, 2021). The result is smoother traffic, shorter travel times, and a better experience for commuters.

Real-time Route Planning: AI is improving navigation by considering live traffic conditions, weather, and user preferences to suggest the best routes (W.-C. Hu et al., 2020). This not only helps individual drivers but also optimizes traffic flow across entire transportation networks.

Smart Parking Systems: AI is making parking in cities easier. Smart parking systems use AI to direct drivers to available spots, reducing time spent searching and cutting down on fuel consumption (Diaz Ogás et al.,

2020). Some systems can even predict parking availability based on historical patterns.

3.4.2 VEHICLE AND INFRASTRUCTURE SAFETY

Autonomous Vehicles: One of the most visible applications of AI in transportation is autonomous vehicles (Khayyam, Javadi, Jalili, & Jazar, 2020). AI helps these vehicles interpret their surroundings, from traffic signals to obstacles, ensuring safe navigation. As technology continues to evolve, autonomous vehicles are expected to drastically reduce traffic accidents and improve overall road safety.

Safety Enhancement: AI is enhancing road safety by analyzing data on road conditions, weather, and historical accidents (Gutierrez-Osorio & Pedraza, 2020). AI-powered systems can identify high-risk areas and suggest preventive measures, such as adjusting speed limits or deploying emergency services in advance.

Infrastructure Risk Assessment: AI is helping assess risks to transportation infrastructure by analyzing factors like soil conditions, weather, and geological data (Wang et al., 2022). It can predict risks such as slope failures or structural weaknesses, allowing engineers to prioritize repairs and reinforcements.

3.4.3 PUBLIC TRANSPORTATION AND SUSTAINABILITY

Public Transportation Optimization: AI is making public transportation more efficient. By analyzing ridership data, AI can predict demand, optimize routes, and schedule buses and trains more effectively (Kozlov, 2022). This leads to better service for passengers and cost savings for transit agencies.

Emissions Reduction: AI is contributing to cleaner air by optimizing traffic flow, which reduces vehicle emissions (Dikshit et al., 2023). Some AI systems even adjust traffic patterns to minimize emissions in environmentally sensitive areas, helping cities reduce their carbon footprint.

3.4.4 MAINTENANCE AND PLANNING

Predictive Maintenance: AI is improving how we maintain transportation infrastructure. By monitoring roads, bridges, and other structures through embedded sensors, AI can detect signs of wear and predict when maintenance will be needed (Baduge et al., 2022). This proactive approach helps avoid sudden failures, reducing repair costs and preventing disruptions.

Agent-Based Modeling: AI enables advanced simulations like Agent-Based Modeling (ABM), which predicts traffic patterns by simulating the actions of individual vehicles and pedestrians (Prédhumeau et al., 2022). This helps transportation engineers design better systems and plan for changes in infrastructure.

3.5 AI IN ENVIRONMENTAL ENGINEERING

AI is driving a shift towards more sustainable and efficient environmental practices, offering new solutions to some of the most pressing ecological challenges we face.

3.5.1 RESOURCE MANAGEMENT

Water Resource Management: AI is improving how we manage water resources by analyzing data on weather, population trends, and water consumption. AI helps forecast demand and optimize water distribution, reducing leaks and ensuring efficient use of this precious resource (Krishnan et al., 2022). AI-driven sensors also monitor water quality, detecting contaminants in real-time to prevent health risks (Popescu et al., 2024). In wastewater treatment, AI is enhancing energy efficiency, making the entire system more sustainable.

Energy Efficiency in Buildings: AI is leading advancements in building energy management by powering smart systems that adapt to occupancy patterns, adjusting heating, cooling, and lighting accordingly (Yan et al., 2021). These systems minimize energy waste and reduce operational costs. AI also helps anticipate maintenance needs, preventing malfunctions that could waste energy.

3.5.2 SUSTAINABILITY AND EMISSIONS REDUCTION

Carbon Emission Reduction: AI is a key tool in reducing carbon emissions across industries. In construction, AI evaluates the environmental impact of materials and helps engineers choose sustainable options. AI-powered environmental monitoring systems track emissions, air quality, and pollution sources, allowing for quicker responses (Popescu et al., 2024). In the energy sector, AI integrates renewable energy sources into grids more efficiently, helping us transition to cleaner energy (Ahmad et al., 2021).

Sustainable Construction: AI is pushing the construction industry toward sustainability by analyzing the environmental impacts of building materials and optimizing designs for energy efficiency. AI-driven simulations help engineers consider the entire lifecycle of a building, from construction to eventual demolition, ensuring that sustainability is embedded in every phase of the project (Adewale et al., 2024).

3.5.3 ENVIRONMENTAL MONITORING AND PROTECTION

AI is transforming environmental conservation. AI-driven drones and satellites monitor pollution levels, detect illegal activities, and track changes in wildlife populations (Haq et al., 2024). In forest management, AI helps assess risks like deforestation or forest fires by analyzing satellite data in near real-time.

3.5.4 WASTE MANAGEMENT

AI is improving waste management by automating sorting processes and making recycling more efficient. AI-powered systems identify and sort recyclables quickly and accurately (Reza & Hassan, 2023). These tools also optimize waste collection routes based on predicted waste generation, reducing fuel consumption and making the entire process more eco-friendly. Additionally, AI improves hazardous waste management by analyzing data on chemical interactions and environmental risks to ensure safe disposal (Ye et al., 2020).

4 RECENT ADVANCEMENTS AND CASE STUDIES

These examples and case studies demonstrate how AI is transforming civil engineering, influencing areas such as structural safety, urban planning, and construction processes. AI is quickly proving to be a crucial tool in developing more efficient, sustainable, and resilient infrastructure. As AI technology continues to evolve, we can expect even more innovative uses in civil engineering soon.

For example, AI-powered sensors and data analysis are being utilized for real-time structural health monitoring. One notable instance is the Golden Gate Bridge in San Francisco, where an AI-based system with sensors and machine learning algorithms detects subtle changes in the bridge's structure, enabling predictive maintenance and early problem detection (Abdeljaber et al., 2017).

AI is also improving construction site monitoring and safety. Komatsu, a Japanese construction equipment company, has rolled out an AI system called "Smart Construction" at various sites (Komatsu, 2021). This system uses drones and AI to create 3D models, track progress, and identify safety risks in real-time, significantly enhancing both safety and efficiency.

In the realm of urban planning, AI is optimizing traffic flow. The city of Pittsburgh, Pennsylvania, has implemented Surtrac, an AI-powered traffic control system that adjusts traffic lights in real time based on current conditions (Smith et al., 2013). This has reduced travel times by 25% and idle time at red lights by 40%, showcasing how AI can streamline urban development.

AI is also being employed to optimize building designs for energy efficiency. Autodesk's generative design tool, "Project Discovery," was used in the design of the MaRS Innovation Complex in Toronto (Autodesk, 2017). The tool generated thousands of energy-efficient design options, ultimately reducing the building's energy consumption by 70%.

In the area of disaster mitigation, AI is being applied to predict and respond to natural disasters. Researchers in Japan have developed an AI system capable of predicting tsunami flooding within seconds (Makinoshima et al., 2021). Tested with data from the 2011 Tohoku earthquake and tsunami, this system offers a promising solution for early warnings in coastal areas.

AI is also advancing the development of new construction materials. Researchers at MIT, using machine learning, have created "super steel," a lightweight yet ultra-strong material that is twice as strong as traditional steel (Ling et al., 2017). This innovation has the potential to significantly improve the durability of buildings.

Additionally, AI is revolutionizing project management through tools like AI-powered Building Information Modeling (BIM). Skanska, a global construction company, used AI-enhanced BIM on projects like the New Karolinska Solna University Hospital in Stockholm (Skanska, 2018). The system improved clash detection, scheduling, and cost estimation, resulting in significant savings in both time and money.

Lastly, AI-controlled construction machinery is boosting safety and efficiency on job sites. Built Robotics has developed AI software that can be retrofitted to existing construction equipment, turning them into autonomous machines (Robotics, 2021). These machines have been deployed on construction sites across the U.S., leading to increased productivity and safety.

5 CHALLENGES AND LIMITATIONS

5.1 CHALLENGES

Applying AI in civil engineering comes with its share of challenges, despite its many benefits. The complexity of civil engineering projects often leads to incomplete or noisy data, which can limit how effectively AI models work (Huang & Fu, 2019). Gathering large, high-quality datasets is also tough due to the varied nature of construction sites and projects, making it harder to build reliable AI models.

The ever-changing and intricate conditions of civil engineering projects make it difficult for AI models to predict outcomes accurately. Handling real-time data for immediate decisions can also be technically demanding.

Integrating AI with traditional engineering practices requires significant expertise and investment (Mun et al., 2020). This integration is complicated by the need for specialized knowledge in both civil engineering and AI. Challenges include potential biases in AI algorithms if they aren't well-designed and trained, difficulties in understanding some AI models due to their "black box" nature, and resistance to adopting new technologies in a traditionally conservative industry.

Many civil engineering firms rely on legacy systems that might not easily integrate with AI tools, leading to compatibility issues (Weber-Lewerenz, 2021). Ensuring AI applications work smoothly with existing software and workflows can be a struggle. Additionally, implementing AI solutions requires specialized

knowledge that may not be readily available, necessitating extensive training for staff.

There's also a pressing need for more robust AI frameworks to handle the uncertainties of large-scale civil engineering projects (H. Hu et al., 2024). Ethical and liability concerns about AI decision-making in critical infrastructure add to the complexity. Barriers to adoption include a lack of understanding, resource constraints, and resistance to change. AI algorithms may incorporate human biases, leading to potentially skewed results.

Navigating compliance with industry standards and evolving regulations can be challenging. AI systems must be designed and used responsibly, with careful attention to ethical issues such as bias and fairness. Understanding how complex AI systems make decisions can be tough, especially when things go wrong. Moreover, AI brings potential security risks, like AI-powered cyberattacks or manipulation of autonomous systems (Yamin et al., 2021). Addressing data privacy, infrastructure needs, and the integration of AI with existing networks is crucial for successful AI implementation in civil engineering.

5.2 LIMITATIONS

AI models rely on historical data for predictions, which can lead to potential limitations (Groumpos, 2023). They may overlook unexpected changes or new factors in a project, and there's a risk of these models being overly dependent on past data that may not accurately reflect future conditions.

The development and implementation of AI solutions can be financially challenging, especially for smaller firms, due to high initial costs and ongoing expenses for maintenance and updates (Hansen & Bøgh, 2021). Many AI systems operate as "black boxes," making it difficult to understand their decision-making processes, which can hinder trust and adoption.

While AI is a powerful tool for decision-making, it doesn't eliminate the need for human judgment, particularly in complex or novel situations. AI tools often require customization for specific projects, potentially limiting their flexibility and effectiveness across various areas of civil engineering (Y. Pan & Zhang, 2021).

AI systems are also susceptible to failures or errors, especially in unexpected or extreme conditions. Over-reliance on AI might inadvertently reduce engineers' critical thinking and problem-solving skills over time (George et al., 2024).

Addressing these challenges and limitations necessitates ongoing research, development, and collaboration among civil engineers, data scientists, and AI specialists. This interdisciplinary approach is crucial for developing more robust, transparent, and adaptable AI solutions for civil engineering applications.

6 FUTURE DIRECTIONS

The future of AI in civil engineering holds immense promise. With ongoing advancements in machine learning, big data analytics, and computational power, innovation is accelerating. As AI becomes more intertwined with emerging technologies like internet of things (IoT), cloud computing, robotics, and augmented reality, it's poised to transform the field (Forum, 2018). This combination will lead to smarter infrastructure management, real-time monitoring of energy use, traffic flow, and environmental impacts, while also streamlining construction processes.

AI has the potential to make civil engineering practices more sustainable by optimizing resource usage, cutting carbon emissions, and reducing construction costs—some projections estimate up to a 20% cost reduction (Company., 2017). Additionally, advancements in AI models will allow for more sophisticated approaches to balancing efficiency, cost, and environmental concerns, especially in construction and urban planning.

For civil engineers, this growing reliance on AI means acquiring new skills, particularly in areas like AI and data analytics. At the same time, there will be a strong focus on making AI more transparent, with an emphasis on explainable AI to build trust in AI-driven decisions and processes.

However, to fully unlock AI's potential, certain hurdles need to be addressed. These include ensuring AI technologies are used ethically and responsibly, tackling issues like data quality, system integration, and the transparency of algorithms (Commission, 2020). Continued research and development, along with the thoughtful and ethical deployment of AI, will be key to reshaping civil engineering, from the design phase through construction and ongoing maintenance.

As AI continues to evolve, its influence in civil engineering will grow, opening new opportunities to enhance safety, reduce costs, and promote sustainability. Ultimately, AI will play a critical role in shaping the future of smart cities and modern infrastructure.

7 CONCLUSION

AI is rapidly transforming civil engineering by providing advanced tools for design, analysis, and project management. These technologies help engineers tackle complex challenges in construction, maintenance, and optimization. From monitoring structural health to managing projects and improving transportation systems, AI applications like machine learning, neural networks, and computer vision are making projects more accurate, efficient, and sustainable.

However, challenges such as data dependency, model interpretability, and integrating AI into existing workflows remain. Addressing these hurdles is essential for AI to reach its full potential. Looking ahead, advancements in machine learning, deep learning, and

predictive analytics promise to make civil engineering even safer and more efficient.

As AI merges with technologies like the Internet of Things (IoT), cloud computing, robotics, and augmented reality, it will pave the way for smarter, more resilient infrastructure that meets modern demands while promoting environmental sustainability.

AI is poised to become indispensable in civil engineering, driving improvements in design, planning, construction, and maintenance. Although issues like data availability and industry adoption need attention, the potential benefits in cost savings, safety, and efficiency are immense. Future research should focus on integrating AI with these emerging technologies to revolutionize the field further.

In conclusion, AI offers vast opportunities for civil engineering, but thoughtful implementation is key. With the right approach, AI will play a major role in creating smarter, safer, and more sustainable infrastructure, transforming industry.

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A Review of Absorbent Properties Derived from Low-Cost Materials and Banana-Stem

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Abstract

Wastewater treatment methods have become expensive making it necessary to seek cost effective treatment. Adsorption is one of these methods that offer relief to the huge cost of municipal wastewater treatment methods. It is made possible by adsorbents materials from agricultural wastes that are accessible, affordable, available and sustainable. The agricultural wastes materials are locally sourced corncobs, coconut husks, rice husks, banana peels and stems. Adsorbents properties of carbon-originated activated carbons is of prominent impact on the final product properties, have good pore size volume and distribution, hardness, and purity. Banana stems was converted through a combination of physical and chemical activation processes to adsorbent material and used as activated carbon to remove organic compounds from water. Analysing the influence of a solution pH level to removal efficiency of methylene blue using banana stem as adsorbent at room temperature, Efficient removal of methylene blue (>99%) was achieved using banana stem-derived activated carbon under optimized conditions. It also reduced water hardness level to 43.56% at time variation of 240 minutes with a thickness of 5 cm on average decreased level of 160.8 mg/L. The longer the contact time of the water sample and the activated carbon, the higher the ability of the media to reduce water hardness. Banana stem was found to possess sufficient adsorptive properties for removal of Pb (II) from aqueous solutions. Pb (II) adsorption to this absorbent was dependent on its initial concentration, adsorbent dosage, temperature, contact time and pH of media.

Keywords: Activated Carbon, Adsorbent, Adsorption, Banana-stem, Wastewater.

1. INTRODUCTION

Increase in anthropogenic activities have led to an increase in the release of organic compounds and contamination of water available for consumption. The search for cost effective adsorbents is necessary especially now the world is experiencing dwindling financial resources. Adsorption is recognized as one of the processes or means to achieve this advanced treatment technology that offers simplicity and cheap alternatives to water treatment technologies especially when low-cost adsorbents like industrial by-products, agricultural waste and other municipal waste, are utilized (Eniola J.O., *et al.,* 2023). Mordhiya B. *et al.,* (2024) used plant waste dead bark of Azadirachta indica plant and activated with phosphoric acid to remove cationic dye methylene blue (MB) from an aqueous solution. The repeated recyclability study performed was in four successive cycles which established the stability and reusability of the adsorbent that retained almost 90% adsorption ability after fourth round of reuse. Salman *et al.,* 2011 used wood to produce activated carbon and the activated carbon characteristics were reported as fixed carbon (59.7%), volatile matter (22.13%), ash (10.5%) and moisture (4.5%). Adsorption (alizarin yellow) data described the Freundlich isotherm, indicating the multilayer adsorption.

Absorbents materials

There are different types of adsorbents that can be classified into natural or synthetic adsorbents. Charcoal, clays, clay minerals, zeolites, and ores are some of the natural adsorbents. They are relatively available, abundant, and less expensive with the potential to be modified and to enhance their adsorption abilities. For synthetic adsorbents, they are mostly adsorbents prepared from agricultural wastes and by-products, industrial wastes, sewage sludges, household wastes and polymers. Each of these adsorbents has its unique adsorbent surface nature, porosity and pore structure. Some of the wastes used are saw dusts, sugar industry wastes, fruit waste, used tires, coconut husks, date nuts, tree bark, rice husk, fly ash, petroleum waste, fertilizer waste, blast furnace slag, chitosan, seafood processing wastes, algae, peat, clays, mud, zeolites, sediment, soil and ores, etc (Rashed N, 2013).

The application of advanced materials for the removal of organic compounds from water and wastewater can be explored from three main perspectives of activated carbon (AC), clays and biochar. Other recent methods and materials that have been reported are molecular imprinted polymers (MIPs), magnetic nanoparticles and

thermo-responsive gel, which are still nascent (Patel *et al.,* 2019). Presently, several materials can be used as adsorbents in the removal of impurities like organic and inorganic pollutants from wastewater. They include activated carbon, biosorbents from agricultural and industrial wastes, polymeric matrices, biomass and chitosan including inorganic matrices like clay soils, zeolites, alumina, mesoporous silicas, and hybrid nanoporous solids.

Of all the various types of adsorbents, carbon-originated materials particularly activated carbon is the most applied and popular adsorbents, widely produced from biomass (Aragaw and Bogale, 2021) for commercial use. The raw material used has a prominent impact on the final product properties, including pore size volume and distribution, hardness, and purity. Therefore, the purpose of this review is to compile recent relevant studies on adsorption process using low-cost agricultural wastes for organic pollutants such as dye, oil and phenols removal from water and wastewater. These studies revealed the great efficacy of the adsorption method and buttressed the potential use of agricultural wastes for this goal and showed the optimal performances of the activated carbon compared to other most used adsorbents.

Activated carbon

The acceptability of activated carbon is based on its physical characteristics, mainly, bulk density, high surface area of up to 1100 m^2/g, pore volumes of 0.40 cm^3/g, low ash content and conductivity. Activated Carbon is made up of micropore-dominant structure with a very high microporous or internal and external surface (Ronny *et al.,* 2019). In addition, its surface functional groups provide the required binding sites for efficient adsorption of pollutants in water. Activated Carbon has effective adsorption capacity on several hydrophobic organic contaminants to heavy metals. It can be produced commercially by or from pyrolysis of any carbon-containing plant materials like bamboo wood, coal, charcoal, kernels, or coconut shells and other fruit shells (Aragaw and Bogale, 2021).

Nevertheless, activated carbon is not foolproof, it has some disadvantages of nonuniform porous structure or tangled porous networks, including poor selectivity and ineffectiveness in removing new emerging organic pollutants from water due to unfavourable kinetics and even a lack of complete removal at low concentrations of pollutants. In addition, regeneration and recovery of the adsorbent can be a challenge (Isaeva *et al.,* 2021). Serafin J. & Dziejarski B. (2023) published that activated carbon is one of the most important forms of carbon with a high surface area (85% to 95% approximately by weight of elemental carbon) and a huge volume of micropores, and a specific surface area that can reach as high as 3000 m^2/g.

Structure of activated carbons significantly impact its substances absorption abilities (Richika *et at.,* 2023). Activated carbon describes a carbon material exposed to the activation of its surface or modification of its structure through metal oxide deposition or functionalization for specific applications. Activated carbons are porous carbons although not all porous carbons are activated carbons (Serafin J. & Dziejarski B. (2023). Porosity of porous carbons covers a wide expanse of pore sizes but activated carbons especially microporous materials. At times, the confines between porous carbons and activated carbons may not appear clear, mostly during processing and application perspectives. Originally, activated carbon was produced from charcoal and or coal. For sustainability and cost considerations, agricultural waste and other renewable resources are now intriguing in making activated carbon.

2. PROCESSING TECHNIQUES

Production of activated carbon begins from the dehydration of raw materials, carbonization, and activation, which increases the diameter of the pores and creates other pores (Alves *et al.,* 2021). Activated carbon resources are produced through firstly, the pretreatment of (biomass) raw materials, followed by carbonization, and finally activation. Majority of the solvable impurities and nutrients are removed by pretreatment process (Misran *et al.,* 2021). Organic lignin and cellulose are transformed to carbonaceous materials during carbonization process including a reduction in the amount of sulphur, hydrogen, oxygen, other elements, nutrients and water. Carbon loss may occur during carbonization process as a result of heating to high temperatures of 400°C and above. Grains in the raw materials are dehydrated with increase to higher temperatures, while oxygen is thereafter released in forms of CO, CO_2, and H_2O. This reaction by-products facilitate the subsequent activation reactions process that follow which, however, can be conducted at the same time. Biochars, which is the main carbonaceous material is usually activated by either physical activation (PA), or chemical activation (CA) approach.

2.1 Physical Activation

A raw material is activated in the temperature range of 750 - 1000 °C in the physical activation process. This usually occurs in a vacuum or inert gas atmosphere.

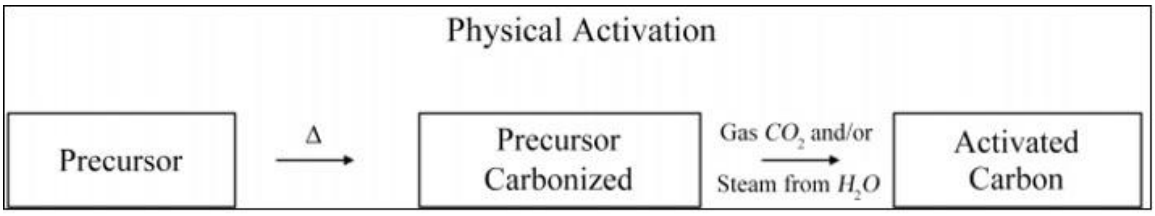


Figure 1. Illustration of Physical activation process patterned after Alves *et at.,* (2021).

2.2 Chemical Activation

Chemical agents are incorporated into raw materials in the chemical activation process which are heated up together in an inert gas, and simultaneously, carbonization and activation occur. Going by Soonmin Ho & Kabbashi N. A (2021), The challenges associated with chemical activation of carbon is a washing step followed by drying required to remove byproducts after chemical activation. This washing, followed by drying that can require some time. Alves *et al.,* (2021) reported the advantage of chemical activation as providing activated carbon with a larger contact area and a more advanced or developed pores, different from thermal activation with its carbon having a smaller area which in turn reduces the surfaces used for adsorption.

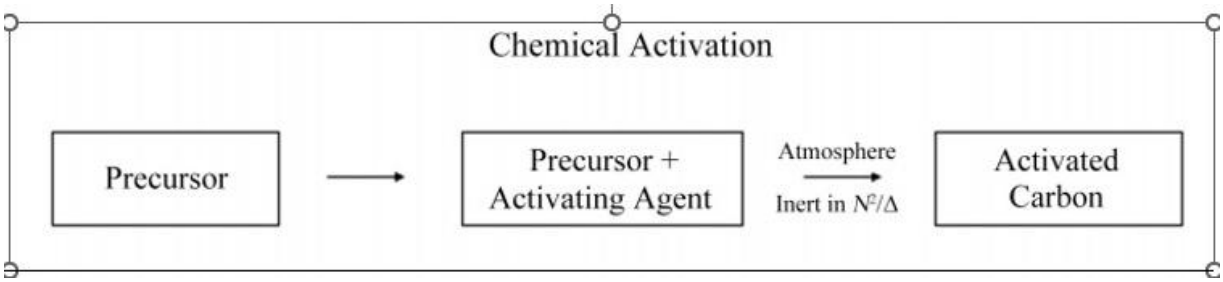


Figure 2. Illustration of Chemical activation process patterned after Alves *et at.,* (2021).

Serafin J. & Dziejarski B. (2023) reported an example of 25 wt.% ammonia used to hydrothermally treat wood in lignin removal. The hydrothermal processing temperature was at 190 °C for 6-to-8-hour duration before the process of carbonization in a vacuum. Succeeding the ammonia treatment, was the heat treatment of the wood at 900 °C for 8 to 10 hours in a vacuum. The carbon was then soaked in a saturated KOH solution between two to three days before finally heat treating the carbon at 750 °C for 8 – to - 10 hours. An activated carbon with a clear three-dimensional (3D) structure was then obtained after it was rinsed by HCl solution and cleaned by water. Chemical activation method involves two stages taking place concurrently, along with the chemical activating agents combining with the precursor to improve performance (Soonmin Ho & Kabbashi N. A., 2021). Normal agents used for activation are mainly salts, acids or bases but includes include KOH, K_2CO_3, $ZnCl_2$, and $CaCl_2$.

Some Applications of Activated Carbon

Waste apricot plants from Malatya as activated carbon using a batch adsorption process was used for removal of naproxen (pharmaceutical residue) An almost total elimination was observed when temperature was increased to 50 °C for a 100 mg/L solution. Also, the use of green synthesis of silver-reduced graphene (Ag-RGO) as activated carbon performed well at 92.62% removal of another pharmaceutical residue - naproxen NPX of 20.2 mg at 24.25 °C temperature and 4.5 pH (Mansouri

et al., 2021). Activated carbon were also exploited in the removal of ibuprofen according to Guedidi *et al.*, (2017) by Kuraray Chemical Co. Ltd., (Japan) where they analysed the removal of the drug using distilled water and reported their elimination efficiency depended on the decrease of pH. Olive waste cake as activated carbon has been used to achieved adsorption of diclofenac drug.

Akbar N. A., *et. al.* (2019) reported activated carbon as widely used in adsorption process because of its porous structure and large surface area with a high adsorption capacity. For large scale use, activated carbons have been produced from non-renewable sources, examples are coal, peat, wood coal, palm oil mill effluent (pome). These contain high carbon substance, a high permeability, as well as a low mineral substance, which made them suitable as activated carbon pioneers (Soonmin & Kabbashi 2021). Rashed M. N. (2013) classified different types of adsorbents into natural adsorbents and synthetic adsorbents. The natural materials are charcoal, clays, clay minerals, zeolites, and ores which are relatively abundant, cheap to supply with potential for enhancement and modification of their adsorption capabilities. Synthetic adsorbents are made from agricultural products and wastes, (household, Industrial, sewage sludge and polymeric adsorbents) with each having its own characteristics like pore structure, adsorbing surfaces and porosity. They include sawdust, rice husk, fruit wastes, scrap tyres, coconut shell, bark and other tannin-rich materials, petroleum wastes, fertilizer wastes, fly ash, sugar industry wastes blast furnace slag, chitosan and seafood processing wastes, algae, seaweed and peat moss, red mud, clays, zeolites, sediment, ore minerals and soil.

Lillo-Rodenas M.A. *et. al.*, (2005), in Rashed M. N. (2013) studied adsorption of methane on granular activated carbon (GAC). Their results indicated that with increasing methane uptake by GAC or decreasing temperature, the adsorption efficacy decreased. Interactions between the surface of carbon and the methane molecules increase the density of methane adsorbed in respect to the density of compressed gas. The effect that the porosity and the surface chemistry of the activated carbons have on the adsorption of two volatile organic compounds (VOC) (benzene and toluene) at 200 ppm (low concentration) were equally studied. Their results indicated that the volume of narrow micropores (size <0.7 nm) seems to govern the adsorption of VOC at low concentration, especially for benzene adsorption. The study stated that AC with low content in oxygen surface groups is best in adsorption capacities. Amongst AC tested, those prepared by chemical activation with hydroxides exhibited higher adsorption capacities for VOC. Their adsorption capacities achieved are higher than those previously shown in the literature for these conditions, especially for toluene. Adsorption capacities as high as 34g benzene/100g AC or 64g toluene/100 g AC have been reported achieved. Soonmin & Kabbashi (2021) reviewed activated carbons produced by employing various precursors under activation process and carbonization process. They reported an extensive survey of preparation, properties and adsorption of pollutants in wastewater treatment using activated carbon from 2000 to 2020 which investigated adsorption capacity and equilibrium data of different pollutants (dyes, oil, grease wastewater, organic pollutants, pesticides, herbicides, heavy metal ions, lignin and tannin colour). Activated carbons are also effective against oil and grease. Oil and grease adsorption from simulated refinery desalter effluent by activated carbon produced from chemical carbonization of corn cobs (CACC) was investigated by Igwegbe *et al.*, (2021) through fixed-bed column studies which revealed that corncobs packed in a fixed-bed column was effective in reduction of oil and grease from refinery desalter effluent.

Banana Stem as Locally Sourced Adsorbents

Efficient techniques exist for the removal of highly toxic organic compounds from water and wastewater. Some of these methods are filtration, coagulation, precipitation, ion exchange, reverse osmosis, ozonation, adsorption, and advanced oxidation processes used for the removal of organic pollutants from water and wastewater. The high capital and operational costs of these methods are their limitations (Rashed M. N., 2013). Amongst these methods, adsorption by solid adsorbents has potential as one of the most efficient methods for the treatment and removal of organic contaminants in wastewater treatment. Adsorption is advantageous over the other methods because of its simple design and low investment cost (initial cost and land required). Adsorption is used extensively in treatment of industrial wastewater from organic and inorganic. In recent times, the quest for low-cost adsorbents with pollutant binding capacities has increased. Locally accessible and available materials such as agricultural wastes and industrial wastes are being utilized as low-cost adsorbents. Activated carbon produced from these materials can be used as adsorbent for water and wastewater treatment (Crini G., 2005), hence the benefits and importance of banana stem.

When it comes to locally available and cheap absorbents or organic compounds, banana stem has not been wildly used and reported like many agricultural wastes like rice husks, corn cobs coconut husks, tree barks, etc. Banana stem has an adsorbent potential because many banana stems contain carbonic hydrate or carbon (Ronny *et al.*, 2019). Misran. E. *et al*., (2021) produced activated carbon from the banana stem to contribute to the conservation of the environment by preservation in removing methylene blue from wastewater. This method of adsorption using banana stem was reported effective and cost effective without producing harmful by-products to harm the environment. Their use of activated carbon from banana stem was produced via pyrolysis at moderate temperature with short pyrolysis time to remove methylene blue solution which had not been previously reported. Their pyrolysis was performed at 900 *C for 30 minutes in which the best results were achieved.

Banana is a perennial crop that takes the appearance of a tree as it matures. Banana, (*Musa paradisiaca), is* a fruit type that grows on a large herbaceous plant, native to Southeast Asia. It is among the world's widely grown and most popular fruit, with many varieties being cultivated for both home and commercial use. Banana stem is a non-woody and herbaceous part of the banana tree. It is that fibrous stalk of the banana plant that has high water content with a fresh and crispy texture with mild taste (Mehak Shah, 2023).

It is grown across all tropical regions and, Nigeria in 2021 produced above 2.74 million metric tonnes of bananas, which globally ranked it 15th. However, domestic consumption still outweighs supply by over 650,000 metric tonnes that is met through annual imports (SME Guide, 2022). Moreover, the fruit only weights approximately 12% of the entire plant, therefore generating a huge amount, about 220 tons per hectare of waste residues, that is the stems, leaves, and rachis during production. Banana stems and leaves are normally abandoned in the farm after harvesting the fruits, which take months to naturally degrade. The banana stem is lignocellulosic in nature, comprising of 35 – 40% cellulose, 25 – 35% hemicellulose, and 8 – 13% lignin17 which makes it a suitable as a raw material for producing absorbents for removal of organic compounds from water and wastewater (Xiyang *et. al.*, 2022).

Bananas are one of the most well-known and important plants in the world. Every part of this plant namely fruit, leaves, flower bud, trunk, and pseudo-stem can be useful. Researchers have used Banana Pseudo as an alternative face mask, and its use will financially benefit farmers (Villatema, *et al.*, 2021). The pseudo-stem fiber of the banana plant is similar to that of the pineapple leaf, sisal, and other hard fibers, but the pseudo-steam fiber is slightly more elastic (Villatema *et al.*, 2021). Lavanya M. *et al.*, (2021) used banana peels and a combination of onion, garlic, pawpaw tomato, potato orange peels for the removal of different organic and inorganic contaminants from aqueous effluents. Bio absorbent was produced from fruit and vegetable peels that replaced other absorbents on mechanism of ion exchange, physical absorption and precipitation process with high efficiency that removed heavy metals too.

The conversion of banana stems to activated carbon involves a combination of physical and chemical activation (Taer E. *et al.*, 2018). Misran E. *et al.*, (2018) prepared activated carbon from banana stem waste through chemical activation via phosphoric acid. That study focused on analysing the influence of solution pH to removal efficiency of methylene blue using banana stem as adsorbent. Room temperature, 90 minutes, 0.2 g (activated carbon), 100 mL methylene blue solution and constant rate (100 rpm) produced higher removal efficiency (>99%) that was observed. Ronny *et al.*, (2019) produced activated carbon charcoal from banana stems which were used significantly to reduce water hardness level. The banana charcoal adsorption process reduced the water hardness level to 43.56% at time variation of 240 minutes with a thickness of 5 cm on average decreased level of 160.8 mg/L. The longer the contact time of the water sample and the charcoal, the higher the level of decrease in total hardness, that is the higher the ability of the media to reduce hardness.

Ogunleye (2014) produced and examined activated carbon from banana stalk to possessed adequate adsorptive properties for removing Pb (II) from aqueous solution which depended on the initial Pb (II) concentration, contact time, temperature, pH and adsorbent dosage. The adsorption capacity increased with increase in initial Pb (II) concentration, temperature, contact time, and pH but decreased with increase in adsorbent dosage. The maximum adsorption capacity was 200mg/g at pH (8) and 250mg/L initial concentration, that was a fast kinetic process reaching equilibrium at 120minutes and concluded that Banana stem is effective and efficient in Pb (II) removal from its aqueous solution.

Akbar N. A., *et al.*, (2019) found banana stem adsorbent as having the capability to remove colour from textile wastewater. At optimum

dosage of 1.0 g in 100 mL synthetic sample within 90 minutes contact time, it removed 91.12% of colour (figure 3). It observed that the adsorption process of colour fitted to the Freundlich model rather than Langmuir model; adsorption kinetic of colour showed that pseudo-second order fit better than pseudo first order

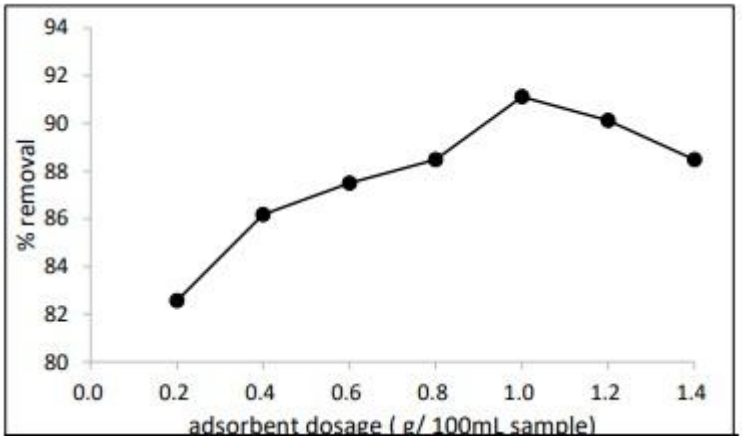


Figure 3. The effect of varied adsorbent dosage (Akbar N. A., *et al.,* (2019)).

kinetic model; chemisorption as the adsorption mechanism responsible for colour removal from textile wastewater sample. The optimum colour removal was 91.12 % at 1.0 g of banana stem adsorbent in 100 mL of synthetic sample. This indicates that banana stem is effective and is a low alternative cost medium for wastewater removal. Pawar *et al*., (2023) employed modified banana pseudo stem (MBPS) adsorbent for Pb (II) adsorption using column studies. The physicochemical and structural characteristics of the developed adsorbent were determined by the SEM-EDX, FT-IR and BET analysis to understand its crystalline structure, functional groups and elements present including surface area of the material. They reported flow rate of the feed to column equalling 5 mL/min, and 49% removal compared to higher flow rates. The lower the flow rate, the higher the removal of Pb percentage. So, for the initial concentration of 50 mg/L of Pb (II), high removal is achieved compared to (>50 mg/L) for the bed height of adsorbent 6 cm. It is found that the Thomas model was used and fitted well to experimental data for Pb (II) adsorption on porous MBPS. The spent adsorbent was also reused for successive two cycles after the adsorbent was regenerated making MBPS an excellent material for the treatment of industrial effluent samples or wastewater.

Mohammed D. *et al.,* (2018) studied the optimization of banana trunk-activated carbon preparation conditions (activation time, activating agent concentration (H_3PO_4), and temperature). This was done to obtain better activated carbon for removal of methylene blue. They used central composite design of response surface methodology (RSM) approach, and the adsorption capacity of activated carbon was calculated as a response. The optimum points for: H_3PO_4 concentration, activation time and activation temperature were found to be 5.09 mol/L, 51 min and 774 °C. With these conditions, the activated carbon prepared from banana trunk had a maximum adsorption capacity of 64.66 mg/g. Banana stem has the capacity to be applied to many things. For example, Taer E. *et al*., (2018) produced activated carbon electrodes from a banana stem used as a supercapacitor for cell applications that was successfully performed. Xiyang *et al.,* (2022) investigated the isotherms and adsorption kinetics of Cd^{2}+ and Pb^{2}+ in aqueous solutions at different pH by biochar prepared from banana stem and leaf (BSL-BC) at 400 °C. The biochar is the green adsorbent generated from biomass feedstock (banana stem and leaf) was effective in removal of these heavy metals (Lead (Pb) and cadmium (Cd)) which are toxic and commonly found in aqueous environments.

Banana stem activated carbon (BSAC) was produced from banana stalk by Ogunleye *et al.,* (2014) which possessed sufficient adsorptive properties for removal of Pb (II) from aqueous solutions. Pb (II) adsorption to the BSAC was dependent on its initial concentration, adsorbent dosage, temperature, contact time and pH. The adsorption capacity decreased with increased

adsorbent dosage but increased with an increase in the initial Pb (II) concentration, contact time, pH and temperature. Maximum adsorption capacity recorded was 200mg/g at 250mg/L initial concentration and pH (8). The adsorption process attained equilibrium at 120minutes making it a fast kinetic process. The data was subjected to pseudo first order, pseudo second order and intra particulate models, with results showing that the pseudo second order model best fitted the adsorption kinetic. Freundlich, Langmuir, Temkin and Dubinin–Radushkevich (D–R) isotherm models were used to analyse the equilibrium adsorption data, which showed that the Langmuir isotherm model fitted the best (R2) 0.998 correlation.

3. CONCLUSION

The absorbent materials ability to remove organic compounds from wastewater has been reviewed and shows great potentials. It justified the importance of using alternative adsorbents materials for effluent treatment, indicating that adsorption is preferred as the most practicable, environmentally friendly and economical technique applicable. Under this orbit, banana stem demonstrated superior cost-efficiency and adsorption capacity, particularly for Pb(II) and methylene blue removal. The studies reviewed here showed that the use of banana stem and other agricultural waste based biosorbents for organic contaminants removal from municipal effluents is a favourable alternative to replace the regularly used materials of greater cost such as conventional polymer based activated carbon, ion-exchange, nanofiltration, reverse osmosis, and electrodialysis. Wastewater treatment is critical in ensuring that effluent disposal is within regulatory standards, ensuring safety of all concerned and availability of clean and safe receiving streams or rivers and viz-a-viz, safe drinking water for all. Presently, agricultural wastes materials have become prominent as effective and low-cost adsorbents to achieve these water quality demands. Thus, comprehensive assessment made in this review of various low-cost adsorbent types have shown acceptable surface adsorption capabilities and applicability within wastewater and water treatment processes. The examined adsorbent types, activated carbon and some of its application in water and wastewater treatment, processing techniques including banana stems use in water treatment as a readily available and accessible materials proved effective. The review furthermore discussed the effect of pivotal factors like pH, contact time, temperature, exposure rate and contaminant concentration. Therefore, the adsorption capacity and efficiency of diverse adsorbent types from low-cost agricultural waste materials in removing effectively organic compounds, hardness, heavy metals and dyes as a focus is attainable and sustainable too.

CONFLICTING INTERESTS

The authors declare that there are no, and they have no conflict or competing interests.

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REVIEW ON RECENT ADVANCES OF BIO-COAGULANT FOR WASTEWATER TREATMENT

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ABSTRACT

This review examined recent advances in the application of bio-coagulants for wastewater treatment, addressing the growing need for sustainable water purification methods. Bio-coagulants, derived from plant, animal, and microbial sources, having emerged as promising alternatives to traditional chemical coagulants. The study analyses various types of bio-coagulants, their mechanisms of action, and their effectiveness in removing turbidity, suspended solids, and heavy metals from wastewater. Recent research indicates that many bio-coagulants can match or exceed the performance of conventional chemical coagulants in certain applications. Environmental and economic benefits, including biodegradability, reduced sludge production, and potential for resource recovery, are highlighted. However, challenges such as performance variability, shelf life's limitation, and scale-up issues are also addressed. The review explores current research trends, including efforts to enhance bio-coagulant stability, develop hybrid treatment systems, and identify novel sources. It concludes by emphasizing the potential of bio-coagulants in advancing sustainable wastewater treatment practices and identifying key area for future research. This comprehensive analysis provides insights into the current state of bio-coagulant technology and its future prospects in addressing global water treatment challenges.

Keywords*: Bio-coagulant, Chemical coagulant, Eco-friendly, Natural coagulant, Wastewater treatment***.**

1.0 INTRODUCTION

In recent years, the global community faces challenges in ensuring universal access to clean, safe, and affordable water (Pandey *et al*., 2021). As a vital resource, freshwater is essential for addressing pressing global issues, including health crises, malnutrition, poverty, and sustainable management of natural resources (Lulesa *et al*., 2022; Singh and Saxena, 2020). Approximately 122 million people worldwide obtained their water directly from surface water in 2020 (UNICEF/WHO, 2021). In 2021, over 2.2 billion people globally did not have secure and hygienic drinking water supplies (World Bank, 2021). If current water usage trends persist, the global community risks facing a 40% water shortage by 2030, emphasizing the urgent need for sustainable water management practices, including conservation, wastewater treatment and reuse (Al-Jabri *et al*., 2020).

The indiscriminate discharge of industrial wastewater, particularly by small industries into water bodies, poses serious environmental and health risks, causing widespread concerns about water pollution and its detrimental impacts on human well-being and ecosystems (Dutta *et al.*, 2021; Eric Mutegoa, 2024; Neksumi *et al*., 2022; Sibiya *et al*., 2022; Zacchaeus *et al*., 2020). The increasing problem of heavily polluted wastewater has necessitated the development of improved and efficient treatment solution (Ahmed *et al.,* 2020*).* To ensure safe discharge, wastewater requires supplemental treatment to remove colour and organic pollutants (Hossain *et al.*, 2019).

Various treatment technologies are employed to purify raw water sources into potable drinking water and treat wastewater, making it safe for discharge into water bodies (UNESCO. 2019; Jorge, 2023). Notably, the coagulation/flocculation procedure has remained a desired treatment approach (Ohale *et al.*, 2020). Coagulation/flocculation is a part of the water

treatment process whereby the colloidal particles are made to agglomerate and settle at the bottom as flocs; and coagulants which are the materials added to wastewater to destabilize the colloidal particles, are necessary for optimizing the process (Aghyani *et al*., 2023; Habtemariam *et al.*, 2023). Coagulants exist in a variety of forms and can be classified into three main categories: inorganic coagulants, synthetic organic polymers, and natural coagulants, each with unique mechanisms, advantages, and disadvantages (Al-Jabri *et al*., 2020; Al-Jadabi *et al*., 2023; Dayarathne *et al*., 2021; Diver *et al.*, 2023)

For many years, inorganic coagulants and synthetic organic polymers are conventionally used, however, they have disadvantages associated with harmful effects on human health (Alazaiza *et al*., 2022; Amal, 2021; Diver *et al.*, 2023; Nweke *et al*., 2021); ineffectiveness in low temperature samples (Dayarathne *et al.*, 2022), large non-biodegradable sludge volumes (Ejimofor *et al*., 2021; Salem *et al*., 2023), relatively high acquisition cost (Diver *et al*., 2023), significant alteration of pH and water alkalinity post-treatment (Salem *et al*., 2021). Thus, the transition towards natural coagulants (bio-coagulants) is gaining increasing attention. Natural coagulants encompass a diverse range of sources, including those derived from plants, animals, and microorganisms (Alazaiza *et al*., 2022; Diver *et al*., 2023; Varsani *et al*., 2024).

It is important to note that, not all natural coagulants are bio coagulants but all bio coagulants are natural coagulants, hence, this review aims to critically analyze recent advances in bio coagulant research for wastewater treatment, focusing on their types, mechanisms of action, effectiveness, environmental and economic impacts, challenges and limitations, and current research trends and future directions.

2.0 TYPE OF BIO-COAGULANTS

Recent studies have explored a diverse array of bio coagulants, broadly categorized into plant-based, animal-based, and microbial sources.

Plant-based coagulants and flocculant are naturally derived organic materials extracted from various plant parts, including leaves, seeds, fruit waste, tree bark, and other botanical sources (Badawi *et al*., 2023). The organic materials are classified into two categories: ionic and non-ionic polymers, with diverse molecular weight profiles. Due to the presence of active compound such as proteins, polysaccharides, and tannins, they exhibit coagulation and flocculation properties (Alazaiza *et al*., 2022; Badawi *et al*., 2023). Plant-based coagulants are considered eco-friendly and sustainable, and their affordability and diversity have made them a more extensively researched option compared to non-plant-based bio coagulants. A wide range of bio-coagulants such as moringa seeds, nirmali seeds, banana peel, cassava peel starch, jatropha curcas, watermelon, carica papaya, beans, okro and many others have been studied previously.

Animal-based coagulants and flocculants are derived from various animal sources, including Chitosan, Alginate, eggshells, bones, and blood. These substances function by introducing a positive charged particles and aggregates negatively charged particles in water, facilitating their settling (Badawi *et al*., 2023). Chitosan is one of the common natural coagulants and flocculants used in wastewater treatment, a biopolymer found in marine invertebrates such as crustaceans and insects. Chitosan is derived from chitin, the second most abundant naturally occurring polysaccharide, through a deacetylation process. With its high molecular weight and cationic properties, chitosan exhibits exceptional flocculation capabilities, facilitating particle bridging and aggregation (Hesami *et al*., 2023; Soros *et al*., 2019). The recent studies have focused on modifying chitosan to enhance its coagulation properties and expand its application range.

Microbial-based coagulants / flocculants are coagulants derived from microbes. Microbial-based coagulants/ flocculants have shown promising alternative to conventional chemical-based treatment methods for wastewater. Microbial-based coagulants are capable of effectively eliminate suspended particles, organic matter, and other contaminants from wastewater, making it suitable for safe discharge into the environment. Certain bacteria and fungi produce extracellular polymeric substances (EPS), comprising complex mixtures of polysaccharides, proteins, and nucleic acids that facilitate enhanced flocculation (Badawi *et al*., 2023). Research has shown that bacterial extracellular polymeric substances (EPS) possess exceptional absorption capabilities for cationic dyes, attributed to the presence of functional groups such as amine, carboxyl, and hydroxyl (Das et al., 2021; Kurniawan et al., 2022). These microbial products offer the advantage of controlled production conditions, potentially addressing the variability issues faced by plant and animal-based coagulants. Table I presents a summary of the 3

major sources of bio-coagulants and common example.

Table I: Sources of Bio-coagulants

Plant-based	Animal-based	Microorganism-based
Moringa Oleifera	Chitosan	Xanthan gum
Cactus.	Chitin	*Aspergillus sp*
Nirmali seeds	Fish scale	*Enterobacter*
Tannin *Streptomonas*	Egg shell	Streptomonas
Jatropha curcas seeds	Alginate	
Banana peel		
Common beans		
Tamarind seeds		

Source: Bahrodin *et al*. (2021); Nimesha *et al*. (2022); Ovuoraye *et al*. (2021).

3.0` MECHANISMS OF ACTION

Understanding the mechanisms by which bio-coagulants operate is crucial for optimizing their performance. Coagulation is essentially the process of destabilizing of colloidal particles with the help of coagulants, utilizing several mechanisms. These mechanisms can be categorized into four main groups based on the dominant process responsible for the development of aggregates; namely, charge neutralization, double-layer compression, interparticle bridging (polymer bridging) and sweep flocculation. (Alazaiza *et al*., 2022; Dayarathne *et al*.,2021; Diver *et al*., 2023; Sibiya *et al*., 2022). In addition, flocculation occurs due to two fundamental processes: orthokinetic flocculation, driven by fluid movement, and peri kinetic flocculation, resulting from Brownian motion (Diver *et al*., 2023). Figure 1 show the process of coagulation-flocculation in wastewater treatment. The mechanisms for the coagulation process are discussed below.

Charge neutralization facilitates particle clustering by neutralizing the electric charge of colloids through the addition of oppositely charged ions, minimizing electrostatic repulsion. Charge neutralization bring the zeta potential close to zero, the electrostatic charge on colloidal particles is effectively neutralized, triggering particle destabilization, aggregation, and settling (Alazaiza *et al*., 2022; Diver *et al*., 2023). The strength of flocs varies with formation mechanism: charge neutralization produces stronger flocs than sweep flocculation, but weaker ones than interparticle bridging, with smaller, spherical flocs (Bahrodin *et al*., 2021). Flocs formed by charge neutralization are more compact, have high fractal dimension; but unlike flocs formed by sweep flocculation (Bahrodin *et al*., 2021). Charge neutralization is widely regarded as the predominant coagulation mechanism when using natural coagulating agents (Alazaiza et al., 2022; Nweke *et al*., 2021).

Interparticle bridging or Polymer bridging, involves long-chain polymers that act as bridges, linking particles together and creating resilient flocs (Dayarathne *et al*., 2021). This mechanism involves extended-chain polymers or polyelectrolytes that destabilize colloidal particles by creating bridges and absorbing particles onto their surface, forming strong macro-flocs (Alazaiza *et al*., 2022). A study shows that flocs structure appears flaky and irregular, indicating polymeric chains have linked colloidal particles, generating a network with varied void spaces (Lek *et al*., 2018). Research shows that, using natural coagulants with interparticle bridging mechanism yields significantly larger flocs-three times or more than chemical coagulants, due to the polymeric chains

capacity to stretch and bind various colloids (Choy *et al*., 2016).In interparticle bridging mechanism, the high molecular weight of polymers enables rapid settling of large flocs, as multiple particles are absorbed along their chains resulting in efficient sedimentation and reduced turbidity (Alnawajha *et al*., 2022). A notable characteristic of polymer bridging is its ability to facilitate flocculation even when the polymer and colloidal particles share the same surface charge (Negin et al., 2024).

Double-layer compression can be defined as a mechanism that use ions of the opposite charge of the colloids to infiltrate the double layer surrounding the colloids (Bahrodin *et al*., 2021). The mechanism operates by introducing a high concentration of electrolyte ions around colloidal particles, allowing oppositely charged ions to penetrate the diffuse double layer, thereby increasing its density (Alazaiza *et al*., 2022). As a result of this mechanism, larger aggregates form, which can then be efficiently removed through sedimentation or filtration processes. Although double-layer compression plays a vital role in destabilizing colloids in natural aquatic environments, it has limited influence on colloid destabilization in water treatment processes (Ghernaout *et al*., 2020).

Sweep coagulation, or sweep flocculation, is a process where colloidal particles are entrapped within a net-like structure formed by the precipitation of amorphous metal hydroxides (Alazaiza *et al*., 2022; Bahrodin *et al*., 2021). Flocculation analysis such as flocculation index (FI), initial floc aggregation (IFA), and relative settling factor (RSF) reveals sweep flocculation produces smaller flocs with excellent settling properties, but formation rates are slower (Bahrodin *et al*., 2021). Sweep flocculation mechanically aggregates colloids without addressing underlying repulsive forces, leading to weak floc formation (Bahrodin *et al*., 2021). In conclusion, the strongest flocs are formed by polymer bridging, followed by charge neutralization and then sweep flocculation (Alazaiza *et al*., 2022; Bahrodin *et al*., 2021). Interestingly, recent studies have shown that some bio-coagulants employ multiple mechanisms simultaneously, contributing to their effectiveness across a range of pollutant types and water condition.

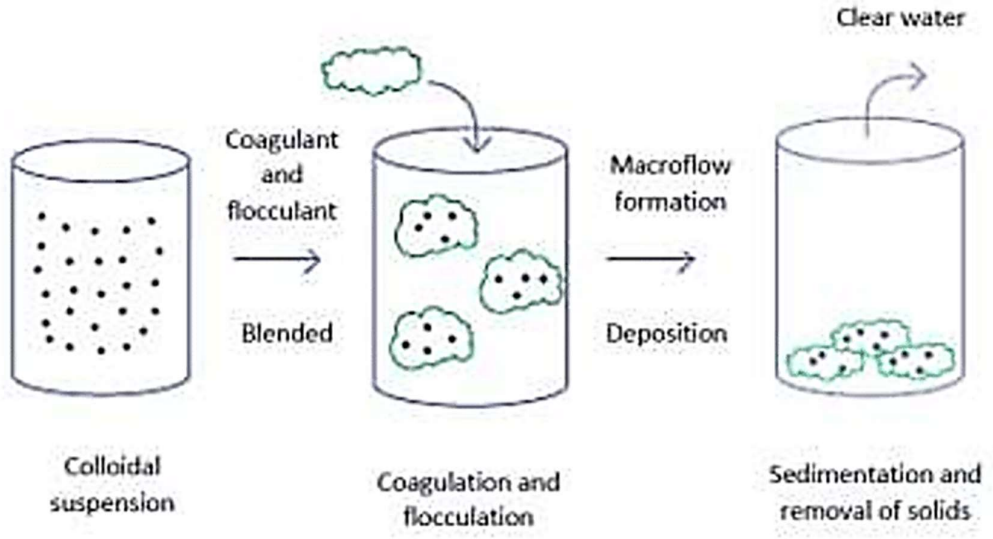


Figure 1. Overview of the coagulation flocculation process. Source: Diver *et al*., 2023.

4.0 EFFECTIVENESS COMPARED TO TRADITIONAL COAGULANTS

A growing body of evidence suggests that bio-coagulants can match or even surpass the performance of traditional chemical coagulants in certain applications. Studies have shown that *Moringa oleifera,* a natural coagulant, can be derived from its seeds, leaves, and stems, offering coagulation performance comparable to or better than conventional chemical coagulants (Jassim *et al.*, 2020). One notable comparison was observed in the removal of bacteria from polluted river water, with *Moringa oleifera* seeds achieving 81.7% removal of coliform bacteria and 96.0% removal of mesophilic bacteria, significantly outperforming alums removal rates of 40.0% and 32.9% respectively (Amran *et al*., 2018). A study by Ejimofor *et al*., (2020) revealed that chito-protein derived from animal sources exhibited comparable treatment efficacy and operational parameters to alum-based treatment for paint wastewater. A researched by Elsayed *et al*., (2020) revealed that fenugreek seed extracts demonstrated exceptional turbidity removal efficiency, reaching 98% in synthetic turbid water, surpassing alum's efficiency of 85%.

Research conducted by Beyene *et al*., (2016) found that utilizing cactus powder and alum as coagulants led to elevated levels of total dissolved solids (TDS), conductivity, and salinity in the treated water sample. The study revealed that cactus powder caused significant increases of 93.8% in TDS, 68.7% in conductivity, and 97.1% in salinity, whereas alum resulted in even higher increments of 167.8% in TDS, 68.7% in conductivity, and 180.0% in salinity. This shows that cactus powder performed better in maintaining TDS, conductivity, and salinity. In the area of sludge production, study revealed that bio-coagulants generated significantly less sludge compared to chemical coagulants. A researched by Tuddao *et al*.,2016; shows that utilizing Jatropha curcas seeds resulted in significantly lower sludge volume, approximately 40 ml/ L, compared to 58 m/l L produced when using alum. A study evaluated effectiveness of two natural coagulants, calcium lactate and tannic acid, and compared their performance to conventional coagulants, polyaluminium chloride and ferric chloride (Kaji *et al*., 2020). An initial turbidity of 900 NTU was utilized to evaluate the sludge production of four coagulants. The results showed that, after 30 minutes, the natural coagulants (calcium lactate and tannic acid) generated less settled sludge compared to the chemical coagulants (polyaluminium chloride and ferric chloride). It was concluded that the application of natural coagulants not only minimized sludge formation but also produced sludge that was easily biodegradable.

Another area of comparison between natural coagulants and chemical coagulants can also be seen in the form treatment capacity and environmental friendliness. Jagaba *et al*., 2020; had evaluated the performance of three coagulants, namely alum as representative of the chemical coagulant, with Moringa oleifera and chitosan as representative of the natural coagulants and with palm oil mill effluent as the wastewater. In terms of treatment capacity, chitosan demonstrated the most effective removal performance, whereas Moringa oleifera and alum exhibited similar removal capabilities. Chitosan removed 95% colour, 95% oil and grease, 98% TSS, and 91% NH_3-N at the optimum coagulant dosage of 500 mg/L. Moringa oleifera removed 93% colour, 87% oil and grease, 95% TSS, and 90% NH_3-N at optimum coagulant dosage of 2000 mg/L, while alum removed 93% colour, 95% oil and grease, 97% TSS, and 95% NH_3-N at optimum coagulant dosage of 4000 mg/L. Assessing environmental friendliness requires examining toxicity as a critical factor. In a study by Awolola *et al.*, 2010; to test the toxicity (LC_{50}) on *Carica papaya* seeds (bio-coagulant) and $CaSO_4$ (chemical coagulant). The results shows that the Carica papaya seed is significantly less toxic with LC_{5O} of 196.49 µg/mL compared to the $CaSO_4$ with LC_{50} of 7.64 µg/mL. The study also revealed that chemical coagulants are highly toxic, posing risks not only to the resulting sludge but also to the treated wastewater. Note; a high value of LC_{50} shows that the coagulant is less toxic, while a low value of LC_{50} shows that the coagulant is highly toxic. Table II, showing comparison performance of bio-coagulant and chemical coagulant in a wastewater treatment.

Table II Comparison performance of bio-coagulant and chemical coagulant in wastewater treatment

Type of wastewater	Chemical coagulant	Removal performance	Bio-coagulant	Removal performance
Paper mill Industry	Alum	Turbidity: 97.1% COD: 92.7%	*Moringa oleifera* seed	Turbidity: 96.0% COD: 97.3%
Concrete plant	Alum and ferric chloride	Turbidity: 99.9%		Turbidity: 99.9%
River water	Alum	Turbidity: 75% Coliform bacteria: 40% Mesophilic bacteria: 32.9%		Turbidity: 62.5% Coliform bacteria: 70.0–93.3% Mesophilic bacteria: 93.7–98.3 %
Palm oil mill effluent (POME)	Alum	TSS: 99.7%		TSS: 95.4%
		Turbidity: 98.7% NH_4-N: 98.5% Color: 94% Oil and grease: 95%		Turbidity: 88.3% NH_4-N: 89.8% Color: 90.2% Oil and grease: 87.1%
	Ferric chloride	TSS: 99.1% Turbidity: 95.8% NH_4-N: 93.7% Color: 66.4% Oil and grease: 95.7%		
Paint industry	Ferric chloride	Color: 89.4% COD: 83.4% Turbidity: 88.5%	Cactus	Color: 88.4% COD: 78.2% Turbidity: 82.6%
Confectionary	PAM	TSS: 93.5% COD: 95.9%		TSS: 92.2% COD: 95.6%
Glue	PAM	TSS: 90.7% COD: 86.3%		TSS: 90.3% COD: 82.1%
Paper and mill	PEI and HE	Color: 80% TOC: 30%	Chitosan	Color: 90% TOC: 70%
	Alum	Color: 80% TOC: 40%		
POME	Alum	TSS: 99.7% Turbidity: 98.7% NH_4-N: 98.5% COD: 75% Color: 94% Oil and grease: 95%	Chitosan	TSS: 99% Turbidity: 98.4% NH_4-N: 95.6% COD: 68.3% Color: 96% Oil and grease: 94.9%
POME	Alum	Turbidity: 82.2% COD: 49.1%	Rice starch	Turbidity: 92.5% COD: 30.9%
Leachate	PACl	TSS: 78% Turbidity: 76% Color: 70% COD: 65% NH_4-N: 25%	*Diplazium esculentum* leaf as coagulant aid	TSS: 88% Turbidity: 87% Color: 76% COD: 68% NH_4-N: 34%
Leachate	Alum	Color: 69%	*Hibiscus rosa* leaf as	Color: 61%

			coagulant	
		Iron: 60% TSS: 45% Turbidity: 36% NH_4-N: 25%	Aid	Iron: 100% TSS: 72% Turbidity: 60% NH_4-N: 54%
Synthetic turbid Water	Alum	Turbidity: 73.1%	Banana peel	Turbidity: 65.6%
			Banana peel as coagulant aid	Turbidity: 94.1%
POME	Alum	COD: 59% BOD: 61% TSS: 71%	*Jatropha curcas* seed	COD: 70% BOD: 65% TSS: 88%
Latex effluent	Ferric sulfate	COD: 98% TSS: 98% Turbidity: 89%	Dragon fruit foliage	COD: 94.7% TSS: 85.9% Turbidity: 99.7%
Artificial turbid Water	Alum	Turbidity: 97.9%	Mango seed	Turbidity: 92%
Dam water	Alum	Turbidity: 98.5%	Watermelon seed	Turbidity: 89.3%

Table II (continued)

Type of wastewater	Chemical coagulant	Removal performance	Bio-coagulant	Removal performance
I.		Color: 98.5%	Watermelon seeds as coagulant aid	Color: 93.9% Turbidity: 99.3% Color: 100%
Cassava effluent	Alum	Color: 49% Turbidity: 56%	*Acacia negara*	Color: 81.5% Turbidity: 91%
Synthetic Wastewater	Alum	Turbidity: 99.6% Sedimentation time: 40 min Sludge volume: 58 mL/L	*Jatropha curcas* seed	Turbidity: 99.6% Sedimentation time: 20 min Sludge volume: 40 mL/L
Paint effluent	Ferric chloride	COD: 82% Color: 89% Sludge volume: 172 mL/L	Commercial NC based on tannin	COD: 87% Color: 99% Sludge volume: 116 mL/L
	Alum	COD: 81% Color: 89% Sludge volume: 220mL/L		

Source: Bahrodin *et al*. (2021).

Bio-coagulants offer triple advantage over traditional coagulants: environmental sustainability, widespread availability, and cost-effectiveness. The use of chemical coagulants in water treatment can result in residual coagulant levels remaining in the water after treatment. Residual alum from chemical coagulation in water treatment has raised health concerns due to its potential link to Alzheimer's disease (Garde *et al*., 2017). Unlike chemical coagulants, natural coagulants produce residues that are environmentally friendly and do not pose health risk. The requirement for coagulant aids to enhance the effectiveness of chemical coagulants like alum in high-turbidity water treatment contributes to increased expenditure and operational complexity, posing significant challenges for adoption in developing countries. Compared to chemical coagulants, the main advantages of natural coagulants are renewability, biodegradability, nontoxicity, and cost-effectiveness, which enhancing the affordability of water treatment (Nimesha *et al*., 2022).

5.0 ENVIRONMENTAL AND ECONOMIC BENEFITS

The environmental and economic benefit of bio-coagulants is to be analyzed under the following sub headings as shown in figure 1: Biodegradability and toxicity, Sludge production, Resource recovery potential, and Cost-effectiveness.

Biodegradability and Toxicity

This is one of the major environmental and economic benefits of using bio-coagulants for wastewater treatment. Unlike chemical coagulants, bio-coagulants have lower toxicity, biodegradable, and reducing the risk of long-term environmental accumulation. Since these coagulants originate from plant sources, their byproducts are organic, biodegradable, and eco-friendly (Hadadi *et al*., 2022). A study by Igbokwe *et al*., (2018) showed Moringa oleifera seeds to be non-toxic, with a high LD_{50} value of 14g/kg, indicating that, it is safe for consumption. A researched by Dopalapudi *et al*., (2019) found that oral administration of Cicer arietinum seed extract to rats at doses up to 2000 mg/kg caused no morality, showing safety and lack toxicity.

Sludge Production This is also one of the environmental and economic benefits of bio coagulants, in the sense that, different research work shows that bio-coagulants generate less sludge, unlike chemical coagulants that produced large volume of sludge (Kristianto *et al*., 2018)). This not only lessens the environmental burden of sludge disposal but can also lead to significant cost savings in wastewater treatment operations.

Resource recovery potential

Resource recovery potential is very important environmental and economic benefits of bio-coagulants. Incineration and pyrolysis are thermal treatment methods that can reduced coagulant sludge volume and eliminate organic pollutant. These thermal processes utilize high temperatures to break down sludge into ash, gas, and heat, minimizing waste volume and destroying harmful pollutants (Cai *et al.*, 2020). Utilizing agricultural waste materials or easily cultivated plants such as *Moringa oleifera* promotes resource efficiency and reduce waste production (Diver *et al*., 2023). Biodegradable natural coagulants provide an attractive option for utilities aiming to reduce environmental impact by decreasing sludge generation and toxicity (Dorca *et al.*, 2018). The organic sludge produced by bio-coagulants can be transformed into environmentally beneficial uses, such as wastewater treatment, construction materials, soil conditioners, and bio-based products, reducing waste and promoting sustainability (Ahmad *et al*., 2016).

Cost-Effectiveness

This is also one of the benefits from environmental and economic perspective of using bio-coagulants for wastewater treatment. According to cost estimates, the following factors are considered when calculating the overall cost of *Moringa oleifera* natural coagulant production: raw materials, chemical compound (n-hexane), electrochemically activated solution, energy consumption, labour costs, storage and logistics expenses. (Hoa and Hue,2018). Bio-coagulants offer distinct advantages as point-of-use water treatmesnt solutions, being cost-effective, unlikely to produce treated water with extreme pH levels outside the WHO-recommended range of 6.5-8.5, and highly biodegradable (Patchaiyappan *et al*.,2020). Bio-coagulants, being locally sourced and cost-effective, enhance water treatment accessibility and affordability, particularly in developing areas (Diver *et al*., 2023).

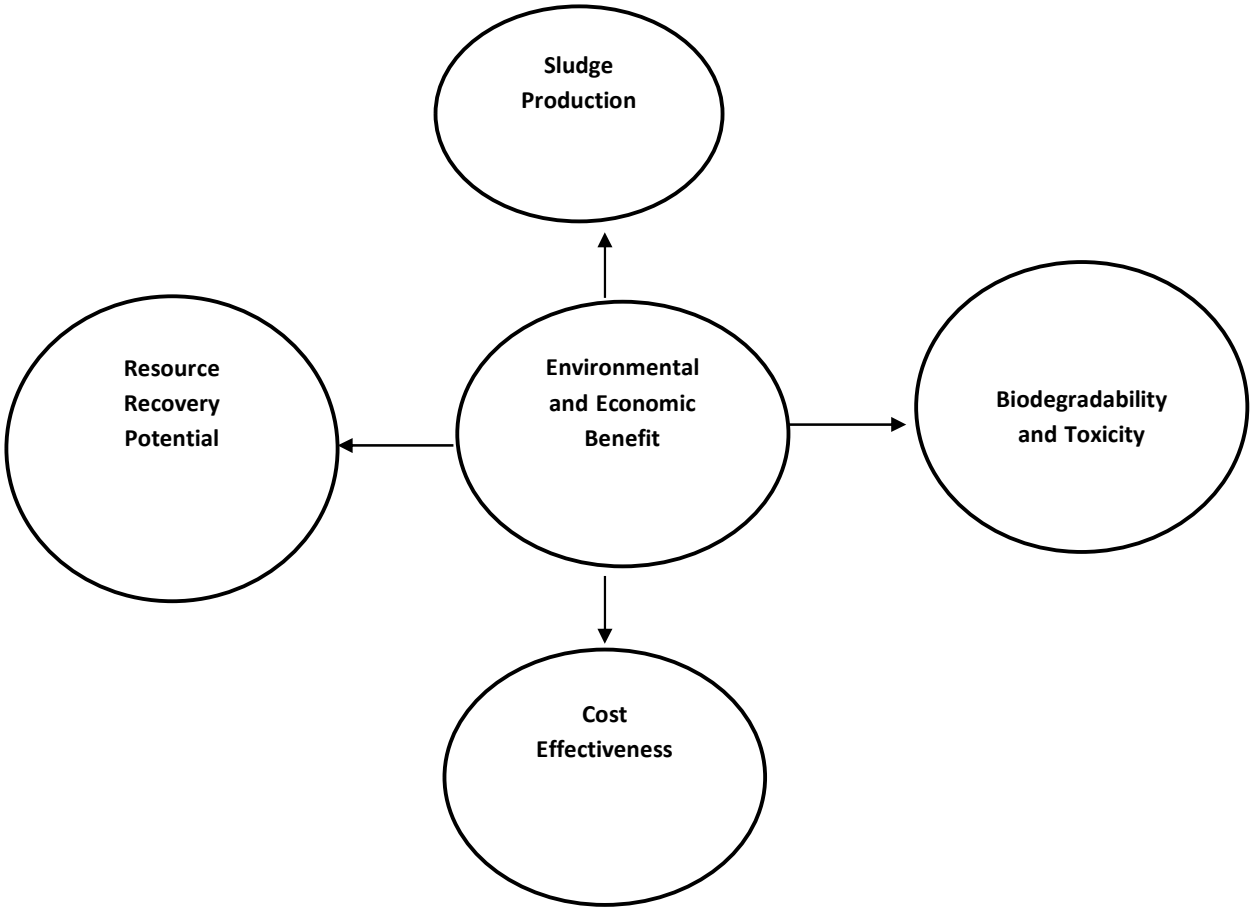


Figure 1: Showing Environmental and Economic Benefits of Bio-Coagulants

6.0 CHALLENGES AND LIMITATIONS

The development and utilization of bio-coagulants are hindered by several challenges that needs to be addressed: Using bio-coagulants increased the organic matter content of the treated water, thereby increased the microbial activity in the distribution system. As a result, more chlorine should be used to sanitize the treated water (Alicja et al., 2023., Debora *et al*., 2013). Due to natural variations in their sources, bio-coagulants can have inconsistent performance across different condition. The effectiveness of bio-coagulants can be inconsistent, thereby limiting their reliability in large-scale industrial applications (Saravanan *et al*., 2017). The unpredictable performance of natural coagulants has hindered the acceptance and integration of bio-coagulants in water and wastewater treatment plants (Diver *et al*., 2023). However, the effectiveness of bio-coagulants decreases when dealing with water of lower turbidity. A study by Asrafuzzaman *et al*., (2011), shows that coagulants dosage increments from 50 mg/L to 100 mg/L increased the efficiency removal from 86.9% to 94.1% for 100 NTU water, compared to coagulants dosage increment from 50 mg/L to 100 mg/L which increased the removal efficiency from 65.6% to 69.4% for lower turbidity of 48 NTU. Hence, the need for further research on how best to increase the effectiveness of bio-coagulants, when dealing with water of low turbidity. Bio-coagulants often need higher dosages to attain optimal treatment

outcomes, which can increase operational expenses and add some challenges to the treatment process (Badawi *et al*., 2023).

In addition, many bio-coagulants have shorter shelves lives compared to chemical alternatives, posing storage and logistics challenges. In other words, the shelf life of a bio-coagulant is the frame within which it can be stored, handled, and used without compromising its performance or safety. Bio-coagulants are susceptible to degradation due to the instability of their active compounds, such as proteins and polysaccharides, which can breakdown during storage, or be altered by microbial attacks and environmental factors during extraction and purification (Abidin *et al.*, 2019). As a result, the commercial viability of bio-coagulants is significantly compromised due to their limited storage stability. This is attributed to the fact that transportation and storage challenges compromise the effectiveness of the coagulants, affecting their performance (Ang & Mohammed, 2020). The problem of shelf life can be addressed by coming up with a method, to process the extracts and also adding preservatives, which will maintain the extract's quality and prevent degradation during long-time storage (Diver et al., 2023). Removing moisture from bio-coagulants to prevent microbial growth and storing in airtight containers or bags to prevent moisture and oxygen exposure is another method to prevent degradation during long-time storage. Lastly, transitioning from laboratory success to industrial-scale application remains a significant challenge for many bio-coagulants (Diver *et al.*, 2023). Therefore, optimizing bio-coagulants performance needs further research to overcome current challenges and unlock their full potential (Nweke *et al*., 2021).

7.0 CURRENT RESEARCH TRENDS AND FUTURE DIRECTIONS

Current breakthroughs in wastewater treatment prioritize enhanced efficiency, reducing costs, and promoting sustainable practices (Badawi *et al*., 2021; Gedda et al.,2021). One significant current research trend is the introduction of advanced oxidation processes (AOPs), which involve the formation of hydroxyl radicals, highly reactive species that oxidize and degrade organic pollutants (El-Gawad *et al*., 2023; Sathasivam et al., 2019).

Another current research trend is the development of improved biological treatment processes (Dutta *et al.*, 2021). For example, combining biological treatment with membrane bioreactors (MBRs), the system produced exceptional effluent quality while reducing physical footprint and sludge production. The application of MBRs technology extends across various sectors, including pharmaceutical production and food processing industries (Al-Asheh *et al*.,2021; Ezube and Rathilal, 2020).

Nanotechnology is another current research trends that presents groundbreaking solutions for wastewater treatment by harnessing the potential of engineered nanomaterials with optimized properties. Nanomaterials like carbon nanotubes and metal oxide nanoparticles possess high surface area and reactivity, making them ideal for pollutant absorption and breakdown (Abdelbasir and Shalan, 2019; Shahedi *et al*., 2020).

Another current research trend is called hybrid system or combined technology. Combining bio-coagulants with other treatment methods, such as membrane filtration or advanced oxidation processes, is showing promise in overcoming individual limitations. It enables the design of high-performance systems that surpass existing solution (Mondal, 2017). By combining treatment methods, it enables the creation of high-performance systems that surpass individual treatment methods in efficiency and effectiveness (Tejedor-Sanz *et al*., 2017).

Further investigation is needed to optimize the processing, packaging, and storage of coagulants derived from plant extracts, facilitating their widespread availability and extended shelf life.

8.0 CONCLUSION

The field of bio-coagulant for wastewater treatment is rapidly developing, offering promising solutions to the challenges of sustainable water management. While significant progress has been made in understanding their mechanisms, showcasing their effectiveness, and exploring their environmental benefits, numerous obstacles still need to be overcome.

Future research should focus on standardizing bio coagulant production and application methods, conducting long-time studies on their environmental impact, and developing strategies for large-scale implementation. Additionally, more comprehensive life cycle assessments and economic analyses are needed to fully understand the potential of bio coagulants in various situations.

As global water challenges intensifies and environmental regulation strengthen, bio

coagulants stand prepared to play a crucial role in the future of wastewater treatment. Their continued development and improvement may well be key to achieving more sustainable and environmentally friendly water management practices worldwide.

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Development of Drought Early Warning System (Dews) in Nigeria: A Review of Progress, Challenges, and Future Directions

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ABSTRACT
Drought Early Warning Systems (DEWS) are important tools for reducing the impact of drought on agriculture, water resources, and food security. This review explores drought trends in Nigeria, assessing the progress, challenges, and future directions of DEWS development. Analysis of past drought occurrences reveals that Nigeria has experienced notable drought episodes in 1914, 1924, 1935, 1943, 1951-1954, 1972-1973, and 1991-1995, with the driest decades recorded between 1970 and 1990. The increasing trend of drought events is linked to climate change, land degradation, and poor water management. Nigeria's primary DEWS, managed by the Nigerian Meteorological Agency (NiMet), employs indices such as the Standardized Precipitation Index (SPI) and the Palmer Drought Severity Index. However, these systems face significant challenges, including data gaps, limited technological integration, and inadequate community participation. An analysis of past studies shows advancements in satellite-based vegetation health indices, climate modelling, and machine learning algorithms. However, DEWS effectiveness is hindered by institutional weaknesses, data limitations, and insufficient stakeholder engagement. Key challenges include governance, coordination, funding, and capacity building. Future research should focus on integrating local knowledge and indigenous practices, developing more complex and integrated DEWS models, improving data quality, and enhancing communication strategies. This review aims to inform policymakers, researchers, and practitioners about the need to strengthen DEWS to support drought resilience and sustainable development in Nigeria.

Keywords: *Drought Early Warning Systems, Nigeria, Climate change, Agriculture, Water Resources, Food Security*

1 INTRODUCTION

Drought is a complex phenomenon characterized by: "A period of abnormally low rainfall that leads to water scarcity and impacts on ecosystems, agriculture, and human societies." (World Meteorological Organization, 2019). Draught ranks first among all natural hazard, based on severity, duration, spatial extent, life/economic loss and other measures. (UNW-DPC). Droughts occur frequently in Nigeria, with an average of 2-3 events per decade (NIMET, 2020). 70% of Nigeria's land area (north) is drought-prone (Olusegun Adeaga, 2011). Drought duration varies from 2-12 months, with severe droughts lasting up to 24 months. Northern Nigeria (Sahel region) is more prone to droughts due to low rainfall and high evaporation rates (Ogunrinde et al., 2019), Southern Nigeria (humid region) experiences fewer droughts but is still vulnerable to water scarcity (Christopher et al., 2020). Climate change is projected to increase drought frequency and severity in Nigeria (IPCC, 2014), and rising temperatures and changing precipitation patterns exacerbate drought risks (NIMET, 2020).

Drought poses negative impacts. Agriculture Droughts reduce crop yields, leading to food insecurity and economic losses (Isreal, 2022). Water Resources Droughts reduce water availability, affecting human consumption, livestock, and hydroelectric power generation (Nigeria Hydrological Services Agency, 2020), Health Droughts increase risk of water-borne diseases and heat-related illnesses (WHO, 2024), Economy Droughts impact GDP, particularly in agricultural and manufacturing sectors (CBN, 2020) and Livestock Droughts lead to livestock deaths, reduced milk and meat production (FMAWR, 2019). The consequences of these is that it leads to hunger and malnutrition, especially in rural areas (IFRC), internal migration, social tensions, and conflict (IOM, 2020), resulting in significant economic losses, (CBN, 2020). Environmental degradation: Droughts exacerbate desertification, soil erosion, and biodiversity loss (FMEnv, 2020). Some of the indicators of droughts are Rainfall anomalies, Soil moisture levels, Streamflow and water levels, Vegetation health indices and Crop yield and agricultural productivity.

Drought Early Warning Systems (DEWS) are critical for mitigating these impacts by providing timely warnings to reduce risks and losses (UNISDR, 2015; FAO, 2018). DEWS play a vital role in food security, water conservation, and climate adaptation (IPCC, 2014). However, existing systems in Nigeria face several challenges, including data gaps, limited technology integration, and inadequate community involvement.

The aim of this research is to assess the progress of current DEWS in Nigeria, identify existing gaps, evaluate

their effectiveness in risk management, and provide actionable recommendations for improvement.

2 OVERVIEW OF DROUGHTS IN NIGERIA

Previous studies indicate that Nigeria has been experiencing a drying trend since the early 20th century with notable periods of drought occurring in 1914, 1924, 1935, and 1943, 1951-1954, 1972-1973 and 1991-1995 (FMEnv, 2018, Tarhule and Woo, 1997). Recent studies have further explored this trend, with the driest decades occurring between 1970 and 1990 (Ogunrinde et al., 2019) particularly in the northern region. In 1981, the northern fringes of Nigeria, spanning from the northeastern to the northwestern part of the country, as well as some smaller areas, experienced a moderately severe drought (Oluwatola et al., 2020). The frequency of drought events in Nigeria has been recorded over the decades as shown in Table 1.

TABLE 1: FREQUENCY OF DROUGHT EVENTS IN NIGERIA

Decade	Number of Drought Events
1970s	3
1980s	4
1990s	5
2000s	6
2010s	7

The data clearly shows an increasing trend in drought frequency over the decades, with a steady rise from three events in the 1970s to seven events in the 2010s. These suggests that Nigeria is experiencing more frequent droughts, which could have severe implications for agriculture, food security, water resources management, ecosystems, health, human settlements, and livelihoods. Throughout the decades, there have been several instances of drought. In the 1970s, three drought events occurred in 1971, 1972, and 1977. Moving into the 1980s, there were four drought events observed in 1981, 1982, 1984, and 1987. The 1990s saw five documented drought events in 1991, 1992, 1994, 1996, and 1999. Subsequently, the 2000s experienced six drought events in 2001, 2002, 2005, 2006, 2007, and 2009. Finally, the 2010s saw seven reported drought events in 2010, 2011, 2012, 2013, 2015, 2016, and 2017, respectively (Oye *et al.*, 2019, NEMA, 2020).

This trend may be attributed to a variety of factors, such as climate change, land degradation, population growth, and unsustainable water management practices. It is crucial for stakeholders, policymakers, and researchers to delve into the root causes of this trend, devise and execute effective drought mitigation and adaptation strategies, improve early warning systems and emergency preparedness, and advocate for sustainable land and water management practices. The severity of environmental conditions documented over the decades, shows a range of impacts. In the context of regional variability in Nigeria, it has been observed that the Sahel region in the northern part experiences more frequent and severe droughts. Conversely, the humid southern region encounters less frequent and less severe droughts. (FMEnv, 2018).

The impacts of droughts are far-reaching and include crop failures and reduced yields in agriculture, reduced water supply and increased evaporation, increased risk of water-borne diseases for human health (IFRC), and losses in agriculture, industry, and tourism for the economy (FMEnv, 2018).

3 DROUGHT MONITORING AND EARLY WARNING SYSTEM

While a comprehensive review of drought early warning systems is not the focus of this paper, this Section aims to explore the existing drought monitoring and early warning systems in Nigeria. Nigeria has seen notable advancements in its drought early warning system in the past few years, implementing several efforts to enhance disaster resilience and response.

Droughts are common in Nigeria, especially in the Sudano-Sahelian states of Kebbi, Sokoto, Zamfara, Katsina, Kano, Jigawa, Yobe, Gombe, and Borno. These areas experience severe droughts from time to time, so it's important to closely monitor them to track the onset, intensity, duration, and frequency of droughts. (FMEnv, 2018).

Effective drought monitoring and early warnings would provide timely information to users for their decision-making and action taking. A comprehensive drought early warning system will ensure effective and efficient drought risk management in the country (FMEnv, 2018).

According to Vicente-Serrano *et al.* (2022) drought, monitoring (DM) refers to the real-time quantification of drought severity over a territory; and is usually done using drought monitoring system. A drought monitoring system is a coordinated set of tools, techniques, and data sources designed to detect, track, and assess the onset, duration, severity, and spatial extent of drought conditions (Vicente-Serrano *et al.*, 2022; Hao *et al.*, 2017). Drought monitoring system (DMSs) are a prerequisite for implementing drought plans since any institutional decisions need to be based on accurate and objective information. The purpose of drought monitoring systems is to offer early warning, guide resource management, and support decision-making to mitigate the socio-economic and environmental impacts of drought. These systems often use drought indices and models to quantify drought severity and predict its future progression.

Traditional drought monitoring is generally based on in situ observations of hydro climatic variables from observation networks at local scales, which falls short in drought characterization at regional scales due to sparse observation (e.g., soil moisture) networks (Hao et al., 2017). In response, significant progress is being made in the integration of multiple indices including,

meteorological data (such as precipitation and temperature), hydrological data (such as streamflow and groundwater levels), soil moisture information, remote sensing data (satellite imagery of vegetation health and water storage), land surface model simulations, and impact data to provide real-time or near-real-time assessments (Hao et al., 2017; Trnka et al., 2020). Additionally, technological advancements continue to enhance drought-monitoring systems. Some notable developments include the use of machine learning and artificial intelligence (Han et al., 2019); cloud-based platforms like Google Earth Engine (An et al., 2023); and crowdsourcing and citizen science (Vadjunec et al., 2022). However, challenges such as data gaps, uncertainty in climate models, and the integration of diverse data types persist (Liu et al., 2016). With advancements in AI, remote sensing, and cloud computing, future drought monitoring systems will likely become more accurate, timely, and accessible, enhancing global drought resilience.

Currently a myriad of DMSs abound across the globe and may be categorized based on diverse factors such as geographic scope (global, regional, national, local), data types (in situ, remote sensing, hybrid), focus (meteorological, hydrological, agricultural, socio-economic), and time frame (real-time, long-term), providing a comprehensive approach to assessing and managing drought conditions across various scales and sectors (Zink et al., 2016). The choice of system depends on the specific needs and available data.

3.1 DROUGHT MONITORING AND EARLY WARNING SYSTEM IN NIGERIA

Drought monitoring in Nigeria is primarily done through the Nigerian Meteorological Agency (NiMet), which has been providing critical data on weather conditions, rainfall, and climate conditions (Abubakar et al., 2013). NiMet uses indices like the Standardized Precipitation Index and Palmer Drought Severity Index for meteorological drought monitoring and their Seasonal Rainfall Prediction (SRP) reports are crucial for early warning and drought preparedness, particularly in agriculture (Hussaini and Matazu, 2023). Also, global systems like Famine Early Warning Systems Network help in monitoring the impacts of drought on food security and agriculture in drought-prone areas, particularly northern Nigeria (FEWS NET, 2012).

Historically, droughts have hit Nigeria very hard, with the major drought episodes recorded, which has caused extensive agricultural losses, reduced water supplies, and impacted rural livelihoods (FMEnv, 2018). In reaction to this trend, there is a National Drought Plan that has been formulated for Nigeria; this aims at enhancing drought resilience through improvement in monitoring systems and early warning and responsive mechanisms to cushion against the impacts of future drought events (FME, 2018).

Along with the efforts of the government and institutions, several researchers of Nigeria also have contributed significantly to further these drought monitoring system (Adedeji et al., 2020; Adegboyega et al., 2016; Dare et al., 2020; Ibitolua and Balogun, 2019; Jimoh et al., 2023; Ogunrinde et al., 2020; Olagbaiye et al., 2021; Usman and AbdulKadir, 2014).

Usman and AbdulKadir (2014) developed a drought monitoring and early warning system for Kano using the Intraseasonal Rainfall Monitoring Index (IRMI), which accurately forecasted severe drought conditions between 1970 and 1990. This research introduces a straightforward method for monitoring drought and early warning based on an Intra-seasonal Rainfall Monitoring Index (IRMI). The index is calculated on a pentad by pentad basis starting from the beginning of May using the formula $(Cpt)2 /(hpt \times Nb \times 100)$, where Cpt is the cumulative pentad rainfall, hpt is the highest pentad total rainfall, Nb is the number of breaks in rainfall (pentads with less than 5 mm of rainfall), and 100 is a factor. The effective onset of rains is determined as the pentad in which IRMI becomes ≥ 1 for the first time. This method provides a clear advantage over current probabilistic seasonal onset forecasts for agricultural decision-making. Applying this intra-seasonal drought monitoring approach to rainfall data in Kano revealed that about two-thirds of the area were prone to drought, with moisture deficiency observed between May and June. This finding aligns with the observations of other researchers in the field of agricultural drought. The study demonstrates the potential for on-farm applications and highlights the effectiveness of the new scheme in capturing signals of severe drought, offering promise as a versatile tool for drought warning and mitigation planning.

Adegboyega et al. (2016) examined drought impacts on vegetation in Sokoto State using 40 years of precipitation data to generate SPI and NDVI maps using Landsat imagery from 1982-2011, revealing that over 90% of the state experienced severely dry conditions between 2002 and 2011. The data from the Meteorological Station's dataset shows that the SPI values range from extremely dry to extremely wet conditions at the station. The figure clearly depicts the Sahelian droughts of the early 70s and the majority of the 80s, with 1987 being the year of the worst drought. There has been a noticeable improvement in Sokoto's rainfall over the last decade. Researchers have noted improvements in Sahelian rainfall since the early 2000s, with the most noticeable wet year occurring in 2010, which was associated with some flooding events in the region. A comparison of the NIMET and CRU observing stations revealed that both stations indicated dry and wet occurrences, albeit with varying intensities. In most cases, the CRU station's intensity is higher than that of the Meteorological station in Sokoto State. The results of the occurrences and frequencies of different ranges are obtained from the Standardized Precipitation Index (SPI) and are presented in Table 2. It is evident that the percentage average of drought occurrence intensity

during the period showed Near Normal condition as the highest and Extremely Wet condition as the least.

TABLE 2: TABLE SHOWING THE PERCENTAGE AVERAGE OF DROUGHT OCCURRENCE INTENSITY RANGE OF 16 CRU OBSERVING STATIONS (1982 – 2011) AND NIMET STATION (1980 – 2010)

Range	NN	MD	MW	SW	SD	ED	EW
%Av. (CRU)	72.18	8.67	7.05	2.22	4.60	3.84	1.62
%Av. (NIMET)	74.19	12.90	6.45	__	__	3.23	3.23

NN-Near Normal Condition, **MW**- Moderately Wet Condition, **MD**- Moderately Dry Condition, **SW**-SeverelyWet Condition, **SD**-Severely Dry Condition, **EW**-Extremely Wet Condition and **ED**-Extremely Dry Condition

Ibitolu and Balogun (2019) explored the spatiotemporal dynamics of drought in Northern Nigeria using MODIS datasets from 2005, 2010, and 2019. It analyzed vegetation index and surface temperature data to develop drought risk maps for decision-making. The outcome indicated that through the comparison of vegetation index and surface temperature data, valuable information on drought risk mapping can be conveyed visually to monitor drought and assist decision-making.

Adedeji et al. (2020) mapped drought risk across Nigeria using National Oceanic and Atmospheric Administration - Advanced Very High-Resolution Radiometer Normalized Difference Vegetation Index (NOAA-AVHRR NDVI) and Moderate Resolution Imaging Spectroradiometer (MODIS) images alongside 32 years of rainfall data. It found the highest drought risk in the northeastern part of the country, covering 5.98% of the landmass, while 42.4% of the area was at low risk.

Dare et al. (2020) focused on meteorological and hydrological drought monitoring in the Kaduna River catchment area. Using the Standardized Precipitation Index (SPI), Reconnaissance Drought Index (RDI), and Streamflow Drought Index (SDI) over 34 years (1967-2001), the study found that drought conditions occurred 33% and 37% of the time for meteorological and hydrological indices, respectively, with more non-drought conditions overall and only one extreme drought event.

Ogunrinde et al. (2020) employed the self-calibrated Palmer Drought Severity Index (sc-PDSI) to assess drought from 1981 to 2015, identifying 5 to 18 drought episodes, with severe events occurring between 1998-2001 and 2006-2008. The study emphasized the importance of using established indices for long-term hydrological drought prediction.

Olagbaiye et al. (2021) analyzed drought occurrences in the Sudano-Sahelian agro-ecological zones of Nigeria using SPI and three variations of the Standardized Precipitation Evaporation Index (SPEI-Thornthwaite, SPEI-Hargreaves, and SPEI-Penman), identifying historical drought periods in 1982-1989, 1992-2002, and 2008-2011. Notably, the Analytic Hierarchy Process (AHP) found SPEI-P to be the most robust and sophisticated index, while SPI scored highest for transparency and extendibility.

Jimoh et al. (2023) evaluated the performance of the SPI and Standardised Precipitation Anomaly Index (SPAI) for characterizing drought in Northern Nigeria, aiming to identify the best method for developing an early warning system. The findings suggest that while the SPI and SPAI perform differently at various timescales, the 6-month accumulation scale showed consistent spatial and temporal drought patterns. The SPAI is useful for periodic rainfall series but may amplify drought signatures due to high climatic variability. SPI has limitations, especially in representing temporal fluctuations. The study recommends exploring the Standardised Nonstationary Precipitation Index (SnsPI) and other indices that incorporate potential evapotranspiration and global warming impacts for more accurate drought monitoring in Northern Nigeria.

While this progress has been made, there are still significant challenges to be met in the extension of in-situ infrastructure across Nigeria, with real-time monitoring systems that will enhance the country's state of drought management and preparedness. It is hoped that continued efforts through relevant government agencies and active research will enhance the nation's resilience through effective policy decisions in the face of socio-economic drought impacts.

3.2 CHALLENGES AND GAPS IN DROUGHT MONITORING AND EARLY WARNING SYSTEM DEVELOPMENT IN NIGERIA

Addressing the challenges related to drought governance, coordination, funding, institutional capacity, and other institutional weaknesses is essential for effective drought management. The absence of clear policies and guidelines for drought management, insufficient institutional framework for drought early warning systems, limited participation of local communities in decision-making and poor coordination among government agencies and stakeholders are significant hurdles that needs to be overcome. (NEMA, 2020).

Inadequate teamwork between meteorological, hydrological, and agricultural agencies, limited sharing of data and information among stakeholders, poor integration of drought early warning systems with existing disaster management frameworks, and insufficient participation of non-governmental organizations and community-based organizations underscore the pressing need for improved coordination mechanisms. (WMO. 2019).

The inadequacy of funding for drought early warning system development and maintenance, limited financial support for research and development of drought-related

technologies, insufficient allocation of resources for drought mitigation and response, and dependence on international donor funding are critical concerns that must be addressed to ensure sustained progress in drought management. Limited technical capacity for drought monitoring and prediction, inadequate training and capacity building for stakeholders, poor data management and analysis capacity, and limited institutional memory and knowledge sharing indicate the need for considerable improvements in institutional capacity. Other Institutional Weaknesses includes poor legislation and regulations for drought management, limited public awareness and education on drought risks, poor community engagement and participation in drought decision-making, and inadequate contingency planning for drought response highlight key areas lacking immediate attention. (FAO. 2018).

The need for a national drought policy and strategic plan, establishment of a national drought early warning system coordination unit, development of standardized drought monitoring and reporting protocols, and strengthening of institutional capacity for drought research and development are vital steps that should be prioritized to bridge existing gaps in drought management. Addressing these multifaceted challenges will require a comprehensive and coordinated approach involving all relevant stakeholders, including government agencies, research institutions, non-governmental organizations, and local communities. By focusing on these critical areas, we can work towards enhancing our resilience to drought and building a more sustainable future for all (FMEnv, 2018).

3.3 INTERNATIONAL BEST PRACTICES IN DROUGHT MONITORING AND EARLY WARNING SYSTEM

International best practices in drought early warning systems involve a multi-dimensional approach to alleviate drought impacts. Here are some key components:

MONITORING AND PREDICTION: Utilize climate models, satellite imaging, and ground-based observations to monitor drought conditions and predict potential droughts. (NIDIS, 2020). Implement drought indices (e.g., Palmer Drought Severity Index) (NDMC, 2020).

RISK ASSESSMENT: Identify vulnerable regions, populations and industries to prioritize interventions (IFRC). Conduct socioeconomic impact assessments (UNDP, 2011).

EARLY WARNING: Establish a timely warning system to alert stakeholders, enabling proactive measures (WMO, 2019).

COMMUNICATION AND COORDINATION: Foster collaboration among government agencies, researchers, and local communities to ensure effective response. Utilize mobile apps, SMS, and social media for dissemination (GSMA, 2019).

IMPACT ASSESSMENT: Continuously evaluate the effectiveness of drought management strategies. (UNDP, 2011).

COMMUNITY ENGAGEMENT AND PARTICIPATION: Involve local communities in monitoring and decision-making (UNCCD, 2019), Support community-based drought management initiatives (IFAD, 2019).

INTEGRATED INFORMATION SYSTEMS: Combine climate, hydrological, and socioeconomic data (WMO, 2019), Utilize GIS and remote sensing technologies (UNCCD, 2019).

CAPACITY BUILDING AND TRAINING: Enhance institutional capacity and training for drought management (UNDP, 2011), Develop drought-related education and awareness programs (WMO, 2019)

4 CONCLUSION

Drought Early Warning Systems (DEWS) are essential for mitigating drought impacts in Nigeria. Despite progress, significant challenges remain, particularly in governance, data accessibility, and stakeholder engagement. Key findings indicate that:

1. Nigeria's DEWS rely heavily on research institutions and international organizations, with limited national coordination.
2. Current DEWS focus primarily on climate and vegetation indices, often neglecting socioeconomic and environmental dimensions.
3. Institutional weaknesses, particularly in governance, funding, and stakeholder collaboration, hinder effectiveness.
4. Limited adoption of integrated information systems, such as GIS, remote sensing, and socioeconomic risk modeling, affects timely decision-making.
5. To enhance drought resilience, Nigeria must strengthen institutional frameworks, invest in predictive modeling, and adopt globally recognized strategies that improve early warning dissemination, stakeholder coordination, and long-term drought preparedness.

5 RECOMMENDATIONS

1. Establish a National Drought Management Agency to centralize efforts, streamline resources, and enhance coordination, mirroring successful models from the United States (NOAA's National Integrated Drought Information System) and Australia (National Drought Policy).
2. Develop a national drought policy and strategic plan, incorporating proactive mitigation measures, risk management strategies, and early response frameworks, similar to the European Drought Observatory.

3. Enhance institutional capacity for drought research and response, integrating machine learning, remote sensing, and predictive modeling to align with WMO and FAO best practices.
4. Strengthen multi-stakeholder collaboration, ensuring active involvement of government agencies, NGOs, and local communities, similar to Africa's IGAD Climate Prediction and Applications Centre (ICPAC).
5. Increase investment in DEWS infrastructure, prioritizing real-time data collection, cloud-based platforms, and mobile dissemination tools, following successful implementations in India and South Africa.

FUTURE RESEARCH DIRECTIONS:

1. Integrating local knowledge and indigenous practices into DEWS.
2. Developing more complex and integrated DEWS models.
3. Improving data quality, and enhancing communication strategies

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Smart GSM-Based Fingerprint and Password Aware Security System for Advancing Automobile Security

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ABSTRACT
GSM-based Fingerprint and Password-Aware Security System for Automobiles encapsulates a thorough investigation into advancing vehicular security through a novel integration of biometric and password-based authentication methods. This paper endeavors to enhance access control and communication capabilities in automobiles, addressing contemporary challenges in the automotive security landscape. The Arduino Uno being programmed with c++, authenticates both the fingerprints and password of any the user and processes these input data verifying it with the stored data of the fingerprint and password of the authorised user. The result is usually denied access if the data didn't match, and a granted access if both data are the same, and these happen within 112ms. Through rigorous testing and user feedback, the research demonstrates the system's robust functionality, secure data management, and user-friendly interfaces. The findings contribute valuable insights to the field, emphasizing the efficacy of combining biometrics, passwords, and GSM communication for a holistic and effective vehicular security solution. The security system serves as a foundational work in the advancement of automotive security technologies.

Keywords: *Automobile, biometrics, communication, fingerprint, password, security*

1 INTRODUCTION

The trend of carjacking is on the increase as there are various reports of motor vehicle theft across the country. In 2013, it was reported that 1.2 cases out of a hundred thousand (100,000) cars were reported stolen in Nigeria. This has prompted the use of theft control systems across various vehicle owners. Although these methods were effective, carjackers have found a way around them. With the rise of vehicle theft, it is essential to adopt a security system which tackles burglary (Anjana et al., 2022). One of the best ways to secure automobiles is to use password, which cannot be established as a key security system for automobiles because it is unreliable and can be guessed or accessed easily. The pattern at which passwords are created can be related to an individual's behavior. Biometrics has made significant changes in security systems, making them more secure, efficient and widely used. In creating layers of security for automobiles, more secure systems make use of password alongside GSM and Fingerprint innovation which is used in automobiles to provide real time tracking and active notification that can help curb an intended theft. According to Delac and Kresimir (2004), fingerprint technology is a biometric system based on physiological characteristics and is generally more reliable than one which adopts behavioral characteristics, even if the latter may be easier to integrate within certain specific applications. Biometrics is one of the applications in Image processing which refers to technologies that used physiological or behavioral characteristics of human body for the user authentication. Biometric recognition is based on uniqueness and permanence. The uniqueness means that there is no similarity of feature between two different biometrics data. A GPS tracking unit is a device that uses the Global Positioning System (GPS) to determine the precise location of a vehicle, person, or other asset to which it is attached and to record the position of the asset at regular intervals (Singh et al., 2015). It is important to know the current location of the vehicle at any given point of time. A GPS system gives real time information on the location, direction and speed of the car which allows the owner to know where the automobile vehicle is at any given point of time. The work of (Noman et al., 2018) explains that Anti-theft security system requires real time fast identification, strong door control and security system which is provided to stop the ignition of the vehicle. This security system with the help of GSM technology is also designed to give user control of the vehicle locking the door remotely as enabled by the owner of the automobile once illegal entry is detected. This immobilizes the vehicle, hereby trapping the unauthorized person in the car and conveying message to the owner with accurate location of the vehicle using GPS and GSM technology. This research seeks to design a GSM based fingerprint and password aware systems for automobiles to improve and develop higher security. In automobile vehicles, particularly cars, advancing security system involves multi layering to avoid the ease of by passing the security. According to (Bukola, 2020) the smart anti-theft security system can be made more efficient and secured by combining other biometric identification systems like Face Recognition alongside the fingerprint authentication feature for more

security. The reliability of the security system reduces the cases of theft of motor vehicles.

TABLE 1: RELATED WORK

S/N	Authors and Dates	Research title	problem Solved	Limitations
1	Anjan *et al.*, 2018.	Anti-theft system for vehicles	Security in vehicles using password	Less reliable source of security
2	Vashist et al., 2021	A Fingerprint based ignition system in vehicles.	Use of biometrics for ignition	Loss of users RFID card
3	Anjana *et al.*, 2022.	Smart security system for vehicle anti-theft\	Eliminate the use of keys to access vehicles.	Didn't account for emergency situations.
4	Komanduri *et al.*, 2011.	Of Passwords and People: measuring the Effect of Password Composition Policies	Complexities of Password to improve security.	Less reliable source of security
5	Ross and Jain 2003.	Information Fusion in Biometrics	Getting Biometric Information Stored In database	Sophistication of Biometric handling
6	Karnan et al., 2011	Biometric personal authentication using keystroke dynamics: A review	Alternative Biometric Authentication	Inconsistency of behavioral biometrics
7	Imadu et al., 2018.	Vehicle Anti-Theft System Based on GSM and GPS Technology	GPS location of Vehicle using GSM	GPS system could be disabled

2 METHODOLOGY

The different modules that form the entire system are listed and discussed (the hardware and software modules).

2.1 THE BLOCK DIAGRAM OF THE SYSTEM

The block diagram of the proposed GSM-based fingerprint and password-aware security system for automobiles provides a high-level visual representation of the system's architecture and functional components.

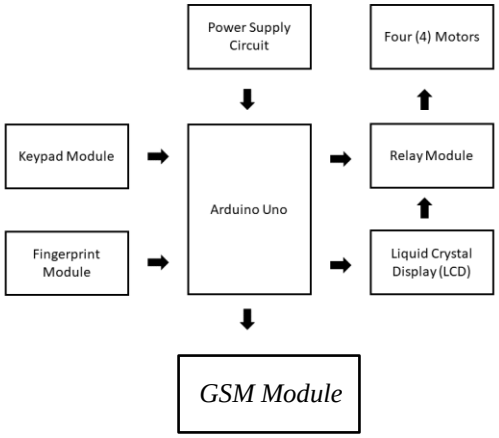


Figure 1: Block diagram of the system

2.2 THE HARDWARE MODULES

The hardware components for the system include:

1. Fingerprint module
2. Keypad module

3. Arduino Uno
4. Relay module2
5. Power supply
6. LCD+12c

2.2.1 FINGERPRINT MODULE

This module, also known as the Adafruit Fingerprint Sensor Library which integrates an advanced optical sensor capable of capturing high-resolution fingerprint images. It boasts a superior accuracy rate and is equipped with the capability to store up to 162 unique fingerprints in its internal memory. The module communicates with the Arduino Uno microcontroller through a standard UART (Universal Asynchronous Receiver Transmitter) interface, making it compatible with a wide range of microcontrollers. One of the key advantages of this module is its versatility in various environments, as it is designed to operate reliably under different lighting conditions and resist external disturbances. Additionally, the Adafruit Fingerprint Sensor module is equipped with an onboard processor that handles fingerprint recognition independently, significantly reducing the processing burden on the micro-controller. This feature is particularly valuable for ensuring real-time and efficient authentication. With its compact form factor and ease of integration, the Adafruit Fingerprint Sensor module proves to be an asset in realizing the GSM-based fingerprint and password-aware security system for automobiles.

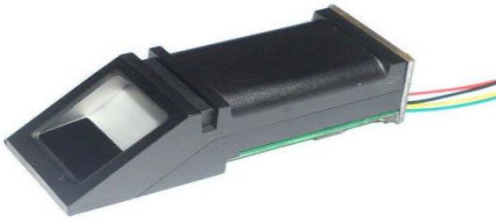


Figure 2: Adafruit Fingerprint Sensor module

2.2.2 KEYPAD MODULE

This module serves as a user interface component, enabling seamless input of access codes for authentication purposes. It features a 4x4 grid layout, offering a total of 16 buttons that can be easily pressed to input numerical or alphanumeric combinations. Each button is labeled with specific characters or numbers, providing a clear and intuitive means of interaction. The Matrix 4x4 Membrane Keypad interfaces with the Arduino Uno microcontroller through a straightforward wiring connection, simplifying integration into the overall security system. Moreover, it operates with minimal power requirements, ensuring energy efficiency in prolonged usage scenarios. Its membrane-based design offers tactile feedback upon pressing, enhancing user experience and reducing the likelihood of input errors. The durability of the module's construction ensures long-term reliability, even in high-frequency usage environments. Overall, the Matrix 4x4 Membrane Keypad proves to be a reliable and user-friendly input component crucial for the functionality of the GSM-based fingerprint and password-aware security system for automobiles.



figure 3: Keypad module

2.2.3 ARDUINO UNO

The cornerstone of this project's hardware is the Arduino Uno microcontroller board Developed by Arduino, this open-source platform has gained immense popularity for its versatility and ease of use. At its core is the ATmega328P microchip, which boasts robust processing capabilities. The board itself is equipped with a host of digital and analog input/output pins, facilitating seamless interfacing with a wide array of electronic components. The Arduino Uno is capable of executing programmed logic, making it an ideal choice for orchestrating the various components of the security system. Its compatibility with a multitude of libraries and shields further extends its functionality. In addition, the board supports multiple communication protocols, such as UART, I2C, and SPI, enabling seamless integration with other modules and devices. The user-friendly Arduino Integrated Development Environment (IDE) simplifies the programming process, making it accessible even to those with limited coding experience.

The Arduino Uno serves as the central nervous system of the project, facilitating communication between the fingerprint module, keypad module, relay module, LCD+i2c, and power supply. Its robust capabilities, extensive community support, and user-friendly interface make it an ideal choice for orchestrating the components of the GSM-based fingerprint and password-aware security system for automobiles.

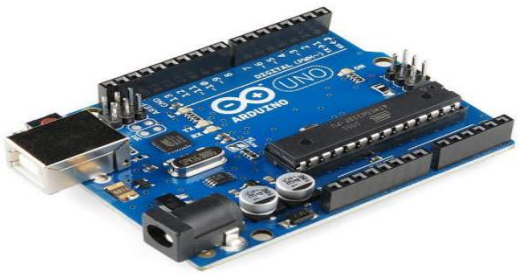


Figure 4: Arduino Uno

2.2.4. RELAY MODULE

This module is a crucial component in the security system as it enables the Arduino Uno to control external electronic devices, such as locks or access control systems. The module is equipped with four individual relays, each capable of switching high voltage and high current loads. This capability makes it suitable for a variety of applications, including controlling electronic locks or other security mechanisms. The 4-Channel Relay Module interfaces seamlessly with the Arduino Uno microcontroller through a straightforward wiring connection, allowing for easy integration into the system. Its isolation between the control and load circuits ensures safety and prevents potential interference with the microcontroller. Furthermore, the module features indicator LEDs for each relay, providing visual feedback on the status of the connected devices. Its compact form factor and robust construction make it suitable for deployment in various environments. Overall, the 4-Channel Relay Module plays a vital role in enabling the Arduino Uno to exert control over external electronic components, an essential function in the GSM-based fingerprint and password-aware security system for automobiles.

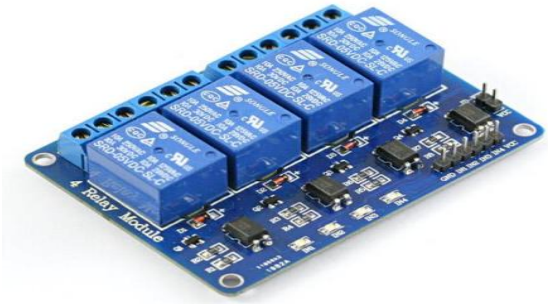


Figure 5: Relay Module

2.2.5. POWER SUPPLY

It provides the necessary voltage and current to power the entire system, including the Arduino Uno. The power supply unit chosen for this project is a regulated DC power supply with specific specifications. This power supply unit is a critical component in the system, providing stable and reliable electrical power to all the connected modules and components. It ensures that the entire system, including the Arduino Uno, fingerprint module, keypad module, relay module, and LCD+i2c, receive the necessary voltage and current levels for proper operation. The regulated feature of the power supply prevents voltage fluctuations or surges, which could potentially damage sensitive electronic components. It also includes built-in protection mechanisms, such as overcurrent and overvoltage protection, to safeguard against any unforeseen electrical issues. The power supply unit interfaces with the main power source and distributes the required power to the individual components through appropriately rated connectors and cables. Its robust construction and safety features make it a reliable and crucial element in the GSM-based fingerprint and password-aware-security system for automobiles, ensuring uninterrupted and secure operation. no, fingerprint module, keypad module, relay module, and LCD+i2c.



Figure 6: Power Supply Module

2.2.6 LCD+I2C

The LCD with I2C (Inter-Integrated Circuit) interface module serves as a crucial visual feedback component in this security system. This specific module is the 16x2 LCD with I2C backpack, a popular choice due to its ease of integration and reduced pin requirements. It consists of a 16-character by 2-line liquid crystal display, which provides clear and easily readable text output. The integration of an I2C interface simplifies the connection process, requiring only two wires for communication with the Arduino Uno. This significantly reduces the pin count and complexity of the wiring setup, which is particularly valuable in projects with multiple components. The module supports various character sets and allows for custom characters, enhancing flexibility in displaying information. It is equipped with a backlight feature, enabling clear visibility in low-light conditions. The LCD module provides visual feedback on system status, authentication results, and user prompts, enhancing user interaction and system operability. Its compact size and straightforward integration make it an invaluable component in the GSM-based fingerprint and password-aware security system for automobiles.

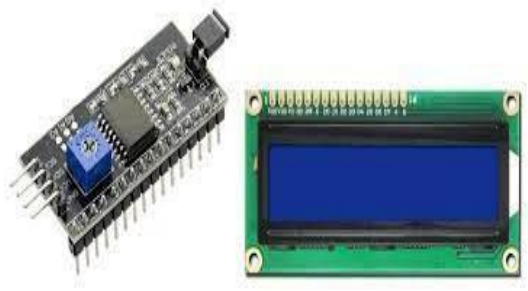


Figure 7: LCD with i2C

2.3. SOFTWARE MODULES

The Software modules are as follows;

1. Arduino IDE (Integrated Development Environment)
2. Fingerprint sensor library
3. C++

2.3.1. ARDUINO IDE (INTEGRATED DEVELOPMENT ENVIRONMENT)

This is the primary software for programming the Arduino microcontroller. It provides an intuitive interface for writing, compiling, and uploading code to the Arduino board. The Arduino IDE (Integrated Development Environment) is a crucial software tool for developing applications on the Arduino microcontroller platform. It provides a comprehensive and user-friendly interface for writing, compiling, and uploading code to the Arduino board. The IDE is compatible with multiple

operating systems, including Windows, macOS, and Linux, making it accessible to a wide range of users. One of its key advantages is its simplicity, making it an excellent choice for beginners and experienced developers alike. It offers a straightforward code editor with features like syntax highlighting and auto-indentation, aiding in code readability and organization.

In summary, the Arduino IDE serves as a fundamental tool for anyone working with Arduino microcontrollers. Its user-friendly interface, built-in Serial Monitor, extensive library support, and seamless integration with Arduino hardware make it an indispensable software for developing a wide range of projects, including the GSM-based fingerprint and password-aware security system for automobiles.

2.3.2. FINGERPRINT SENSOR LIBRARY

The Fingerprint Sensor Library is a vital software component specifically designed to facilitate seamless communication between the Arduino microcontroller and the fingerprint sensor module.

This library is custom-tailored to support the features and functionalities of the chosen fingerprint sensor module, ensuring accurate and reliable interaction. It encapsulates a set of pre-written code and functions that abstract the low-level details of data transmission, allowing developers to focus on high-level application logic.

One of the primary functions of the Fingerprint Sensor Library is to manage the process of capturing, processing, and comparing fingerprint data. This includes tasks like enrolling new fingerprints, searching for a match, and managing the stored fingerprint templates. The library optimizes these operations by taking into account the specific capabilities and protocols of the chosen fingerprint sensor. The library often includes error handling mechanisms and feedback mechanisms, providing valuable information to the developer for debugging and troubleshooting. This ensures that the interaction between the Arduino and the fingerprint sensor module is robust and reliable, even in scenarios where unexpected issues may arise. The library may offer additional features and utilities,

depending on the capabilities of the fingerprint sensor. These could include functions for adjusting sensitivity settings, managing security levels, and handling template storage.

Ultimately, the Fingerprint Sensor Library serves as a critical bridge between the hardware components, allowing for seamless integration of the fingerprint sensor module into the overall security system. It significantly simplifies the development process, enabling developers to leverage the full potential of the fingerprint sensor without needing to delve into the intricacies of low-level communication protocols. This level of abstraction is crucial for efficiently implementing the GSM-based fingerprint and password-aware security system for automobiles.

2.3.3. C++

C++ is a powerful, versatile, and widely used programming language known for its efficiency and flexibility. It is an extension of the C programming language with added features like object-oriented programming (OOP) capabilities. C++ provides a comprehensive set of tools for developing a wide range of software applications, making it a preferred choice for system-level programming, game development, embedded systems, and high-performance applications. One of the primary strengths of C++ lies in its support for object-oriented programming. This paradigm allows developers to organize code into reusable, modular units called classes. Classes encapsulate data and behavior, providing a clean and structured approach to software design. This facilitates code reusability, maintainability, and scalability, making it an excellent choice for complex projects. C++ also offers low-level control over system resources, allowing developers to manage memory allocation and pointer manipulation. This makes it suitable for tasks that require fine-grained control over hardware resources or performance optimization.

In summary, C++ is a versatile and powerful programming language, well-suited for a wide range of applications. Its support for object-oriented programming, low-level system access, extensive standard library, and flexibility in programming paradigms make it a valuable tool for developing complex and performance-critical software solutions, including the creation of systems like the GSM-based fingerprint and password-aware security system for automobiles.

The circuit diagram is shown below;

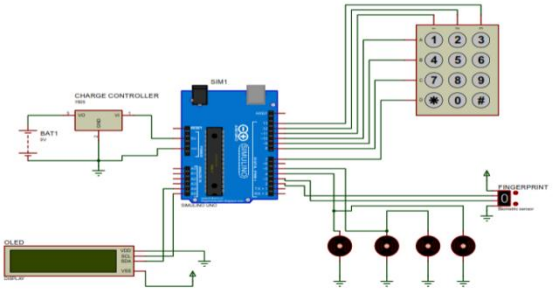


Figure 8: Schematic Diagram of the system

2.3.4 FUNCTIONALITY AND FLOW CHART

The flow chart of the proposed GSM-based fingerprint and password-aware security system for automobiles outlines the step-by-step sequence of actions and decision points within the system's operation. It begins with the initiation of the system, where the Arduino Uno initializes all connected modules and components. The flow then diverges into two main authentication paths: one for fingerprint-based authentication and the other for password-based authentication. In the fingerprint authentication path, the system prompts the user to place their finger on the sensor. The sensor captures the fingerprint data, which is then processed for matching with stored templates. If a match is found, the system grants access. If not, the user is prompted for password input. In the password authentication path, the system prompts the user to input a password using the Matrix 4x4 Membrane Keypad

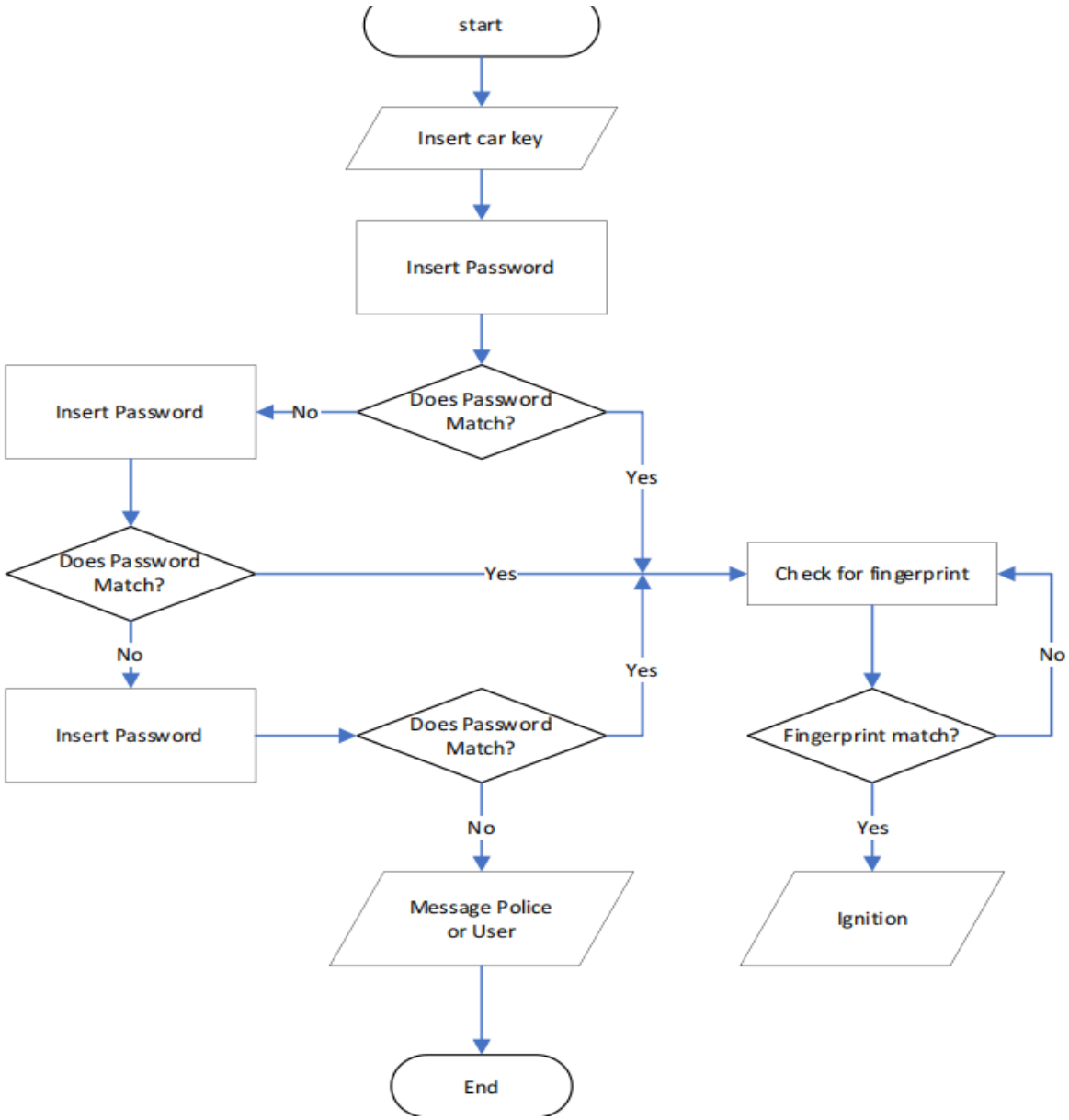


Figure 9: Flow chart of the system

The input is verified against the stored password. If correct, access is granted; if not, the user is given another attempt. Both authentication paths converge at the decision point for access permission. If access is granted, the system activates the relay module to control external devices. Simultaneously, the system sends an SMS message using the GSM module to alert the authorized user about the access event. The flow chart provides a clear and structured representation of the system's operational logic, helping to visualize the authentication process and subsequent actions in securing automobile.

3. RESULT AND DISCUSSIONS

These are the outcomes and discussions related to the implementation of the GSM-based fingerprint and password-aware security system for automobiles. The results are derived from thorough testing, validation, and user's feedback, providing insights into the system's performance, reliability, and user experience.

3.1 SYSTEM FUNCTIONALITY AND PERFORMANCE

The implemented system demonstrated robust functionality during testing. Both fingerprint and password-based authentication methods were successfully executed, showcasing the system's dual authentication workflow. The Fingerprint Module exhibited high accuracy in recognizing enrolled fingerprints, with a minimal false rejection rate. Password input through the Matrix 4x4 Membrane Keypad was responsive and accurate, providing an alternative means of user authentication. The 4-Channel Relay Module effectively controlled external devices, simulating the locking and unlocking of automobile doors. The GSM module performed reliably in sending SMS alerts to authorized users upon successful access and providing remote control functionality.

3.2. USER AUTHENTICATION WORKFLOW

The user authentication workflow was seamless, ensuring a secure and user-friendly experience.

The integration of both password-based and biometric authentication methods offered flexibility and redundancy. The system efficiently guided users through the authentication process, providing clear prompts and feedback via the 16x2 LCD with I2C interface module. Users reported a satisfactory and intuitive interaction with the Matrix 4x4 Membrane Keypad indicating a positive user authentication experience.

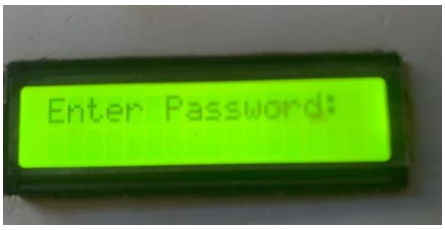


Figure 10: User authentication

3.3 ERROR HANDLING AND SECURITY FEATURES

The system demonstrated effective error-free handling mechanisms, addressing scenarios such as failed fingerprint recognition or incorrect password input. Visual and SMS alerts were generated in response to unauthorized access attempts, and sent to the authorized user with 112 ms, enhancing the system's security features. The secure storage of fingerprint templates and encryption of sensitive data were implemented, ensuring the protection of user information.



Figure 11: User authentication display showing invalid input

3.4 COMMUNICATION WITH GSM MODULE

Communication with the GSM module proved reliable, with the system successfully sending SMS alerts and receiving remote commands within 112 ms as seen in Figure 12. This feature enhanced the system's capability for real-time notifications and remote control, contributing to its overall effectiveness as a security solution.



Figure 11: Device communicating with GSM Module

3.5 DISCUSSION OF RESULT

The results indicate that the implemented GSM-based fingerprint and password-aware security system for automobiles meets the specified requirements and offers a robust solution for enhancing vehicular security. The dual authentication methods provide a comprehensive approach to access control, and the integration of GSM communication ensures timely alerts and remote management. User feedback has been positive, highlighting the user-friendly interface and the system's overall reliability. Further refinements and optimizations

could be explored, such as potential enhancements to the error handling mechanisms and additional security features such as facial recognition and iris biometric.

In conclusion, the results and discussions affirm the successful implementation of the proposed security system, showcasing its potential for improving automobile security through advanced authentication and communication technologies.

4. CONCLUSION

The completion of the GSM-based fingerprint and password-aware security system for automobiles research marks a significant stride in advancing vehicular security through innovative biometric and password-based authentication methods. The system demonstrated robust functionality, successfully integrating the Fingerprint Module, Matrix 4x4 Membrane Keypad, 4- Channel Relay Module, 16x2 LCD with I2C interface, and GSM module into a cohesive and effective security solution. The dual authentication workflow, combining biometrics with a password, provides a comprehensive approach to access control, enhancing the overall security. User feedback underscored the system's reliability, ease of use, and the seamless integration of multiple authentication methods. The error handling mechanisms and security features, including secure fingerprint template storage and data encryption, further contribute to the system's effectiveness. Successful communication with the GSM module, enabling realtime alerts and remote control, adds a layer of sophistication to the system. Overall, the project has achieved its objectives by delivering a functional and user-friendly security system for automobiles.

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Designing a Smart Hand Gesture Robotic Car Receiver for Achieving Transformative Transportation

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ABSTRACT

This paper explains the design and performance of a hand gesture robotic car receiver aiming to provide an easy-to-use solution for mobility so that paraplegics can have some aid in their daily routines. Through the integration of gesture recognition and robotics technology, this system is designed to enable users to independently move through their environment with natural hand gestures. A MPU6050 added to the transmitter of the car makes it easy to control and communicate with the car using real-time hand gestures. The microcontroller processes these gestures and converts it to angles that control the movement of the car. In all, the system translates five crucial hand gestures into correlating vehicle movements such as forward movement, reverse direction, turning left, turning right and stopping. The classified commands are sent to the microcontroller which controls motors and moves respective parts as requested. The receiver uses NRF24L01 radio module to wirelessly communicate with the transmitter. Arduino IDE is the key software stack used to operate the system configuration and integration. The average response time for five different observations of the forward, backward, right, left and break movement of the robotic car was recorded as: 106.4ms, 106.2ms, 99.2ms, 97.4ms and 102.2ms. The experimental results show that the robotic system is able to detect and control a car with accurate gesture recognition in real time, with a total average response time of 102.28 ms, resulting to 95% accuracy.

Keywords: *Hand Gesture, Micro Controller, MPU6050, NRF24L01, Receiver, Robotic*

1 INTRODUCTION

A good robotic system must have human-machine interaction as a key component. Early on, the only means of communication with a robot was through programming, which took a lot of effort. The advancement of science and robotics led to the creation of gesture-based recognition. Though they can start from any physical state or motion, gestures most frequently come from the hands or face. Gesture recognition is one approach toward making computers capable of reading human body language. As a result, there is now less demand for GUIs (Graphical User Interfaces) and text interfaces (RCCIIT, 2023).

In this world of advanced technology, various types of technology have been created to facilitate the Inter networking of physical devices that are embedded with electronic devices, software, sensors, or actuators that can make the data transfer possible. IoT can help paraplegic people in several ways. At its most basic level, it can help the disabled people to carry out everyday tasks in a simple manner without the involvement of humans. This eliminates the need for a helper throughout the day and can do simple tasks like object picking and placing for the disabled people. This can be introduced in the medical field for efficient operations and maneuverability in tasks (Venugopal and Balu Adityan, 2023).

Hand gesture controlled robotic cars have emerged as an innovative field in human-computer interaction and robotics. This technology aims to provide intuitive and natural ways for users to control vehicles, potentially enhancing accessibility and user experience.

This work is on a Hand gesture robotic car receiver which aims at providing an easy-to-use solution for mobility so that paraplegics can have some aid in their daily routines. This reduces the complexity encountered in existing systems. The NRF24L01 wireless module used in the system provides reliable and fast communication between the robotic car and the control system, allowing smooth and precise control compared to using Bluetooth modules like HC-05 or HC-06 that have been used in previous works. The low power consumption of NRF24L01 makes it suitable for battery-powered robotic cars, enabling longer operation times compared to using Wi-Fi modules like ESP8266 or ESP32 which consumes more power. Finally the system discussed in this work - Hand gesture robotic car receiver – reads all round gesture (360^0) unlike previous work that could read in specific directions but not in all directions.

Wadaye et al. (2023) presents an innovative integrated system combining a hand gesture-controlled robotic arm with an all-terrain surveillance car. The study showcases the potential of accelerometer-based gesture recognition for dual control of both the robotic arm and car movement, while also incorporating surveillance capabilities through an integrated camera. This multi-functional approach demonstrates the versatility of

gesture-controlled systems in complex, all-terrain environments. However, the research has several limitations. These include potential constraints in gesture vocabulary complexity, challenges associated with wearable sensor dependence, and a lack of clarity regarding the system's operational range and environmental robustness.

In the research made by (Neto et al., 2019), a gesture recognition system was designed using a depth sensor and machine learning algorithms. The system was integrated with a robotic arm for tasks such as pick-and-place and assembly. The system's performance was also evaluated in terms of accuracy, efficiency and user experience. The system's accuracy being affected by variations in lighting and environmental conditions in the study is a significant limitation.

Agarwal et al. (2016) presented a gestured-controlled robotic car whose hand gesture interface was integrated with a digital system which makes the system's performance in terms of accuracy and efficiency to be analyzed. The system was limited to recognizing a specific set of pre-defined gestures and the system's accuracy was affected by noise and interference in the signals.

2 METHODOLOGY

In this Section the different modules that form the entire system are discussed and the steps taken to achieve the assembly of the system are underlined.

2.1 BLOCK DIAGRAM OF THE SYSTEM

Figure 1 illustrates several components of the receiver design and the way they are connected. The receiver is composed of Arduino Uno microcontroller, Radio Module NRF224L01, l298 Motor Driver and Motors.

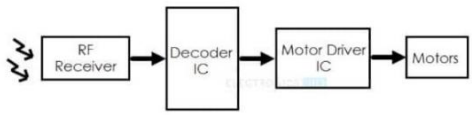


Figure 1: Block Diagram Of the System

The receiver of the hand gesture-enabled robotic car is a crucial component that enables the robotic car to receive and respond to hand gestures wirelessly. The Arduino Uno which is the Control unit of the system receives input in the form of signal from the Radio module NRF24L01 which is the wireless communication component. The Radio module connected to the Arduino Uno microcontroller is used to enable wireless communication, receive and decode commands, and provide reliable connectivity for remote control of the robotic car.

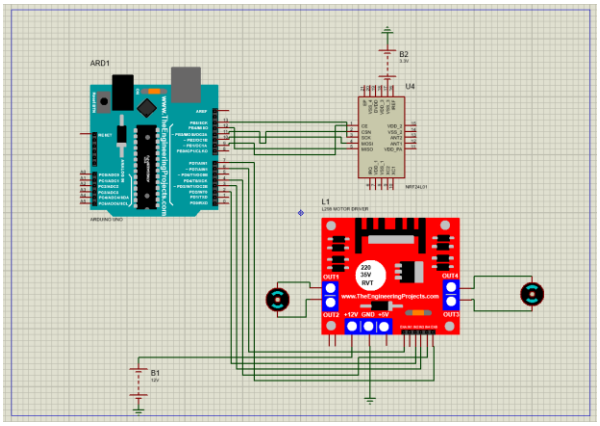


Figure 2: Circuit Diagram of the receiver of hand gesture-enabled robotic car

2.2 HARDWARE COMPONENTS

The system Consists of the following hardware:

1. Wireless Communication Unit
2. Motor Control Unit
3. Control Unit
4. Power Management Unit

2.2.1. WIRELESS COMMUNICATION UNIT:

The NRF24L01 radio module is a wireless component that serves as the wireless communication unit of the receiver. The NRF24L01 is a low-power, high-data-rate, and long-range wireless module that is small, cost-effective, and easy to use, making it a popular choice for wireless communication in various applications.

In the system, NRF24L01 radio module receives and decodes radio frequency (RF) signals, enabling wireless communication between the transmitter and receiver, and providing a reliable link for controlling the robotic car. The NRF24L01 radio module have a frequency range of 2.4 – 2.5Ghz ISM band, data rate of 250kbps , and it's Operating Voltage is 1.9 – 3.6V with Max. operating current of 12.3mA.

The NRF24L01 radio module can cover up to 30-100 meters.

Figure 3 illustrates the wireless communication Unit of the Receiver of the hand gesture-enabled robotic car



Figure 3: NRF24L01 radio module

2.2.2. MOTOR CONTROL UNIT:

The Motor Control Unit is made up of the L298N Motor Driver which acts as an interface between the Arduino Uno and the motor, providing the necessary voltage and current to drive the motor. L298N Motor Driver Module is a high-power motor driver module for driving the DC and Stepper Motors.

The L298N is a dual H-Bridge motor driver that allows speed and direction control of two DC motors at the same time. The L298N can drive DC motors that have voltages between 5 and 35V. With a peak current up to 2A.

The DC voltage used to power the Motor driver is 11.1V

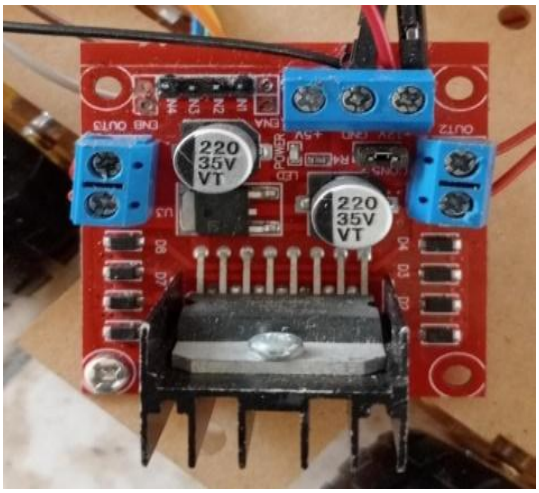


Figure 4: Motor Driver Used in the system

2.2.3. CONTROL UNIT:

The Arduino Uno is a microcontroller board that serves as the central processing unit of the System. In the system, the Arduino Uno is to receive the data of the hand gesture from Radio Module Nrf24l01 and recognize the gesture, also to process the signal and generate control signals to drive the motor drive.

Figure 5 shows the schematic design of Arduino Uno which has 14 pins used for digital input/output to read digital signals and 6 analog input pins for reading analog signal outputs which can control analog devices, a reset button for microcontroller reset. The connecting wire from Radio Module Nrf24l01 is connected to an analogue input and the Motor driver is connected to the output unit using connection wires.

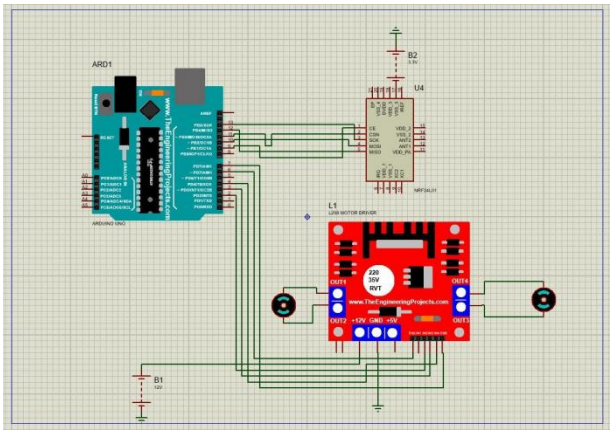


Figure 5: The Schematic diagram of the hand gesture robotic car comprising both the transmitter and receiver

2.2.4. POWER MANAGEMENT UNIT:

The Power Management Unit of the receiver of the hand gesture-enabled robotic car is responsible for managing the power supply to the various components of the car. The Power Management Unit consists of the battery, the voltage regulator and the capacitor. Though the Voltage regulator and the capacitor are secondary components of the receiver in the sense that the receiver will still function well without both, but it's needed to make the system more efficient.

2.2.4.1. THE VOLTAGE SOURCE

The voltage source of the receiver of the robotic car is the battery, 3 batteries (rechargeable) with 3.7V was connected in series, making it 11.1V. The reason why the batteries were connected in series is to have a high Voltage that can power the Motor driver, microcontroller and the motors.



Figure 6: Lithium battery (Manthiram, 2017)

2.2.4.2. THE CAPACITOR AND THE VOLTAGE REGULATOR

The capacitor in this system serves to stabilize the power supply and reduce noise. It acts as a temporary energy storage device, smoothing out voltage fluctuations and providing a more consistent power flow to the components. The Capacitor used is 10UF, which makes the power supply to be stabilized.

The voltage regulator plays a crucial role in maintaining a stable and appropriate voltage level for the electronic components. It takes the input voltage from the battery (which may vary as the battery discharges) and converts it to a steady, lower voltage suitable for the microcontroller, Motor driver and motor. This is essential because the Arduino Uno and wireless module require a specific operating voltage of 5V. The voltage regulator ensures that these components receive the correct voltage regardless of fluctuations in the battery's output, protecting them from potential damage due to overvoltage and ensuring consistent performance. Figure 7 shows the connection of the capacitor and Voltage regulator on the board



Figure 7: Capacitor and Voltage Regulator used in the system

2.3 SOFTWARE COMPONENT

Arduino IDE is the programme used to operate the system's hardware components (Integrated Development Environment). The programme is written using this software, which then compiles it for the Arduino Uno Module Installed and running on the system of the constructed device. The software code used to program the Arduino Uno Microcontroller is written in the C++ programming language. Figure 3.11 shows the snapshot of the Arduino IDE when programming the microcontroller in what way to accept data from the radio module.

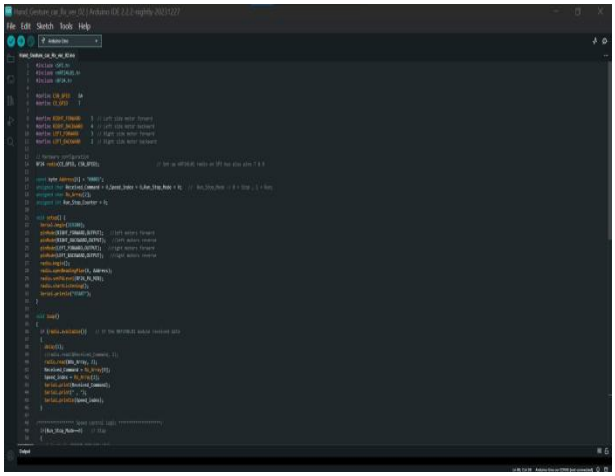


Figure 8: Snapshot of Arduino IDE

The Following was the Algorithm of the Coding Process of the Arduino Uno Microcontroller:

1. Include the nRF24L01.h library to the Arduino IDE.
2. Initialize the NRF24L01 radio module and set up the SPI bus and pins.
3. Set up the serial communication and define the pins for the motors.
4. Initialize variables for received command, speed index, run/stop mode, and counter.
5. In the loop function:
    a. Check if data is available from the NRF24L01 radio module.
    b. If data is available, read the received command and speed index.
    c. Print the received command and speed index to the serial monitor.
    d. Control the motors based on the received command and speed index.
    e. If the run/stop mode is stop, increment the counter and switch to run mode if the counter reaches a certain value.
    f. If the run/stop mode is run, increment the counter and switch to stop mode if the counter reaches a certain value.
6. Repeat the loop function continuously.

2.4. PRINCIPLE OF OPERATION

The receiver of the hand gesture-enabled robotic car is a crucial component that enables the robotic car to receive and respond to hand gestures wirelessly. The Arduino Uno which is the Control unit of the system receives input in the form of signal from the Radio module NRF24L01 which is the wireless communication component. The Radio module connected to the Arduino Uno microcontroller is used to enable wireless communication, receive and decode commands, and provide reliable connectivity for remote control of the robotic car.

The Arduino software (IDE) is used to program the Arduino Uno, communicate with the Radio module NRF24L01, control the motors, and debug the code, making it a crucial tool in the development of the hand gesture-enabled robotic car receiver. The Motor Driver is the output that is connected to the Arduino Uno and it plays a crucial role in controlling the motors of the robotic car, enabling it to move in response to hand gestures, and providing a reliable and efficient way to control the speed and direction of the motors. The Capacitor is connected to the L298 Motor Driver and the Arduino Uno, it helps in ensuring stable and reliable operation of the robotic car by filtering out noise, regulating voltage, and protecting the components from voltage spikes. The Voltage Regulator is also connected to the L298 Motor Driver, and it ensures a stable and consistent power supply to the components, protecting them from voltage fluctuations and spikes, and enabling reliable operation of the robotic car. The Motor is connected to the L298 Motor Driver and it is the actuator that enables the robotic car to move and perform various tasks in response to hand gestures, making it a crucial component of the hand gesture-enabled robotic car system.

The flowchart depicted in Figure 9 shows the steps involved in enabling the robotic car to receive hand gesture commands, control its movements, and adjust its speed accordingly.

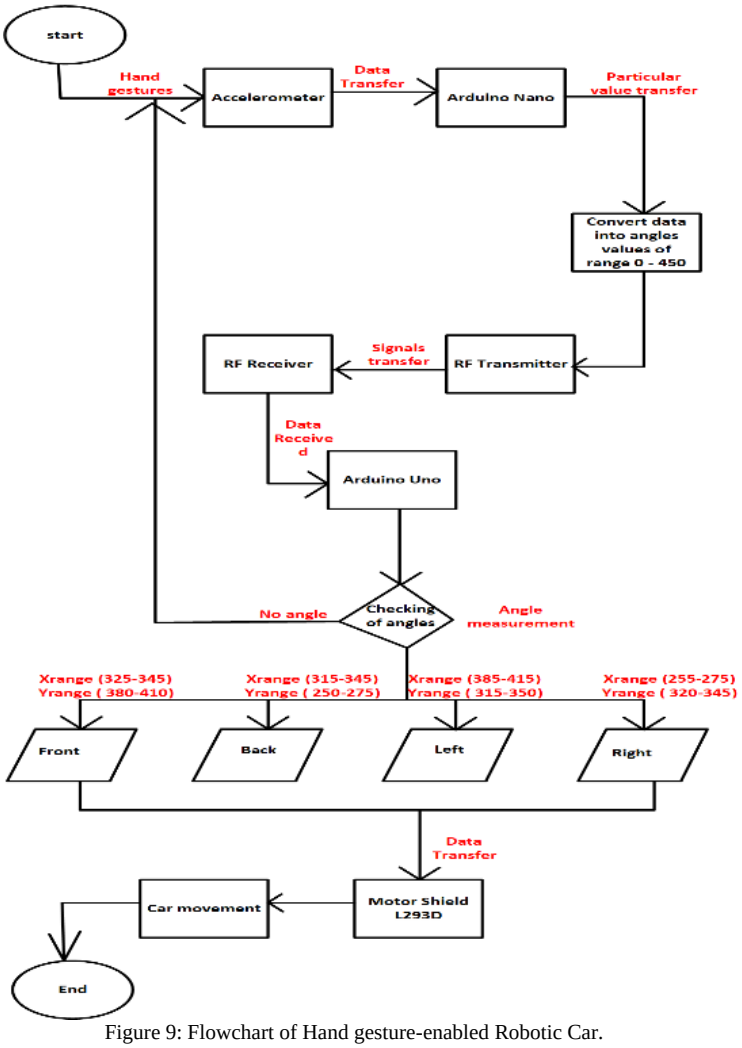


Figure 9: Flowchart of Hand gesture-enabled Robotic Car.

2.5. TESTING DURING METHODOLOGY AND CHALLENGES ENCOUNTERED DURING IMPLEMENTATION

To test the system, multimeter was used to check the voltage and current at each port of the board, and in every point during methodology to ensure accuracy. The response time of the receiver was gotten from the Arduino IDE which was displayed in real time and properly recorded. One of the challenges that was encountered during the implementation of the system was that the Arduino Uno was prone to quick damaged whenever there is high voltage, but it was checkmated by connecting a voltage regulator to the Arduino Uno and the L298 Motor Driver to regulate the power supply to the system. To avoid a break in communication, it was ensured that the pins were properly soldered, and they were well firmed to the board

3 RESULTS AND DISCUSSION

The tests carried out on the project work to determine the performance of the system were done by changing hand gestures to different positions and observing how quick the car responds. When the hand glove's accelerometer is in the straight position or the robot car does not receive any signal from it, it will initially remain motionless. However, if the hand palm glove is tilted in any direction, The Arduino will measure the angle of that tilt and send a command to the motor shield to turn on the corresponding motors, causing the robot car to begin moving in that direction.

Figure 10 illustrates the process of coupling the Radio Module NRF24L01 and the Motor Driver to the Arduino Uno on the Robotic Car .

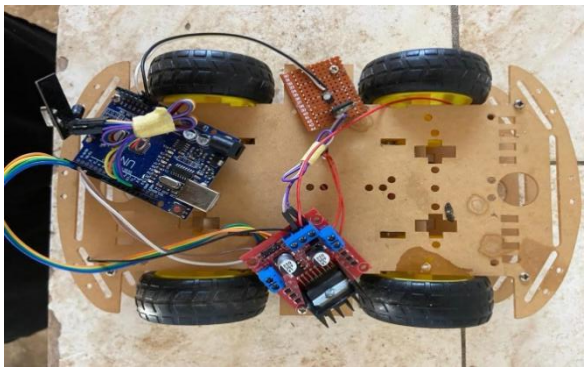


Figure 10: Coupling of the Receiver of the Car

3.1 TABULATION

This subsection delves into the analysis of the data obtained in the process of testing the accuracy of the axis on the receiver and the response time.

The inputs on the data pins of the Arduino uno determines the output of the motor drivers which gives the car its direction. The car moves according to the accelerometer orientation from the transmitter.

The Response time refers to the time it takes the car to respond to hand gestures. All movement of the car was observed 5 times each to get the average response time of each movement of the Robotic Car. Table 1,2,3,4,5 shows the response time of the car in different directions.

TABLE 1: RESPONSE TIME FOR 5 OBSERVATIONS OF FORWARD MOVEMENT OF THE CAR

Observation	Response (ms)
1	112
2	92
3	125
4	79
5	124

Average Response time = (112+92+125+79+124)/5 = 106.4ms

TABLE 2: RESPONSE TIME FOR 5 OBSERVATIONS OF BACKWARD MOVEMENT OF THE CAR

Observation	Response (ms)
1	110
2	79
3	139
4	64
5	139

Average Response time = (110+79+139+64+139)/5 = 106.2ms

TABLE 3: RESPONSE TIME FOR 5 OBSERVATIONS OF RIGHT MOVEMENT OF THE CAR

Observation	Response (ms)
1	93
2	81
3	137
4	93
5	92

Average Response time = (93+81+137+93+92)/5 = 99.2ms

TABLE 4: RESPONSE TIME FOR 5 OBSERVATIONS OF LEFT MOVEMENT OF THE CAR

Observation	Response (ms)
1	123
2	79
3	81
4	121
5	83

Average Response time = (123+79+81+121+83)/5 = 97.4ms

TABLE 5: RESPONSE TIME FOR 5 OBSERVATIONS OF IDLE/BREAK MOVEMENT OF THE CAR

Observation	Response (ms)
1	92
2	87
3	130
4	73
5	129

Average Response time = (92+87+130+73+129)/5 = 102.2ms

Total Average Response time = (106.4+106.2+99.2+97.4+102.2)/5 = 102.28ms

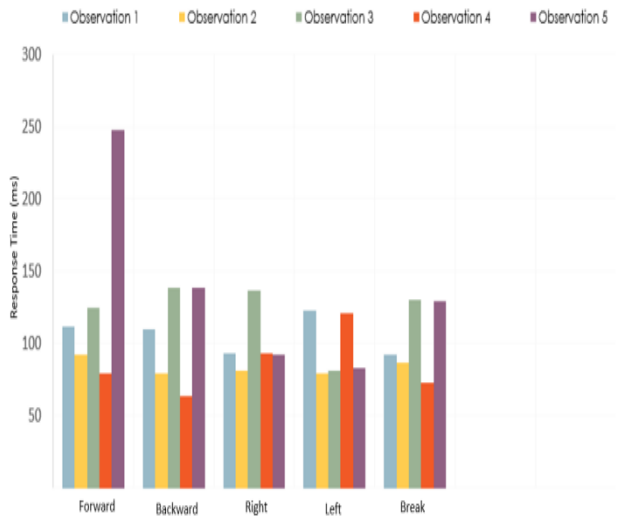


Figure 11: Response time for movements of the Car

3.2 DISCUSSION OF RESULT

The gesture recognition system achieved a commendable accuracy rate of approximately 85-90%, with the car responding correctly to most hand movements. The performance evaluation test shown in Table 4,5,6,7,8 reveals the response time of the system is 102.28 milliseconds on average, providing generally a smooth user experience. Wireless communication utilizing the NRF24L01 module, maintained reliable control up to distances of about 20-25 meters indoors and 50-100 meters in open spaces. Overall, the results indicate that while the hand gesture-Enabled robotic car successfully demonstrates the concept, there's room for improvement in accuracy, response time, and advanced control features. The paper not only achieved its primary goal of gesture-based control but also provided valuable insights into the challenges and potential of gesture recognition technology in consumer robotics.

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4 CONCLUSION

The research presented in this paper have demonstrated the design of a Smart hand gesture robotic car receiver for achieving Transformative Transportation for disabled (paraplegic) individuals to move to wherever they want to go with their hand gestures without the need of complex buttons or joystick controls. The Arduino Uno, a Radio module, L298 Motor Driver and Motor were all used in the construction of the receiver.

The system's ability to receive hand gestures and convert it to signals that can control the robotic car was archived with the help of Radio module Nrf24l01. The car shows proper movements for the pre-determined and calibrated different hand gestures. The data from the hand movements with the help of the accelerometer are fed into the Microcontroller. Then the values are transmitted with the help of Nrf24l01. Nrf24l01 receives the value in the receiver part, where it is decoded by Arduino Uno and sent to the motor driver L298D. Then motors are controlled with the data obtained from the motor driver. The car only moves when the accelerometer is moved in a specific direction as per the given values of the accelerometer.

The work is highly recommended because it is simple, reducing the complexity encountered in previously existing systems. It also recognizes

and reads gestures in all directions. It requires low power consumption. These features make it promising when compared to existing systems.

This work could generate a new generation of small-scale automatic wheelchairs and exoskeletons, both devices to help paraplegics with their mobility challenges, making them less dependable on care givers or heavy bulky chairs; all these can be significantly improved upon

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Potential of Natural and Stabilized Sedimentary Basin Soils for Use in Road Construction

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ABSTRACT
The sedimentary basin soils of Nigeria are mostly unsuitable for road construction due to fine nature of the soils. The soils have not being generally characterized in literature for use as road construction materials. The few literature on the use of sedimentary basin soils for road construction did not consider the stabilization alternative of the soils. This work studied the characteristic of ten (10) soils distributed over the Bida and Anambra basins of Nigeria. Index properties, compaction tests, unconfined compressive strength (UCS) and California bearing ratio (CBR) tests were conducted on the ten (10) untreated soil samples collected five (5) each from the Bida basin and Anambra basins. UCS tests and CBR tests were also conducted on the ten samples treated with 4% cement. The results revealed minimal to non-composition of gravel and clay sized particles except for soil collected from Ayo which possess 10% clay sized particles. The soils generally classified between clayey sand (SC) to clay of high plasticity (CH). The average maximum dry densities (MDD) of samples collected from Bida basin is 2.171Kg/m^3 while that of Anambra basin is 1.915Kg/m^3. Conversely, the average optimum moisture content (OMC) of the soils collected from Bida basin is 9.4% while that of Anambra basin is 12.3%. Only natural soils collected from Koton-Karfe, Isuochi, Ishiagu and Ameashi satisfy the 80% minimum unsoaked CBR and 30% minimum soaked CBR to be used as base course material for low trafficked roads based on Nigerian General Specification for Road and Bridges (2016). Except for soils collected from Ideato, Ishiagu and Ayo, all other soils treated with 4% cement satisfy the 150% minimum soaked CBR for soils to be used as base material for highly trafficked roads.

Keywords: *Anambra basin, Basement complex, Bida basin, California bearing ratio, Unconfined compressive strength*

1 INTRODUCTION

Generally, the geology of the world can be grouped in to two – The Basement complex soils and the Basin soils (Muhammad and Saad, 2017; Ande, 2019; Bankole et-al, 2020). The basement complex soils are those soils formed from the base rock due to physical and chemical processes acting on the rock. The soil deposits exists directly on the base rock thereby making the bedrock to be shallow from the ground surface (Haruna, 2017). The basin soils however are those soils deposited by rivers and lakes over a long geological time. The base rock in this area is very far from the ground surface which results to great depth of soil deposits (Odundun and Ogundoro, 2019). It is a common knowledge that soil deposits in basin areas are found to be fine in nature with large percentages of silt and sandy soils (Kolawale et al, 2015). Population growth in the world, especially in developing nations has led to increased demand for roadways, railways, dams, and other related infrastructures. These required infrastructures demand that the soils to be used satisfies specific requirements of which grading is one of the major requirements. Soils with good grading is required to bear the weight of these structures (Chen, 1988). There are instances where roads are constructed over a long span of basin soil deposits which will require the use of good soil materials for the construction of the road structure. However, most of these basin soils in their natural state does not possess suitable engineering properties for construction of road bases. Haulage of soil materials to these sites may be economically unwise and will require modification or stabilization to improve its engineering properties (Steinberg, 2000). Previous studies on the geotechnical properties of basin soil deposits for construction of road structures exists.

1.1 GEOTECHNICAL PROPERTIES OF SOILS FROM BIDA AND ANAMBRA BASINS

The study the study by Akhirevbulu (2011) investigate the occurrence of clay around Kutigi in Bida basin so as to evaluate its geotechnical properties. The author mapped an area, collected soil samples and conduct necessary geotechnical properties on the soils. The results showed an average natural moisture content of 0.9% and 0.7% for sections A and B respectively, an average liquid limit of 19.9% and 22.1% for sections A and B respectively, average plasticity index of 5.8 and 5.3% for sections A and B respectively. The soils from locations A and B both classified as clay of low plasticity. The soil deposits from the Patti formation of the Bida basin was also studied for its geotechnical and mineralogical appraisal (Ojo et al, 2020). Fifteen (15) soil samples were collected and tested for Atterberg limits and grain size analysis. Result of the grain size analysis showed large composition of well-graded fines with average liquid limit of 51% and plasticity index of

29%. A predictive model for quick evaluation of strength of soils collected from Patti formation using the index properties was developed (Obasaju et al, 2023). Strength properties like unconfined compressive strength (UCS) and California bearing ratio (CBR) were considered for the model. The resultant model revealed that the liquid limit, plastic limit and shrinkage limit correlated well with the CBR and UCS with R^2 ranging from 0.8 to 0.91.

Soils from another location of Patti formation (Gerinya clay) was studied for the appraisal of its geotechnical and mineralogical characteristics (Oyetade et-al, 2022). The tests conducted on the soil samples include index properties and shear strength parameters. The liquid limits ranges from 46% to 56% while the plasticity index ranges from 20.2% to 35.4%. The specific gravities ranges from 2.55 to 2.70. The author therefore concluded that Gerinya clay is not suitable for construction of road structures.

Three lateritic soils derived from three different parent rocks (Abeokuta formation, Patti formation and Ajali formations) were studied for their suitability as construction materials. Results showed that soils derived from Abeokuta formation are silty sand, that of Patti formation are clayey silt while that of Ajali formation are clayey sand. All the soils have low to intermediate plasticity with cohesion values ranging between 26 and 85KPa at standard proctor compaction energy and 70 to 120kPa when compacted at modified compaction energy level. The result of compaction and CBR indicate that the samples are only suitable for use as fill and subgrade materials in road construction.

The work on the consolidation characteristics of expansive soils collected from part of Imo shale in Anambra basin was carried out (Okeke et al, 2020). The result of the index properties of the soils revealed liquid limit ranging from 33 to 56% while the plasticity index values ranges from 30 to 31%. The dry densities ranges from 1.11Mg/m^3 to 1.58Mg/m^3. The compression index values ranges from 0.73 to 0.68. A comprehensive geotechnical properties of soils from Nanka and Ajali formations in Anambra basin was studied to identify their characteristics that make them prone to gully erosion (Ochelli et al, 2021). The results indicate 90.9% sand in Nanka formation and 95.1% sand in Ajali formations. The silt contents of the soils from Nanka formation and Ajali formations are 3.0% and 1.43% respectively. The plasticity index of soils collected from Nanka formation and Ajali formations are 5.29% and 2.70% respectively. Ogbuagu and Okeke (2019) studied some lateritic soils from part of Anambra basin (Nimo and Njete). The grading of the two soils revealed gravel, sand, silt and clay compositions to be 10%, 55%, 35% and 0% respectively for Nimo lateritic soil while the values are 46%, 43%, 11% and 0% respectively for Njete lateritic soils. The maximum dry densities (MDD) were observed to be 1.93 and 2.09Mg/m3 for lateritic soils from Nimo and Njete respectively while the optimum moisture contents (OMC) for Nimo and Njete lateritic soils are 14% and 10% respectively. The California bearing ratio (CBR) values of the samples are 89% and 143% for lateritic soils from Nimo and Njete respectively. Ogbuagu and Okeke (2019) studied some lateritic soils from part of Anambra basin (Nimo and Njete). The grading of the two soils revealed gravel, sand, silt and clay compositions to be 10%, 55%, 35% and 0% respectively for Nimo lateritic soil while the values are 46%, 43%, 11% and 0% respectively for Njete lateritic soils. The maximum dry densities (MDD) were observed to be 1.93 and 2.09Mg/m3 for lateritic soils from Nimo and Njete respectively while the optimum moisture contents (OMC) for Nimo and Njete lateritic soils are 14% and 10% respectively. The California bearing ratio (CBR) values of the samples are 89% and 143% for lateritic soils from Nimo and Njete respectively. The geotechnical properties of part of Nanka formations of Anambra basin was investigated to ascertain their implication towards the hazard of gully erosions. The results showed that the liquid limit ranges from 26.8 – 36.7%, the plasticity index ranges from 3.3% - 8.3%, the sand content ranges from 86% - 96%, the silt composition ranges from 1.0% - 5.0%. The clay composition were observed to be absent. The compaction characteristics showed MDD values ranging from 1.40 – 2.00Mg/m3 while the OMC values ranging from 8.6 – 11.8%. The results obtained from Ajali formations of Anambra basin revealed that the liquid limit ranges from 21.4 – 27.1%, the plasticity index ranges from 0.0% - 5.4%, the sand content ranges from 87% - 100%, the silt composition ranges from 0.0% - 2.6%. The clay composition were observed to be zero. The compaction characteristics showed MDD values ranging from 1.10 – 2.80Mg/m3 while the OMC values ranging from 6.4 – 10.7%. According to Surendra and Sajeey (2017), plasticity index (PI) of zero indicate sandy soil, non-plastic and non-cohesive. Plasticity index between 1 – 7% indicate sandy/silty soil with low plasticity and partly cohesive. PI between 7 – 17% indicates silty/clayey soil of medium plasticity and cohesive while the PI above 17% indicate clay with high plasticity and cohesive.

Most of these studies did not characterize the soils for possible use as road construction material thereby making it difficult for road engineer to prescribe these soils for use as road construction materials. It is therefore pertinent to study the geotechnical properties of basin soils for possible use as road construction material and also consider the alternative of stabilization for the sedimentary basin soils that does not meet specifications.

1.2 LOCATION OF STUDY AREA

This study was carried out within Bida basin and Anambra basins of Nigeria. Bida basin is located

Within latitude 4.5^0 E to latitude 7.5^0 E and longitude 7.5^0 N to longitude 10.5^0 N (see figure 1a). The study area is geologically located in one of the Sedimentary

Basin terrains of Northern Nigeria, precisely in the Mid-Niger (Bida or Nupe) Basin. The Basin, which is NW–SE trending intracratonic sedimentary basin, extending from Kontagora in Niger State of Nigeria to areas, slightly beyond Lokoja to the south. It is bounded to the North and South by crystalline rocks of Basement Complexes, and delineated to the East by Benue Through. The basin soils to be used in this study was collected at five (5) different locations around the entire Bida basin.

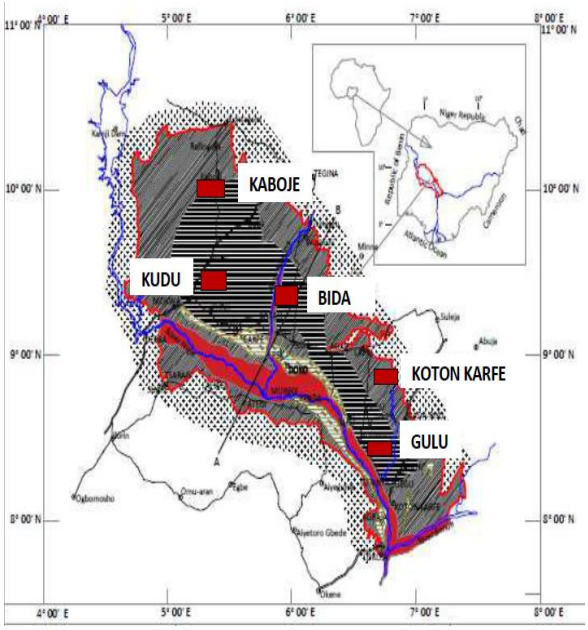


Figure 1a: Map of Bida basin showing test locations

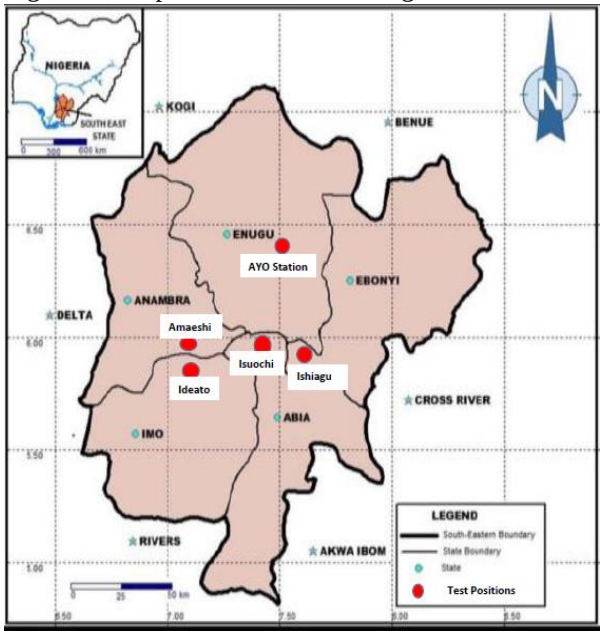


Figure 1b: Map of Anambra basin showing test location

These locations are Bida (latitude 9.08^0N and longitude 6.0^0E), Kudu (latitude 9.2^0N and longitude 5.3^0E), Kaboje (latitude 10.1^0N and longitude 5.4^0E), Gulu (latitude 8.6^0N and longitude 6.5^0E) and Koton Karfe (latitude 8.6^0N and longitude 6.7^0E). The Anambra basin on the other hand contains post-deformational sediments of Campanian Maastrichtian to Eocene ages. The area is located within latitude 6.5^0 E to latitude 8.5^0 E and longitude 4.5^0 N to longitude 7.5^0 N (see figure 1b). The stratigraphy comprises cyclic sedimentary sequence that started in the early cretaceous time (Reyment, 1965). Marine and fluviatile sediments comprising friable to poorly cemented sands,

shales, clays and limestone were deposited, with occasional coal, peat and thin discontinuous seams of lignite. These sediments have been affected by the major Santonian folding and a minor Cenomanian folding and uplift. The stratigraphy of the Anambra basin is made of the Asu river group, Ezeaku Formation, Nkalagu Formation, Nkporo Shales, Ajali Formation, Nsukka Formation and the Nanka Formation. These formations are often overlain by a considerable thickness of red earthly sands, Saterite, which are formed by weathering and ferruginization of the formations (Aweda *et al.*, 2015). The soil samples were collected from Ameachi (Enugu State) at latitude 6.404^0 and longitude 7.537^0, Ishiagu (Ebonyi State) at latitude 5.992^0 and longitude 7.533^0, Akokwa (Imo State) at latitude 5.921^0 and longitude 7.110^0, Ameshi (Anambra State) at latitude 5.934^0 and 7.097^0, and Ugwueme (Abia State) at latitude 6.001^0 and longitude 7.401^0. All the soil samples were collected at shallow depth of between 1.0m to 1.5m.

2 MATERIALS AND METHODOLOGY

2.1 MATERIALS

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2.2 METHODOLOGY

The soil samples were visually inspected to observe the colour and texture of the soils. To effectively characterize and understand the behavior of the basin soils used in this study, Index properties tests such as natural moisture content, sieve analysis, specific gravity, and Atterberg limits test were conducted on the untreated basin soils. Compaction test was conducted on the untreated soil at Modified Proctor compaction energy level. Geotechnical properties such as

unconfined compressive strength (UCS) and California bearing ratio (CBR) tests were conducted on the untreated basin soils and basin soils stabilized with 4% cement.

3 RESULTS AND DISCUSSION

3.1 INDEX PROPERTIES

The result of the index properties of the soils collected at the ten locations is shown on table 1. This is to allow for the classification of the basin soils from the ten (10) trial pits over the Bida and Anambra basins. The results showed that soils collected from Bida basin classified within the range of A-6 through A-4 to A-2-6 based on AASHTO soil classification test while soils collected from Anambra basin falls under A-2-4 to A-7-6 subgroup based on AASHTO soil classification system. Soils collected from Bida, Kaboje, Ideato, Isuochi, and Ameashi possess high composition of sand fraction with little silt while samples from Gulu, Kudu, Kotonkarfe, Ishiagu and Ayo comprises of high proportion of silt size particles with little sand. Gravel sized particles were observed to be relatively absent in all the ten soil samples collected.

This soil satisfy the criteria to be used as road construction material based on AASHTO soil classification system. This probably resulted from the sample location which is located towards the boundary of the Bida basin towards a basement complex.

3.2 GRAIN SIZE ANALYSIS

The grain size analysis graph of soils collected from Gulu and Koton Karfe are very close and showed more uniformity compared to soils collected from other locations. Soils collected from Bida, Kaboje and Kudu has higher characteristic of well-gradedness. The grain size analysis graph showed very little of gravelly soil ranging from 0 to 0.6%. Soils collected from Gulu and Koton-Karfe maintain the same characteristic in terms of percentages of the particle sizes.

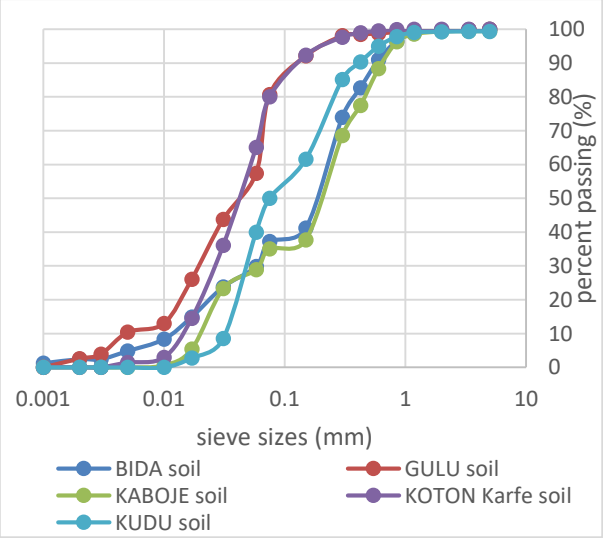


Figure 2a: Grain size analysis for Bida basin

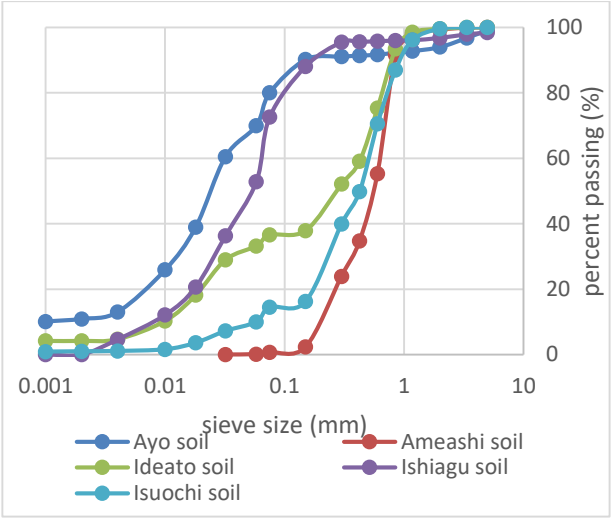


Figure 2b: Grain size analysis for Anambra basin

The soil from these two locations, with close proximity as shown in figure 1, contains lower percentages of sand and higher percentages of silt without clay sized particles. Soils collected from Bida and Kaboje has similar higher sand sized particles and lower silt sized particles. The general absence of gravel sized particle in all these soils will discourage their performance as road construction material.

3.3 COMPACTION CHARACTERISTICS

The compaction characteristics of each of the soils collected from both the Bida basin and Anambra basins are shown on figure 3 and 4. The maximum dry densities (MDD) for each of the soils and at British Standard Heavy (BSH) compaction energy level is shown on figure 3

The MDD values for soils collected from Bida basin ranges from 2.061 Kg/m3 to 2.278 Kg/m3 with an average value of 2.171 Kg/m3. The MDD of soils collected from Anambra basin ranges between 1.823 Kg/m^3 and 1.981 Kg/m3 with an average value of 1.915 Kg/m^3. The highest and lowest values of MDD were observed in Bida soil and Kotonkarfe soils respectively for the soils collected from Bida basin. The Anambra basin soils recorded the highest and lowest MDD values in Ameashi soil and Ayo soil respectively.

Conversely, the optimum moisture contents (OMC) of all the soils collected from both the Bida basin and Anambra basin are shown on figure 4. The maximum and minimum OMC values of
soils collected from Bida basin are 11.2% and 7.6% respectively with an average value of 9.4%. The OMC for soils collected from Anambra basin recorded maximum and minimum values of 17.7% and 9.7% with an average value of 12.3%.

The soils from Bida basin possess higher average MDD with lower average OMC while soils collected from Anambra basin possess lower average MDD with higher average OMC. This trend in compaction characteristic is in agreement with literature.

Table 1: Summary of Index properties result for the ten sample locations

Properties	Quantities									
	Gulu	Bida	Kudu	Kaboje	Koton-Krf	Ideato	Isuochi	Ishiagu	Ameashi	Ayo
Gravel	0.0	0.0	0.6	0.5	0.0	0.0	0.0	1.6	0.0	0.8
Sand	19.3	62.8	40.9	64.4	10.4	63.4	85.5	25.8	99.3	19.2
Silt	78.1	34.8	50.0	35.1	80.0	32.4	13.5	72.6	0.7	69.1
Clay	2.6	2.4	0.0	0.0	0.0	4.2	1.0	0.0	0.0	10.9
Liquid limit	25.0	22.4	24.7	26.7	27.1	37.9	21.7	29.2	28.5	53.0
Plasticity Index	10.7	9.2	12.2	12.1	3.5	17.4	NP	13.1	11.0	30.3
Nat. moist. cont. (%)	9.0	6.2	4.0	2.4	12.9	15.0	4.0	11.5	14.0	10.5
Specific gravity	2.61	2.66	2.63	2.60	2.63	2.61	2.63	2.54	2.61	2.66
MDD (BSH)	2.097	2.278	2.185	2.234	2.061	1.920	1.938	1.913	1.981	1.823
OMC (BSH)	11.2	7.6	8.6	8.6	11.2	12.9	9.7	11.2	10.1	17.7
AASHTO classifict system	A-4	A-4	A-6	A-2-6	A-4	A-6	A-2-4	A-6	A-2-4	A-7-6
Unified Soil classif system	ML	SC	CL	SC	ML	SC	SM	CL	SC	CH

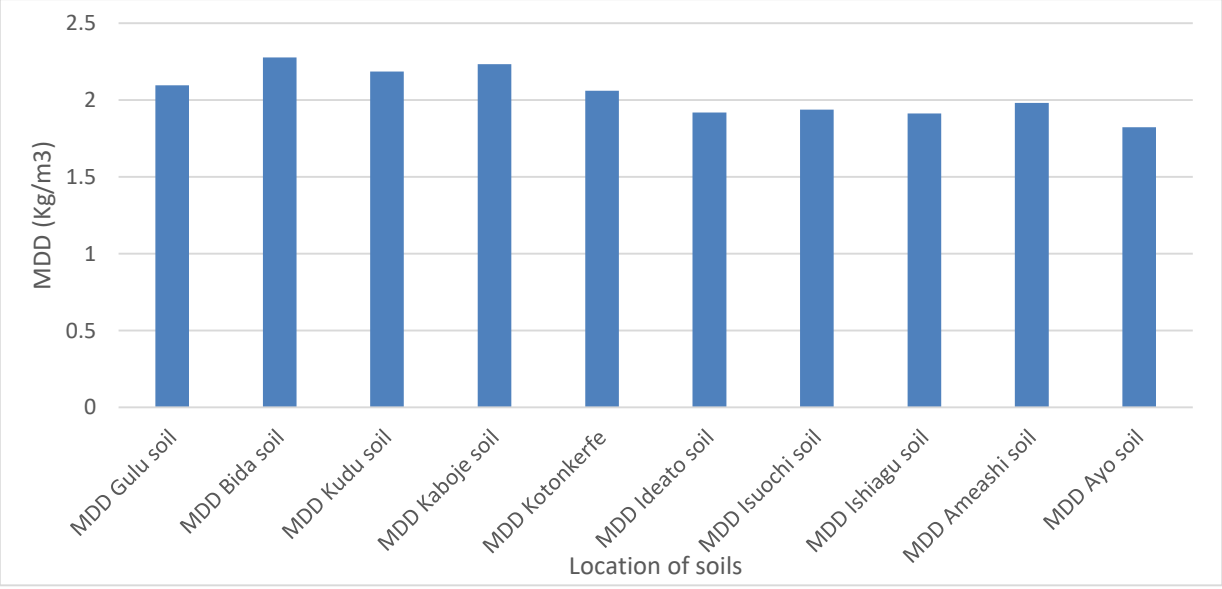


Figure 3: Maximum dry densities of soils from Bida and Anambra basins

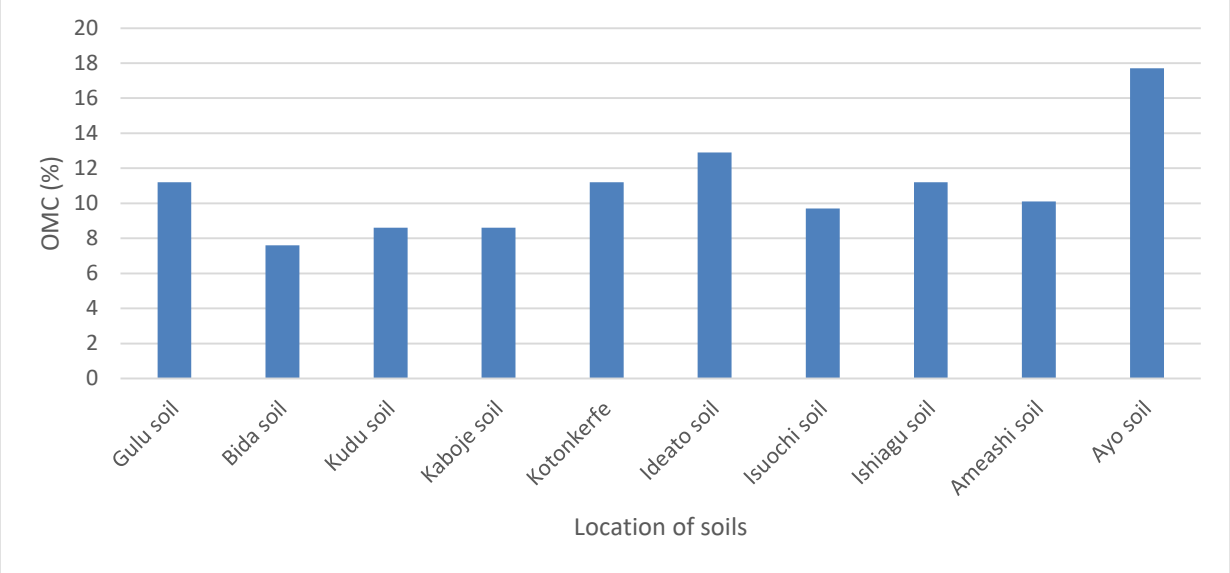


Figure 4: Optimum Moisture Content of soils from Bida and Anambra basins

3.4 UNCONFINED COMPRESSIVE STRENGTH

The results of the unconfined compressive strength (UCS) of the untreated soils and soils treated with 4% cement are shown on figure 5. All the untreated soils collected from both the Bida basin and Anambra basins recorded UCS values less than 500kN/m^2 and cannot be employed as sub-base in lightly trafficked roads based on Road Note 31 (1992). The highest UCS value of 2500kN/m^2 was recorded for soils collected from Kaboje followed by UCS value of 1916kN/m^2 recorded in soils collected from Bida.

These two soils coincidentally recorded the highest MDD values which is probably responsible for the high UCS values. The average UCS values of soils collected from Bida basin and treated with 4% cement is 1465 kN/m^2 while the average UCS values of soils collected from Anambra basin and treated with 4% cement is 1304 kN/m^2.

Based on Nigerian General Specification for Roads and Bridge Works (2016), all the soils collected from both the Bida basin and Anambra basin met the 720kN/m^2 minimum (UCS) specification for soils to be used as sub-base material for low trafficked roads. However, only soils collected from Bida and Kaboje met the 1500kN/m^2 minimum UCS specification for use as sub-base for highly trafficked roads. Similarly, only soils collected from Ideato, Isuochi and Ayo met the 1500kN/m^2 minimum specification for soil to be used as sub-base for highly trafficked roads.

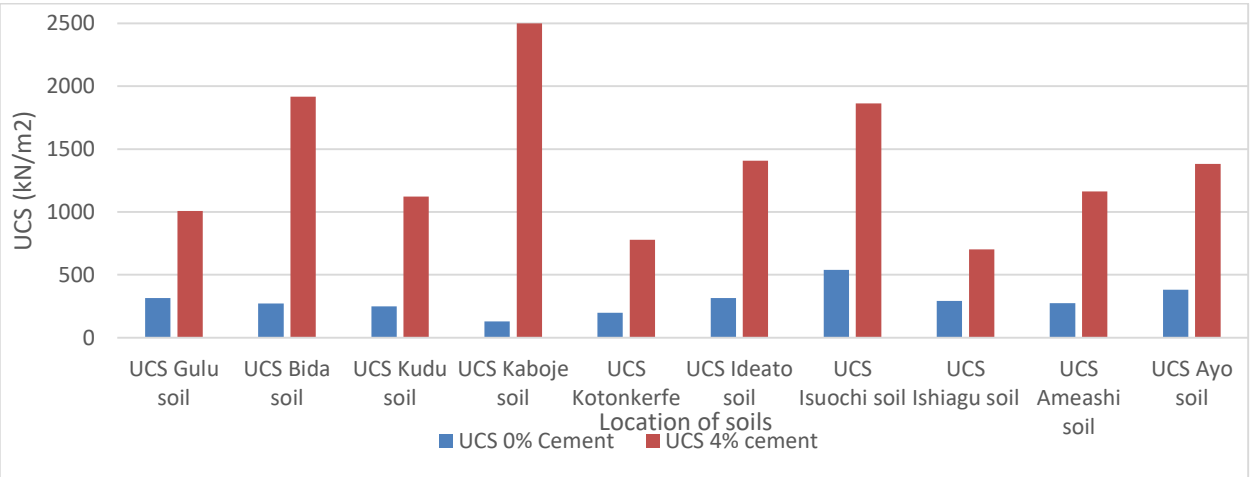


Figure 5: Unconfined compressive Strength of soils from Bida and Anambra basins

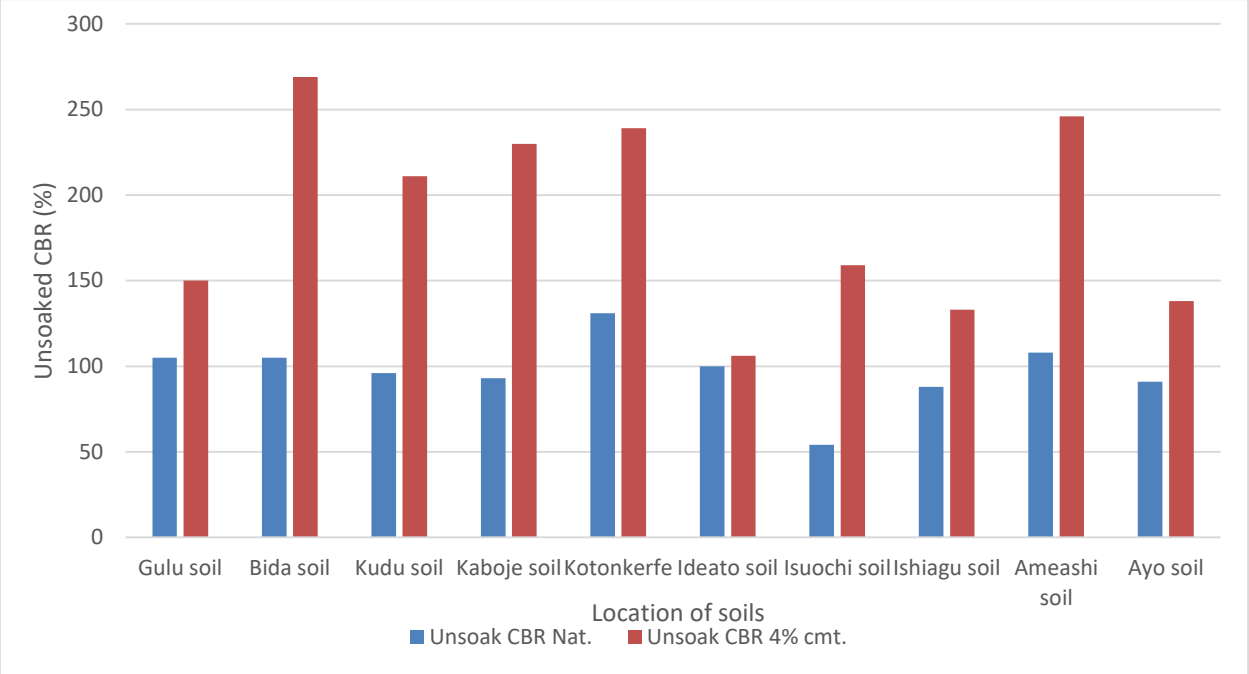


Figure 6: Unsoaked California Bearing Ratio of soils from Bida and Anambra basins

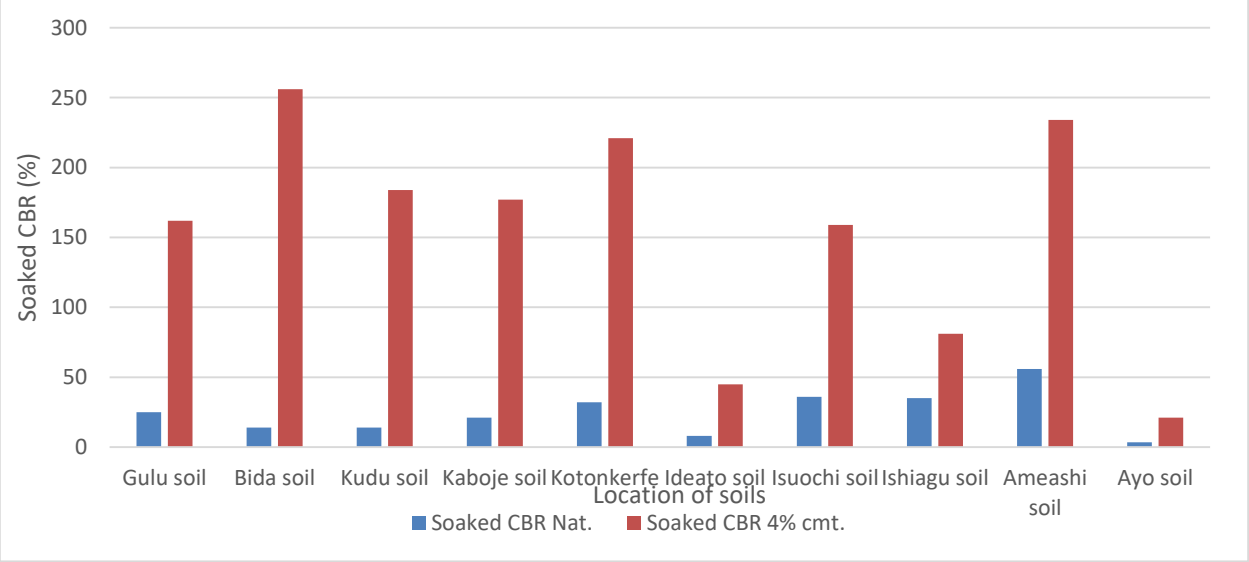


Figure 7: Soaked California Bearing Ratio of soils from Bida and Anambra basins

3.5 CALIFORNIA BEARING RATIO TESTS

The result of the unsoaked and soaked California bearing ratios (CBR) of soils collected from both the Bida basin and Anambra basins are shown on figures 6 and 7. All untreated soils collected from both the Bida basin and Anambra basins satisfy the 80% minimum unsoaked CBR for soils to be used as base course for low trafficked roads based on Nigerian General Specification for Roads and Bridges (2016) except for soil from Isuochi (see figure 6).

However, the most important condition of the same soil to achieve a soaked CBR of 30% minimum for the soil to be used as both sub-base and base course material was only achieved by soils collected from Koton-Karfe, Isuochi, Ishiagu and Ameashi (see figure 7). This implies that only untreated soils collected from Koton Karfe, Isuochi, Ishiagu and Ameashi satisfy the specification to be used as base course material for low trafficked roads while the untreated soil collected from Isuochi only satisfy the specification to be used as sub-base course material for low trafficked roads based on Nigerian General Specification for Roads and Bridges (2016).

For soils treated with 4% cement, the soaked CBR values of all the soils collected from Bida basin and Anambra basins met the 150% minimum soaked CBR

for soils to be used as base course for highly trafficked roads based on Nigerian General Specification for Roads and Bridges (2016) except for soils collected from Ideato, Ishiagu and Ayo which falls low of the specified CBR (see figure 7). Generally, it is observed that untreated soils from Bida basin recorded higher unsoaked CBR but lower soaked CBR while untreated soils collected from Anambra basin recorded lower unsoaked CBR but higher values of soaked CBR.

Except for soils collected from Ideato, Ishiagu and Ayo, all other soils treated with 4% cement showed minimal variation between unsoaked and soaked CBR values. The wide variation in unsoaked and soaked CBR values of soil collected from Ideato, Ishiagu and Ayo can be attributed to relatively high clay size particles for soils from Ideato, high silt content for soils collected from Ishiagu and high Atterberg limits which classified the soil under clay of high plasticity (CH) based on unified soil classification test (USCS) for soils collected from Ayo.

4.0 CONCLUSIONS

1. All the soils collected are characterized by little or complete lack of gravel and clay sized particles except for soil collected from Ayo with more than 10% clay sized particles. The soils are predominantly sand and silt sized particles which is in agreement with literature.
2. The soils generally classified between clayey sand (SC) to clay of low plasticity (CL) except for soil collected from Ayo which classifies as clay of high plasticity (CH) based on USCS.
3. The average MDD values of soils collected from Bida basin is 2.171 Kg/m^3 while the average MDD values of soils collected from Anambra basin is 1.915 Kg/m^3. Conversely, the average OMC values of soils collected from Bida basin is 9.4% while the average OMC values of soils collected from Anambra basin is 12.3%.
4. Based on CBR results, only untreated soils collected from Koton Karfe, Ishiagu and Ameashi satisfy the specification (80% unsoaked CBR and 30% soaked CBR) to be used as base course material for low trafficked roads Base on Nigerian General Specification for Roads and Bridges (2016). For soils treated with 4% cement and soaked for 72 hours, the CBR value of all the soils met the 150% specification to be used as base course for highly trafficked roads except for soils collected from Ideato, Ishiagu and Ayo which falls short of the specification.

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Effects of Waste Glass Powder and Cassava Peel Ash on Compressive Strength of Concrete

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ABSTRACT
This study investigates the effects of incorporating glass waste powder (GWP) and cassava peel ash (CPA) as partial replacements for cement on the compressive strength of concrete. A total of 294 concrete cubes were prepared with varying proportions of GWP and CPA (0%, 5%, 10%, 15%, 20%, 25% and 30% replacement levels). Both materials were characterized by X-Ray Fluorescence (XRF) analytical method. The slump of fresh concrete with WGP and CPA of 0, 5, 10, 15, 20, 25 and 30% respectively by weight of cement was investigated in accordance with standard procedures. The results show that the compressive strength of concrete increased with the addition of GWP and CPA up to a certain replacement level. The 28 days compressive strength of concrete with 15% WGP/CPA content was 16.4 % more than normal, while that of concrete with 20% WGP/CPA content was 11.9 % less than normal.. The optimal replacement levels for GWP and CPA were found to be 15% and 5%, respectively. The study concludes that the use of GWP and CPA as partial replacements for cement can improve it compressive strength, it sustainability and reduce the environmental impact of concrete production. The results of slump tests of different percentages of CPA/GWP as a partial replacement of cement in concrete production were observed for all proportion ranging between 12 – 41mm. **However 20% GWP/CPA replacement was considered as optimum for structural concrete.**
Keywords: Waste glass Powder, Cassava peel ash, Specific gravity, Slump, Compressive strength,

1 INTRODUCTION

Concrete is the most widely used construction material globally. However, its production process is energy-intensive and significantly contributes to carbon emissions due to the substantial amount of cement required. This has led researchers to explore sustainable alternatives, including the incorporation of waste materials like glass waste powder (GWP) and cassava peel ash (CPA) as partial replacements for cement in concrete. This study investigates the effects of GWP and CPA on the compressive strength of concrete, aiming to provide a more environmentally friendly and cost-effective solution for the construction industry. The reliance on industrially manufactured cement has resulted in high construction costs, prompting the need for innovative, sustainable approaches.

The over dependence on the utilization of industrially manufactured binding materials (cement) have kept the cost of construction financially high, and this has up till now prevented third world countries like Nigeria in providing good housing for its citizen particularly rural dwellers that are mostly agriculturally dependent (Agbede & Joel, 2011; Krammart, 2004). Aggregate is a basic component of concrete, that are obtained in our environment , which are used by civil engineers for the constructions of most of their infrastructure such as roads, buildings, airport (Amartey *et al*., 2013). Aggregate to be consider as quality aggregate it must be clean, strong, durable, hard and free from clay. In the other hand, a modern life style alongside the advancement of technology has led to an increase in the amount and types of waste being generated, leading to waste disposal crisis, (Yunusa, 2015). This research tries to tackle problem of the waste that is generated from cassava peels and glass waste.

According to Anwar *et al*. (2000) suggest that combining multiple waste materials in concrete can lead to performance enhancements, as each material contributes unique benefits. For instance, CPA's ability to enhance long-term strength and WGP's ability to improve durability could result in concrete mixes that are both strong and sustainable. However, it is hypothesized that the synergistic effects of CPA and WGP could lead to enhanced strength and durability due to their complementary properties. CPA provides pozzolanic activity, while WGP acts as both a pozzolan and a micro-filler.

Cassava peel is a by-product of cassava processing, either for domestic consumption or industrial uses. According to Adesanya *et al*. (2008) cassava peel

constitutes between 20 – 35% of the weight of tuber, especially in the case of hand peeling. Based on 20% estimate, about 6.8 million tons of cassava peel is generated annually and 12 million tones are expected to be produced in the year 2022 (Adesanya *et al.,* 2008).

Glass is a material with high silica content, the amorphous forms of silica are composed of silica tetrahedral arranged in a random three-dimensional network without regular lattice structure (Aboshio *et al.,* 2015). The higher silica content in glass make it potential pozzolana. (Federico & Chidiac, 2009; ILO, 2015; Jin *et al.,* 2000) reported that the global production of glass was estimated at 115 million tons in 2007. They further reported that the demand for glass in Nigeria was estimated at 360,000 tons per year.

2.0 MATERIALS AND METHODS

2.1 MATERIALS

The Glass Waste Powder (GWP) was sourced from recycled glass and ground into fine powder, while the Cassava Peel Ash (CPA) was produced by burning dried cassava peels, yielding ash with pozzolanic properties at Ahmadu Bello University, Zaria, Kaduna state. Cement is Ordinary Portland Cement (OPC) sourced at local vendor in Minna, Niger State. Aggregates are standard fine and coarse aggregates used in the control concrete mix. Water is a clean potable water for concrete mixing source at concrete laboratory of Federal University of Technology, Minna.

2.2 MIX DESIGN

Concrete mixes was prepared by partially replacing cement with GWP and CPA at varying proportions of 0%, 5%, 10%, 15%, 20%, 25% and 30% . A control mix without GWP or CPA will serve as a benchmark. Slump test was carried put to measure concrete's workability and ease of placement. Compressive strength tested was carried out at 7 and 28 days to determine how GWP and CPA affect strength development.

2.3 SLUMP OF TEST

Slump test was conducted on CPA and GWP-concrete in accordance with BS EN 12350 Part 2 (1999) using the mixes in the Table 3.2. The concrete slump test is an empirical test that measures the workability of fresh concrete. In order to maintain standard consistency for all the concrete mixes. The cone was filled in three layers and compacted 25 times for each layer using tamping rod. The excess was removed and the cone was lifted vertically with slow motion. Finally the cone was inverted and placed by the side of the concrete using a straight edge across the top of the cone. The drop of the concrete was measured with a meter rule and recorded.

2.4 COMPRESSIVE STRENGTH OF CPA /GWP-CONCRETE

The compressive strength tests of CPA /GWP-concrete was carried out in accordance with BS 12390 Part 4 (2000) using the mixes in the Table 3.1. Cassava peel ash content of 5, 10, 15, 20, 25 and 30% respectively by weight of cement and 10% of glass waste powder were measured and used for the preparation of the cubes. Mixing was done mechanically and cast in steel cube moulds of 100mm x 100mm x 100mm and cured in clean water for 7 and 28days, in accordance with BS 1881 part 111 (1983). At the end of the curing age, three samples were crushed in accordance with BS 1881, part 116, (1983) using a compressive testing machine of 600kN load capacity and average taken. During crushing, care was taken to ensure that the cubes were properly positioned and aligned with the axis of the thrust of the compressive machine to ensure uniform loading on the cubes as recommended by Neville (2003).

3. RESULTS AND DISCUSSION

The experimental results was analyzed to determine the relationship between GWP/CPA content and their influence in the development of strength properties of concrete. Strength trends was identified and optimal mix design was proposed based on strength developments.

3.1 PHYSICAL PROPERTIES OF AGGREGATE MATERIALS

The results of physical properties of fine and coarse aggregate were shown in Table 1 and the particles size distribution of fine aggregate presented in Figure 1. The fine aggregate used was found to be sharp sand with tested specific gravity of 2.66 which fall within the limit for natural aggregates with the value between 2.6 - 2.7 (Neville, 1995). The coarse aggregate used are crushed granite of nominal size 19mm with tested specific gravity of 2.76; this value obtained fall within the limit for natural aggregates with the range of 2.5 – 3.0. This implies that the aggregates can be conveniently used for construction work without much need for mix proportioning adjustment (Neville, 1995).

Table 1: Physical Properties of Aggregate

Properties	Value	
	Fine Aggregate	Coarse Aggregate
Specific Gravity	2.66	2.67
Moisture Content (%)	9.81	2.36
Loose Bulk Density (kg/m^3)	1490	1564.25
Compacted Bulk Density (kg/m^3)	1710	1642.17
Average Crushing Value (%)	----	22.38
Aggregate Impact Value (%)	----	27.83

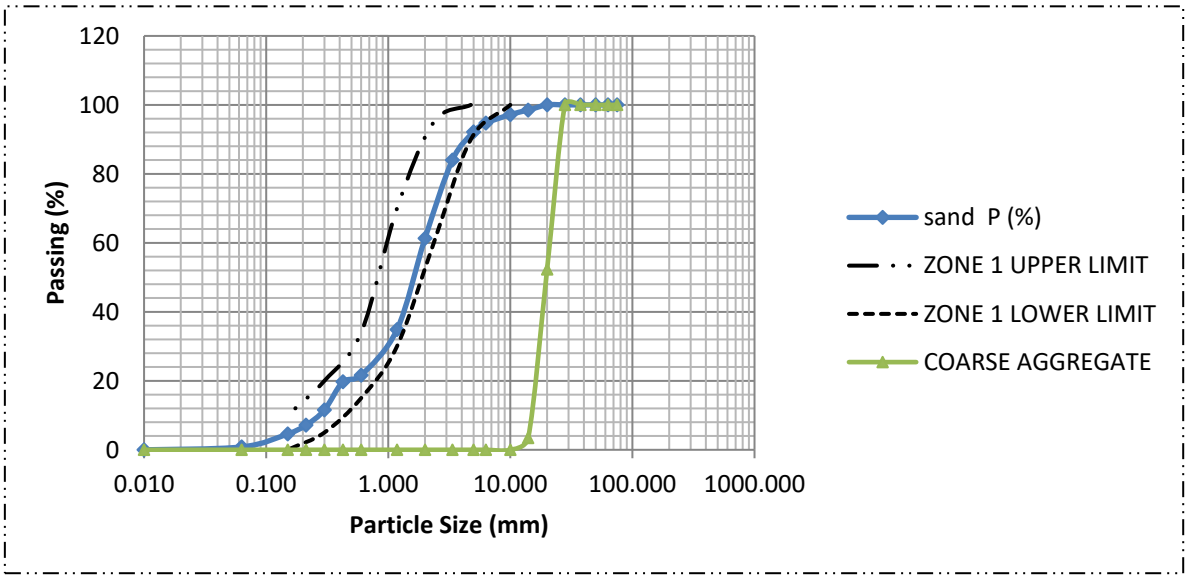


Figure 1: Particle Size Distribution of Fine and Coarse Aggregate

3.2 CASSAVA PEEL ASH (CPA) AND WASTE GLASS POWDER (WGP)

The physical properties of CPA and WGP are shown in Table 2. The physical properties of Cassava Peel Ash (CPA) revealed that CPA has a specific gravity of 2.12 and a loss on Ignition (Lol) value of 7.84%, which is within ASTM C618 acceptable limit of 10% for class N pozzolana. This therefore indicates that the CPA was properly burnt. The physical properties of glass waste powder (GWP) revealed that GWP has a specific gravity of 2.59. The grain size distribution of GWP obtained by sieving through 75µm sieve indicated that GWP obtained through 75µm sieve is of less grains.

Table 2: Physical Properties of Cassava Peel Ash (CPA)

Properties	Value	
	WGP	CPA
Moisture content (%)	1.25	1.58
Specific gravity	2.59	2.12
Bulk density (kg/m^3)	839.05	694
Loss on Ignition (%)	----	7.84
Fineness (% passing BS sieve No. 200 (75μm))	100	100
Colour	Grayish white	Brownish grey

3.3 CHEMICAL PROPERTIES OF CEMENT, WGP AND CPA

The oxide composition of CPA is presented in Table 2 and it shows that, the predominant oxide is SiO_2 (56.73%) and a combined SiO_2, Al_2O_3 and Fe_2O_3 content of 66.75%; This shows that CPA contain insignificant CaO content which is lower than 20% composition for cementitious materials (Ljubica *et.al*,2005). The SO_3 content was found to be 1.30%, which according to ASTM C618 (2008) should not be more than 5.0%. Nuruddeen, (2012) reported that, the SO_3 content affect the strength of mortar and concrete specimens to some degree. The higher the SO_3 content, the higher the resultant strength.The oxide composition of WGP is presented in Table 2 and it shows that, the predominant oxide is SiO_2 (69.5%) and a combined SiO_2, Al_2O_3 and Fe_2O_3 content of 71.76%. This shows that WGP is pozzolanic. The SO_3 content was found, which according to ASTM C 618, (2014) should not be more than 5.0%. (Ejeh *et al.*, 2014) reported that, the SO_3 content affect the strength of mortar and concrete specimens to some degree.

Table 2: Oxide Composition of OPC, WGP and CPA

	Oxide Value (%)										
	SiO_2	Fe_2O_3	Al_2O_3	CaO	K_2O	SO_3	MgO	Na_2O	MnO	ZnO	LOI
Cement	18.1	4.82	3.10	68.37	0.35	1.82	1.48	0.32	0.03	0.00	1.27
WGP	69.3	1.25	2.01	10.08	0.65	0.21	3.01	12.65	---	---	---
CPA	56.73	2.78	7.24	8.65	3.93	1.30	2.58	0.41	0.78	0.05	7.842

3.4 SLUMP OF CPA/GWP – CONCRETE

The results of slump tests of different percentages of CPA/GWP as a partial replacement of cement in concrete production is shown in Fig. 2, it is observed that the slump for all proportion ranging between 12 – 41mm. Reduction in workability was observed with increase in the percentage CPA over GWP. The decrease in slump with the addition of CPA/GWP indicates that more water is required to maintain the same consistency as the CPA/GWP content increases. The CPA has potential to absorb more water than GWP and ordinary Portland cement in the mix (Agbenyeku & Aneke, 2014). According to Memon *et al*. (2019) reported that fineness of material mix with the concrete decreases the workability of concrete.

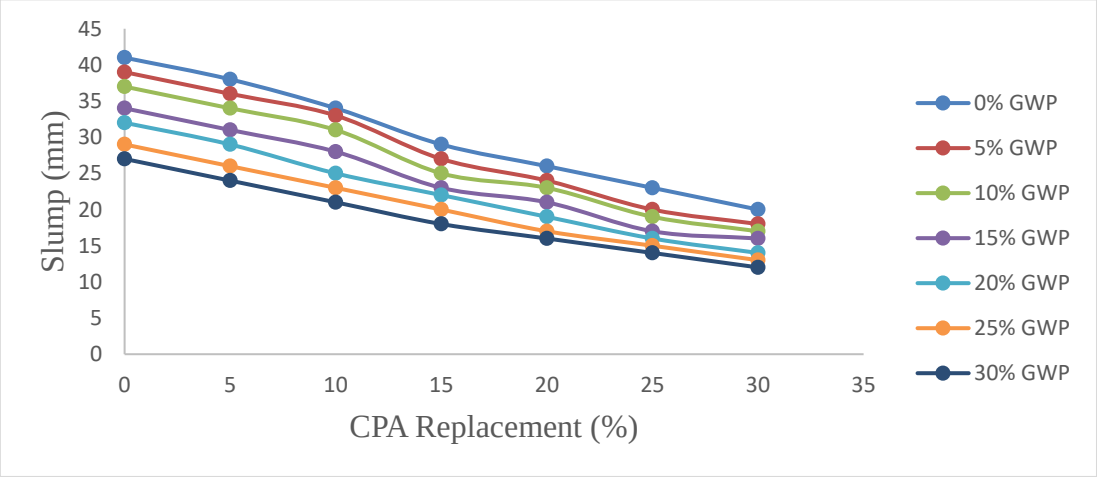


Figure 2: Slump of CPA/GWP concrete

3.4 COMPRESSIVE STRENGTH OF CPA/GWP – CONCRETE

The result of compressive strength of cement-CPA and GWP blended concrete is shown in Figures 3 and 4. It was observed that the strength increased with the curing age and deceased with increase in content of CPA/WGP content for all the concretes. Control concrete gained 52% after 7 days of curing against its 28 days compressive strength. The compressive strength of control samples was less than that of samples of up to 15% ternary blend CPA/WGP but higher than the 20% blend of CPA/WGP at all ages. It was observed that the 28days compressive strength of concrete with up to 20% CPA/WGP content exceeded the design characteristics strength, and basically meet the minimum standard in (BS 1881-116, 1983) that recommended the compressive strength for 28 days to be within 20N/mm^2 to 34N/mm^2 for normal weight concrete.

The decrease in compressive strength of concrete with increase in CPA/WGP content would be due to dilution effect of Portland cement and weaker formation of C-S-H gel as a result of slow in pozzolanic reaction of CPA and WGP. This is in line with the conclusion by Salau et al. (2012) report on CPA and Oyekan & Kamiyo (2011) reports on RHA. Also, the reduction in strength is in agreement with the explanation of Ogork and Solomon (2014) in their studies, on the influence of Sawdust Ash (SDA) as admixture in Cement Paste and Concrete.

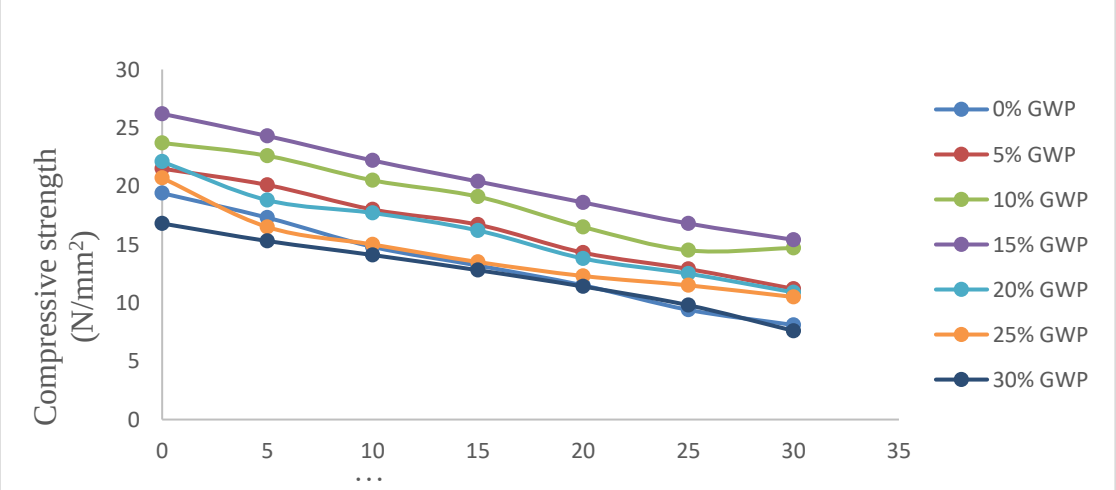


Figure 3: 7Days Compressive Strength of CPA/ESP – Concrete

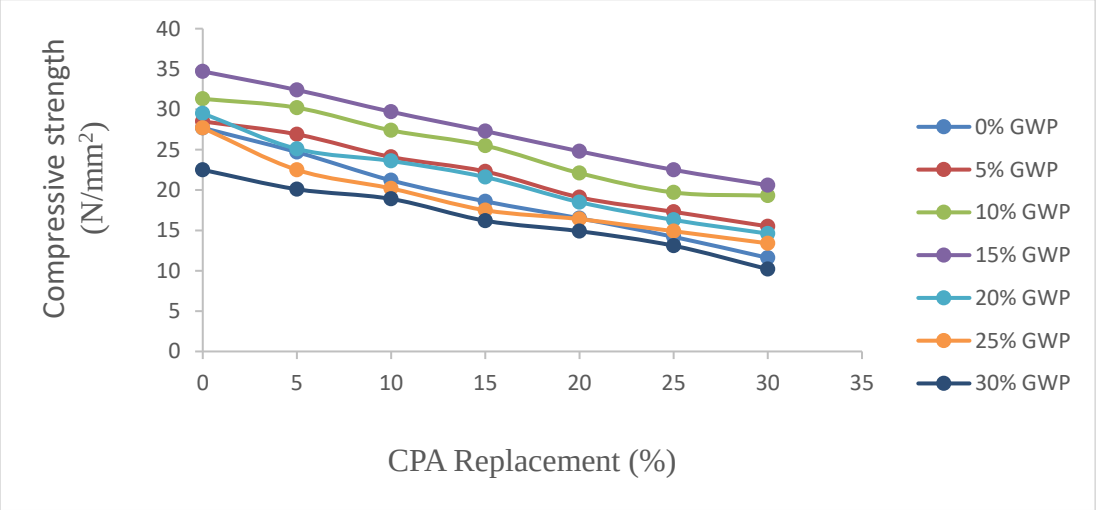


Figure 4: 28Days Compressive Strength of CPA/ESP – Concrete

4.0 CONCLUSION

Based on the study conducted on CPA/WGP Concrete, the following conclusions can be drawn.

i. With the increase in the percentage of CPA/WGP, the compressive strength of concrete increases up to an optimized value and beyond that value, the strength starts reducing. Though, with increase in the percentage of CPA over the WGP, the strength decreases.

ii. By replacing with CPA/WGP above 15%, reduction in compressive strength was high at the age of 28 days, especially when the percentage of CPA is higher than that of WGP.

iii. Results proved that adding of glass waste power with 25% of weight will leads to improvements in compressive strength. Hence, glass waste power may be used as a way for safe disposal of waste glass.

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Estimating Sediments Inflow into *Guesselbodi* River Using Field Measurements

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ABSTRACT
This paper estimated sediments inflow into Guesselbodi River, focusing on suspended sediment concentration, particle size distribution, and total sediment inflow using field measurements and laboratory analyses. Field measurements revealed that the river average velocity is 0.91 m/s and average discharge of 7.020m^3/s, while laboratory analysis revealed a predominantly fine-grained soil composition, with 80.94% silt and 19.06% clay particles. The results revealed that the average sediment concentration was 4.76 x 10^{-5} Tons /year, with a total sediment inflow of 759.15 Tons/year from 1981 to 2022. Empirical equations estimated varying sediment discharge rates, with Dhruvnarayan's equation yielding the highest value (744,223 Ton/year). The findings indicate a significant positive correlation between rainfall, runoff, and sediment concentration, emphasizing the impact of land use/land cover, soil type, and river morphology on sedimentation. The study further highlighted the need to address sedimentation to prevent habitat disruption, water quality degradation, loss of biodiversity, and changes in river morphology. The results provide valuable insights for sustainable and effective river management and conservation strategies.

Keywords: *Sediments inflow, Guesselbodi river, particle size analysis, filed measurement, laboratory analysis .*

1 INTRODUCTION

According to Gupta *et al*. (2023), sediment inflow refers to the entry or influx of sediment into a body of water, such as rivers, lakes or other reservoirs. It plays a critical role in shaping the geomorphology of watercourses, influencing aquatic ecosystems and influencing water resource management (Larsen *et al*., 2021). Hatono and Yoshimura (2020) described estimating the sediment inflow using the empirical method or field measurement as a valuable approach to understanding sediment dynamics in water bodies. By making direct measurements and building empirical relationships, this method enables accurate estimation of sediment inflow, enabling effective modeling of sediment transport, watershed management, and environmental impacts (Hatono and Yoshimura, 2020).

Due to erosion, runoff, and stream flow velocity, sediment enters into reservoir and settles as the dead load (Nda *et al*., 2020). With time this sediment can occupy completely the dead storage and threatens the useful storage of reservoir and thus becomes a great concern by affecting the reservoir capacity (Karmakar and Musthafa 2020). The important task of sedimentation issues is the reservoirs sediment assessment, since the sediment buildup can reduce the reservoir storage capacity, affect the productivity and efficiency of hydroelectric power plants, and alter water quality (Kondolf, M., and Yi, 2022). Addressing these challenges and uncertainties in the estimation of sediment inflow using the empirical method or field measurement is crucial to enhance the accuracy and reliability of sediment transport assessments (Van *et al*., 2021).

Accurate estimation of sediment inflow is crucial for understanding sediment transport dynamics, managing water resources, and assessing the environmental impact of sedimentation (Ayele *et al*., 2021). The empirical method is a widely used approach for estimating sediment inflow, relying on direct measurements and empirical relationships established from field data (Kang *et al*., 2022). This study appraises the significance of sediment inflow estimation for effective water resource management and aims to address the estimation of sediment inflow of empirical methods by focusing on field measurement. It aims to address this need by applying field measurements to quantify sediment inflow rates into the stream with the following objectives; 1, to analyse the particle size distributions of the sediment collected from the stream for sediment deposits classification, 2, estimate the hydrological and hydraulic parameters such as flow velocity, and discharge measurements of *Guesselbodi* Stream, and 3, estimate the suspended sediment concentration (SSC) in (g/liter) of the stream using field measurements

The outcomes of this research will contribute to enhancing our understanding of sediment transport processes with respect to stream flow velocities and provide valuable insights for water resource management and environmental impact assessment.

2 METHODOLOGY

2.1 DESCRIPTION OF STUDY AREA

The area selected for this investigation is located near Niamey (Figure 1). The area receives about 400-500 mm of rainfall per year and is located in the semi-arid part of Niger republic. In that area is located a stream named Guesselbodi of about 50 m long. It flows from NE to SW direction mostly during rainy season with an important discharge. Three (03) main bridges are built across the stream.

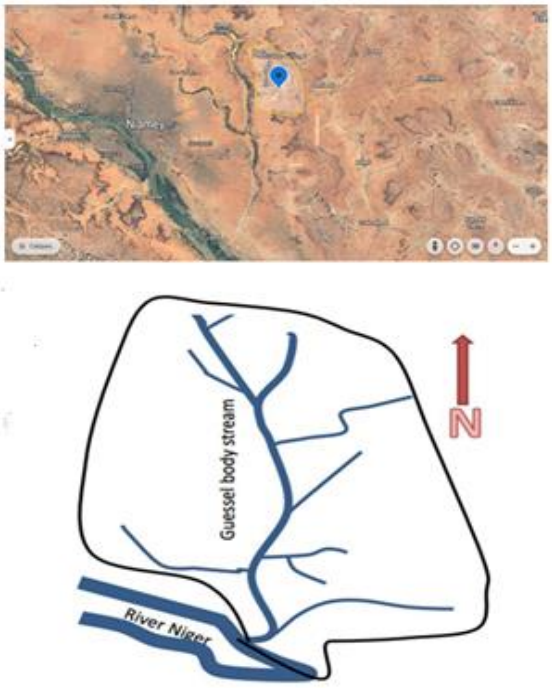


Figure 1: Site map of Guesselbodi Stream. Source: Google

Data were obtained from the hydrological office (Ministry of Water resources), and the Office of meteorology (Ministry of Transport). The recent pictures of the *Guesselbodi* river are as shown in Figures 2



Figure 2: *Guesselbodi* rivers with bridge across

2.2 FIELD MEASUREMENT FOR ESTIMATING WATER FLOW VELOCITY AND DISCHARGE

Estimating water flow velocity and discharge involved a simple method tagged floatation method. In this approach, the float and cross section technique was used to estimate of water flow from the stream. The method is best used in streams with calm water and during periods of good weather when there is little wind. It is a simple method for measuring small to large water flow with a good accuracy. A float being used was a piece of wood or a smooth tree branch about 30 cm long and 4-5 cm wide. Also being used was a small well-caped bottle 10 cm tall, containing enough matter (such as water, soil or pebbles) so that when it floats in the stream, the top of bottle will be just above the surface. These two techniques were used for cross checking of the results. A straight length of at least 20 m along the stream will be chosen for the exercise. This was a portion of the stream where the water is calm and free from water plants so the float will flow easily and smoothly. As shown in Figure 3, the portion chosen was marked with stakes on both sides of the stream at points AA and BB and a line between the stakes was stretched.

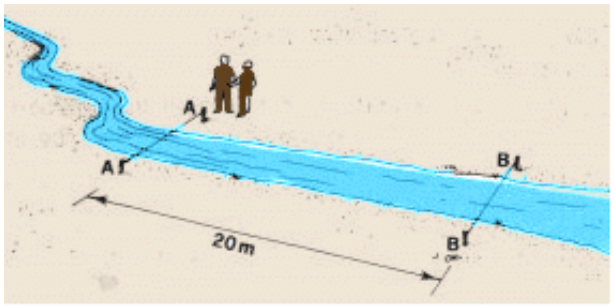


Figure 3: Floatation method of estimating flow velocity and discharge

2.3 STREAM CHARACTERISTICS, SEDIMENT SAMPLING AND ANALYSIS TECHNIQUES

Sediment sample parameters such as sediment concentration (C) or sediment weight, from field measurements of the specific study area and time period of interest were estimated. In addition, laboratory tests of the sediment sample to determine the particle size distribution of the sediment samples collected will also be carried out. This information is crucial for understanding the composition of the sediment and proceed to its classification.

2.4 WATER SAMPLE DATA

Water sample data were collected which will included water discharge data for the same study area and velocity. To achieve this, 30 bottles of different volumes were used which represented a total of 30 different velocities of water flow of the studied element. This was then used to determine the Sediment Moisture Content (SMC), and

the sediment concentration per liter that is being transported within each bottle of known volume

2.5 LABORATORY ANALYSIS OF SEDIMENT SAMPLES

The laboratory analyses included determining sediment concentration, grain size distribution, and other relevant parameters. This will be followed by established laboratory protocols where appropriate analytical techniques and equipment were adopted. The following general steps when performing laboratory analysis of sediment samples:

2.5.1 SAPLE COLLECTION

The collected sediment samples were prepared for analysis by removing any debris or large particles and homogenizing the sample to ensure representative sub-sampling. This involved air-drying the samples or using other appropriate methods based on the specific analysis requirements.

2.5.2 PARTICLE SIZE ANALYSIS

The particle size distribution of the sediment sample was accomplished using techniques such as sieving, where sediment samples are sieved through a series of sieves with different mesh sizes. The retained sediment on each sieve was weighed, and the percentage distribution by weight determined. Sediment grain size analysis is crucial for understanding sediment transport, erosion, and deposition processes. This analysis provided information about the grain size composition, which can be useful for understanding sediment transport and depositional processes.

2.5.3 PARTICLE SIZE ANALYSIS

The obtained data were analyzed using appropriate statistical or quantitative methods. Interpret the results in the context of the research objectives and existing knowledge and draw conclusions about the sediment properties or environmental conditions.

3 RESULTS AND DISCUSSION

Particle sizes distribution of the sediment sample is shown in Figure 4. The hydrometer analysis of the soil sample indicated a predominantly fine-grained soil composition. Approximately 80.94% of the soil particles were classified as silt, highlighting a substantial presence of particles within the 0.002 mm to 0.075 mm size range. The remaining 19.06% of the soil sample was composed of clay particles, smaller than 0.002 mm. The absence of sand particles, as evidenced by the 100% passing the 0.075 mm sieve, further emphasizes the dominance of fine-grained material. Based on these results, the soil can be categorized as a silty clay, characterized by its high silt content and significant clay component.

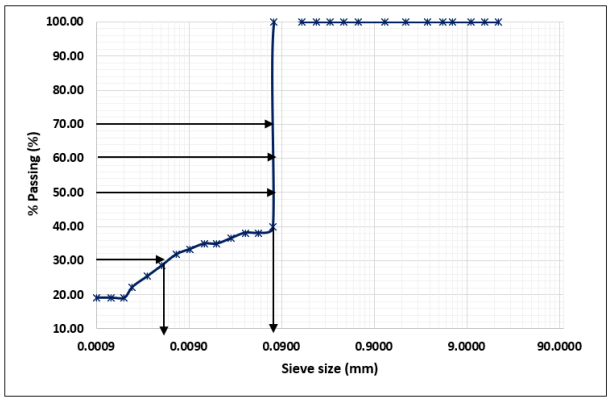


Figure 4: Particle size distribution curve

From the curve in Figure 4.1, D_{10}, D_{30}, D_{60}, and D_{70} are estimated as follows:

D_{10} = 0, this means that no particle is 10%

D_{30} = 0.0046 which means median size and that materials are 30 % finer than the rest of the materials. This also means that the materials that are 30 % finer pass through the sieve size 0.0046 mm

D_{50} = 0.0750. This means 50 % finer than the rest of the particles.

D_{60} = 0.0750

D_{70} = 0.0750

Uniformity coefficient and Coefficient of gradation cannot be calculated from these materials as D_{10} does not exist. From the results analyzed above, the distribution indicates a relative size of both granular and finer particles, justifying the fact that the sample is of total load, that is, it consists of both suspended loads and bed loads.

3.1 LABORATORY AND FIELD MEASUREMENTS OF SUSPENDED SOLIDS CONCENTRATION (SSC)

The results of laboratory measurements of suspended solids concentration (SSC) contained in the stream water sample was shown in Figure 2. It was observed that the SSC in the samples ranged from 12.5g/L to 699.03 g/L. The relationship between the suspended solids concentration and volume of water samples collected was represented in Figure 4.2. It would be observed that there is similar trend observed between the two parameters throughout the sampling process.

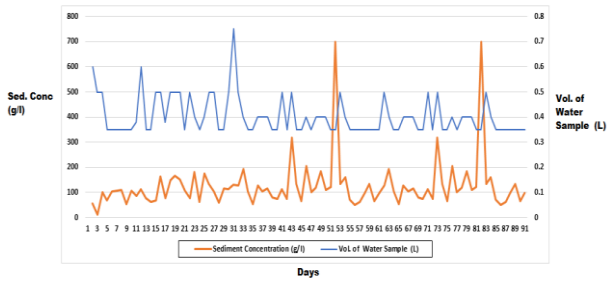


Figure 5: Sediment concentration and volume of water sample

3.2 TOTAL SEDIMENT INFLOW INTO THE GUESSELBODI STREAM USING TOTAL ANNUAL RUNOFF

Total sediment inflow into the Guesselbodi stream using total annual runoff was obtained based on the sediment concentration in water sample collected from River Guesselbodi. 60 sampling trials were used in the sampling. From the results, the average sediment concentration obtained was 4.76 * 10-5 Ton/year.

The relationship between the annual runoff and the total sediment concentration also shows positive correlation as presented in Figure 6 which is consistent with Niu *et al*., (2021). This significantly shows that the more runoff in the basin, the more the sediment concentration over the course of the study period (1981 to 2022). This also means increased runoff has encouraged increased sediment concentration over the years giving rise to increased sediment entrainment and transport. Many factors have been attributed to this positive correlation. Among these factors are; land use/land cover as reported by Daramola *et al*., (2022), soil type and moisture content (Fortesa *et al*., 2020), rainfall intensity and duration (de Almeida *et al*., 2021) and river morphology and hydraulic condition (Boota *et al*., 2021). The highest annual runoff of 25,345,944 m^3/year was recorded in the year 2017 with the sediment concentration of 1,205.33 Ton/year while the lowest annual runoff of 8,937,396 m^3/year was recorded in the year 1984 with the sediment concentration of 425.02 Ton/year. This was consistent with rainfall trend as the lowest annual rainfall depth was observed in the year 1984 while the highest recorded in the basin was in the year 2017.

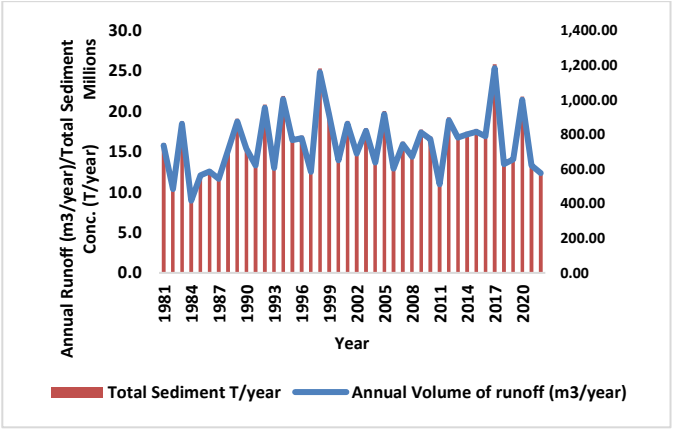


Figure 6: Annual relationship between annual runoff and sediment concentration

Figure 7 shows the cumulative total sediment inflow into the Guesselbodi river from 1981 to 2022. The figure shows a remarkably worrisome scenario where the river is being overwhelmed by the sediment inflow over the years as shown.

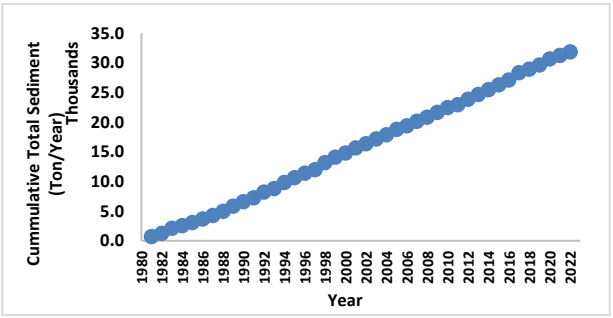


Figure 7: Cumulative sediment inflow into the Guesselbodi River

Figure 8 shows the appraisal of the sedimentation impact on Guesselbodi river over some period of years (1991 to 2022). The rapid sedimentation of the river has been attributed to drought, erosion, land degradation. Based on Figure 4.8, there is urgent need to arrest the sedimentation rate in order to avoid habitat disruption (Gupta *et al*., 2023), water quality degradation (Akhtar *et al*., 2021), loss of biodiversity (Ogidi and Akpan 2022)., changes in river morphology (Yuan *et al*., 2021).

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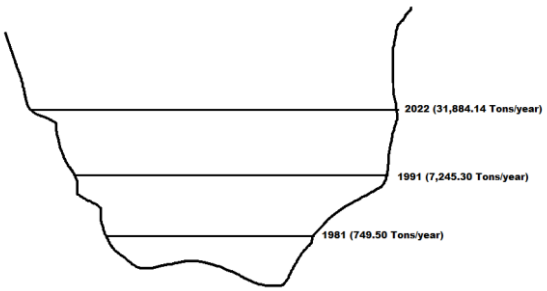


Figure 8: Conceptual pattern of the Guesselbodi river showing the level of sedimentation with year

From Table 1 A & B, annual sediment concentration was obtained by multiplying the annual runoff volume in cubic meter by the total sediment concentration in one cubic meter. Total amount of sediment concentration in Ton/year from the study was recorded as 4.76 * 10^{-5} Ton/year. This is then multiplied by the annual runoff to obtain the annual total sediment inflow for the year (Table 1 A & B). In 1981, the annual runoff was obtained as 518.1 mm. The total runoff volume considering the catchment area of 78 km^2 was 15,760,602.0 m^3/year. This was multiplied by the calculated sediment concentration (4.76 * 10^{-5} Ton/year) and the result obtained as total sediment inflow for 1981 was 749.50 Ton/year. The results for the remaining study period of 1981 to 2022 are as presented in Table 4.5 a & b. On average, the total sediment inflow, from field measurements, using the available data from 1982 to 2022, was estimated as 759.15 tons/year.

TABLE 1A: ESTIMATE OF SEDIMENT INFLOW USING THE ANNUAL RUNOFF ESTIMATED BY RATIONAL METHOD OVER A CATCHMENT REA OF 78 KM^2

Year	Average Annual Rainfall (mm)	Annual Volume of runoff (m^3/year)	Sediment Concentration = 0,0000475552 T/m^3	Total Sediment T/year	Cumulative Total Sediment T/year
1981	518.1	15,760,602.0		749.50	749.50
1982	341.4	10,385,388.0		493.88	1,243.38
1983	606	18,434,520.0		876.66	2,120.03
1984	293.8	8,937,396.0		425.02	2,545.05
1985	396.3	12,055,446.0		573.30	3,118.35
1986	412	12,533,040.0		596.01	3,714.36
1987	381.9	11,617,398.0		552.47	4,266.83
1988	498.9	15,176,538.0		721.72	4,988.56
1989	616	18,738,720.0		891.12	5,879.68
1990	506.7	15,413,814.0	4.75552E-05	733.01	6,612.69
1991	437.3	13,302,666.0		632.61	7,245.30
1992	671.7	20,433,114.0		971.70	8,217.00
1993	426.5	12,974,130.0		616.99	8,833.98
1994	707.1	21,509,982.0		1,022.91	9,856.90
1995	540.8	16,451,136.0		782.34	10,639.23
1996	548.3	16,679,286.0		793.19	11,432.42
1997	411.6	12,520,872.0		595.43	12,027.85
1998	816.6	24,840,972.0		1,181.32	13,209.17
1999	641.8	19,523,556.0		928.45	14,137.62

TABLE 1B: ESTIMATE OF SEDIMENT INFLOW USING THE ANNUAL RUNOFF ESTIMATED BY RATIONAL METHOD OVER A CATCHMENT REA OF 78 KM^2

Year	Average Annual Rainfall (mm)	Annual Volume of runoff (m^3/year)	Sediment Concentration = 0,0000475552T/m^3	Total Sediment T/year	
2000	458.4	13,944,528.0		663.13	14,800.75
2001	606.5	18,449,730.0		877.38	15,678.13
2002	485.5	14,768,910.0		702.34	16,380.47
2003	577.6	17,570,592.0		835.57	17,216.04
2004	448.8	13,652,496.0		649.25	17,865.29
2005	645.8	19,645,236.0		934.23	18,799.52
2006	423.6	12,885,912.0		612.79	19,412.31
2007	523.3	15,918,786.0		757.02	20,169.34
2008	472.9	14,385,618.0		684.11	20,853.45
2009	571.7	17,391,114.0		827.04	21,680.48
2010	543.7	16,539,354.0		786.53	22,467.02
2011	359.8	10,945,116.0		520.50	22,987.51
2012	621.3	18,899,946.0		898.79	23,886.30
2013	550.4	16,743,168.0		796.22	24,682.53
2014	563.3	17,135,586.0		814.89	25,497.41
2015	574.4	17,473,248.0		830.94	26,328.36
2016	556.3	16,922,646.0		804.76	27,133.12
2017	833.2	25,345,944.0		1,205.33	28,338.45
2018	442.4	13,457,808.0		639.99	28,978.44
2019	461.4	14,035,788.0		667.47	29,645.91
2020	704.3	21,424,806.0		1,018.86	30,664.77
2021	437.5	13,308,750.0		632.90	31,297.67
2022	405.4	12,332,268.0		586.46	31,884.14
Total		670,465,926.00		31,884.14	667,485.31
Average				759.15	

3.3 FIELD MEASUREMENTS AND EMPIRICAL METHODS OF SUSPENDED SEDIMENT CONCENTRATION

Various empirical methods were employed in the estimation of annual sediment concentration for the Guesselbodi River. The empirical methods used are Khosla's equation (1953), Joglekar's equation (1960), Varsheneys equation, and Dhruvnarayan equation. The common parameters involved in these equations is the catchment area of the river basin. Table 2 shows the summary of the empirical estimation of suspended concentration rate as they vary from one to another. The highest sediment rate in the river was given by Dhruynaryan equation as 744,222.7 Ton/year while the lowest was given as 97,464 T/year by Khosla's equation. The limitations observed in all these equations are in the applicability of the equations in complex river and the fact that there is only one parameter (Basin Area, A in km^2) in the equations except for Dhruynaryan equation, which has water discharge (in m^3/s) as one of the parameters.

TABLE 2: EMPIRICAL EQUATIONS FOR ESTIMATING SUSPENDED SEDIMENT CONCENTRATION

S/N	EMPIRICAL METHODS OF ESTIMATION	SEDIMENT DISCHARGE FORMULAS	CALCULATED SEDIMENT RATE	CALCULATED SEDIMENT RATE (T/year)
1	Khosla's equation (1953), (Mm3/year)	$Qs = 0.00323 (A)^{0.75}$	0.0744	97464
2	Joglekar's equation (1960), Mm3/year	$Qs = 0.00597A^{0.76}$	0.164	214840
3	Varsheneys equation	$Qs = 0.59 (A)^{-0.24}$	0.207	271170
4	Empirical Dhruvnarayan et al equation (1983) T/year	Qs = 5.5 + 11.1 Q	744222.7	744222.7

As shown in Figure 9, it was observed that Dhruvnarayan equation gave the highest estimate of annual sediment inflow as 744222.68 Tons/year, followed by Varsheneys' equation (271170 Tons/year). The lowest as observed from the figure was the estimate obtained from field measurement (759.15 Tons/year). The observations from the estimates revealed that as against the findings of Walling (2017) and Zerihun (2023), field measurement underestimated the sediment inflow by more than 200 %.

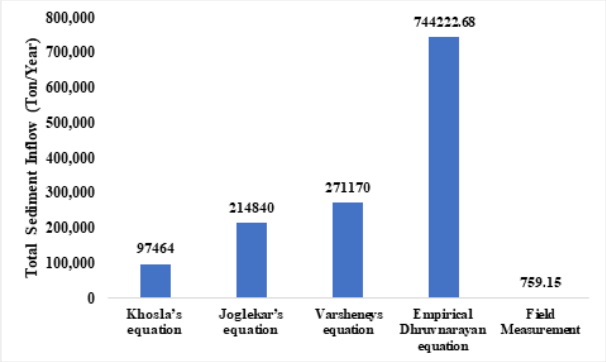


Figure 9: Annual Sediment inflow from empirical equations and field measurement

4 CONCLUSION

Estimation of sediment inflow into *guesselbodi* gorou river using empirical methods and field measurements has been studied. The study investigated the rainfall-runoff correlation, the particle size distribution, sediment concentration, and total sediment into Guesselbodi River. The methodology's accuracy is proven by its consistency with previous studies and the reasonable agreement between measured and estimated values. The estimated average annual sediment inflow into the Guesselbodi River was 759.15 tons per year, based on field measurements. Empirical equations (Khosla, Joglekar, Varsheneys, and Dhruvnarayan) were used to estimate sediment inflow, with Dhruvnarayan equation yielding the highest estimate (744.223 tons /year). The findings suggest that sedimentation in the Guesselbodi River is significantly influenced by rainfall, runoff, and land use/land cover factors. The study highlighted the importance of accurate sediment measurements and estimation methods for effective river management and conservation and provides recommendations for future research and river management strategies.
extensions.

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MODELLING THE TURBIDITY REMOVAL EFFICIENCY IN HOSPITAL WASTEWATER USING *MORINGA OLEIFERA* AND *TAMARIND*

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ABSTRACT
This study investigated the efficacy of *Moringa Oleifera* and *Tamarind* as natural coagulants for turbidity removal in hospital wastewater. Laboratory experiments were conducted to evaluate the effects of varying dosage (1250mg/L) of *Moringa* and *Tamarind* seed powders on turbidity reduction. The results showed significant turbidity removal efficiencies of 52.7-63.9 % for *Tamarind* and 53.6-67.1 % for *Moringa Oleifera*. A Statistical model was developed to predict turbidity removal efficiency based on coagulant dosage and initial turbidity. The model revealed a strong correlation between coagulant dosage and turbidity removal (R^2=0.981). *Moringa Oleifera* demonstrated higher turbidity removal efficiency than *Tamarind*. The study concludes that both *Moringa Oleifera* and *Tamarind* are effective natural coagulants for hospital wastewater treatment, offering a sustainable alternative to conventional chemical coagulants. The developed model can be used to optimize coagulant dosage for efficient turbidity removal in hospital wastewater treatment plants.

Keywords: *Moringa Oleifera, Tamarind, Turbidity Removal, Hospital Wastewater, Natural Coagulants, Statistical Modelling.*

1 INTRODUCTION

Water is an essential resource for all life on Earth, as water is required for several domestic, commercial, and agricultural activities. Approximately 1400 million cubic kilometres of water exist on Earth, with freshwater bodies accounting for 2.5 % and marine ones for 97.5 % (Koul et al.,, 2022). The community's requirement for water has significantly increased as a result of the recent surge in urban population. As a result, there is significant demand on the existing water resources. Water contamination can be caused by a variety of non-anthropogenic reasons, such as hydrogeologic processes, variations in climate, natural disasters such as floods, droughts, earthquakes, etc., and atmospheric deposition, which can occur fast or gradually.

Water is essential to hospital hygiene and operations. All across the world, water is necessary for the effective operation of hospitals and other healthcare facilities. Together with all other medical waste, HWW can contaminate surface and groundwater and reach watersheds when handled and disposed of incorrectly in the hydrosphere, posing a major risk to public health and the environment (Biswal, 2013). According to (Majumder *et al.*, 2021), the hospitals' water use results in the production of large volumes of wastewater. This is because hospital care is specialized and the effluent from these facilities contains a wide range of pollutants. These include chemicals, metals, bacteria, disinfectants, and prescription drugs. Certain pollutants have the potential to be harmful or contagious, which means they can affect living organisms as well as the environment. The extreme susceptibility of hospital wastewater to the spread of various infections makes it a serious threat to human health security. (Prichard and Granek, 2016) illustrated that the risks to human health and the environment are associated with the types and quantities of chemicals discovered in hospital wastewater.

The treatment of wastewater using traditional chemical coagulants is receiving significant interest. Concerns regarding the long-term impact on human health and the environment, caused by the production of non-biodegradable sludge as a by-product, have become prominent topics of discussion. Shifting from chemical to natural coagulants can serve as an effective approach to mitigate these aforementioned drawbacks. The treatment of wastewater from industrial and agricultural operations can be achieved through the use of chemical coagulation and biological techniques. Wastewater generated from agricultural husbandry is known to contain high levels of chemical oxygen demand (COD), biological oxygen demand (BOD), turbidity, and various organic and inorganic pollutants. A comprehensive analysis has been conducted to compare the effectiveness of organic and inorganic coagulants, as well as the optimal conditions necessary for achieving a high percentage of pollutant removal from wastewater. It has been found that chemical coagulation, electrocoagulation, and biological methods exhibit similar capabilities in removing pollutants from wastewater. However, the biological method has proven

to be highly effective in pollutant removal, albeit requiring more time and generating a smaller volume of sludge compared to the chemical method (Akinnawo *et al*., 2023).

Turbidity removal from hospital wastewater is crucial to prevent environmental pollution and protect public health. Natural coagulants offer a sustainable and eco-friendly solution. Hospital wastewater contains high levels of turbidity, caused by suspended particles, bacteria, and viruses. Conventional chemical coagulants have limitations, such as toxicity and residual sludge generation. Natural coagulants, derived from plants and biodegradable materials, provide an alternative. Various natural coagulants have been studied in the past to remove the turbidity in the HWW REF. *Moringa oleifera* seeds have been used effectively in removing turbidity and heavy metals from HWW with reasonable outcomes. *Moringa oleifera* has historically been used to treat inflammation, cancer, heart disease, liver illness, wounds, and discomfort (Pareek et. al., 2023). It is a member of the following groups; Order: *Capparales*; Family: *Moringaceae*; Genus: *Moringa*; Species: *oleifera*; Super division: *Spermatophyta*; Division: *Magnoliophyta*; Class: *Magnoliopsida*; Sub class: *Dilleniidae*; Order: *Plantae* (Mallenakuppe *et al*., 2019).

Cactus as a natural coagulanr has demonstrated remarkable potential as a bio coagulant/flocculent in wastewater treatment as well as a role in environmental sustainability due to its abundance and non-toxicity to human health. This prompted Ayat *et al*., (2021) which is based on experimental design, to optimize the two operating factors: bio-coagulant dosage and initial pH. The response surface methodology (RSM) based on a central composite faced design (CCFD) was used to study the effect of these factors on turbidity and chemical oxygen demand (COD) reduction performance when treating sewage wastewater from plants through the coagulation/flocculation process. The effect of pH on supernatant turbidity removal and COD reduction was quite considerable, although coagulant dosage did not affect COD removal efficiency. The most effective reduction of turbidity and COD was achieved with a coagulant dosage of 28 mg/l and a pH of 12. Turbidity and COD were removed with 98.33% and 96.55% efficiency, respectively, under these ideal conditions.

The aim of this study was to model the performance Moringa oleifera in terms of turbidity removal from hospitals wastewater taking into consideration the influence of key operating parameters. The specific objectives of the study were 1, to analyze the physicochemical characteristics of hospital wastewater, 2, to investigate the coagulation and flocculation properties of *Moringa Oleifera* extract through laboratory experiments, assessing its efficacy in turbidity removal and identifying optimal dosage and treatment conditions, 3, to develop a statistical model or empirical equations to predict the turbidity removal efficiency of *Tamarind* and *Moringa Oleifera* extracts.

2 METHODOLOGY

The study area for this research is the city of Minna in the Niger state of Nigeria, located in the north-central region of the country. It is the state capital and the second largest city in Niger state, after Suleja. Minna is a major economic centre in the region, known for its agriculture, manufacturing, and commerce. The geographical coordinates of the study area are 9° 15'N and 6° 10'E.

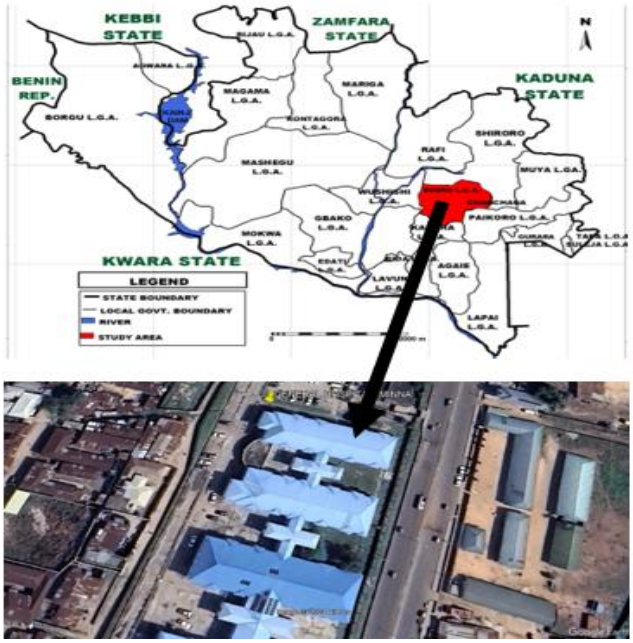


Figure 3.1: Location of the study area

WASTEWATER SAMPLING AND CHARACTERIZATION

Hospital effluent was collected from a government-owned hospital. The wastewater being generated from this hospital is expected to vary in quantity and in loading concentrations. General Hospital, Minna located at Latitude 9.611677º North and 6.543834º East was used in the study as case studies. In this hospital, for easy sampling of wastewater, the wastewater from each service was drained by PVC pipes to a storage tank. In the hospital that was visited, three wastewater sampling points labeled TH1, TH2, and TH3 was sampled. This was done so as to ensure a detailed characterization of the hospital wastewater for the period of the study.

EXPERIMENTAL METHOD AND MATERIALS PREPARATION

Moringa oleifera seeds that were used in this study were be sourced and harvested in Minna. Mature Moringa oleifera pods from dried, cracked fruit was selected. The seeds was extracted from the fruits by cracking them, and they were then given two days to air-dry. The outer shells of the seed kernels were removed using a knife, and the kernels were then crushed in a mortar and pestle before being sieved through a 600 mm stainless steel sieve size to create a fine powder. The fine powder was maintained in a refrigerator in a sterilized plastic rubber container. 2 g of residues were dispersed in 100 mL of NaCl 1 M solution, stirred for 30 min then left to settle for 15 min; afterward, the supernatant was filtered on Whatman1 filter paper.

PREPARATION OF *MORINGA OLEIFERA* AND TAMARIND COAGULANTS

Tamarind and Moringa oleifera seeds were sourced from Minna, Niger State, Nigeria. The seeds were processed for use as coagulants. Tamarind seeds were soaked, washed, dried (5 days + 105°C/30min), crushed, and pulverized into 600-micron powder. Moringa seeds were extracted from dried pods, air-dried (2 days), shelled, crushed, and sieved into 600mm powder. The powders were stored in sterile containers (Tamarind) and refrigerated (Moringa). For residue analysis, 2g of sample was dispersed in 100mL NaCl solution, stirred (30min), settled (15min), and filtered through Whatman1 paper. The processed powders were used for coagulation studies.

Stock solutions of Moringa and Tamarind seed powders were prepared for coagulation studies. Moringa solutions were made by dissolving 500-1250mg of powder in 250ml distilled water, yielding concentrations of 2-5mg/ml. Tamarind solutions were prepared similarly, but in 0.5M NaCl solution. The mixtures were formed into pastes, then dissolved and filtered through Whatman filter paper. Concentrations of 1g/L (250mg/250ml) were achieved. Four concentrations (500, 750, 1000, 1250mg/250ml) were prepared for each seed powder. The filtered solutions were ready for coagulation activity testing.

3 TURBIDITY REMOVAL EFFICIENCY

Turbidity Removal Efficiency R (%) was calculated according to the following equation:

$$R\ (\%) = (N_1 - N_2/N_1) * 100 \quad (1)$$

Where;
$N1$and $N2$ represent the initial hospital wastewater turbidity (NTU) and residual turbidity after coagulation-flocculation (NTU), respectively.

Turbidity removal was carried out under four different scenarios as previously mentioned. The first scenario is using only Moringa Oleifera as a coagulant. The stock solution prepared for the purpose was added to the wastewater being tested. This is after the initial turbidity must have been recorded. The turbidity level will also be recorded after the treatment. The turbidity removal efficiency (TRE) was obtained. This was followed by the second scenario, where tamarind seed stock solution was added to the wastewater and turbidity level before and after treatment recorded in order to calculate the TRE.

4 DATA ANALYSIS

STATISTICAL MODELLING

4.1.1 RESIDUAL TURBIDITY

To manipulate the results, statistical models was built using multiple regression analysis using SPSS 20 package which was adopted to perform the stepwise multiple regression analysis. The general multiple regression equation adapted was:

$$Y = a0 + b1X1 + b2X2 + b3X3 + b4X4 + e \quad (2)$$

Where;
Y = Dependent variable,
$a0$ = Intercept,
$b1$, $b2$, $b3$, $b4$ = Partial regression coefficients,
$X1$, $X2$, $X3$, $X4$ = Independent variables, and
e = Error term (residuals).

It is noteworthy to mention that e must be normally and independently distributed with mean μ = 0 and standard deviation σ = 1, (it is written as NID (0,1). In this study, the dependent variable is the residual turbidity ($N2$) which was predicted for the optimum dosage using Moringa Seeds.

The investigation of the Moringa Oleifera as coagulants will lead to nine (9) models with each coagulant having three models each. The dependent variable for all the models was Y = $N2$, so that the analysis was performed for the purpose of Modelling $N2$ (residual turbidity) for Optimum Dosage Using Moringa Seeds.

The independent variables for the coagulants was:
$X1$ = pH,
$X2$ =$N1$ (Initial turbidity)
$X3$ = TEMP and
$X4$ = COD

The choice of which independent variables to use were observed when the data were subjected to correlation analyses. The results of correlation analyses enabled the choice of which of the parameters will serve as independent variables. The same modelling was applied

for Tamarind and the modelling will follow the same patterns as Moringa Oleifera

5 RESULTS AND DISCUSSION

The laboratory results of the raw water samples are presented in Table 1.

TABLE 1: RESULT FOR RAW WATER ANALYSIS

Parameter	Values	WHO	NSDQW
PHYSICAL PARAMETERS			
pH	8.26	6.5 – 8.5	6.5 – 8.5
Turbidity (NTU)	184	<5	5
Total Dissolved Solid (TDS)	731	300	500
Temperature (ºC)	25	NIL	Ambient
Electrical Conductivity (uS/cm)	1220	400	1000
CHEMICAL PARAMETERS			
Hexavalent Chromium (mg/L)	BDL	0.05	0.05
Calcium (mg/L)	480	100-300	100
Magnesium (mg/L)	288	50	20
Total Hardness (mg/L)	2500	NIL	100
Chloride (mg/L)	799	250	250
Phosphates (mg/L)	12.3	1	10
Chemical Oxygen Demand (COD) (mg/L)	600	250-500	250-500
Iron (mg/L)	1.14	0.3	0.3

LABORATORY ANALYSES OF HOSPITAL WASTEWATER

Table 2 presents lab analysis of hospital wastewater treated with Tamarind. Initial turbidity was 184 NTU. After treatment with 1.25g Tamarind, residual turbidity ranged from 67-87 NTU, showing significant reduction. The table displays various parameters' initial and final values, demonstrating Tamarind's effectiveness in wastewater treatment.

TABLE 2: PHYSICAL PROPERTIES OF HOSPITAL WASTEWATER BEING TREATED WITH *TAMARIND*

S/N	pH.	N_1	TDS	Temp (ºC)	(COD) (mg/L)	N_2
1	8.26	184	731	26	600	87
2	6.3	178	12747	28	400	73
3	6.3	169	11390	25	266	68
4	6.3	174	11710	27	351	72
5	6.1	162	11550	31	309	65
6	7.2	155	11390	29	310	56
7	7.3	165	11230	31	320	67
8	6.8	176	11070	25	289	72
9	6.8	183	10910	26	321	82
10	7.8	184	10750	27	276	83

N_1= Intial Turbidity
TDS= Total Dissolved Solids
COD= Chemical Oxygen Demand
N_2 = Residual Turbidity

Table 3 presents lab analysis of hospital wastewater treated with Moringa Oleifera. Initial turbidity was 184 NTU. After treatment with 1.25g Moringa, residual turbidity removal efficiency ranged from 51-85 NTU, showing effective removal. The table displays various parameters' initial and final values, demonstrating Moringa's efficacy in reducing wastewater turbidity.

TABLE 3: PHYSICAL PROPERTIES OF HOSPITAL WASTEWATER BEING TREATED WITH *MORINGA OLEIFERA*

S/N	pH.	N_1	TDS	Temp (ºC)	(COD) (mg/L)	N_2
1	8.26	184	731	25	600	85
2	6.3	178	542	27	450	73
3	6.3	169	633	26	370	68
4	6.3	174	675	28	348	72
5	6.1	162	776	25	520	65
6	7.2	155	682	31	450	51
7	7.3	165	721	30	487	62
8	6.8	176	692	29	462	70
9	6.8	183	598	27	365	85
10	7.8	184	701	26	453	81

N_1= Intial Turbidity
TDS= Total Dissolved Solids
COD= Chemical Oxygen Demand
N_2 = Residual Turbidity

TURBIDITY REMOVAL EFFICIENCY FOR *MORINGA OLEIFERA*

Turbidity Removal Efficiency R (%) was calculated for each of the sampling periods from Day 1 to Day 10. Equation 1 was used in the removal efficiency calculation;

$$R\ (\%) = (N_1 - N_2/N_1) * 100$$

For trial 1, where initial turbidity, N_1 is 184 NTU and residual turbidity, N_2 is 87NTU, removal efficiency is calculated as;

(184-87)/184 * 100 = 52.72 %.

The results for the rest of the Days are as shown in Table 4

TABLE 4: TURBIDITY REMOVAL EFFICIENCY FOR *TAMARIND*

Trial	Initial Turbidity (N1)	Residual Turbidity (N2)	R%
1	184	87	52.7174
2	178	73	58.9888
3	169	68	59.7633
4	174	72	58.6207
5	162	65	59.8765
6	155	56	63.871
7	165	67	59.3939
8	176	72	59.0909
9	183	82	55.1913
10	184	83	54.8913

The Table 4 shows that the Tamarind has good turbidity removal efficiency which is far above average in all the sampling. The removal efficiency from all the 10 trials ranged from 52.7 % in trial 1 to 63.9 % in trial 6.

TURBIDITY REMOVAL EFFICIENCY FOR *MORINGA OLEIFERA*

For Moringa Oleifera analysis, the initial turbidity, N_1 is 184 NTU and residual turbidity, N_2 is 85 NTU, removal efficiency was calculated as;
(184-85)/184 * 100 = 53.80 %.
The results for the rest of the dosages are as shown in Table 5

TABLE 5: TURBIDITY REMOVAL EFFICIENCY FOR *MORINGA OLEIFERA*

S/N	Initial Turbidity (N1)	Residual Turbidity (N2)	R%
1	184	85	53.8043
2	178	70	60.6742
3	169	68	59.7633
4	174	72	58.6207
5	162	65	59.8765
6	155	51	67.0968
7	165	62	62.4242
8	176	70	60.2273
9	183	85	53.5519
10	184	81	55.9783

Table 5 shows that *Moringa Oleifera* has good turbidity removal efficiency as the efficiency are far above the average in all the trials. The removal efficiency from all the 10 trials ranged from 53.6 % in trial 9 to 67.1 % in trial 6. From the two treatments, *Moringa Oleifera* was adjudged to be more effective in treating HWW as it possesses higher removal efficiency (67.1 %) compared to *Tamarind* (63.9 %).

CORRELATION ANALYSES AMONG THE PARAMETERS FOR *TAMARIND* TREATMENT

From the results of correlation analysis between the HWW physio-chemical parameters where *Tamarind* was used as natural coagulant., the residual turbidity, N_2 was observed to be very strongly correlated with Initial turbidity, N_1, moderately correlated with pH (0.492) and having a negative, but strong correlation with temperature (-0.525). Positive correlation was also observed between the N2 and COD (0.502). This shows that all these parameters could predict N_2 accurately.

MODELLING RESIDUAL TURBIDITY (N_2) IN HWW *TAMARIND* TREATMENT

The modelling of residual turbidity is now easy to analyze since the parameters that influence it have been observed. Applying the data from the multiple regression model represented by equation 5, using SPSS version 20, the appropriate stepwise multiple regression model for *Tamarind* residual turbidity, N_2 treatment was:

$$N_2 = 0.881\ N_1 + 1.79\ pH + 0.38\ Temp - 105.06 \quad (3)$$

This means that the independent variable of COD was insignificant statistically based on the outcome of the statistics. The regression was highly insignificant, though the obtained R_2 value, 0.981, which indicates that the regression contribution ratio was very acceptable (Pallant 2005). In other words, equation 3.3 can precisely predict the residual turbidity of HWW being treated with *Tamarind*

CORRELATION ANALYSES AMONG THE PARAMETERS FOR *MORINGA OLEIFERA* TREATMENT

From the correlation analysis results, the residual turbidity, N_2 was observed to be very strongly correlated with Initial turbidity, N_1 (0.96), slightly correlated with pH (0.318) and having a negative, but strong correlation with temperature (-0.665). There was no correlation whatsoever observed between the N_2 and COD (0.042) as well as TDS (-0.206). This shows that N_1, Temperature and pH are the only parameters that could predict the N_2 accurately with *Moringa Oleifera* treatment. These correlated parameters was used in the linear regression for modelling residual turbidity estimation.

MODELLING RESIDUAL TURBIDITY (N_2) IN HWW *MORINGA OLEIFERA* TREATMENT

The modelling of residual turbidity for Moringa Oleifera treatment of HWW is influenced by the appropriate parameters as influenced by correlation analysis. Applying the data from the multiple regression model represented by equation 5, using SPSS version 20, the appropriate stepwise multiple regression model for *Tamarind* residual turbidity, N_2 treatment was:

$$N_2 = 0.878\ N_1 + 0.481\ pH - 1.238\ Temp - 50.18 \quad (4)$$

This means that the independent variables, COD and TDS were insignificant statistically based on the outcome of the statistics. The regression was highly insignificant, though the obtained R_2 value, 0.980, which indicates that the regression contribution ratio was very acceptable according to Pallant (2005). In other words, equation 3.4 can precisely predict the residual turbidity of HWW being treated with *Moringa Oleifera*.

6 CONCLUSION

From the results of the study, it was concluded that Moringa Oleifera and Tamarind treated the hospital wastewater efficiently, which means they have good and similar coagulation/flocculation properties, and they were both competent for turbidity removal. This, in turn indicates the possibility of using these coagulants in large-scale field applications as evident in their coagulating tendencies. It was also concluded that, with the knowledge of initial turbidity of the hospital wastewater, the residual turbidity using these coagulants could be estimated with good precision Another fact from this study is that the most statistically significant parameter in the flocculation process were the initial turbidity, pH, and temperature as shown by equations (3) and (4).

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STRENGTH CHARACTERISTICS OF EGGSSHELL POWDER (ESP) AS FILLER IN HOT MIX ASPHALT

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ABSTRACT
This research work Investigate the strength characteristics of eggshell powder as filler in hot mix asphalt. Eggshell powder/Ash has been effectively used over the years in the production of low/ high impact cement concrete but with limited use in asphalt concrete. The objective of this paper is to Reuse Eggshell Powder (ESP) as mineral filler in hot mix asphalt (HMA) mixes at percentage replacement of granite stone dust to eggshell powder of 0, 20, 40, 60, 80 and 100% by weight at bitumen content of 4, 4.5, 5, 5.5, 6, 6.5 and 7% respectively so as to modify on the strength and volumetric properties of the asphalt concrete. The physical and chemical properties tests conducted on the constituent materials were accordance to the standard specification and confirmed satisfied including the XRF test on ESP show high percentage of CaO. The optimum bitumen content (OBC) for modified sample was 5.40 % and 80 % optimum ESP were obtained at maximum stability, maximum unit weight and average of 4 % of air void and the corresponding values are 100, 40 and 80% respective using Marshall Mix method. From the Volumetric analysis test, the sample prepared with 80 % ESP replacement at 5.40 % bitumen content satisfy the required standard code (NGSR&B/FMW&H, 2016) on wearing course

Keywords: *Eggshell Powder, Bitumen, Hot Mix Asphalt, Optimum Bitumen and Replacement Content, Volumetric Analysis.*

1 INTRODUCTION

In highway construction, efforts are made to utilize waste materials to improve the strength and durability properties of bituminous mixes rather than disposing in landfills or incinerating them. These efforts are carried out with the view to manage waste, reduce the asphalt production cost, and reduce the detrimental environmental effects associated with the production of cement (Shuaibu, Otuoze, Ahmed and Musa, 2020).

Azaz; Nadeem; Ayaz.; and Shaukat. (2020). Define flexible pavement to consist of admissible proportion of mineral fillers in the upper layer, which is the ongoing development in the asphalt concrete design.

Waste material recycling into useful products has become the primary solution to waste disposal problems. So, research into new and innovative uses of waste materials is extensively encouraged. Many highway agencies are conducting various studies and research projects concerning the feasibility, environmental suitability, and performance of using recycled products in highway construction (Destaw, Emer, Abel, 2020).

Filler is the component of bituminous concrete which fills the voids or open spaces among the aggregates and binder in a pavement. It helps in the densification of the bituminous concrete. It modifies the quality of conventional asphalt. Nowadays it has become a very useful and environment friendly component of the hot mixed asphalt. The use of filler, contributes to the mix cohesion, enhance serviceability and resistance to rutting. The role of mineral filler's importance is well acknowledging in the properties of hot mix asphalt mixtures (HMA) (Azaz.et al., 2020).

In 2016, the effects of RHA as filler on Marshal Stability and moisture susceptibility of asphalt mixtures were investigated. The results of the study showed that using RHA could increase the stability of mixes by 65%

Ghadah Ghassan Masued (2019). Evaluate the ability to use eggshell powder, in hot mix asphalt mixtures as filler by comparing the performance of mixtures of different eggshell powder percentages, 0, 3, 6, 9, 12, 15, 20, 25 and 100% and finding optimal eggshell content (OESC). The results showed that the effective eggshell content was 6% and the eggshell is one of the substances that can be used as a filler in asphalt mixture blend

Up to 70% of filler may be added, depending on various factors (Naglaa, 2016)

Currently lots of waste and agricultural by-products are presently being used to replace natural aggregates in

hot mix asphalt either partially or fully along with stone dust. This research has shown the strength characteristics of eggshell powder (ESP) as filler in hot mix asphalt production**.** This waste possess some properties of oxide composition such as CaO, Fe_2O_3 and SiO that are capable in enhancing HMA up to some limit.

Efforts has also been made in this research to assess the effects of eggshell powder as filler materials in hot mix asphalt at the percentages of 20, 40, 60, 80, and 100% of granite stone dust.

Although, there are little or no much research carried out using eggshell either as aggregates, ash or powder.in hot mix asphalt using

2 MATERIALS AND METHODS

2.1 MATERIALS

The Materials used for this study are as follows:

a. Fine aggregate,
b. Coarse aggregate
c. Stone dust
d. Eggshell powder
e. Bitumen.

Preliminary tests were conducted on coarse aggregate, fine aggregate, fillers and bitumen in Department of Civil Engineering, The Federal polytechnic, Bida, Niger State.

The aggregates used is crush rock (stone) and the bitumen is of 60/70 penetration grade, they are both obtained at the quarry site of Arab Contractor Company, off horse rise yard after Ilorin Garage along Mokwa road, Bida, Niger State, while eggshell waste was obtained from Bread bakeries in Bida South, Niger State Nigeria, the obtained eggshell waste was wash dried and crushed to grounding into powder form then were passed through No. 200 (75µm) sieve in Department of Civil Engineering The Federal polytechnic, Bida, Niger State.

2.1 METHODS

Marshall Mix Design was adopted. In preparing the samples, aggregates were proportioned by the trial-and-error method giving rise to 57%, 36%, and 7% coarse, fine and filler materials respectively and are heated to a standard temperature of 135^0C. The quarry dust mineral filler is gradually replaced with eggshell powder at an interval of 20, 40, 60, 80 and 100%. Bitumen content is added at an interval of 0.5%, from 4 to 7% and stirred to get a homogenous mix.

2.2.1 TEST ON FINE AGGREGATES

The tests conducted on the fine aggregates are specific gravity (ASTM C128, 2015), sieve analysis (ASTM C136 /C136M-19. 2019).

2.2.2 TEST ON COARSE AGGREGATES

The Test conducted on coarse aggregates are aggregate impact value/hardness test (BS 812 part 111, 1990), aggregate crushing value (BS 812 part 112, 1990), Aggregate specific gravity (ASTM, C127, 2015), sieve analysis (ASTM C136 /C136M-19. 2019) and Flakiness and Elongation index test ASTM D4791D-19. (2019).

2.2.3 TEST ON MINERAL AGGREGATES ASTM D242/D242M. 2019 (stone dust and eggshell powder)

The Test conducted on stone dust and eggshell powder are Aggregate specific gravity (ASTM, C128, 2015), and Oxide composition using XRF (ASTM E1621 - 2013) and sieve analsis (ASTM D546-17, 2017).

2.2.4 TEST ON BITUMEN

Tests on bitumen are: Penetration Test (ASTM D5/D5M-20, 2020), Softening point (Ring and Ball) Test (ASTM D36/D36M-14, 2020), Ductility Test (ASTM D113-17, 2017), Specific gravity Test (ASTM D70/D70M-21, 2021), Viscosity Test (ASTM D4402/D4402M-15, 2015), Flash and Fire Point Test (ASTM D92-18, 2018), and Solubility test (ASTM D2042-15, 2015). Marshall Method for designing asphalt for paving mixtures was adopted for this study. The optimum binder content and the optimum blend of stone dust-eggshell powder in hot mix asphalt was obtained. The relationships between binder content, percent replacement by weight (20, 40, 60, 80, and 100%) of stone dust-eggshell powder and the properties of mixtures such as stability, flow, bulk density, voids filled with bitumen (VFB), void in mineral aggregate (VMA) and void in the mix (VIM) at both control and percent replacement were established. Three specimens each were made for seven bitumen content (4, 4.5, 5.0, 5.5, 6.0, 6.5 and 7%) in accordance with standard specifications ASTM D6926-15. (2016). The optimum binder/percent replacement content, Marshall stability-flow and void analysis were performed and checked against the limits specified by the Nigerian General Specifications for Roads and Bridges (FMPW&H, 2016) for use as wearing course of heavily-traffic road.

3.0 RESULTS AND DISCUSSIONS

3.1. OXIDE COMPOSITION OF EGGSHELL POWDER (ESP)

The oxide composition of eggshell powder was carried out in chemical engineering laboratory of BUK, Zaria. The result of the chemical analysis is presented in Table 1. The result shows that CaO has the highest percent content and aids in the performance, in strength, stiffness and stripping in the production of hot mix asphalt.

TABLE 1 OXIDE COMPOSITION FOR EGGSHELL POWDER (ESP)

Main Oxide	ESP (%)
CaO	97.64
MgO	0.5
SrO	0.42
SO_3	0.41
SiO_2	0.26
P_2O_5	0.20
K_2O	0.17
Al_2O_3	0.16
Cl	0.12
Fe_2O_3	0.06

3.2. TEST ON BITUMEN

From the result obtained on Bitumen in table 2, the physical properties of Unmodified bitumen fall within specification and the value of bitumen penetration is 62.8 which was within the Range of grade 60/70. Therefore, the bitumen is said to be suitable for use as binder in the production of Hot Mix Asphalt HMA.

TABLE 2: TEST CONDUCTED ON UNMODIFIED BITUMEN

Test conducted	Codes/ Specification	Result	FMPW&H(2016)			Remarks
			Light traffic	Medium traffic	Heavy traffic	
Penetration (0.1mm) @25ºC	(ASTM D5/D5M-20, 2020)	62.8	40/50	60/70	80/100	OK
Ductility (cm) @25ºC	(ASTM D113-17, 2017)	110	100 Min.	100 Min.	100 Min.	OK
Softening Point (ºC)	(ASTM D36 / D36M-14, 2020)	49.00	52-60	48-56	42-50	OK
Flash Point (ºC)	(ASTM D92-18, 2018)	249	250 Min.	232 Min.	250 Min.	OK
Fire Point (ºC)	(ASTM D92-18, 2018)	218	NIL	NIL	NIL	OK
Specific Gravity (NIL)	(ASTM D70/D70M-21, 2021)	1.04	1.01-1.06	1.01-1.06	1.01-1.06	OK
Solubility in C2S (%)	(ASTM D2042-15, 2015)	100	99.5 Min.	99 Min.	99.5 Min.	OK
Viscosity @ 60 oC (Secs)	(ASTM D4402/ D4402M-15, (2015),	1520	NIL	NIL	NIL	OK

3.3 TESTS ON AGGREGATES

Table 3 shows the physical properties of aggregates test and specification range obtained which falls within the standard specification for road and bridges (FMW&H, 2016) and the aggregates used satisfied the requirement on the need in hot mix asphalt.

TABLE 3: PHYSICAL PROPERTIES OF AGGREGATES

Test conducted	Codes/ Specification	Result	FMW&H(2016)		Remarks
			Min.	Max.	
Specific Gravity (Coarse Aggregate)	(ASTM C127-15, 2015)	2.64	2.6	2.9	OK
Specific Gravity (Fine Aggregate)	(ASTM C128-15, 2015)	2.53	2.64	2.9	-
Specific Gravity (eggshell powder)	(ASTM D242/D242M, 2019)	2.17	-	-	-
Flakiness Index	(ASTM D4791-19, 2019)	26.23	-	35	OK
Elongation Index	(ASTM D4791-19, 2019)	22.73	-	25	OK
Aggregate Crushing value (%)	(BS 812-110, 1990)	22.48	-	30	OK
Aggregate Impact value (%)	(BS 812-112, 1990)	25.79	-	35	OK
Los Angel's Abrasion Value (%)	(AASHTO T96, 1998, ASTM C131M-20, 2020)	23.4	25.7	30	OK

3.4 AGGREGATES AND FILLER GRADATION

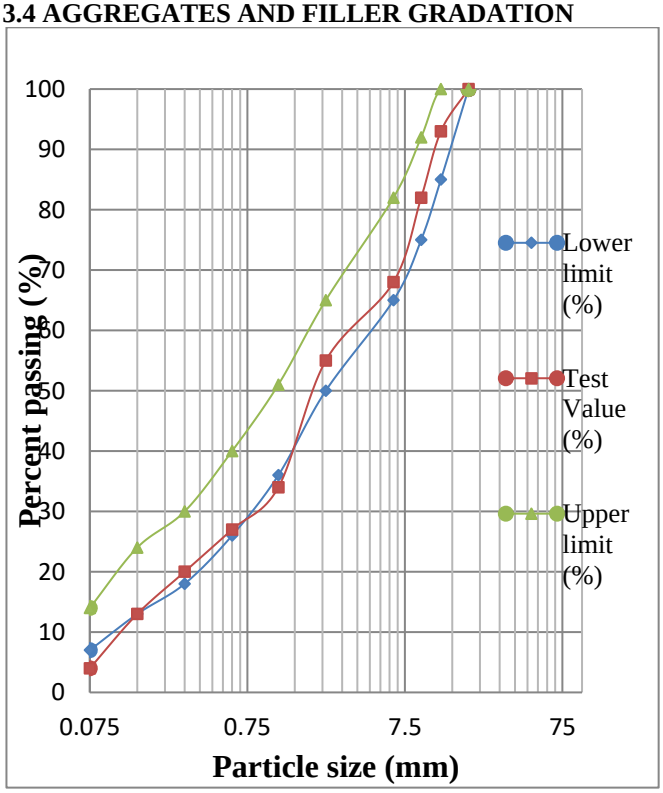


Figure 1: particle size distribution of aggregates and filler

Figure 1 shows the graph of particle size distribution for the aggregates and filler. The results of the gradation obtained indicate that the aggregates and filler are well graded and compacted given raise to maximum volume of aggregate and dense material. The results obtained satisfy standard specification of (ASTM C136 /C136M-19, 2019) and the curve fall within the envelop which is also in agreement with (FMW&H, 2016 and Abdulfatai, Yakubu, Adekunle, 2020).

3.5 MARSHAL TEST RESULTS FOR MODIFIED HOT MIX ASPHALT PRODUCTION

The aggregates were proportioned as 57%, 36%, and 7% coarse, fine and filler materials respectively which were used in the preparation of samples in the Marshal Mix method of design. The results obtained were of stability, flow and volumetric properties of the HMA produce at different percentages replacement (0, 20, 40, 60, 80 and 100%) by the total weight of samples with Bitumen content of 4, 4.5, 5, 5.5, 6, 6.5 and 7% respectively (FMW&H 2016).

3.5.1 MARSHAL STABILITY

Figure 2: Variation of stability with bitumen content and ESP.

Figure 2 shows the variation of stability with bitumen content and eggshell powder. The curve indicated that the stability increases at first with increase in bitumen content (BC) then reaches maximum at 5 kN points and decreases with increase in BC, although there is increase in ESP content. The curve experiences its stability of 5 kN on 100% ESP at 5.5 BC. The decrease in stability may be due to high amount of ESP in the mix thereby preventing proper mixture. This trend agrees with (Taih, 2011) and (Murana, Musa, Olowosulu, 2020) when carbide waste was used to partially replace in HMA where stability value is 7.60 kN. The value obtained conforms to (ASTM D6927-15. 2015) and Nigeria road and bridges (FMW&H, 2016).

3.5.2 MARSHAL FLOW

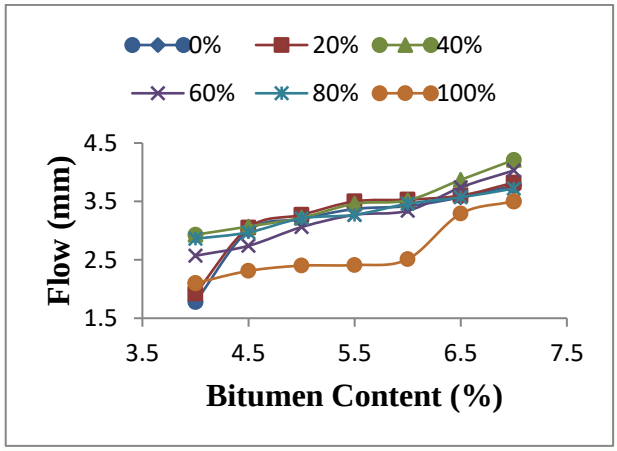


Figure 3: Variation of flow with bitumen content and ESP.

From the variation of flow with bitumen content and ESP, the graph shows that the flow increases with increase in BC and then decreases in the addition of ESP content. The flow has a 4.2 kN at 7% BC of 40% ESP. The value obtained on flow are within the standard specification (FMW&H, 2016) and (ASTM D6927-15. 2015) stipulated that the value of flow must be between 2-6 mm. The trend is equally in line with (Jaafar, Jibrin, Ochepo, and Ahmad, 2014).

3.5.3 UNIT WEIGHT

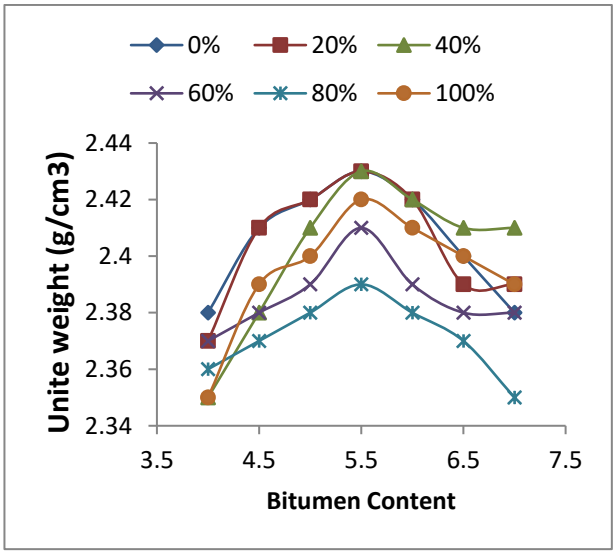


Figure 4: Variation of Unit Weight with bitumen content and ESP

Figure 4 shows the variation of Unit weight with Bitumen content and ESP value. The graph indicates that unit weight increases with increase in BC until it reaches maximum then start to decrease and decreases in the percent replacement of ESP content. The increase in unit weight is as a result of lower value in the specific gravity of ESP. Although the highest unit weight is obtained at 2.42 g/cm^3 of 20 and 40% ESP at 5.5 BC and the lowest Unit weight is at 2.35 g/cm^3 of 80% ESP at 7 BC. The trend is equally observed by (Nwaobakaba & Agwunwamba, 2014, Aliyu, et al., 2015).

3.5.4 VOID IN THE MINERAL AGGREGATE

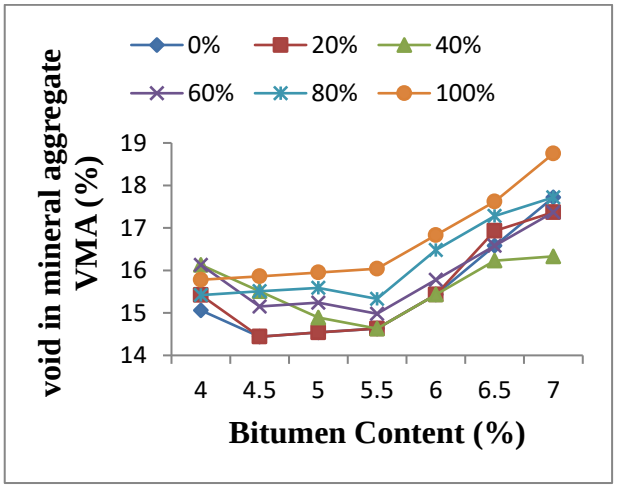


Figure 5: Variation of VMA with bitumen content and ESP

The variation of VMA with bitumen content and ESP in figure 5 shown that the VMA decreases to minimum at 5.5% BC, its then increases to maximum at 18.75% VMA of 100% ESP at 7% BC. The continue increase in VMA is as a result of pore spaces in ESP to absorbed bitumen thereby reduces VFB. Although there is a decreases in VMA in all ESP replacement which is an indication of insufficient bitumen to blend the aggregates together. This trend was equally observed by (Shuaibu, et al., 2020). Almost all the VMA values at different percent replacement of ESP content are within the specification of greater than 15% as stipulate (FMW&H, 2016).

3.5.5 VOID FILLED WITH BITUMEN

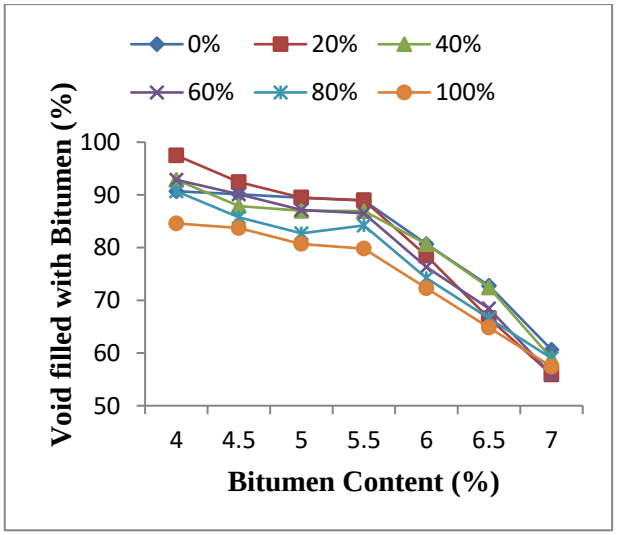


Figure 6: Variation of VFB with bitumen content and ESP

As shown in figure 6, the variation of VFB with bitumen content and ESP. the graph indicates that VFB decreases with increase in BC and decrease in ESP content. The decrease in VFB is due to the insufficient bitumen content in mixture as a result of higher percentage of ESP and the values are in line with (FMW&H, 2016). The trend is also observed by (Shuaibu *et al*., 2020; *and* Murana *et al*., 2020). More so, as VFB increases, VIM decreases and vice versa.

3.5.6 Voids in Total Mix

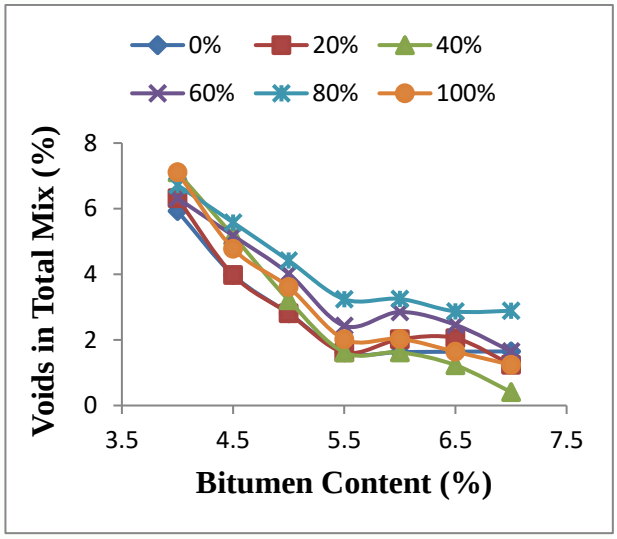


Figure 7: Variation of Pa with bitumen content and ESP

Figure 7 shows Voids in total mix with bitumen content and ESP. the graph shows that Pa decreases with increase BC and ESP content. The decrease in Pa is due to the inability of the bitumen to absorbed lower specific gravity of ESP content and the increase in ESP replacement trend is due to the present of CaO in the mixture. The most of the value of Pa is within specification of 3-5% (FMW&H, 2016, AASHTO T 312, 2009). This trend was equally observed by (Mohammad, 2012).

4.0 CONCLUSIONS

From the result of the research carried out, it can be concluded that the result revealed some improvement on the following properties of the samples

1. From the test result carried out on the constituent material, All the test values carried out on constituent material including oxide test meet with the standard specification. As such, the materials are suitable for use in the production of HMA
2. The partial replacement of Eggshell Powder in the HMA was studied in detail with regard to Strength and Volumetric properties

3. The Strength and Volumetric test of Varying eggshell powder in HMA mix is higher than that of the control mix at all ESP replacement
4. There is a general increase in the strength with increase in the ESP of 20, 40, 60, 80 and 100% except at 100% replacement in flow
5. The optimum percentage of eggshell powder content in HMA Mix is obtained at 80%.while optimum bitumen content is obtained at 5.4%

CHALLEGES

Base on the research, sourcing for the materials used for this work are tasking and challenging most especially availability of eggshell waste in a required amount.
Processing eggshell waste into powder form is another challenging and time consuming as it required removing of dirty within and around the eggshell waste, air dried, grinding into powder form and chemical analysis.

LIMITATIONS

On the basis of previous research, there are not much literature on eggshell waste or eggshell powder/ash used as a filler or aggregates in the production of hot mix asphalt. All processes carried out in achieving the end results are limited to laboratory (experimental) work without considering the durability aspect. Although, experimentally, eggshell powder it has been proving useful in concrete work

RECOMMEDATIONS

1. With regards to this research, the uses of eggshell powder as partial replacement of stone dust (filler) in HMA mixture can be used for

   HMA production at 80% replacement and 5.4% BC.
2. Blend eggshell powder with another waste such as Municipal solid waste, industrial non-hazardous waste or another agricultural or animal waste.

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MUNICIPAL SOLID WASTE CHARACTERIZATION FOR DIFFERENT INCOME LEVELS; A CASE STUDY OF ANKPA TOWNSHIP IN KOGI STATE

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ABSTRACT
Effective management of municipal solid waste is a significant environmental challenge in developing countries. This study examines the characteristics of municipal solid waste in Ankpa, Kogi State, Nigeria, in terms of composition, mass, and percentage generated per district. The results show that According to the study, biodegradable matter accounted for about 44.06% of the total solid waste created in the Ankpa Area of Kogi state while non-biodegradable matter accounted for the remainder which is 55.94%. The study area's range of per capita waste generation ranged between 0.36 and 0.524 kg/capita/day. Using the results of this characterization study as a guide, the results clearly indicate the necessity to create formal composting (for 44.06% of the waste) and recycling facilities (for 55.94% of the waste) facilities within the Kogi state urban region. With 0.524 kg/capita/day, high-income households were found to produce more garbage than the others, closely followed by mid-income households with 0.46 kg/capita/day. The study area's range of per capita waste generation ranged between 0.36 and 0.524 kg/capita/day. Using the results of this characterization study as a guide, the results clearly indicate the necessity to create formal composting (for 44.06% of the waste) and recycling facilities (for 55.94% of the waste) facilities within the Kogi state urban region. To address these issues, the study recommends adequate funding, proper legislation, staff training, community involvement, and establishment of formal composting and recycling facilities.

Keywords: *Ankpa, Characterization,Municipal Solid Waste, Income levels, Recycling.*

1 INTRODUCTION

Waste is defined as unwanted and unusable materials and is regarded as a substance which is of no use. Waste that we see in our surroundings is also known as garbage. Garbage is mainly considered as a solid waste that includes wastes from our houses (domestic waste), wastes from schools, offices, etc. (municipal wastes) and wastes from industries and factories (industrial wastes).

The proliferation of waste in the environment, occasioned by its inadequate management by residents and authorities has posed a growing concern in developed and developing nations (Aluko *et al*., 2022). Since waste is generated by all humans and at all times, population explosion and the humans' continues crave for a better life have increased the complexity of waste over the years. Municipal solid waste (MSW) disposal has therefore become a global concern across the world, as poverty, population growth, high urbanization rates and industrialization combined with ineffectual and under-funded government policies to present efficient management of wastes (Simon and Ijaola 2022).

Municipal solid waste includes wastes generated from residential, commercial, industrial, institutional, construction, demolition wastes. Household or residential wastes are generally food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, metals, ashes, special wastes (e.g., bulky items, consumer electronics, white goods, batteries, oil, tires), and household hazardous wastes. In order to implement a proper waste management system within a municipality, the waste must be characterized for compositional evaluation.

Waste characterization is a fundamental component in any municipal waste management system (MWMS) of urban solid waste in a city but such data are not commonly compiled in cities across Africa (Knickmeyer, 2020). Waste characterization therefore, consists of information on the types and amounts of waste materials (paper, food waste, glass, yard waste, etc.) present in a waste stream. It depends on a number of factors such as food habits, cultural tradition, socioeconomic and climatic conditions and varies not only from city to city but even within the same city itself (Knickmeyer, 2020; Paiho *et al*., 2020).

One factor affecting solid waste treatment is a lack of knowledge and training in specific skills and practices by waste management authorities in underdeveloped nations. Municipalities are often in charge of trash management in cities, however there are various barriers to providing an effective and efficient system due to a lack of financial resources and organizational capacity

(Batista *et al*., 2021). This research study is based on the environmental health difficulties linked with waste pollution, and because it is a major worry for the developing world's rising population, it is critical to identify and understand the impacts and causes of these problems. It has been noted that incorrect bin collection systems, bad route planning, a lack of knowledge about collection schedules, insufficient infrastructure, and poor roads all have an impact on waste collection and transfer (Carlos-Alberola *et al*., 2021). Because of insufficient labor, equipment, and government budget for disposal system and procedure, solid trash cannot be packed and hoisted on a regular basis, increasing operational costs.

This study is aimed at enhancing sustainable Municipal Solid Waste Stream in some selected households in Ankpa Local Government Area of Kogi State. The specific objectives of this study are to: 1, to estimate the solid waste moisture content so as to estimate the actual quantity of solid waste more accurately generated in the study area for the purpose of logistical planning, such as transportation and storage. 2, to analyze and determine the quantity, the types and proportions of various materials present in the waste stream generated in some selected households in Ankpa township at a particular time of the year for effective waste management strategies and facilities, 3, to carry out a compositional analysis of waste streams from a representative area of Ankpa township that will aid in planning infrastructure, allocating resources, and assessing the effectiveness of waste support economic development.

2 METHODOLOGY

Ankpa town, an headquarter of Ankpa Local Government Araea in Kogi State is located at 70 26'N, 70 38'E in the Eastern Senatorial Zone of Kogi State, Central Nigeria (Figure 1). Ankpa town covers 1200 Square Kilometers with estimated population of 267,353 temperature ranging from 28 to 310C. The area is the Agricultural and commercial hub of the State, with petrol vending as one of the most lucrative business endeavors.

The government agency in charge of the city's solid waste management system is Kogi State Sanitation and Waste Management Board (KSSWMB). The core objective of KSSWMB is to stop the indiscriminate dumping of waste and haphazard physical development in the entire Kogi State. Most of the waste collection jobs have been contracted to the local contractors under a private-public participation arrangement). This covers litter control, street sweeping, solid waste collection and transfer, and vegetation control and all other activities performed by these local contractors under KSSWMB supervision.

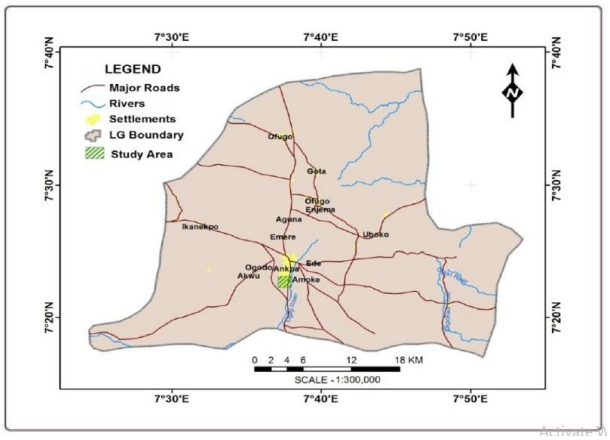


Figure 1: Map of Nigeria showing the study area, Ankpa Local Gov't Area

2.1 DATA COLLECTION: WASTE COMPOSITIONAL STUDY

This study investigates solid waste management in a metropolitan area using a material-based classification approach. Household samples were collected and sorted into various components, including paper, plastic, glass, and biodegradable materials. A systematic random sampling technique was used to select households, and a questionnaire administered to gather data on waste disposal methods, awareness of risks, and other factors. The collected samples were transported to a sorting facility, weighed, and segregated into different components. The weights of the separated components were determined as a percentage of the sample's total weight. Moisture content analysis was conducted on each sample material. Descriptive statistics and principal component analysis were used to analyze the results and examine the factors affecting environmental health in the study area. These factors include residential location, household size, educational background, and awareness of risk involved in keeping waste in the residence.

2.2 MOISTURE CONTENT DETERMINATION

Air oven method was used for waste moisture content determination. This method is based on moisture loss on drying at oven temperature of 1050C. Besides water, the loss will include other matters volatile at 105oC. Materials used in the waste moisture content determination include:

1. Flat bottom silica dish
2. Thermostatically Controlled Hot Air Oven with Fan
3. Analytical Weighing Balance
4. Desiccator

Three samples were collected at random from the three categories used from the study area. All the samples were analyzed in duplicates and the results obtained using equation 1.

$$Moisture\ Content\ \% = \frac{Wet\ Sample - Dry\ Sample}{Wet\ Sample}\ x\ 100 \qquad 1$$

2.3 DESIGN OF SURVEY QUESTIONNAIRE

The study included three distinct questionnaire surveys that included homes, businesses, and waste policymakers, as well as a government body tasked with waste management in Kogi State (Kogi State Sanitation and Waste Management Board, KSSWMB). The format of all three questionnaires was similar, but each was tailored to obtain the necessary responses from the intended group. The rationales for the selection of questions were as follows: (1) the need to gain data that, upon analysis, may help meet the immediate objectives of the research; and (2) to collect data in crucial areas of MSW management in the City where none now exist. Taherdoost (2019), and Kineber et al., (2020) have all identified the fundamental components of an effective survey and advocated best practices for questionnaire design and administration. Following their advice, the questionnaires were developed for self- or guided completion and intended to be quick, easy to read, and understand; absolutely free of bias or ambiguity.

2.4 DATA ANALYSIS METHOD

As stated earlier, the questionnaires were administered to three categories of respondents: households, businesses, and policymakers in government agencies in Ankpa town each charged with waste management. In all cases, it was ensured that respondents are those residing within Ankpa township or those who work within the study area. In order to determine a suitable sample size, a sample size calculator provided by Research Information (2008) was utilized. A City population of 405,000 (National Population Commission, 2008), and a confidence level of 95% (0.05) after (Munn and Drever, 1990) was adopted for initial calculation to arrive at the sample size. Household questionnaires were completed by the head of the household or a responsible adult in their absence.

2.5 DESCRIPTIVE STATISTICAL ANALYSIS

Descriptive statistical analysis therefore involved the use of frequencies, percentages, means, and standard deviation to describe various variables encountered during the study. These techniques were employed for analyzing data relating to the characteristics of the respondents or organizations they represent. Graphical was also utilized to present the results from these analyses and this include pie charts, bar charts, and tables.

3 RESULTS AND DISCUSSION

Ankpa Township, a town within the Ankpa Local Government Area in Kogi State, was chosen as the sampling area, with a focus on towns and areas that broadly capture the range of socio-demographic characteristics found in most parts of the city and are relevant to this study. These findings were based on a questionnaire administered in the research area. 15 families/households were chosen from each sampling zone used in the study. The district/study area was divided into three sampling zones using the methodology outlined by Parizeau *et al.* (2006): Governors Lodge Area, College Staff Quarters, and Ojede Area. Table 1 provides an overview of the socio-demographic features of the sampling area.

TABLE 1: OVERVIEW OF SOCIO DEMOGRAPHIC CHARACTERISTICS OF SAMPLING AREA

Sample Area	No of household sampled	Geographical Description	Demographical Classification	Average Household Size	Income Classification
1	15	Governors Lodge Area	High-Density	3-9	Low-Income
2	15	College Staff Quarters	Middle-Density	4–8	Middle-Income
3	15	Ojede Area	Low-Density	3-9	High-Income

3.1 POPULATION DISTRIBUTION OF THE STUDY AREA

A percentage of the population was sampled to arrive at a size appropriate and manageable in the study (Table 2). To determine the appropriate sample size for the study, the Taro Yamane formula (Yamane 1964) was applied. Three sub-study areas considered in this study are all within Ankpa township, in Kogi state with a combined population of 171,672 according to the 2006 National Population Census (Table 2).

TABLE 2: POPULATION DISTRIBUTION OF THE STUDY AREA

Location	Male	%	Female	%	Total
Low-Income	22,300	39.26056	34,500	60.73944	56,800
Mid-Income	19,230	44.04489	24,430	55.95511	43,660
High-Income	19,650	39.26859	30,390	60.73141	50,040
Total	61,180		89,320		150,500

Source: Field Survey, 2024

3.2 MOISTURE CONTENT ANALYSIS

Municipal Solid Waste samples were randomly selected from the households used in the study: 15 households in low-income area, another 15 households in middle-income areas and also 15 households in high-income areas. The approximate moisture content of waste samples from the study area was determined as detailed in the previous chapter. 15 grammes of wet samples (Ww) were weighed and oven dried at 105ºC for 24

hours. Final weights (Wf) of samples were noted at the end of drying. Dry weights (Wd) were obtained as the difference between final weight and weight of container (Wc). Moisture content was calculated as the difference between wet weight and dry weights (Hernández-Berriel *et al.*, 2008).

TABLE 3: PERCENTAGE (%) MOISTURE CONTENT OF WASTE SAMPLES

TRIAL	METHOD	RESULT (%)
TRIAL 1	Air Oven Method	35.44
TRIAL 2	Air Oven Method	28.99
TRIAL 3	Air Oven Method	36.35

3.3 RESULTS OF MSW COMPOSITION ANALYSIS FOR LOW-INCOME, MID-INCOME AND LOW-INCOME HOUSEHOLDS

The graphical representation of the results of waste analysis by weight is as presented in Figure 2. The results cover the three regions in the study area: Low-Income, Mid-Income and High-Income study areas.

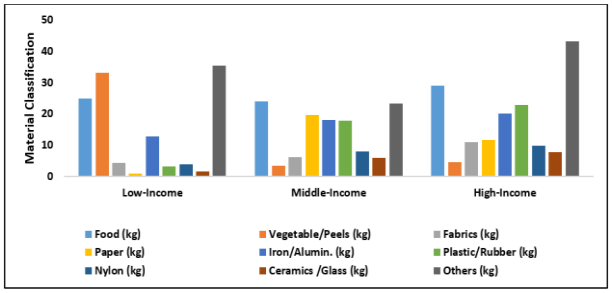


Figure 2: Composition of waste samples from the three sampling areas

From Figure 3, the main components of waste samples could be summarized as: For Low-Income households, food (20.9%), vegetable/peels (27.7%), Fabrics (3.51%), Paper (0.67%), iron/alum (10.69%), plastic/rubber (2.67%), nylon (3.13%), ceramics/glass (1.25%) and others (29.56%). From the above statistics it could be seen that 'others' referred to here, includes polythene, electronic waste and organic matter where 50% of the combination is organic. Hence from statistics, out of 54.6% of the waste component categorized as 'others', 24.3% is putrescible. Conclusively, 70.44 % of the waste sample from the study area is biodegradable, mostly comprising of high wet weight and high moisture content kitchen wastes.

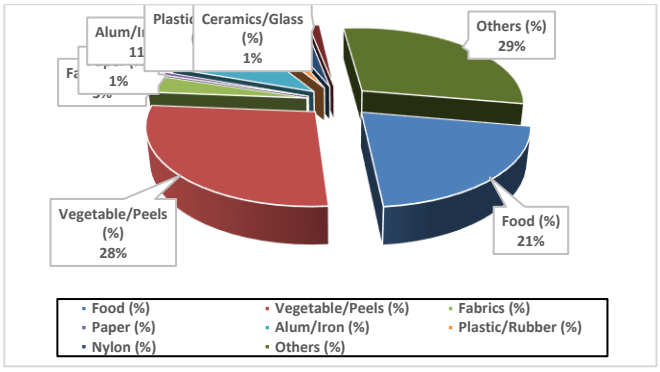


Figure 3 : MSW Composition Analysis for Low-Income household

3.4 RESULTS OF MSW COMPOSITION ANALYSIS FOR MID-INCOME HOUSEHOLDS

Samples were collected mainly from College Staff Quarters of Ankpa Local Government Area in Kogi State, middle-density neighborhood. The MSW composition analysis of samples collected from the sampling area is shown in Figure 4. The percentage composition of the waste for middle-income households as shown in Figure 4 are: food (19%), vegetable/peels (2.69%), fabrics (4.91%), paper (15.6%), alum/iron (14.26%), plastic/glass (14.03%), Nylon (6.34%), ceramics/glass (4.75%), and others (18.38%). From the above statistics it could be seen that others includes polythene, electronic waste and organic matter where 50% of the combination is organic. Hence from statistics, out of 5.56% of the waste component categorized as others, 2.78% is putrescible. Conclusively, 76.8% of the waste sample from the study area is biodegradable, mostly comprising of high wet weight and high moisture content kitchen wastes. The inorganics which include iron/alum, plastic/rubber, nylon, glass /ceramics were higher in the middle income area than the low-income area. The organics which include food, vegetable and others of the samples here was observed to be lower than that of low-income household same as the percentage composition of others which include E-waste, polythene and organic matter was observed to be higher in the low-income household area.

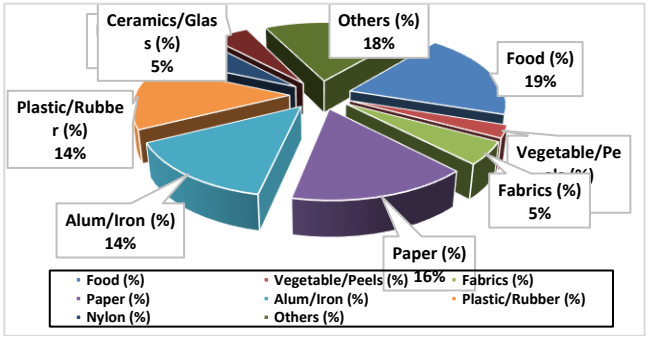


Figure 4: MSW Composition Analysis for Medium-Income household

3.5 RESULTS OF MSW COMPOSITION ANALYSIS FOR HIGH-INCOME HOUSEHOLDS

From this sub-study area, samples collected at Ojede area within the metropolis of Ankpa Local Government Area in Kogi State. Figure 5 shows the percentage MSW composition analysis of samples collected from the sampling area. From Figure 5, the composition gave Food (18.17%), vegetable/peels (2.82%), Fabrics (6.83%), paper (7.27%), alum/iron (12.53%), plastic/rubber (15.35%), nylon (6.08%), ceramics/glass (4.89%), and others (27.07%). From the above statistics it could be seen that 'others' includes polythene, electronic waste and organic matter where more than 50% of the combination is organic. Hence from statistics, out of 70.05% of the waste component categorized as others, 35.03% is putrescible. Conclusively, 72.93% of the waste sample from the study area is biodegradable, mostly comprising of high wet weight and high moisture content kitchen wastes.

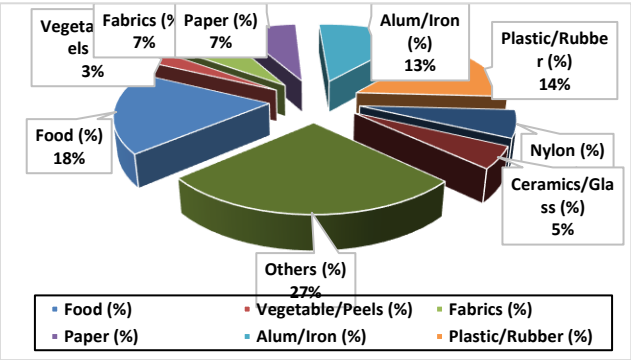


Figure 5: MSW Composition Analysis for High-Income household

3.6 DISCUSSION OF RESULTS

The study analyzed solid waste management in Ankpa metropolis, Kogi state, revealing ineffective waste management methods. Factors contributing to this include open dumping, inadequate enforcement, rapid urbanization, and poor funding. The composition of solid waste varies among low-, middle-, and high-income households. Organic materials (food, vegetables, and fabrics) dominate in low-income households, while inorganic materials (plastics, iron, nylon, and ceramics) are more prevalent in middle-income households. Composting or biodegradation can dispose of the organic component, with potential for fertilizer production.

The study highlights the impact of income rate on solid waste composition, with low-income households generating more biodegradable waste and middle-income households generating more non-biodegradable waste. High-income households exhibit a balanced consumption of organic and inorganic materials.

Currently, there are no official recycling or composting facilities in the area, with scavengers collecting recyclable materials without proper protection, posing health risks. Recycling and composting are identified as effective and eco-friendly methods for managing solid waste, with potential to reduce waste management expenses.

The weekly and daily per capital waste generation for the city of Ankpa was shown in Table 4 for the study area's per capita waste generation. With 0.524 kg/capita/day, high-income households were found to produce more garbage than the others, closely followed by mid-income households with 0.46 kg/capita/day. At 0.36 kg/capita/day, low-income households generate the least amount of garbage (Table 4). Igbinomwanhia and Olanikpekun (2007) discovered 0.56 kg/capita/day in Mushin, Lagos, and Solomon (2009) found 0.49 kg/capita/day in typical Nigerian communities with residential and commercial hubs, while Dauda and Osita (2003) found 0.25 kg/capita/day in Maiduguri. The average of 0.64kg/capital/day was determined by the people's socioeconomic position and consequently the location.

TABLE 4: TOTAL WASTE GENERATED PER CAPITAL/DAY

Location	No of Male	No of Female	Total	Total Waste Generated	Per Capita Waste Generation (PCWG) kg/Person/Day
Low-Income	48	59	107	194.4	0.36
Mid-Income	35	42	77	233.0	0.46
High-Income	18	23	41	268.0	0.52
Total	101	124	225	695.4	1.34

4 CONCLUSION

The characterization of solid waste in the Ankpa Area of Kogi state has been researched. This is the primary step required for any community to achieve sustainable solid waste management. The first stage in solid waste management is to understand the waste kinds that are generated in order to establish appropriate collection and disposal methods, which can be accomplished through solid waste characterization. The majority of waste generated in Ankpa Area of Kogi state can be composted rather than disposed away. Food, vegetable/peels, fabrics, glass/ceramics, metals (alum/iron), paper, plastic/rubber, nylon and others make up the majority of the solid waste produced. According to the study, biodegradable matter accounted for 44.06% of the total solid waste created in the Ankpa Area of Kogi state while non-biodegradable matter accounted for the remainder which is 55.94%. The study area's range of per capita waste generation ranged between 0.36 and 0.524 kg/capita/day. Using the results of this characterization study as a guide, the results clearly indicate the necessity to create formal composting (for 44.06% of the waste) and recycling facilities (for

55.94% of the waste) facilities within the Kogi state urban region.

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Department of Civil Engineering
Federal University of Technology, Minna, Nigeria

Enhancing the Consistency Limits of Lateritic Soil - RHA Mixtures with Bentonite for Use as Landfill Liner Materials

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ABSTRACT
The enhancement in the consistency characteristics of geomaterials developed by the combined treatment of lateritic soil with rice husk ash (RHA) and bentonite for geostructures such as landfill liners was investigated. Consistency limit tests namely: liquid limit (LL), plastic limit (PL), plasticity index (PI) and linear shrinkage (LS) were conducted on soil mixtures containing RHA added at a constant ratio of 8% and bentonite at stepped increment of 0, 3, 6, 9 and 12%. Test results indicated that the lateritic soil belongs to SM subgroup according to USCS classification system. For 0, 3, 6, 9, and 12% bentonite content, LL of the mixtures were 57, 72, 78, 84 and 89% respectively, whereas the PL were 20.23, 26.65, 28.99, 30 and 32.27% for the same sequence of treatment resulting in an increase in PI values from of 36.77% when soil sample was treated with 10% RHA content to 57.45% at 12% bentonite content. Similarly, the linear shrinkage (LS) varied from 9.11% at 0%bentonite+8%RHA to 10.63% for mixture containing 12% bentonite. These findings show that the consistency limit properties of both the natural and soil mixtures fulfilled the primary criteria for landfill liner applications (i.e., LL = 30 – 90%; PI = 10 – 65%) usually prescribed by most regulatory authorities.

Keywords: *Bentonite; Consistency limits; Lateritic soil; Landfill liners; Rice husk ash*

1 INTRODUCTION

Treatment of soils with additives and mixing of soil and water produce changes in the consistency characteristics of resulting soil mixtures. Understanding the changes in the consistency characteristics of soil materials used for different geotechnical applications including landfill liners is worthwhile especially where the control of these parameters can be used in achieving the required performance and prevention of potential problems. For landfill liner systems, the consistency limits of construction materials give indication whether a soil will satisfy the hydraulic conductivity criterion and acceptable shrinkage strains (Osinubi and Nwaiwu, 2006; Jain, 2024).

Consistency limits are empirical indices of the critical water contents describing physical states of the soil which is mainly divided into the solid, semisolid, plastic and liquid phases. The water content of the soil at the point of transition from solid to semisolid state is designated as the shrinkage limit (SL), and from semisolid to plastic state is described as the plastic limit (PL), while the water content of the soil at the point of transition from plastic to liquid state is defined the liquid limit (LL). Plasticity index (PI) value is defined as the difference between the liquid limit (LL) and the plastic limit (PL) of the soil. These limits represent mineralogical and physical properties of clayey soils directly and provides an indication in terms of the engineering behavior to be exhibited. Together with mechanical analysis, these parameters provide a basis for the identification and engineering classification of soils and aid in judging their suitability for engineering structures.

Although lateritic soils show potential for use as engineered landfill liners (Osinubi and Nwaiwu, 2006; Emmanuel *et al.*, 2019), their relatively high permeability limits their effectiveness. Efforts to reduce permeability, such as adding bentonite, have been successful investigated (Aswathy and Sunil, 2024; Devapriya and Thyagaraj, 2024; Jain, 2024). Bentonite composed of mineral from the smectite group, finds extensive adoption as the ideal material for landfill liners due to its favourable properties, namely: high swelling, remarkably low hydraulic conductivity, self-healing properties and sufficient absorption capacity (Eyo *et al.*, 2021; Jain, 2024). While bentonite has numerous favourable properties for landfill liners, there are certain difficulties associated with its utilization such as increase in desiccation induced shrinkage and lowering in strength. To address some of these associated challenges, the combination of rice husk ash and bentonite has been contemplated. This mixture aims to leverage the strengths of both materials.

Rice husk ash (RHA) is derived from rice husk. It possesses pozzolanic properties and is known to exhibit cementitious behavior when mixed with appropriate binders (Alhassan and Alhaji, 2017) and can be utilized to stabilize and improve the engineering properties of soils, reducing plasticity, increasing shear strength, and mitigating settlement (Alhassan and Alhaji, 2017). The combination of bentonite and RHA for treatment of soils has shown promising potential in enhancing the physical properties of soils for landfill liners application.

While Daniel (1993) recommended the following requirements for a soil to satisfy the hydraulic conductivity criterion: percentage fines = 30%–50%, plasticity index (PI) = 10%–65%, percentage of gravel ≤ 20% – 50%, and maximum particle size = 25–50 mm, Benson *et al.* (1994) suggested the following soil properties: liquid limit ≥20%, PI ≥ 7%, percentage of fines ≥30%, and percentage of clay ≥15% for materials to be used as landfill liners.

2 MATERIALS AND METHODS

2.1 MATERIALS

2.1.1 LATERITIC SOIL

Disturbed lateritic soil sample used for this study was collected from a borrow pit in Minna (Latitudes 9°31'1"N and Longitude 6°26'15"E). The lateritic soil sample was air-dried in the Civil Engineering laboratory of Federal University of Technology, Minna.

2.1.2 RICE HUSK ASH (RHA)

The Rice Husk used for this study was obtained from a rice milling plant in Minna, Niger State. The collected rice husk was burnt at a control temperature of 700°C in a laboratory furnace at the Civil Engineering laboratory, Federal university of Technology, Minna to obtained Rice Husk Ash (RHA). The ash was sieved through sieve 75µm and stored in polythene bags to avoid any form of hydration.

2.1.3 BENTONITE

Bentonite was procured from borehole material vendors in Minna, Niger State, Nigeria.

2.1.4 TAPE WATER

Tap water used for the study was collected from Civil Engineering laboratory, Federal University of Technology, Minna.

2.2 METHODS

The natural lateritic soil was mixed with 0, 3, 6, 9, 12% of bentonite and a fixed percentage of Rice Husk Ash (8%) by dry weight of the soil.

Standard laboratory tests namely LL and PL and LS were carried out on natural lateritic soil sample and samples treated with varying percentage proportions of bentonite and fixed percentage (8%) of RHA, which falls within the optimum range as reported by Alhassan and Alhaji (2017). The Atterberg limit tests were performed in accordance with BS 1377, 1924 (1990). X-ray diffraction and (XRD) and X-ray florescence (XRF) tests were also carried out to determine the mineralogical and chemical properties of the lateritic soil, bentonite, and RHA.

3 RESULTS AND DISCUSSION

3.1 CHARACTERIZATION OF MATERIALS

The particle size distributions of the soil, obtained by standard sieving test is shown in Fig. 1. As the soil had 6% sand fraction and 79.79% fines (<0.075 mm), the sample met the requirements for clay liners (fine fraction ≥30%, clay fraction ≥15%).

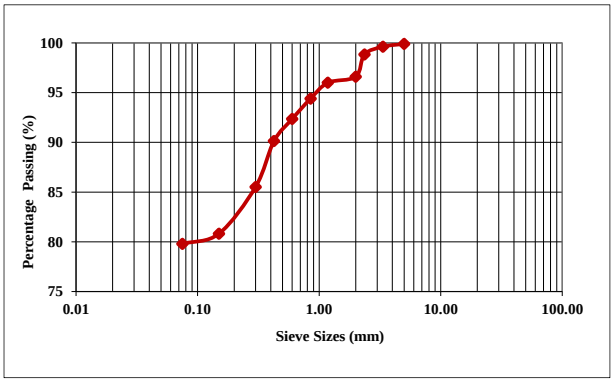


Figure 1: Particle size distribution curves for soil used in the study

The soil's liquid limit (LL), plastic limit (PL), and plasticity index (PI) were 64.2, 27.76, and 36.44% respectively and a specific gravity of 2.61. The soil sample is inorganic and had high plasticity, as it was classified as CH (fat Clay) as per USCS (Unified Soil Classifications System).

Bentonite, known for its exceptional water absorption and swelling properties, exhibits an extremely high LL of 320%, making it ideal for enhancing sealing properties but prone to increasing shrinkage when used excessively. It has a specific gravity of 2.17 typical of bentonite clay found in literature (Amadi and Isah, 2024; Aswathy and Sunil, 2024). RHA, on the other hand, is non-plastic and rich in silica, with pozzolanic properties that reduce water retention and improve dimensional stability by promoting particle flocculation.

Table 1 present a summary of the basic properties of materials used in the study, while the oxide compositions of the materials are reported in Table 2.

The oxide composition of the bentonite used closely agrees with typical values reported by Amadi and Isah (2024) as well as Devapriya and Thyagaraj (2024). Meanwhile, the combined concentrations of SiO2, Al2O3 and Fe2O3 in RHA is greater than 70%, hence,

the RHA can be said to be pozzolanic (ASTM C618, 2019).

TABLE 1: BASIC PROPERTIES OF MATERIALS

Basic characteristics	Lateritic soil	Bentonite	RHA
% larger No.200 sieve (>0.075 mm)	20.21	-	7.9
% passing No.200 sieve (<0.075 mm) (%)	79.79	-	92.1
Liquid limit (%)	64.2	320	
Plastic limit (%)	27.76		
Plasticity index (%)	36.44		
Linear shrinkage (%)	10.1		
Specific gravity	2.61	2.17	2.17
Soil class	CH		

TABLE 2: OXIDE COMPOSITION OF THE MATERIALS USED IN THE STUDY

	Samples		
Oxide	Laterite	Bentonite	RHA
SiO_2	40.39	66.8	72.5
AI_2O_3	20.6	20.5	4.3
Fe_2O_3	30.64	4.08	1.5
MnO	0.07	0.03	0.55
CaO	0.6	1.69	4.45
P_2O_5	-	0.08	8.58
K_2O	0.9	0.6	5.35
TiO_2	1.1	0.15	0.45
SO_3	0.04	0.1	0.15
Na_2O	0.85	1.65	0.02
LOI	0.04	0.04	0.02

LOI – Loss on ignition

3.2 PLASTICITY CLASSIFICATION OF SOIL MIXTURES

Evaluation of test data indicated that the lateritic soil used in the study is classified as clay with high plasticity (CH according to USCS classification) with a LL of 64.2%, while PI is 36.44%. Equally, all the resulting soil mixtures from the addition of RHA and bentonite are of high plasticity and this indicates that the mixtures will swell when it is in contact with water. The Casagrande classification chart (Fig. 2) places all the mixtures in the high plasticity/compressibility region and hence they would be expected to exhibit high swelling potential (Osinubi and Nwaiwu, 2006; Emmanuel *et al.*, 2019). While materials plotting below the A – line such as sand and silt are described as unsuitable materials for landfill liner construction, soils/materials which plot above the A-line imply suitability in terms of ability to produce low hydraulic conductivity, k.

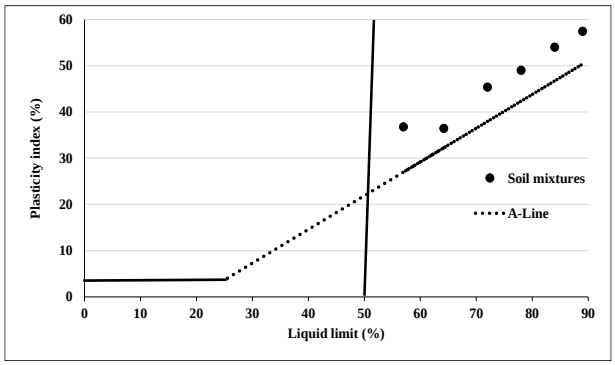


Figure 2: Plasticity chart for the soil mixtures

3.3 THE COMBINED EFFECTS OF RHA AND BENTONITE ON LIQUID LIMIT (LL) OF LATERITIC SOIL

The results demonstrate that the addition of bentonite raised the LL. For 0, 3, 6, 9, and 12% bentonite content, LL of the mixtures were 57, 72, 78, 84, and 89%. The consistent rise in LL across the mixtures highlights the influence of bentonite on their plasticity and water-holding capacity. Upon contact with water, bentonite particles create a diffused double layer around themselves, leading to an enhanced water holding capacity (Eyo *et al.*, 2021; Cheraghalikhan *et al.*, 2023). Within the range of LL required for clay liner applications as depicted in Fig. 3, both the natural and soil mixtures (containing 0 to 12% bentonite) satisfied the guideline requirement of LL = 30 – 90%.

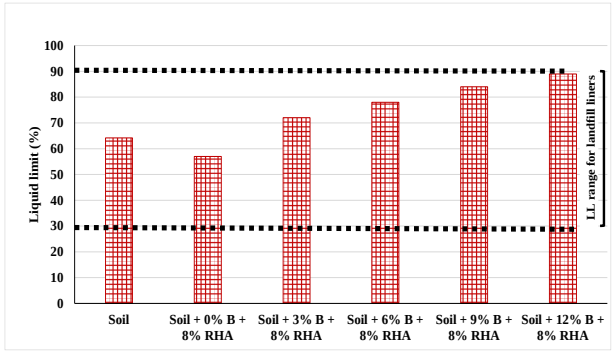


Figure 3: Liquid limit of lateritic soil with varying bentonite content at fixed rice hush ash content

3.4 THE COMBINED EFFECTS OF RHA AND BENTONITE ON PLASTIC LIMIT (PL) OF LATERITIC SOIL

The introduction of rice husk ash (RHA) with minimal natural plasticity, mixtures exhibited slight decrease in PL from 20.23% at 0% bentonite to 32.37% at 12% bentonite (Fig. 4). As the percentage of bentonite increased, a rising trend in PL is observed across each of the soil mixtures. The increment in PL is associated with the water retention capacity and swelling characteristics of bentonite. As bentonite particles come into contact with water, they create a diffused double layer around them, improving water-holding capacity, thereby leading to an enhanced PL. This trend is consistent with the results of past research works of Devapriya and Thyagaraj (2024).

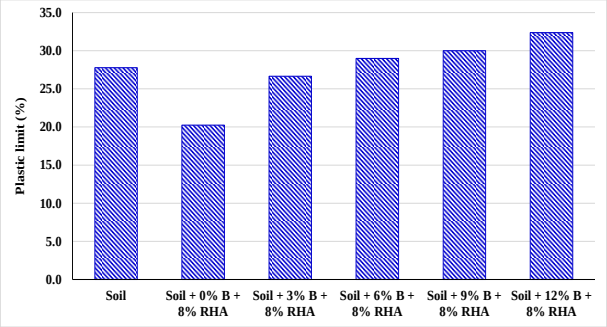


Figure 4: Plastic limit of lateritic soil with varying bentonite content at fixed rice hush ash content

3.5 THE COMBINED EFFECTS OF RHA AND BENTONITE ON PLASTICITY INDEX (PI) OF LATERITIC SOIL

With an increasing percentage of bentonite, a consistent trend of higher plasticity index was apparent across all mixes. For 0, 3, 6, 9, and 12% bentonite content, the PI values of the soil mixtures were 36.77, 45.35, 49.01, 54, and 57.45% respectively. The water retention capacity of bentonite and swelling properties caused the increase in plasticity in less-plastic soil-RHA mixtures thereby enhancing PI and resulting in an expanded plastic range (Fig. 5). This is an improvement making the resultant material to meet up with the plasticity specification for liner material. High plasticity characteristics strongly correlates with the self-healing capability and hydraulic conductivity (Aswathy and Sunil, 2024; Devapriya and Thyagaraj, 2024) of materials for liner systems. Similar trends in PI were also seen in earlier works on soil-bentonite mixtures reported by Cheraghhalikhan *et al.* (2023), Amadi and Isah (2024) and Jain (2024).

All the soil mixtures fulfilled the prescribed criteria for the plasticity index (PI) values i.e., PI of 10 – 65% prescribed by most regulatory bodies.

3.6 THE COMBINED EFFECTS OF RHA AND BENTONITE ON LINEAR SHRINKAGE (LS) OF LATERITIC SOIL

Knowledge of variations in linear shrinkage is crucial for landfill liner applications where drying-induced shrinkage influences material behavior, such as in construction, where cracks must be minimized. This consideration suggests that the material would be subjected to swelling and shrinkage during alternate dry and wet seasons typical of tropical climatic conditions. The average linear shrinkage for tested samples slightly increased from 9.11 at 0%B+8%RHA to 10.63% at 12%B+8%RHA (Fig. 6). As the percentage of bentonite increases, a trend develops, highlighting the influence of bentonite on shrinkage characteristics of mixtures. The introduction of bentonite particles, with their water-absorbing properties, acts as a moisture reservoir within the mixture. This hinders rapid moisture loss during drying, reducing the extent of shrinkage and resulting in a higher SL (Eyo *et al.*, 2023; Amadi and Isah, 2024).

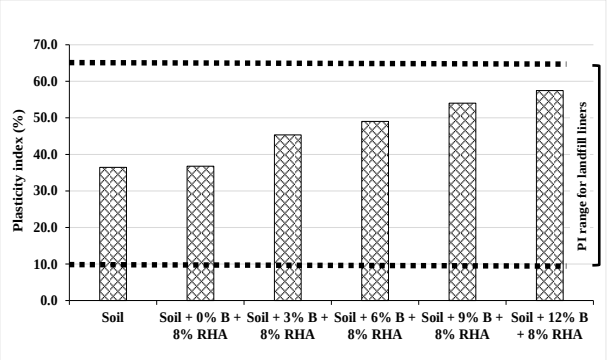


Figure 5: Plasticity index of lateritic soil with varying bentonite content at fixed rice husk ash content

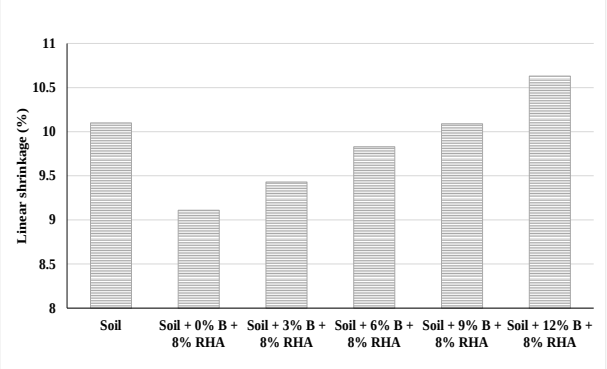


Figure 6: Linear shrinkage of lateritic soil mixed with bentonite and rice husk ash

4 CONCLUSION

Consistency limit tests namely: liquid limit (LL), plastic limit (PL), plasticity index (PI) and linear shrinkage (LS) were conducted on lateritic soil treated with rice husk ash (RHA) and bentonite developed for use as landfill liner material. The natural lateritic soil was mixed with 0, 3, 6, 9, 12% of bentonite and a fixed percentage of Rice Husk Ash (8%) by dry weight of the soil. The results of laboratory tests indicate that the addition of RHA to the soil resulted in marginal decrease in consistency limits. Furthermore, liquid limit increased to 89% from 57 %, plastic limit increased from 20.23 to 32.37% and plasticity index increased from 36.77 to 57.45% while linear shrinkage increased to 10.63% from 9.11% with the addition of bentonite.

The findings suggest that incorporating bentonite into lateritic soil and RHA mixtures enhances their consistency characteristics making them suitable for landfill liner applications.

Generally, all the soil mixtures fulfilled the primary criteria for both liquid limit (LL = 30 – 90%) and plasticity index (PI = 10 – 65%) normally specified by most regulatory agencies

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Department of Civil Engineering
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Empolying Artificial Intelligence (AI) in Cadastral Mapping

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ABSTRACT
Cadastral mapping is essential for land administration, property ownership, and urban planning. Traditional methods of cadastral data collection and mapping can be time-consuming, labor-intensive, and prone to human errors. However, recent advancements in Artificial Intelligence (AI) have introduced new opportunities to automate and enhance cadastral mapping processes. This paper explores the application of AI techniques, particularly machine learning (ML), deep learning (DL), and computer vision, in improving cadastral mapping accuracy and efficiency. Using remote sensing data, geographic information systems (GIS), and AI, this paper demonstrates the potential to streamline the creation, maintenance, and update of cadastral maps. Case studies and practical applications are reviewed, highlighting how AI can reduce costs, improve data accuracy, and expedite the cadastral mapping process.
Keywords: Artificial Intelligence (AI), Cadastral Mapping, Geographic Information Systems (GIS).

1 INTRODUCTION

A map is a pictorial representation of a large area in small scale. Among various types of maps, cadastral maps are created by cadastral surveying. Cadastral maps are used for land management-related activities in many countries because they show land details. Proper land
management is important because poor land management leads to encroachments (Krishnan, 2012).

A cadastre is normally a parcel based, and up-to-date land information system containing a record of interests in land (e.g. rights, restrictions and responsibilities). It usually includes a geometric description of land parcels linked to other records describing the nature of the interests, the ownership or control of those interests, and often the value of the parcel and its improvements (FIG,1995).

Odedare (2001) described three main aspects of cadastre as first, the Fiscal aspect, which is concerned primarily with generating revenue for constitutional authority. The second is the legal aspect, which binds the interests of the land attached to a particular person or group of people and lastly, the technical aspect that spells out the method of demarcation survey and preparation of plans for the plots. The technical aspect is powered by a cadastral system.

Cadastral mapping with a chain survey considers the Earth to be flat. If a chain surveyed area is larger than 250 square kilometres, the curvature of the Earth should be considered for calculating areas and determining land dimensions, as recommended by American Survey Institute (Kanetkar, 1994). It is accepted that when cadastral information is part of integrated information systems, it can improve the efficiency of the land transfer process as well the overall land management process. In short, the Danish cadastral system has met the challenge of into the modern digital GIS-world (Enemark, 1994).

Cadastral mapping plays a crucial role in land administration, property ownership registration, tax assessment, and urban planning. Traditionally, cadastral data has been gathered using manual field surveys, aerial photography, and paper maps, often resulting in delays, inaccuracies, and high operational costs. With the rapid advancement of Artificial Intelligence (AI), the process of cadastral mapping can now

be significantly enhanced through automation, data integration, and spatial analysis (Liu,2019).

AI technologies, particularly machine learning (ML) and deep learning (DL), have demonstrated their ability to process large volumes of spatial data, extract valuable features from satellite imagery and aerial photos, and even automate the delineation of property boundaries. Additionally, computer vision techniques have made it possible to automate the interpretation of remote sensing data, facilitating more precise cadastral mapping (Zhang,2020).

This paper demonstrates the significant potential of AI to enhance cadastral mapping through automation and advanced data analysis, offering solutions to the challenges faced by traditional methods and improving land administration and urban planning.

2. Challenges in Traditional Cadastral Mapping

Despite its importance, traditional cadastral mapping methods are fraught with challenges, including:

- **High Costs:** Field surveys are expensive, involving manual labor, equipment, and travel costs.
- **Time Consumption:** The process of collecting, processing, and updating cadastral maps can take months or even years.
- **Data Inaccuracy:** Traditional mapping can be subject to human error, outdated data, or inconsistencies between maps and real-world conditions.
- **Limited Updates:** As urban environments evolve, cadastral maps can become outdated quickly, and frequent updates are required to reflect new land divisions, boundary changes, and urbanization.

Given these limitations, AI technologies can offer significant improvements in cadastral mapping efficiency, accuracy, and scalability (Hong,2021).

3.0 AI Technologies in Cadastral Mapping

3.1 Machine Learning (ML) for Data Classification and Boundary Delineation

Machine learning algorithms, particularly supervised learning models such as Support Vector Machines (SVM), Random Forests (RF), and k-Nearest Neighbors (k-NN), can be trained to classify land cover types, identify boundaries, and distinguish between different features in remote sensing data.

- **Property Boundary Extraction:** ML models can be trained to identify and classify features such as fences, roads, rivers, and other natural or man-made features that demarcate property boundaries.
- **Land Use Classification:** Machine learning can be applied to classify different land use types (e.g., residential, commercial, agricultural, forested) in high-resolution satellite imagery, providing useful information for land administration.

3.2 Deep Learning (DL) for Image Segmentation and Feature Extraction

Deep learning, especially **Convolutional Neural Networks (CNNs)**, has become a powerful tool in remote sensing and cadastral mapping. CNNs excel in detecting spatial patterns and are highly effective in image segmentation tasks.

- **Automated Boundary Detection:** CNNs can be applied to high-resolution satellite images or aerial photographs to automatically detect property boundaries, buildings, roads, and other cadastral features. This method reduces the need for manual interpretation, which can be error-prone.
- **Object Recognition and Mapping:** DL models can detect and recognize objects in satellite imagery, including buildings, roads, and land parcels, providing accurate cadastral information for mapping.

3.3 Computer Vision for Automated Mapping and Feature Recognition

Computer vision techniques, which involve the analysis of digital images to extract useful information, can be combined with AI to automate cadastral data collection. Techniques like **image matching**, **image registration**, and **change detection** allow for:

- **Automated Extraction of Building Footprints:** Using high-resolution satellite images or UAV (drone) images, computer vision algorithms can automatically extract building footprints and other property boundaries.
- **Change Detection:** Computer vision techniques can detect changes in land cover and boundaries over time, helping to keep cadastral maps up to date with new developments, land subdivision, or environmental changes.

3.4 Geographic Information Systems (GIS) for Spatial Data Integration

AI can be integrated with GIS platforms to enhance spatial data analysis and decision-making. GIS enables the visualization, manipulation, and analysis of spatial data, while AI techniques can be used to automate tasks such as:

- **Geospatial Data Integration:** AI can be used to combine multiple data sources, such as satellite imagery, UAV data, and field survey data, to create comprehensive and up-to-date cadastral maps.
- **Boundary Conflict Resolution:** AI algorithms can assist in identifying and resolving boundary disputes by analyzing historical cadastral records and satellite imagery to determine the most accurate property lines.

4. Benefits of AI in Cadastral Mapping

The application of AI to cadastral mapping offers numerous benefits, including:

- **Cost Reduction:** Automation reduces the need for extensive manual labor, leading to significant cost savings in land survey and map creation processes.
- **Increased Accuracy:** AI algorithms reduce human error in boundary delineation and land classification, improving the accuracy of cadastral maps.
- **Faster Processing:** AI can process large amounts of geospatial data quickly, allowing for the rapid creation and updating of cadastral maps.
- **Improved Decision-Making:** With real-time data processing and accurate boundary detection, AI enhances land administration and urban planning decision-making.

5. Challenges and Limitations

Despite the promising potential of AI in cadastral mapping, there are several challenges:

- **Data Availability:** High-quality and high-resolution satellite or aerial imagery is essential for AI-based mapping. In many regions, such data may not be readily available.
- **Complexity of Land Parcels:** In densely built-up areas, property boundaries can be complex and irregular, making them difficult to detect and delineate accurately using AI.
- **Technological Barriers:** AI-based cadastral mapping requires significant computational resources and expertise, which may be a barrier in some regions.

6. CONCLUSION

AI technologies, including machine learning, deep learning, and computer vision, hold tremendous promise for revolutionizing cadastral mapping. By automating tasks such as boundary delineation, land use classification, and change detection, AI can significantly improve the speed, accuracy, and efficiency of cadastral mapping processes. The integration of AI with remote sensing, GIS, and field data collection systems can streamline land administration and enable more effective urban planning, land management, and property registration.

With continued advancements in AI and data availability, the future of cadastral mapping is

poised for significant transformation, paving the way for smarter, more efficient land management systems worldwide.

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Index Analysis and Geotechnical Classification of Residual Soils from Selected Sites in the Fringes of Minna, North Central Nigeria

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ABSTRACT
This paper reports the characterization of index properties of residual soils from selected locations in the fringes of Minna, North central Nigeria. Forty-five disturbed soil samples collected at approximately 2.0m depths by manual excavation from defined locations were subjected to laboratory tests. Tests conducted on representative soils samples include: Natural moisture content test, consistency limits (LL, PL and PI), particle size distribution (relative percentage of soil particles in the samples), specific gravity and compaction tests. Test results revealed that natural moisture content and specific gravity values ranged from 0.79% to 30.8% and 2.59 to 3.06, respectively. Also, the PI varied between 0% and 35.38% with a mean value of 21.48% showing that the soils ranged from pure sands to clay (of both low and high plasticity). The optimum moisture content and maximum dry density of soils ranged from 7.12 to 22.88% and 1.511 to 2.258g/cm3 respectively. The amount of gravel, sand, and fines in the soil samples ranges from 0% to 75.15 %, 15.23% to 68.09 % and 4.18 % to 68.02 % respectively. The collected soils were classified under the CH, CL, MH, and ML subgroups according to the USCS, while the AASHTO system categorizes them into A-1, A-2, and A-7 grades. These findings are expected to provide guidance for design and construction, serve as a baseline dataset for planning and urban development in the study area, and support further research.

Keywords: *Geotechnical Classification, Index characteristics, outer city development, Residual soils*

1 INTRODUCTION

Index characteristics of soils are features that are extensively used by engineers to indicate the condition of soils, classify different kinds of soil into broad categories and provide a relationship with engineering properties. They are therefore valuable tools for evaluating and characterizing soils (Amadi, 2010). In view of this, knowledge and understanding as well as the proper characterization of the index properties of soils used in construction either as foundation or material fill is of great importance for the design and construction of infrastructure projects (Emmanuel *et al.*, 2019, Olofinyo *et al.*, 2019).

Residual soils found in many parts of the world are the product of the in-situ weathering of various types of underlying rock. Their abundance and extensive use in construction resulted in a considerable experience of their characteristics.

Common problems associated with residual soils as natural foundation or material fill is the discrepancy in the material properties due to variation in the parent geology and in weathering profile with depth and extent. As a result, residual soils have a wide range of index and engineering properties depending on their parent rock forming minerals, intensity of weathering, amount of rainfall and temperature. These factors are in turn governed by the geographical location and the prevailing weather conditions.

Soil classification systems provide valuable information on soil characteristics in a concise mode. Numerous soil identification and classification systems exist such as: Unified (ASTM D2487, 1993), America Association of State Highway and Transportation Officials (AASHTO M145, 1988) and U.S. Department of Agriculture (USDA) soil classification system.

The Unified system is based on the Casagrande system that classify soil by type. In this system, the Coarse-grained soils (sands and gravels) are classified according to their grading, while fine-grained soils (silts and clays) and organic soils are classified according to their plasticity. The system is basically, used for virtually all geotechnical engineering work except road construction.

On the other hand, the AASHTO system classifies soils into seven primary groups, namely A-1 through A-7, based on their likely quality for road subgrades.

To classify soils, laboratory tests which measure soil properties such as particle size, mineral composition, organic matter content and plasticity are conducted.

Hence, this study is necessary and required to identify, characterize and classify residual soils within delineated locations in the fringes of Minna town to facilitate future design and construction of infrastructure projects in view of potential city expansion.

2 MATERIALS AND METHODS

2.1 SAMPLES LOCATION

Geotechnical properties of soils were determined by analysis of 45 representative soil samples from 5 selected sites. The geographical coordinates of the sites are presented in Table 1.

TABLE 1: DESCRIPTION OF SAMPLING LOCATION

Sampling location/ Sample ID	Latitude	Longitude
LPG	9.536063°N	6.469160°E
GK	9.531396°N	6.459834°E
GM	9.569042°N	6.493685°E
GW	9.562651°N	6.600197°E
BR	9.581121°N	6.556154°E

LPG – Lapai Gwari, GK – Gidan Kwano, GM – Gidan Mangoro, GW – Gidan waya, BR – Brighter

These areas are basically underlain by rocks of the Nigerian Basement Complex system comprising chiefly of granite, gneiss, marmatites and schist with rock outcrops which can be observed in streambeds and occasionally on ridges (Alhaji, 2008).

2.2 SAMPLE PREPARATION AND TESTING PROCEDURE

From the samples taken from each of the sites, natural moisture content, specific gravity, Atterberg limits, compaction tests were performed in accordance with procedures outlined in BS 1377 (1990). Particle Size distribution of each of the soil was carried out using the dry-sieving method, Atterberg limit tests performed to determine the plastic, liquid limits, and plasticity index (PI) and compaction tests using British standard light (BSL) energy to evaluate the moisture – density relationship.

3 RESULTS AND DISCUSSION

Table 2 provides a statistical summary of the measured index properties of the soils.

3.1 NATURAL MOISTURE CONTENT (NMC)

The natural moisture content values of most soil samples generally range from low to high (0.79% to 30.8%). While samples from GW recorded the highest NMC (w = 30.8%), samples from BR had the lowest NMC (w = 0.79%). 15 soil samples representing 33.33% of the samples had NMC higher than 10% while the remaining samples had NMC lower than 10% (Table 2). The greater percentage of the soils having relatively low NMC is largely due to the period (November – December) when the soil samples were collected which coincides with the inception dry season. Moisture variation in soils is largely determined by intensity of rain, depth of sample collection and texture of the soil (Olofinyo *et al.*, 2019).

3.2 SPECIFIC GRAVITY (GS)

The specific gravity (Gs) of the soils ranged from 2.59 recorded at GM site to 3.06 observed at GK location (Table 2). The range of Gs values obtained in this study falls within the range reported by Emmanuel *et al.* (2019) for lateritic soils found in tropical and sub-tropical regions of Africa with moderate degree of laterization and dehydration. About 98% of the soil samples had Gs greater than 2.6. According to Bowles (2012), the Gs of clayey and silty soils may vary from 2.6 – 2.9 while for organic soils the value ranges between 1.0 and 2.6. It can therefore be inferred that greater percentage of the soil samples from these locations are silty – clayey in nature.

3.3 PARTICLE SIZE DISTRIBUTION ANALYSIS

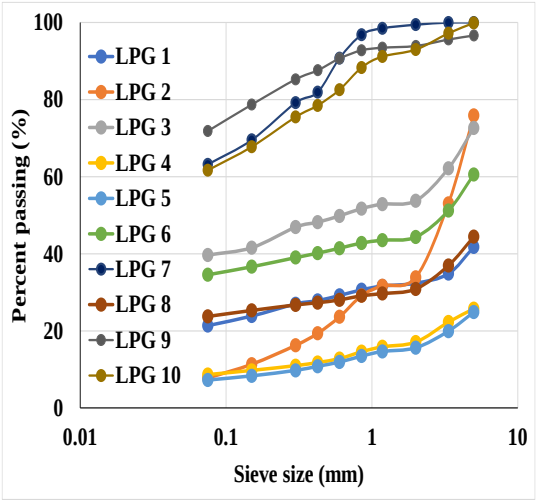
From the particle size distribution curves (Fig. 1) as well as from data in Table 2, the soils consisted of gravel ranging from 0% (which occurred at LPG, GK and GM sampling locations) to 75.15% recorded at LPG site.

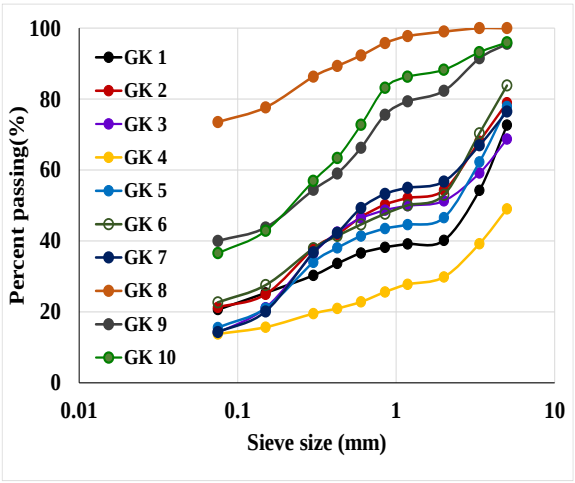
Similarly, sand fractions varied from 15.23% observed at site GM to 68.09% that occurred at LPG location. The highest percentage of fines (84.77%) occurred at GM sampling location while site BR possess the lowest value of 4.18%.

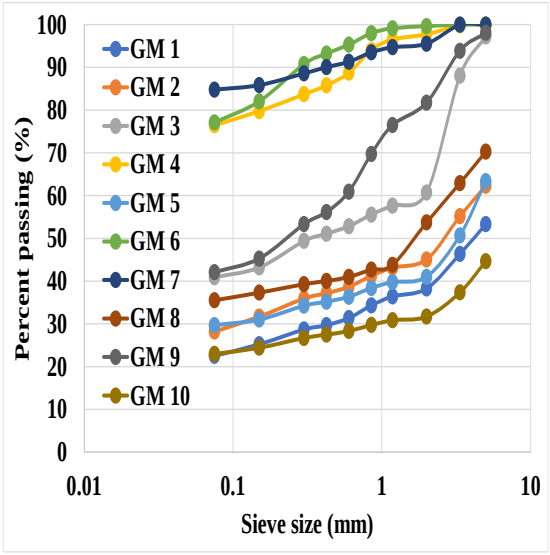
Standard specification by Federal Ministry of Works and Housing (Nigerian General Specification, 1997) requires subgrade soils to possess less than 35% fines. When the results obtained from this study are juxtaposed with this Specification, fifteen soil samples

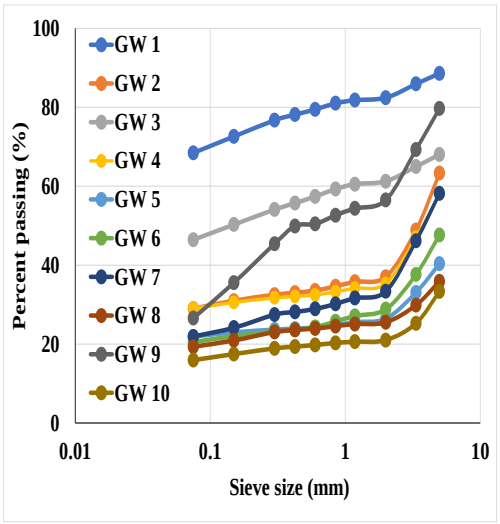
representing 33.33% failed to conform to the specification requirements.

This suggests that such soils may be prone to shrinkage and swelling during alternate dry and wet seasons characteristic of the climatic conditions of the study area (Emmanuel *et al*., 2019).









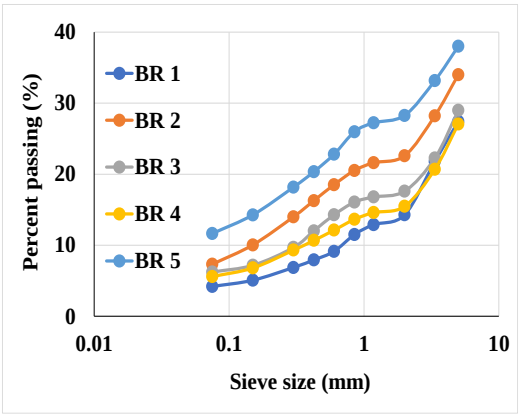


Figure 1: Particle size distribution curves for soils from the selected sites

3.4 CONSISTENCY LIMITS RESULTS

The liquid limit (LL), the plastic limit (PL) and the plasticity index (PI) of the soils from the selected locations are reported in Table 2. The LL, PL and PI of soil ranged from 20.51% to 68.02%, 0% to 43.45% and 0% to 35.38% respectively. The highest LL value (68.02%) as well as the lowest LL value (20.51%) were obtained from GK sampling location.

The maximum LL value of 68.02% recorded in the GK location is higher than 50% while fifteen (15) soil samples had a liquid limit greater than or equal to 50% usually rated as high swelling soils. The PI varied between 0% and 35.38% with a mean value of 21.48% showing that the soils collated ranged from pure sands to clay of high plasticity (fat clay).

TABLE 2: DESCRIPTIVE STATISTICAL ANALYSIS OF THE PROPERTIES OF TESTED SOIL SAMPLES

Location	Statistics	NMC	Gs	Gravel	Sand	Fines	LL	PL	PI
	Mean	13.77	2.79	35.756	30.265	33.98	57.127	32.81	24.32
	Std dev.	5.54	0.08	29.339	15.324	24.48	8.19	4.21	5.85
LPG	Variance	30.77	0.006	860.81	234.83	599.48	67.08	19.67	25.24
	Median	12.66	2.78	33.415	25.405	29.15	59.85	19.68	23.18
	Min.	7.21	2.67	0.0	17.13	7.24	45.72	27.14	18.32
	Max.	24.09	2.92	75.15	68.09	71.87	68.02	39.72	34.68
	Mean	8.22	2.78	20.092	52.676	27.232	32.84	19.51	20.59
	Std dev.	5.51	0.146	15.164	21.15	18.71	12.76	8.41	6.54
GK	Variance	30.32	0.021	229.96	147.64	350.29	162.71	70.67	42.75
	Median	6.26	2.73	21.575	56.63	20.95	32.93	20.39	17.03
	Min.	2.92	2.61	0	26.47	13.75	20.51	0	16.61
	Max.	17.53	3.06	50.97	62.33	73.53	62.09	33.95	28.14
	Mean	9.88	2.81	21.085	32.909	46.006	47.099	25.613	21.486
	Std dev.	3.63	0.12	22.25	13.82	24.07	9.268	3.835	5.759
GM	Variance	13.17	0.015	495.45	191.10	579.54	85.907	14.712	33.169
	Median	8.41	2.785	16.25	32.255	38.19	45.225	25.67	20.03
	Min.	5.46	2.59	0.0	15.23	22.5	35.25	20.4	14.85
	Max.	15.77	2.99	55.37	56.38	84.77	67.97	32.59	35.38
	Mean	9.692	2.858	42.684	27.41	29.906	47.847	28.839	19.008
	Std dev.	7.786	0.057	18.403	11.42	15.97	11.31	6.312	6.462
GW	Variance	60.637	0.003	338.69	130.59	255.07	127.917	39.841	41.765
	Median	7.98	2.87	41.85	24.37	24.255	48.025	27.405	19.74
	Min.	3.5	2.74	11.40	16.54	15.94	26.9	21.58	5.32
	Max.	30.8	2.92	66.67	53.12	68.45	63.67	43.45	29.3
	Mean	2.428	2.818	69.034	24.198	6.768	24.644	0	0
	Std dev.	1.008	0.097	4.65	2.424	2.847	2.177	0	0
BR	Variance	1.018	0.009	21.653	5.877	8.108	4.739	0	0
	Median	2.5	2.85	71.0	23.25	6.21	23.76	0	0
	Min.	0.79	2.7	62.0	21.48	4.18	22.7	0	0
	Max.	3.32	2.91	72.93	27.12	11.64	27.01	0	0

3.5 CLASSIFICATION OF SOILS IN THE LOCATIONS

The Unified Soil Classification System (USCS) using the Casagrande's chart shows that the collated soils are classified as inorganic clay of high plasticity (fat clay), inorganic clay of very low to medium plasticity (lean clay), inorganic silt of low to medium compressibility or organic silt of low compressibility (ML or OL) and inorganic silt of high compressibility or organic clay of high plasticity (MH or OH) as shown in Figs. 2 and 3.

Table 3 presents the classes of collated soil samples according to AASHTO method of classification. The data in Table 3 revealed that the soil samples in the area are predominately granular consisting of A-1 and A-2 grades of soil which are rated as excellent or good subgrade materials. On the contrary, the remaining soil samples categorized as A-7 soils are graded as fair to poor subgrade materials.

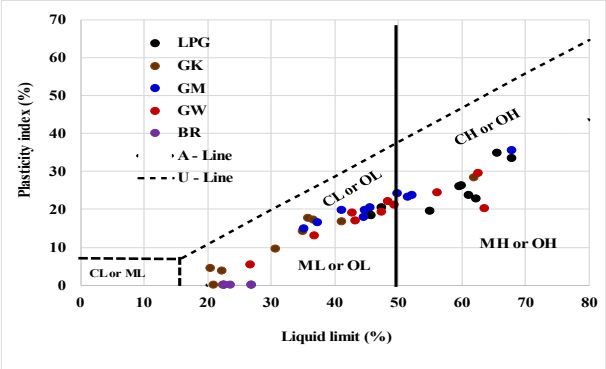


Figure 2: Plasticity chart for USCS classification of soil samples

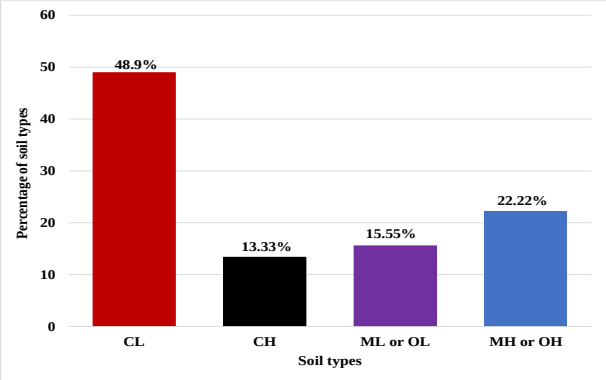


Figure 3: Number of soil types in the collated soils

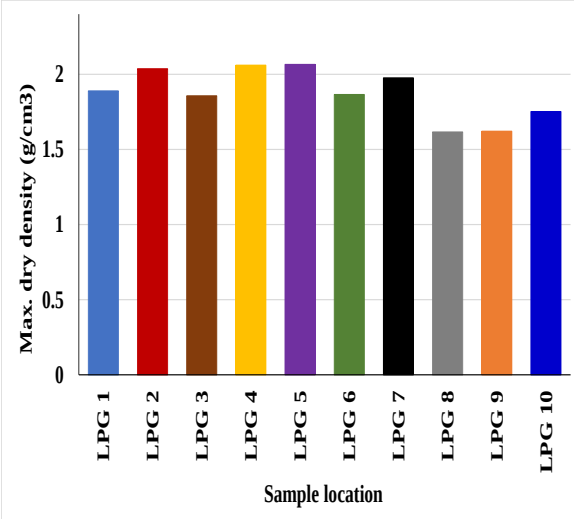
TABLE 3: NUMBER OF SOIL TYPE BASED ON AASHTO SOIL CLASSIFICATION

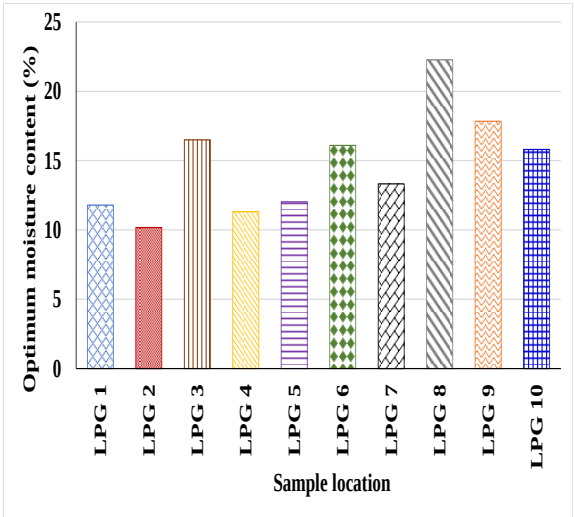
Group classification	Number of soil samples
A – 1	8
A – 2	24
A-7	13

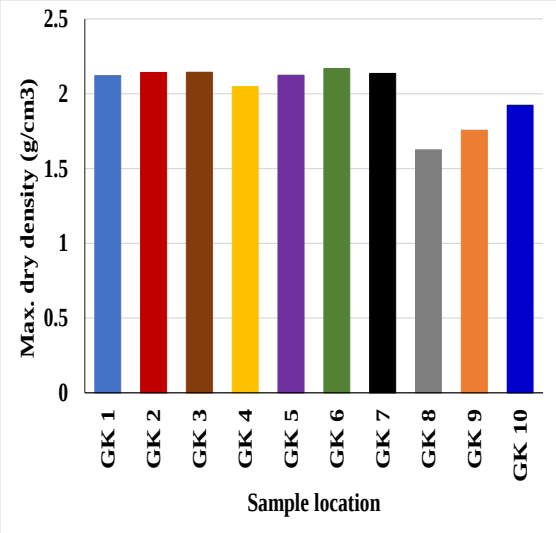
3.6 RESULTS OF COMPACTION TESTS

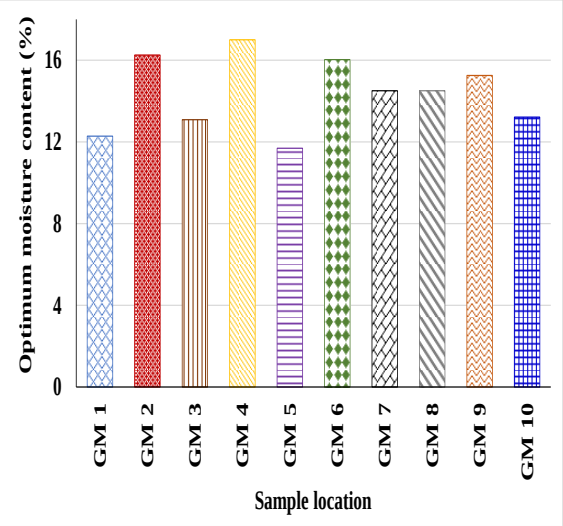
From the compaction tests conducted, the values of MDD and OMC are reported in Fig. 4. The results indicate that the highest value of MDD (2.258g/cm^3) with corresponding OMC value of 12.74% was recorded at BR site while the lowest value was at GW (1.511g/cm^3) with OMC value of 22.88%. Similarly, the highest OMC (22.88%) occurred at GW site and the least OMC value of 7.12% was recorded at GK sampling location.

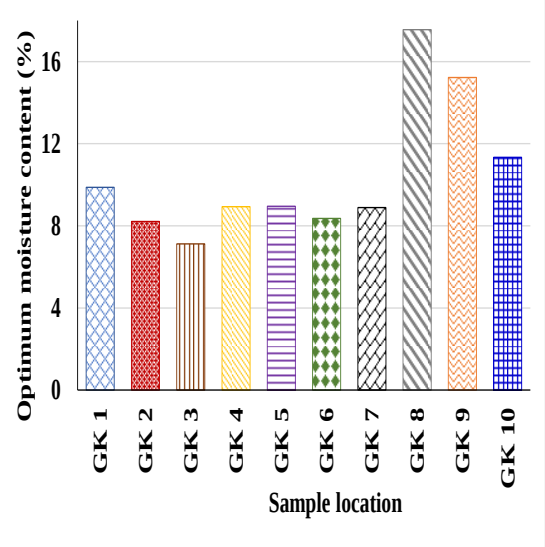
In addition, 70% of the soils achieved MDD within the range 1.0 – 1.8g/cm^3 whereas 30% had MDD within 1.8 – 2.2g/cm^3 range. Similarly, 75% of the samples had OMC within the range 10 -20%; 20% achieved OMC below 10% while 15% had OMC ranging from 20 – 30%.

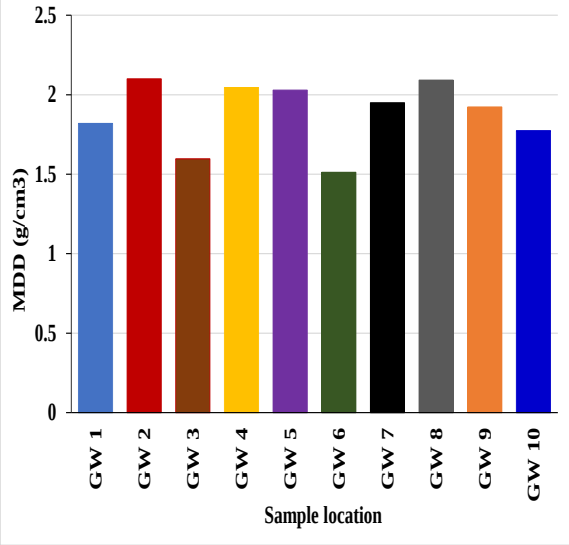


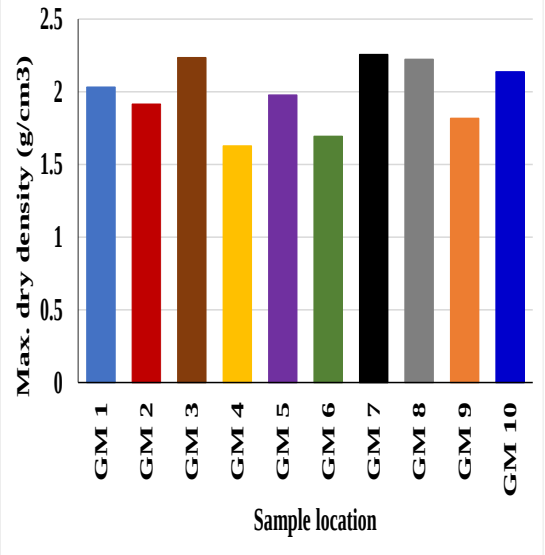


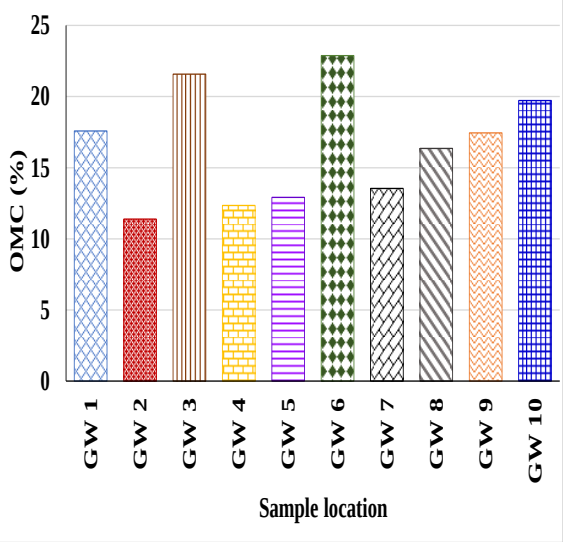

Max. dry density (g/cm3)
2.5
2
1.5
1
0.5
0
GK 1
GK 2
GK 3
GK 4
GK 5
GK 6
GK 7
GK 8
GK 9
GK 10
Sample location

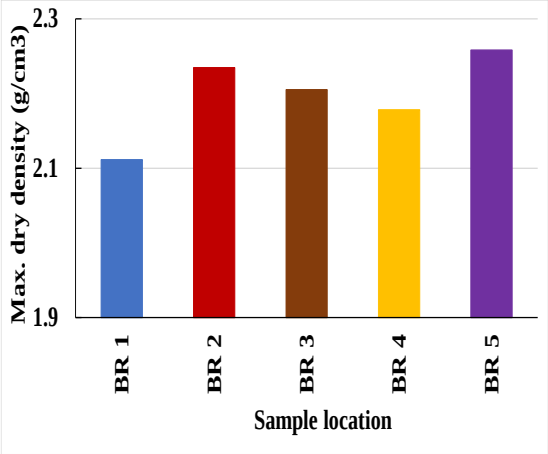

Optimum moisture content (%)
16
12
8
4
0
GM 1
GM 2
GM 3
GM 4
GM 5
GM 6
GM 7
GM 8
GM 9
GM 10
Sample location

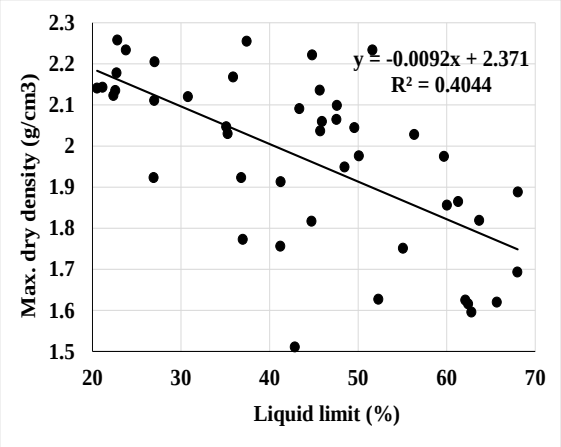

Optimum moisture content (%)
16
12
8
4
0
GK 1
GK 2
GK 3
GK 4
GK 5
GK 6
GK 7
GK 8
GK 9
GK 10
Sample location

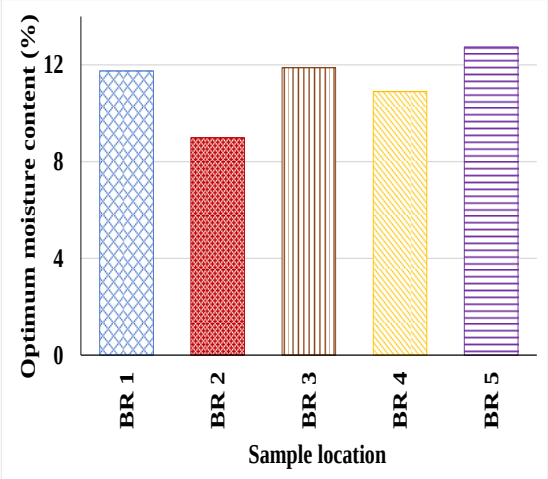

MDD (g/cm3)
2.5
2
1.5
1
0.5
0
GW 1
GW 2
GW 3
GW 4
GW 5
GW 6
GW 7
GW 8
GW 9
GW 10
Sample location


Max. dry density (g/cm3)
2.5
2
1.5
1
0.5
0
GM 1
GM 2
GM 3
GM 4
GM 5
GM 6
GM 7
GM 8
GM 9
GM 10
Sample location


OMC (%)
25
20
15
10
5
0
GW 1
GW 2
GW 3
GW 4
GW 5
GW 6
GW 7
GW 8
GW 9
GW 10
Sample location







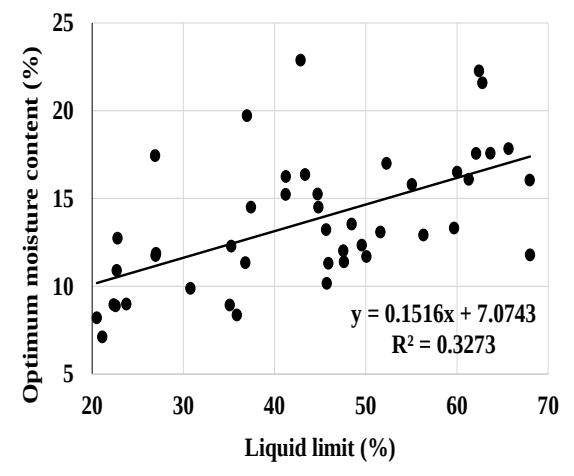
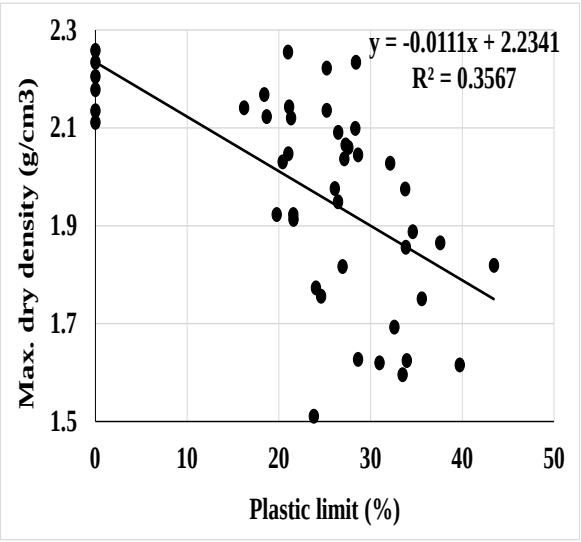
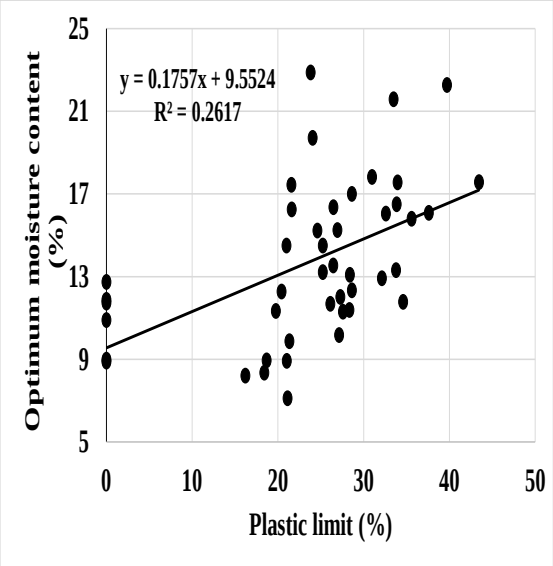


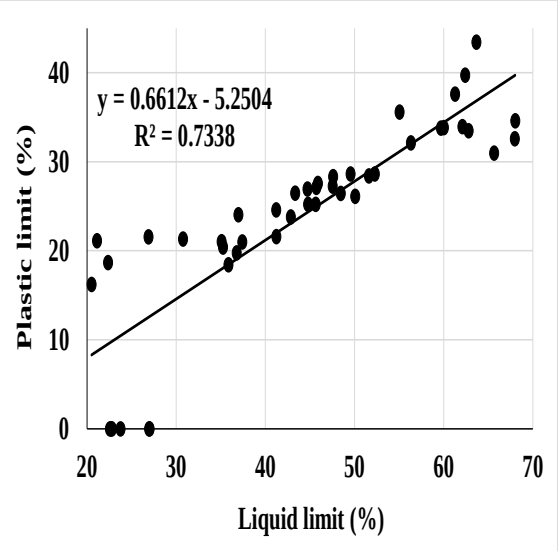
Figure 4: Compaction characteristics of the soil samples from selected sites

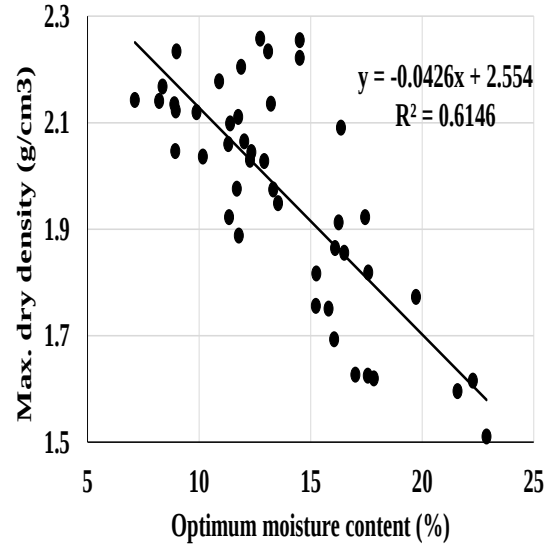
3.7 Correlation Analysis of Different Index Properties of Collated Residual Soils

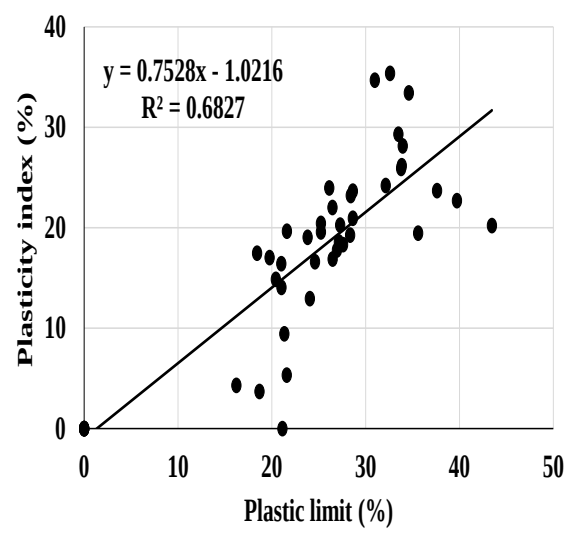
Correlation analysis carried out with the various index properties indicate a strong positive linear relationship between plasticity index (PI) and liquid limit (LL) and plastic limit (PL) as well as plastic limit (PL) versus liquid limit. On the other hand, there is a strong negative linear correlation between MDD and OMC. All other relationships exhibited poor correlation with R^2 values less than 0.5 (Fig. 5). The established relationships with strong correlation can be used to estimate the index properties of these soil with insignificant error.

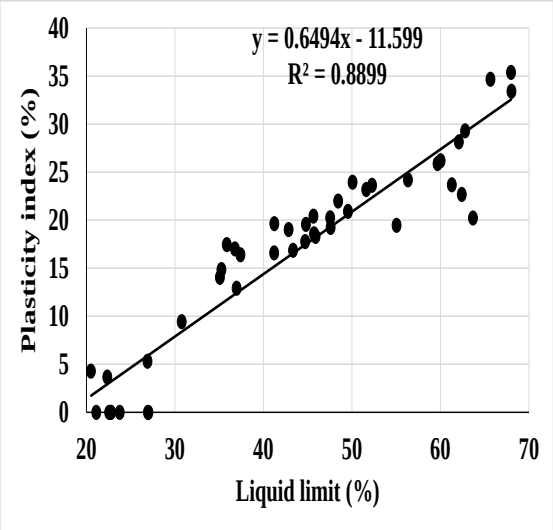


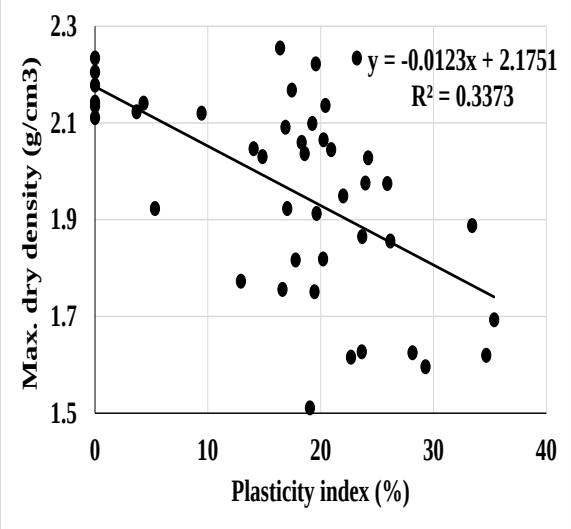

y = 0.1757x + 9.5524
R² = 0.2617
Optimum moisture content (%)
Plastic limit (%)


y = 0.6612x - 5.2504
R² = 0.7338
Plastic limit (%)
Liquid limit (%)


y = -0.0426x + 2.554
R² = 0.6146
Max. dry density (g/cm3)
Optimum moisture content (%)


y = 0.7528x - 1.0216
R² = 0.6827
Plasticity index (%)
Plastic limit (%)


y = 0.6494x - 11.599
R² = 0.8899
Plasticity index (%)
Liquid limit (%)


y = -0.0123x + 2.1751
R² = 0.3373
Max. dry density (g/cm3)
Plasticity index (%)

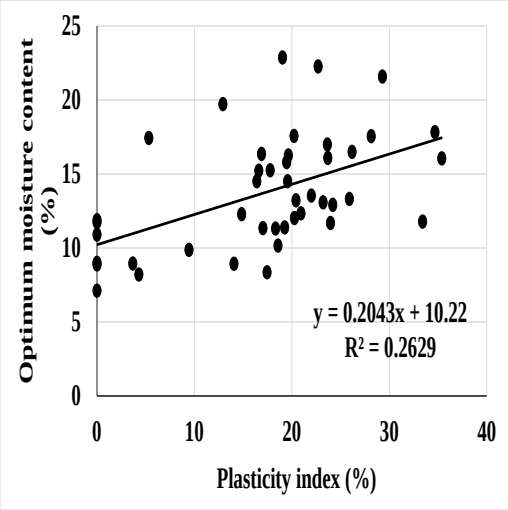


Figure 5: Correlation of LL, PL, PI, OMC and MDD of soils

4 CONCLUSION

This study characterized the index properties of residual soils from selected sites in Minna environs, North Central Nigeria to create a database for planning of future construction of infrastructure projects in these areas or areas having soils similar to those used in this study. Results of laboratory tests revealed that the PI varied between 0% and 35.38% with a mean value of 21.48% showing that the soils ranged from pure sands to clay of high plasticity (CH).

Classifications based on the unified soil classification systems (USCS) on the soil samples indicate four distinct groups namely; CH, CL, MH and ML sub group while AASHTO categorized them as A-1, A-2 and A-7 grades. While A-1 and A-2 soils exhibit favorable strength and stability, making them ideal for structural and road applications, CH, CL, MH, and A-7 soils pose challenges due to their high plasticity, poor drainage, and potential for volumetric changes. Therefore, appropriate soil improvement techniques, such as stabilization and compaction control, are necessary to enhance the performance of the less suitable soils.

The optimum moistures and maximum dry densities of the soils in the study area range from 16.5% to 25.9% and 2.258g/cm^3 to 1.511g/cm^3 respectively. The variation in optimum moisture content and maximum dry density indicates differences in soil compaction characteristics across the study area.

From the correlation analysis, a strong linear relationship was observed between PI vs PL, PL vs LL, PI vs LL and MDD vs OMC. Every other relationship yielded a correlation value less than 0.5.

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Department of Civil Engineering
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Assessment of Physical and Textural Characteristics of Tropical Residual Soils from Selected Locations in Niger State, Nigeria

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ABSTRACT
Detailed understanding of the basic physical properties of tropical residual soil and documentation of such data in an area is crucial for planning and design. Considering the rapid infrastructure development in recent times, the need for studies related to soils prevalent in an area is inevitable. This paper summarizes the results of an evaluation of basic physical properties of residual soils from selected locations in Niger state: Maikunkele (MK), Kuta (KT), Gunu (GN), Pyata (PY) and Gidan Waya (GW) in Niger state, Nigeria. Ten (10) soil samples from each location were collected by manual excavation from a depth of about 1.5m. Physical properties of the residual soils such Natural Water Content (NMC), particle size distribution, specific gravity (Gs), Atterberg limits and compaction characteristics (Maximum Dry Density-MDD and Optimum Moisture Content- OMC) were determined. Results of the investigation showed that NMC, Gs, Liquid Limit (LL), Plastic Limits (PL) and Plasticity Index (PI) ranging from 2.33–30.8, 2.57–3.04, 26.9–84.98, 17.47–53.53 and 00–45.28%, respectively. In general, the percentage of gravel, sand, fines in the soils range from 0 - 66.67, 13.56 - 82.68 and 4.56 - 85.85% respectively. Classifications of the soil, based on the Unified Soil Classification Systems (USCS) of the soil samples indicated four distinct groups; clay of low plasticity (CL), clay of high plasticity (CH), silt of low plasticity (ML) and silt of high plasticity (MH), while the soils generally fall between A-1, A-2 and A-7 groups based on American Association of State Highway and Transportation Officials (AASHTO) method of classification. Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) were found to range from 1.13 - 2.24 g/cm3 and 10.55 – 24.24% respectively. Correlations analysis between some properties (OMC versus LL, OMC versus PL, PL versus LL, MDD versus LL, MDD versus PL, MDD versus OMC and PI versus Gs) of the studied soils have R2 values ranging from 0.5 to 0.8, while other relationships have R2 value less than 0.5. This result is intended to serve as a preliminary guide for city planners, civil and geotechnical designers, in estimating the characteristics of soils from this area.

Keywords: *Physical properties, Residual soils, Textural properties, Tropical soils*

1 INTRODUCTION

In the tropical and sub-tropical regions, residual soils are the main soil type frequently involved in engineering construction either as construction material for roads, embankment and dams or under footings supporting the foundations of building, bridges and load bearing structures. Their occurrence is widespread and the engineering properties not only vary with spatial locations but also with depth (Amadi *et al.*, 2019). With the extensive construction activities taking place to meet the needs for economic and social development in Minna urban centre, spatially explicit geotechnical information of the residual soils from the outer city becomes inevitable for managing the potential expansion after the development of urban centre in the nearest future.

Tropical residual soils are rock materials derived from weathering and decomposition of parent rocks that have not been transported from their original place usually found in tropical climates. This soil group has a wide range of index and engineering properties depending on their parent rock-forming minerals, intensity of weathering, topography, amount of rainfall and temperature. These factors are in turn controlled by the geographical location and the prevalent weather conditions (Amadi *et al.*, 2019).

Residual soils are generally recognized to have distinctive behavior which is considerably different from that of sedimentary soil because of how they are formed. While sedimentary soils are formed by transportation and deposition, residual soils are the result of the weathering of parent rock, a process that results in strength reduction. More importantly, the mechanical properties of residual soil are not controlled

by stress history but rather the outcome of weathering, making the framework developed for sedimentary soils fail to predict the behavior of residual soil accurately (Amadi and Isah, 2024).

These soils can be highly variable in nature, depending on the type of parent rock, and the weathering process influenced by climatic conditions. The natural variability of residual soils has caused limitations in understanding of these soil group, accurate prediction of soil parameters (Olofinyo *et al.*, 2019) and thus hindered the effective use of these soils as fill material for various construction activities. To address this concern, systematic assessment of the geotechnical index/engineering properties in the various locations is required.

Many studies have been carried out to determine the physical and engineering properties of residual soil in Minna city centre (Alhaji, 2008; Amadi *et al.*, 2019) but not much data can be found for the properties of residual soil in locations at outer city. Thus, the purpose of this study is to investigate the basic physical properties required for recognizing, identifying, and classifying residual soil categories within the selected locations in Minna environ, north central Nigeria ahead of the expected development expansion.

2 MATERIALS AND METHODS

2.1 COLLECTION OF SOIL SAMPLES

A total of fifty (50) disturbed bulk soil samples were collected from five locations at depths ranging from 1–2m, below the ground level. The geographical coordinates of the five locations namely Maikunkele (MK); Gunu (GN); Kuta (KT), Pyata (PY) and Gidan Waya (GW) are listed on Table 1. The residual soils in these areas are underlain by granite basement and is surrounded to the north and south by the older basement rocks of the Precambrian to upper Cambrian age (Alhaji, 2008). Soil samples for natural moisture content determination were collected from the sites in watertight (polythene) bags while samples for other tests were air-dried for seven (7) days before they were subjected to geotechnical tests.

TABLE 1: GEOGRAPHICAL COORDINATES OF SAMPLING LOCATIONS

Sampling location	Latitude	Longitude
MK	9.676468°N	6.455172°E
KT	9.859391°N	6.711774°E
GN	9.666226°N	6.719130°E
PY	9.669936°N	6.526143°E
GW	9.581121°N	6.556154°E

2.2 SAMPLE PREPARATION AND TESTING PROCEDURE

The collected soil samples were subjected to two classes of laboratory tests, namely: classification tests (natural moisture content, Atterberg limits, specific gravity as well as particle size distribution) and compaction tests. These tests were carried out in accordance with BS 1377 (1990). The natural moisture content of the soil samples was determined in the laboratory using the oven-drying method, their particle size analysis by the dry sieve method while the specific gravity was determined by the pycnometer method. The plasticity index is a calculated difference between the liquid limit and the plastic limit. The British standard light (BSL) energy was used in the compaction of specimens

3 RESULTS AND DISCUSSION

3.1 NATURAL MOISTURE CONTENT (NMC)

The basic characteristic features of the various soil samples from the selected sites as presented on Table 2 shows that the natural moisture contents of the samples range from 2.33–30.8%, with the samples collected from GW and KT having the highest and least natural moisture contents, respectively. Natural moisture content gives indication of the in-situ states of the soil and the degree of drying required to bring the soil to their maximum dry density as well as the water retention capacity of the soils.

While some of the studied soils have high NMC based on the range (5–15%) specified by Nigerian General Specification (1997) for engineering construction, others are well below this range.

3.2 PARTICLE SIZE DISTRIBUTION CHARACTERISTICS

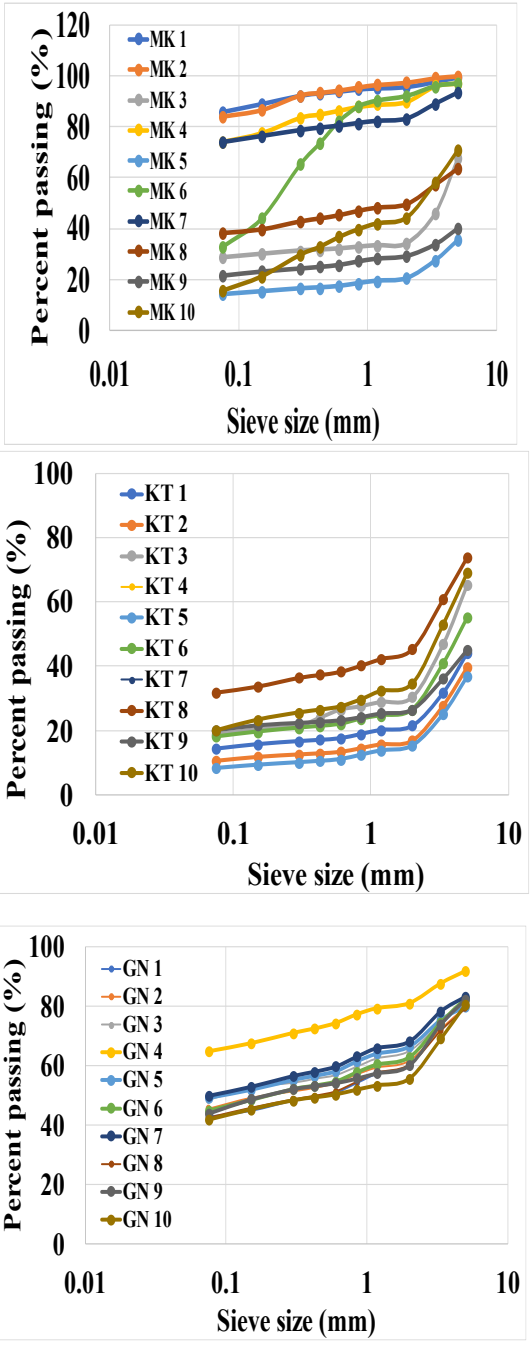
The particle size distribution of the studied soils is summarized in Figures 1 and Table 2. The fines fraction ranged from 4.56 - 85.85%, sand content varied from 13.56 - 82.68%, while the gravel fraction ranged from 0 - 66.67%.

The residual soils contain fines ranging from 4.49% at PY to 85.85% at MK, indicating that some the soil deposit can be use as subgrade, subbase and base

materials for road construction (Nigerian General Specification, 1997; Olofinyo *et al.*, 2019).

3.3 SPECIFIC GRAVITY (GS)

Specific gravity of the soils ranged from 2.57 to 3.04 (Table 2). These values are similar to those reported by Alhaji, (2008) for residual soils within the basement complex of north-central Nigeria. The least value of 2.57 was recorded at PY while higher values were recorded at KT and MK. The higher Gs values in these locations is attributed to presence of free irons in these locations which are heavier than ordinary soil particles.



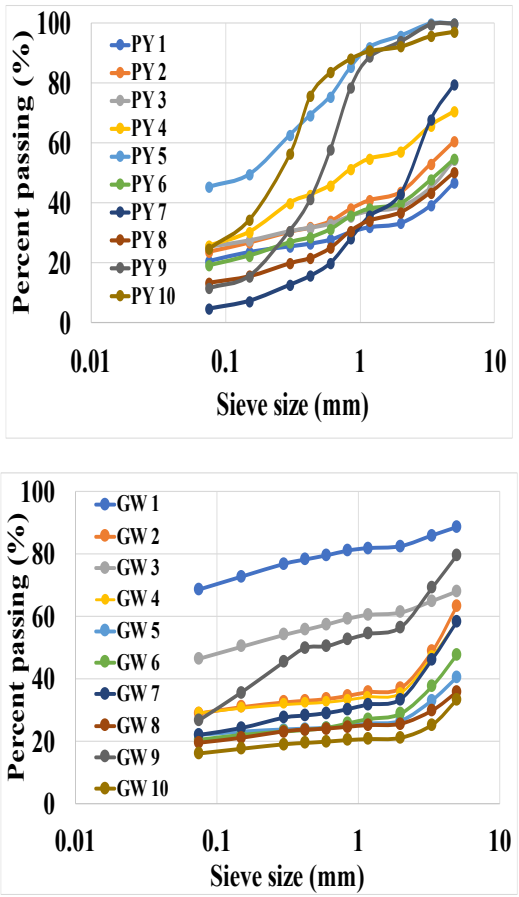


Figure 1: Particle size distribution curves for soils from the selected sites

3.4 ATTERBERG LIMITS RESULTS

The Atterberg limits: liquid limit (LL), plastic limits (PL), and plasticity index (PI) enables the engineer to understand the consistency of clay and to classify them. The LL, PL, and PI obtained ranges from 26.9 to 84.98%, 17.47 to 53.53% and 0 to 45.28% respectively (Table 2). Samples from GW have the lowest value (26.6%) of LL, while highest value (85.85%) was recorded from soil from MK as compared to the values from other sites. In all, 54% of the soil samples are within 50 and 20% maximum LL and PI respectively, specified by Nigerian General Specification (1997), for highway subgrade materials, while the other soil samples have values above the maximum standard limits making them unsuitable for use as subgrade materials for road.

TABLE 2: STATISTICAL INFORMATION OF THE PROPERTIES OF TESTED SOIL SAMPLES

LOCATION	STATISTICS	NMC	GS	GRAVEL	SAND	FINES	LL	PL	PI
	MEAN	11.53	2.74	23.36	29.78	46.85	54.54	27.76	26.78
	STD DEV.	5.123	0.103	24.65	17.54	29.23	15.88	6.34	10.05
MK	VARIANCE	26.24	0.011	607.82	307.87	854.77	252.3	40.24	100.9
	MEDIAN	11.69	2.72	17.96	22.15	35.58	54.61	27.62	26.99
	MIN.	3.77	2.63	0.00	13.56	13.97	29.77	17.47	11.61
	MAX.	18.97	2.96	64.67	63.94	85.85	84.98	39.7	45.28
	MEAN	3.134	2.826	44.11	37.85	18.04	36.48	24.22	12.26
	STD DEV.	0.772	0.122	13.61	9.17	6.43	5.42	2.12	4.27
KT	VARIANCE	0.597	0.015	185.17	84.09	41.28	29.39	4.49	18.26
	MEDIAN	2.85	2.85	40.8	39.42	18.71	34.38	24.58	10.13
	MIN.	2.33	2.64	26.29	24.98	8.21	30.62	21.23	8.21
	MAX.	4.75	3.04	63.32	49.07	31.90	44.64	26.64	18.00
	MEAN	9.115	2.805	17.89	34.36	47.74	53.45	34.70	18.75
	STD DEV.	1.918	0.064	3.61	4.42	6.97	8.02	6.15	7.56
GN	VARIANCE	3.678	0.004	13.04	19.50	48.60	64.43	37.81	57.28
	MEDIAN	9.285	2.815	18.51	35.39	45.14	55.46	35.6	20.85
	MIN.	6.11	2.71	8.33	26.93	41.72	40.51	23.56	2.11
	MAX.	12.77	2.89	20.86	39.02	64.74	64.42	44.46	28.89
	MEAN	8.029	2.678	28.68	49.42	21.90	44.51	35.36	5.06
	STD DEV.	3.365	0.096	21.41	20.57	10.473	10.98	9.06	8.44
PY	VARIANCE	11.329	0.009	458.6	423.45	109.68	120.6	82.09	71.27
	MEDIAN	7.64	2.665	34.55	40.81	22.05	40.81	34.64	5.12
	MIN.	3.06	2.57	0.00	26.27	4.49	28.40	23.87	0.00
	MAX.	16.25	2.92	53.34	82.68	45.23	62.46	53.53	26.17
	MEAN	9.692	2.858	42.684	27.41	29.906	47.84	28.84	19.08
	STD DEV.	7.786	0.057	18.403	11.42	15.97	11.31	6.31	6.46
GW	VARIANCE	60.637	0.003	338.69	130.6	255.07	127.9	39.84	41.76
	MEDIAN	7.98	2.87	41.85	24.37	24.26	48.02	27.40	19.74
	MIN.	3.50	2.74	11.40	16.54	15.94	26.9	21.58	5.32
	MAX.	30.8	2.92	66.67	53.12	68.45	63.67	43.45	29.30

3.5 AASHTO AND USCS CLASSIFICATION SYSTEM

Classifications based on the Unified Soil Classification Systems (USCS) (ASTM, 1993) indicate four distinct soil groups namely; clay of low plasticity (CL), clay of high plasticity (CH), silt of low plasticity (ML) and silt of high plasticity (MH). Fifteen (15) samples fall within the low plasticity (CL), and six (6) falls within the high plasticity (CH) categories in the Casagrande's chart which indicate that they belong to clay and silty clay in textural classification, respectively (Figure 2). This implies that both samples may be rated as fair to good sub-grade highway materials.

According to the AASHTO (1986) system of classification, soils with less than 35% passing through sieve No. 200 are classified under groups A-1 to A-3, typically granular soils, while soils with more than 35% passing through the No. 200 sieve are classified under groups A-4 to A-7, typically clayey/silty soils. Based on the results, the soils are classified as A-1, A-2 and A-7 (Table 3). It can be inferred from the dataset that over 50% of the soil samples is silty and the remaining is clayey-sand. All soils from the deposits are below the A-line (Figure 2). The suitability of soils in these classification categories vary from fair to poor for use as subgrade materials for pavements.

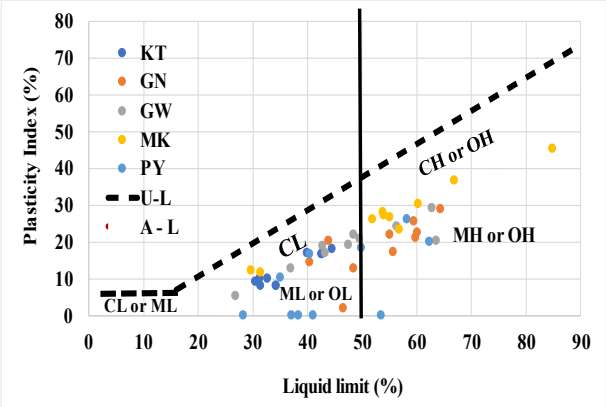


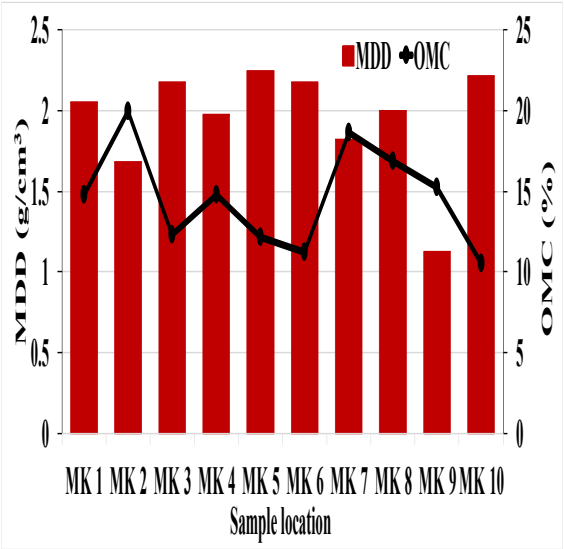
Figure 2: Plasticity chart for USCS classification of soil samples

TABLE 3: SOIL SAMPLES CLASSIFICATION ACCORDING TO USCS AND AASHTO SYSTEMS

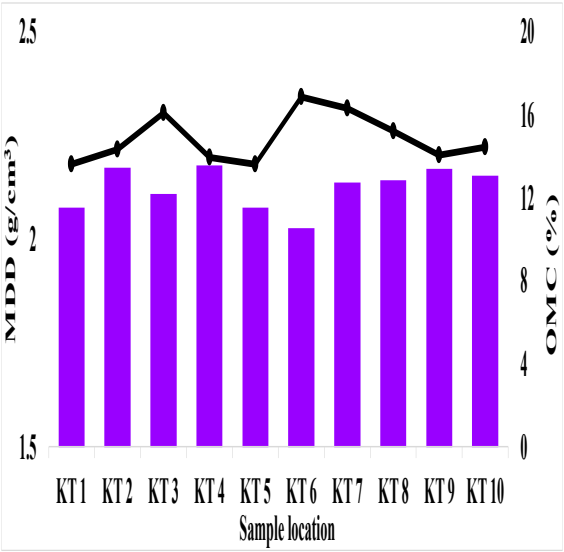
Classification system	Sub-group	Number of soil samples
USCS	CL	15
	CH	6
	ML	15
	MH	14
AASHTO	A – 1	3
	A – 2	29
	A – 7	18

3.6 COMPACTION CHARACTERISTICS

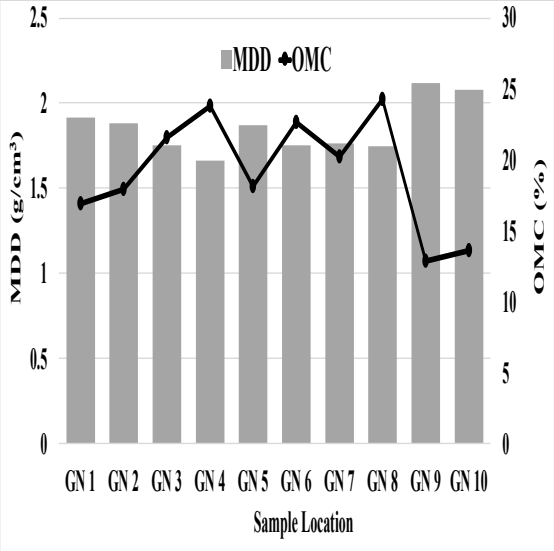
The Maximum Dry Density (MDD) and Optimum Moisture Contents (OMCs) obtained from laboratory compaction test are given in Figure 3. The MDD of the soils ranged from 11.48–2.07 g/cm^3 at Optimum Moisture Content (OMC) of 11.3–30.3%. Nine samples have MDD values above the maximum 1.7g/cm^3 as specified by Nigerian General Specification (1997). The results indicate that soils from KT possess higher compaction values with lower moisture content compared to the samples from other locations.



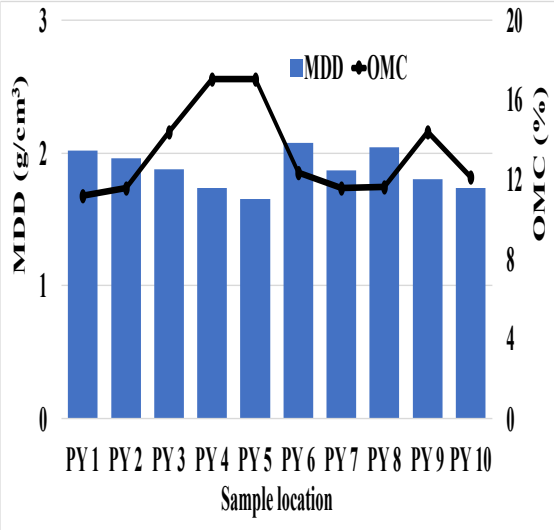
a.



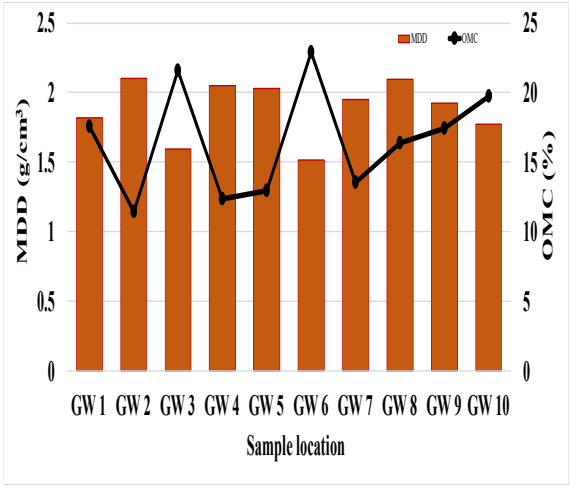
b.



c.



d.



e.

Figure 3: Compaction Parameters of the soil samples from selected locations

3.7 Correlation Analysis

When the basic physical properties of the residual soil samples were correlated to each other, relatively strong relationships were obtained. The relationship between the liquid limits (LL), plastic limit (PL), plasticity index (PI), specific gravity (Gs), Maximum dry density (MDD) and OMC is presented in Table 4. From the table, a strong positive linear correlation between OMC versus LL, OMC versus PL, and PL versus LL with R-values of 0.6171, 0.7503 and 0.6414 respectively were determined. As for the relationship of MDD versus LL, MDD versus PL and MDD versus OMC, there is a strong negative linear relationship with R^2 values of 0.6512, 0.7098, and 0.8107 respectively. From the correlation analysis, it can clearly be said that PI has a very poor relationship with other variables except PI versus Gs which shows a strong negative linear relationship of 0.6215. Every other correlation exhibited a correlation value less than 0.5. These correlations are expected to be useful for researchers and engineers to understand the preliminary behaviour of these soils.

TABLE 4: CORRELATIONS BETWEEN PHYSICAL PROPERTIES OF RESIDUAL SOILS FROM SELECTED LOCATIONS IN MINNA ENVIRON

Variables	Correlation	R^2	Trend/scale of correlation coefficient
MDD = f(LL)	MDD = -0.0123LL + 2.5771	0.6512	Strong negative correlation
OMC = f(LL)	OMC = 0.212LL + 6.0976	0.6171	Strong positive correlation
Gs = f(LL)	Gs = 0.212LL + 6.0976	0.0233	Very low negative correlation
PI = f(PL)	PI = 0.3124PL + 8.112	0.0732	Very low positive correlation
PI = f(LL)	Gs = 0.5602LL - 9.4729	0.6215	Strong negative correlation
PL = f(LL)	PL = 0.4767LL + 7.151	0.6414	Strong positive correlation
MDD = f(PL)	MDD = -0.02PL + 2.6029	0.7098	Strong negative correlation
MDD = f(PI)	MDD = -0.0098PI + 2.1605	0.2143	Low negative correlation
MDD = f(Gs)	MDD = 0.3172Gs + 1.105	0.0286	Very low positive correlation
MDD = f(OMC)	MDD = -0.0473OMC + 2.7634	0.8107	Very strong negative correlation
OMC = f(PL)	OMC = 0.3571PL + 5.7348	0.7503	Strong positive correlation
OMC = f(PI)	OMC = 0.1872PI + 13.057	0.243	Low positive correlation
OMC = f(Gs)	OMC = 0.3644Gs + 15.347	0.0001	Very low negative correlation
Gs = f(PL)	Gs = -0.0031PL + 2.8755	0.0558	Very low negative correlation
Gs = f(PI)	Gs = -0.0004PI + 2.7889	0.0014	Very low negative correlation

4 CONCLUSION

Series of laboratory tests were conducted on residual soils from selected deposits in Niger state to evaluate their physical and textural characteristics. The properties include natural moisture content, particle size distribution, specific gravity, Atterberg limits and compaction characteristics. Results of the investigation show that the natural moisture content of the soils range from 2.33 at KT to 30.8% at GW, while the specific gravity (Gs) varies from 2.57–3.04. The averages of LL, PL and PI varied from 36.48 – 54.54%, 24.22 – 35.36%, and 5.06 – 26.78%, respectively, while the average MDD ranged from 1.87 – 2.13 g/cm^3, with average OMC ranging from 13.34 – 19.18%. In general, the average percentage of gravel, sand and fines (silt and clay) range from 0 - 66.67%, 13.56% - 82.68% and 4.56% - 85.85% respectively. This result is intended to serve as a preliminary guide for city planners, civil and geotechnical designers, in estimating the characteristics of soils from this area.

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Modal Analysis of Barikin Saleh Bridge Deck Using Finite Element Software Simulation Method

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ABSTRACT
The increase in traffic along Barikin Saleh area of Minna Niger State calls for the analysis of the bridge deck due to the increasing and fluctuating traffic volume. In this paper, the modal analysis of the Barikin Saleh bridge deck based on finite element software simulation method was studied. The simulation was carried out to determine natural frequencies and the corresponding mode shapes of the bridge deck using ANSYS workbench software. The parameters of the bridge used in the simulation were Length,16m; Width, 10.75m; Second moment of inertia I, 4.16m4; Area A, .56m2; Young's modulus E, 35300MPa; Density p, 2600 kg/m3, and Concrete Grade G, 50MPa. Based on the simulation output, the bridge exhibited six (6) clear mode shapes and corresponding natural frequencies of 20.299Hz,20.436Hz, 22.875Hz, 25.087Hz, 30.003Hz, and 35.205Hz. The highest natural frequency for the bridge was 35.205Hz, at the bridge deck mid-span. The implication of this is that the lifespan of the bridge might be reduced due to fatigue damage that can occur as a result of repeated loading and unloading of the bridge deck at this frequency. The findings from this study provide valuable insights into the dynamic behavior of Barikin Saleh bridge deck, which can be useful for its maintenance, repair and retrofitting.

Keywords: *Bridge deck, Modal analysis, Natural frequency, Mode shape*

1 INTRODUCTION

The finite element method is a numerical procedure that can be applied to obtain solutions to a variety of problems in engineering. Steady, transient, linear, or nonlinear problems in stress analysis, heat transfer, fluid flow, and electromagnetism problems may be analyzed with finite element methods. The origin of the modern finite element method may be traced back to the early 1900s when some investigators approximated and modeled elastic continua using discrete equivalent elastic bars (Moaveni, 2015).

According to Prakash *et al.*, (2018), Finite element method is a numerical technique generally employed for solving complex engineering problems. It is mostly preferred during design and product development which involves complicated geometries, complex dynamic loadings and the corresponding material property changes that cannot be obtained analytically. In the case of analytical solutions, analysis is typically carried out using dramatic idealization and simplification.

Modal analysis is a process whereby a structure is described in terms of its natural characteristics which are the frequency, damping and mode shapes (Avitabile, 2001.). According to Nikitas & Tsavdaridis (2018), the conception of vibration modes dated back to the eighteenth century and the pioneering studies and debates of Daniel and John Bernoulli, Euler, and d'Alembert who while studying the problem of the vibration of a taut string came up with the notion of the modal shape contributions that build up the total observed oscillations.

Vibration monitoring of a bridge is a useful and widespread technique for assessing the current condition of a bridge, in which damages or structural degradation can be detected, for example, by changes in the natural frequencies or in the frequency spectrum of the response due to ambient excitation (Eberle & Oberguggenberger 2023).

ANSYS is an engineering simulation software (computer-aided engineering, or CAE) developer that is headquartered south of Pittsburgh in Canonsburg, Pennsylvania, United States. The ANSYS Workbench interface consists primarily of a Toolbox region, the Project Schematic, the Toolbar, and the Menu bar (Sai, 2021). Moaveni (2015) described ANSYS as a comprehensive general-purpose finite element computer program that contains more than 100,000 lines of code which is capable of performing static, dynamic, heat transfer, fluid flow, and electromagnetism analyses.

Barikin Saleh Bridge is a 16m long span bridge. The bridge is simply supported and of concrete beam and slab construction which forms part of a larger structure. Six longitudinal beams support a slab with a layer of asphalt acting as the road surface. Plate I below shows a pictorial view of the bridge while plate II shows the aerial view of the bridge with coordinate 90 35' 29" N 60 32' 16" E.

There exists limited data or studies that provides the current dynamic behavior of the Barikin Saleh bridge, so, this study tends to investigate the dynamic behavior of

the bridge using ANSYS workbench as a simulation tool to determine the bridge natural frequencies and the corresponding mode shapes. The outcome of this study will provide a basis for comparison between ANSYS simulation results and that of physical measurement of the bridge dynamic response.



Plate I: Barikin Saleh Beam and Slab Bridge



Plate 1I: Aerial view of the bridge

2 METHODOLOGY

2.1 BRIDGE MODAL ANALYSIS

Modal analysis for the bridge was conducted in ANSYS finite element software to determine the bridge's natural frequencies and their corresponding mode shapes. The flowchart for the modelling and analysis of the bridge is presented in Figure 2.1 while the parameters of the bridge are presented in Table 2.1.

TABLE 2. 1 BRIDGE PARAMETERS

L(m)	16
W(m)	10.75
I(m4)	4.16
A (m2)	5.56
E (MPa)	35300
p(kg/m3)	2600
G(MPa)	50

Where;
L = Bridge deck span
W = Bridge deck width
I = Bridge second moment of inertia
A = Bridge deck cross-sectional area
E = Young modulus of elasticity
P = Density of concrete
G = Grade of concrete

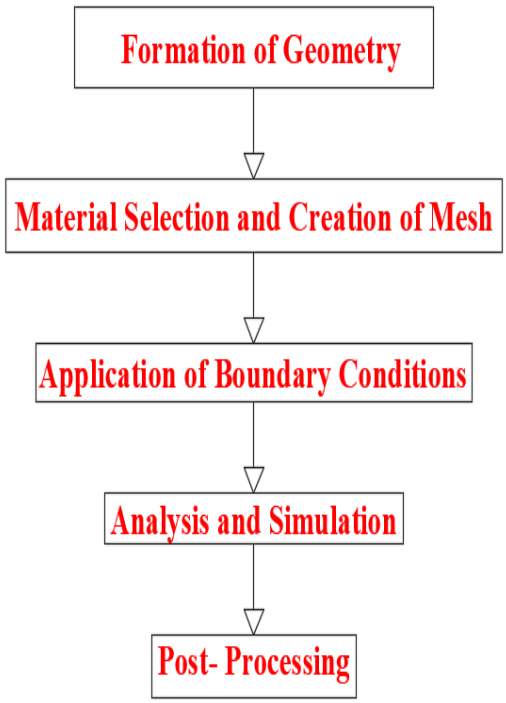


Figure 2.1: Flowchart for Modal Analysis

3 RESULTS AND DISCUSSION

3.1 BRIDGE MODAL ANALYSIS

The modal analysis for the bridge was conducted using the ANSYS workbench finite element software. It was observed from the results that the bridge has six mode shapes and natural frequencies. Figure 3.1 presented the bridge deck model with the slab and six longitudinal beams.

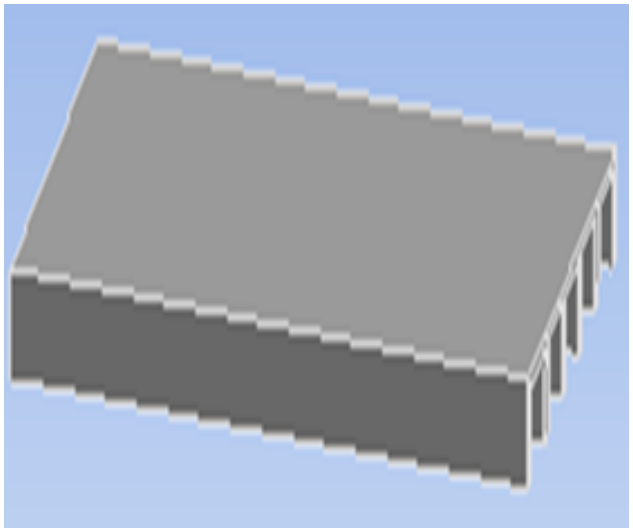


Figure 3.1: Bridge Deck Model

3.1.1 Mode shapes

The six mode shapes for the bridge are presented in Figures 3.2 to 3.7.

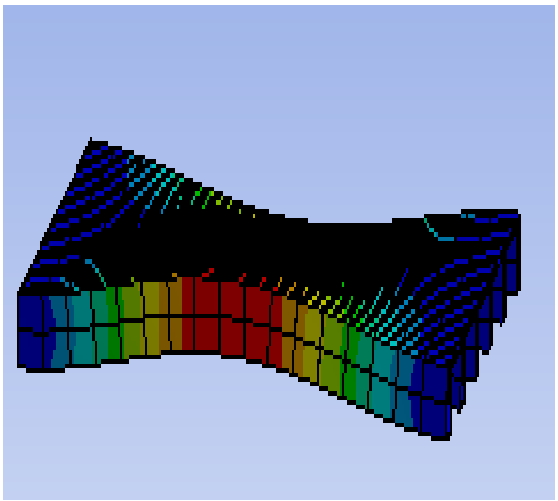


Figure 3.2: Mode Shape 1

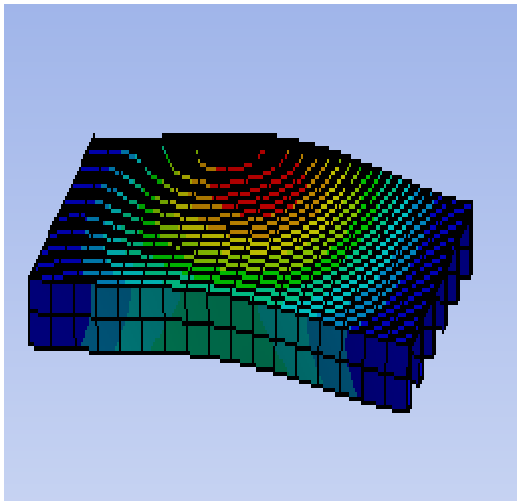


Figure 3.3: Mode Shape 2

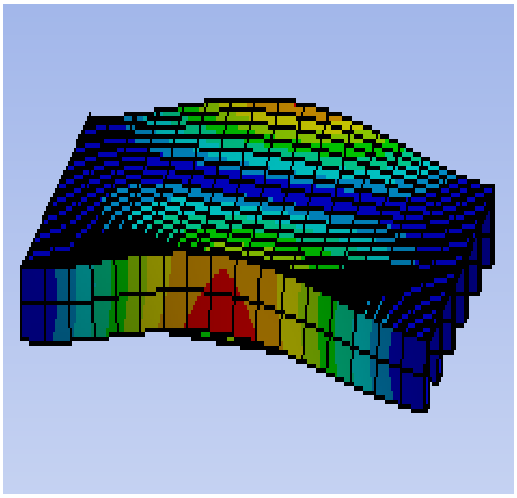


Figure 3.4: Mode Shape 3

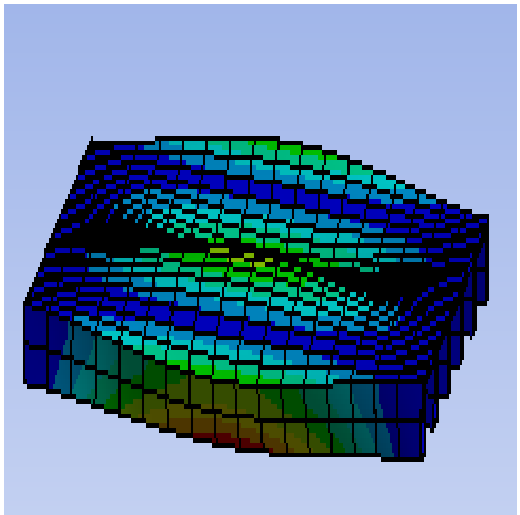


Figure 3.5: Mode shape 4

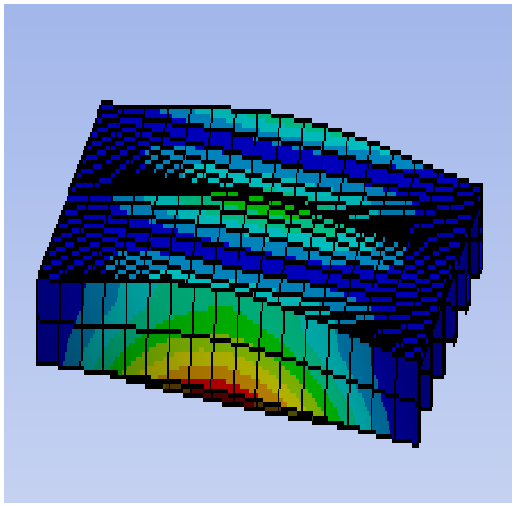


Figure 3.6: Mode Shape 5

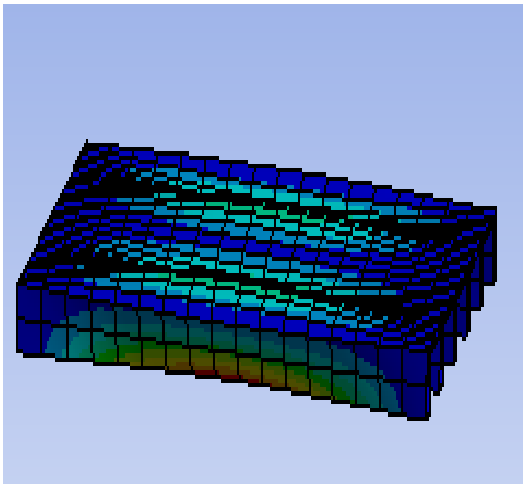


Figure 3.7: Mode Shape 6

The results from the modal analysis showed that the bridge deck can deflect in six different ways. The maximum deformation for each mode shape from mode shape one to six were 0.0051935m, 0.0042058m, 0.0059059m, 0.0067845m, 0.0079419m, 0.0078377m respectively. All the mode shapes have their maximum deformation at the mid- span of the bridge, this showed that the most critical section of the bridge is the mid-span. It was observed that mode shape five has the highest deformation of 0.0079419m which consequently is the most critical

3.2 NATURAL FREQUENCY

The natural frequencies for each mode shape from mode shape one to six were, 20.293Hz, 20.438Hz, 22.862Hz, 25.118Hz, 30.092Hz, and 35.308Hz respectively. The highest natural frequency for the bridge was recorded at mode shape 6 as 35.308Hz.

The plot of natural frequency against mode is shown in Figure 3.2. It was observed that mode shape 6 has the highest natural frequency of 35.205Hz, this implies that the most critical of all the mode shapes were mode shapes five and six due to their values of deformation and frequency.

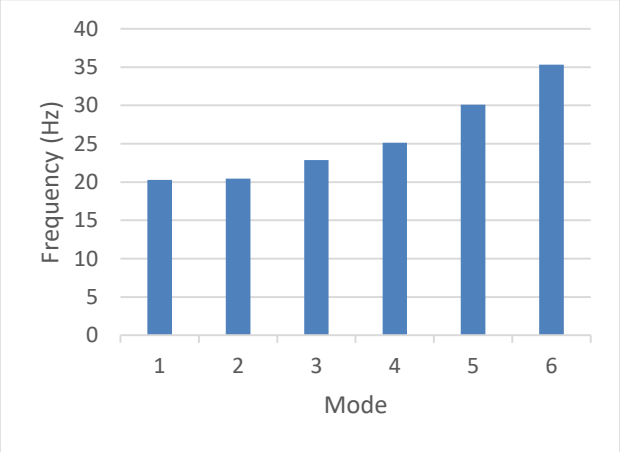


Figure 8: Plot of Frequency against mode

4 CONCLUSION

Modal analysis was carried out on Barikin Saleh bridge deck based on finite element software simulation method. The bridge deck recorded six modes shapes and natural frequencies of 20.299Hz, 20.436Hz, 22.875Hz, 25.087Hz, 30.003Hz 35.205Hz respectively. The highest natural frequency for the bridge was 35.205Hz at the bridge mid-span. The implication of this is that the lifespan of the bridge might be reduced due to fatigue damage that can occur as a result of repeated loading and unloading of the bridge deck at this frequency.

Recommendations

1. The findings from this study provide valuable insights into the dynamic behavior of Barikin Saleh bridge deck, which can be useful for its maintenance, repair and retrofitting.
2. Physical measurements should be carried out in the future to determine the natural frequencies and mode shapes of the bridge deck.

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DEVELOPMENT OF MODELS FOR PREDICTION OF SOIL COHESION USING MACHINE LEARNING ALGORITHMS

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ABSTRACT
Accurate prediction of soil cohesion is crucial for the safe and economical design of geotechnical structures. This study employed five machine learning models—Artificial Neural Network (ANN), Random Forest (RF), Support Vector Regression (SVR), Gradient Boosting (GB), and Decision Tree (DT)—to predict cohesion (c) using a laboratory dataset of 233 samples. The dataset, augmented to 5000 samples using Getel, was split into 70% training and 30% testing sets. Model performance was evaluated using R-squared and Mean Squared Error (MSE). Results showed that Random Forest outperformed other models, achieving the highest R-squared score of 0.622 and the lowest MSE of 56.74, indicating excellent model fit and high predictive accuracy. Feature importance analysis revealed that plasticity, primarily influenced by Liquid Limit (LL) with an importance score of 0.879606, and Plasticity Index (PI) with an importance score of 1.441646, significantly impacts cohesion. Natural Moisture Content (NMC) also showed significant influence with a score of 0.670434. Particle Size Distribution and Specific Gravity (Gs) also contributed to the predictions. This study demonstrates the potential of machine learning models to enhance the accuracy and efficiency of soil characterization and geotechnical engineering design in predicting soil cohesion.

Keywords: Machine learning Algorithms, Soil Cohesion, Prediction, Index Properties

1 INTRODUCTION

Soil shear strength is a fundamental parameter in geotechnical engineering, crucial for the stability and performance of various civil infrastructure projects, including foundations, slopes, embankments, and tunnels (Sharma *et al.,* 2021; Ly, *et al.,* 2020; Fondjo *et al.,* 2023). Accurate prediction of shear strength parameters, such as cohesion and the angle of internal friction, is essential for safe and economical design, risk assessment and mitigation, selection of suitable ground improvement techniques, and environmental impact assessment (Chen *et al.,* 2019; Habte *et al.,* 2024)

Traditional methods for determining soil shear strength, such as laboratory testing and empirical correlations, have limitations. Laboratory testing is invasive, time-consuming, and costly (Ly *et al.,* 2020; Irfan and Osman, 2012; Ozelim *et al.,* 2022). while empirical correlations may not be universally applicable and may not adequately capture and address these limitations, there is a growing demand for robust and accurate predictive models that can effectively and efficiently estimate soil shear strength parameters using readily available data, such as geophysical data, geotechnical data, and remote sensing data complex interactions between soil properties. (Awais *et al.,* 2023). These models aim to improve the efficiency and cost-effectiveness of geotechnical investigations and enhance our understanding of soil behavior.

Machine learning (ML) algorithms offer a promising approach for developing predictive models in geotechnical engineering (Awais *et al.,* 2023). ML algorithms excel at analyzing large and complex datasets, identifying intricate patterns and relationships, and demonstrating high predictive accuracy in various engineering domains. Furthermore, their flexibility and adaptability allow for customization to different soil types and site conditions.

This study aims to develop and evaluate various machine learning models for predicting soil shear strength parameters, including cohesion and the angle of internal friction. A comparative analysis of the performance of different ML algorithms, such as Support Vector Machines (SVM), Artificial Neural Networks (ANN), and Random Forest, will be conducted. The accuracy and reliability of the developed ML models will be assessed in comparison to traditional methods, quantifying potential improvements in prediction accuracy and efficiency. The sensitivity of model predictions to

different input parameters and site conditions will be investigated to enhance our understanding of model behavior and limitations. Finally, the study will explore the potential applications of the developed ML models in geotechnical engineering practice, such as optimizing site investigations, improving design decisions, and enhancing risk assessment procedures.

2 LITERATURE REVIEW

Cohesion is a fundamental parameter in soil mechanics, representing the shear strength of a soil when there is no normal stress acting on the failure plane. It is a crucial factor in determining the stability and behavior of various geotechnical structures such as foundations, slopes, embankments, and tunnels (Suljić, 2013; Hoque *et al.*, 2023).

In recent years, machine learning (ML) algorithms have emerged as promising tools for overcoming limitations of traditional method. ML algorithms can effectively analyze large and complex datasets, identify intricate patterns and relationships within soil properties, and develop predictive models with high accuracy. Several studies have explored the application of various ML algorithms for predicting soil shear strength.

Artificial Neural Networks (ANNs) have emerged as powerful tools for predicting soil shear strength parameters, offering potential advantages over traditional empirical methods. Several studies have demonstrated the effectiveness of ANNs in accurately estimating these critical geotechnical properties. For example, Muusha *et al.* (2024) successfully employed ANN models to predict soil shear strength parameters, achieving high correlation values of approximately 0.99 for cohesion and 0.98 for the angle of internal friction. These promising results highlight the potential of ANNs to provide reliable and accurate predictions of soil shear strength, which can significantly enhance the design and analysis of geotechnical structures.

Support Vector Machines (SVMs), another powerful machine learning (ML) technique, have demonstrated significant potential in predicting soil shear strength parameters. Ly and Pham (2020) investigated the use of SVM models for this purpose, identifying moisture content, liquid limit, and plastic limit as the most influential factors. Their findings highlighted the effectiveness of SVM in accurately predicting soil shear strength. Furthermore, Besalatpour *et al.* (2012) observed that optimized SVM models, employing the simulated annealing algorithm, achieved superior accuracy in predicting soil shear strength compared to traditional multiple linear regression, with a coefficient of correlation of 0.98. These studies collectively demonstrate the capability of SVM models to provide accurate predictions and outperform traditional empirical correlations in estimating soil shear strength parameters.

Machine learning (ML) algorithms, including Random Forests, Decision Trees, and Gradient Boosting Machines, have shown strong capability in predicting soil shear strength. Zhang *et al*. (2021) found that Random Forest-based methods demonstrated superior performance in predicting the undrained shear strength of soft clays, achieving improved accuracy and interpretability compared to other methods. Furthermore, Pham *et al.* (2020) reported that a hybrid model combining Random Forest with Particle Swarm Optimization (RF-PSO) achieved high accuracy (R = 0.89) in predicting soil shear strength. These studies collectively demonstrate the potential of ML algorithms to enhance the accuracy and efficiency of soil shear strength prediction, offering valuable insights for geotechnical engineers.

Further research is necessary to comprehensively evaluate the performance of a wider range of Machine Learning (ML) algorithms, including but not limited to: Artificial Neural Networks (ANNs), Support Vector Machines (SVMs) with different kernel functions, Ensemble methods (Random Forests (RF), Gradient Boosting (GB)), Decision Trees (DT) across diverse soil types.

3 METHODOLOGY

3.1 Index properties were determined, including sieve analysis (ASTM D6913 and AASHTO T27), Atterberg limits (ASTM D4318 and AASHTO T89 for Liquid Limit and Plastic Limit, with Plasticity Index calculated from these values), natural moisture content (ASTM D2216 and AASHTO T265)

3.2 Triaxial testing (Undisturbed soil samples were subjected to triaxial compression tests in an unconsolidated undrained (UU) setting), These tests were conducted to determine the shear strength parameters of the soil, specifically the cohesion (c). Triaxial tests were performed on these samples to determine their shear

strength parameters (φ and c). ASTM D2850-24 (2024) was followed in the performance of the tests.

Table 3.1 shows the parameters utilized in developing the models.

PARAMETER	CONFIGURATION
Input Data	SG, NMC, LL, PL, PI, 2.0mm, 0.425mm, 0.075m
Output Data	Cohesion

3.4 Method of Data Pre-Processing

Machine learning models, such as Artificial Neural Networks (ANN), Support Vector Machines (SVM), Gradient Boosting (GB), Random Forest (RF), and Decision Trees (DT), require a substantial amount of high-quality data to effectively learn the complex relationships between input parameters and the corresponding output.

The relevant features extracted from the dataset included: Specific gravity, Natural moisture content, Sieve analysis data, Liquid limit, Plasticity index and Cohesion. The augmented dataset of 5000 data points was then utilized for training, testing, and validating the performance of the chosen machine learning models.

3.5 Data Cleaning Process for Soil Properties Dataset

Data cleaning procedures was implemented to ensure the quality and reliability of a soil properties dataset for use in machine learning models.

The following Steps was taken:

Import Necessary Libraries: Python libraries like Pandas, NumPy, and Matplotlib were used for data manipulation, analysis, and visualization.

Loading Data into Pandas DataFrame: The dataset was loaded into a Pandas DataFrame, facilitating initial examination and identification of potential issues.

Data Type Verification and Correction: Data types for each column were verified and inconsistencies rectified (e.g., converting text strings to numerical formats).

Handling Missing Values: Missing values were identified and addressed. This included:

Counting missing values per column using df.isnull().sum().

Potentially converting object data types to float for numerical operations.

Exploratory Data Analysis (EDA): EDA was conducted to gain insights into the data and identify patterns:

Summary Statistics: Key statistics like mean, standard deviation, and percentiles were calculated for each variable.

Data Grouping: The dataset was grouped into numerical (moisture content, plasticity) and categorical data (soil type).

Visualizing Data Distributions: Histograms were used to visualize the distribution of numerical variables, revealing potential skewness or outliers.

Correlation Matrix and Multicollinearity Handling: The correlation matrix assessed relationships between numerical variables. Highly correlated variables (indicating multicollinearity) were potentially removed to improve model stability and interpretability.

The data cleaning process prepared the soil properties dataset for feature analysis and machine learning model development.

4 RESULT AND DISCUSSION

4.1 Feature Importance Analysis

The plot shows the permutation feature importance scores for different soil properties in predicting cohesion (C). Permutation feature importance measures how much the model's performance (in this case, likely the accuracy or error) degrades when the values of a specific feature are randomly shuffled. Higher scores indicate that the feature is more important for the model's predictions.
The permutation feature importance analysis reveals the following key findings:

Plasticity Index (PI): PI emerged as the most influential feature, with an importance score of 1.441646. This indicates that PI plays a crucial role in determining cohesion.

Liquid Limit (LL): LL exhibited the second highest importance score (0.879606), signifying its significant influence on cohesion.

Natural Moisture Content (NMC): NMC showed strong importance (0.670434), further emphasizing the influence of moisture content on cohesion.

Particle Size Distribution: Features related to particle size distribution, such as the percentage of particles retained on the 0.075 mm, 0.425 mm, and 2.0 mm sieves, demonstrated significant importance. This suggests that the grain size distribution of the soil significantly influences its cohesion.

Specific Gravity (Gs): Gs showed relatively lower importance compared to the other features, with an importance score of 0.189158.

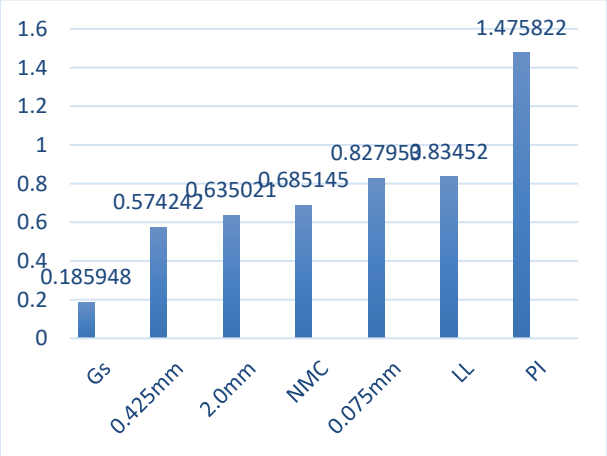


Figure 4.1: Feature Importance

The feature importance plot provides valuable insights into the factors that most strongly influence soil cohesion. The high importance of PI and LL confirms the established relationship between soil plasticity and its strength. The moderate importance of particle size distribution suggests that the presence of different particle sizes can also significantly affect cohesion.

4.2 Model Training, Testing, and Evaluation

To accurately predict cohesion (c) and the angle of internal friction (φ), Five machine learning models were trained and evaluated: Artificial Neural Network (ANN), Random Forest, Support Vector Regression (SVR), Gradient Boosting and Decision Tree.

Each model was trained on the prepared training dataset, allowing them to learn the underlying patterns and relationships between the input features (Specific gravity, Natural moisture content, Sieve analysis data, Liquid limit, Plasticity index) and the target variables (cohesion).

After training, each model's performance was rigorously evaluated using the reserved testing dataset. This step provided an unbiased assessment of how well each model could generalize its predictions to unseen data. Key performance metrics, such as Mean Squared Error (MSE) and Coefficient of Determination (R-squared), were calculated to quantify the accuracy and predictive power of each model.

This comprehensive evaluation process enabled the selection of the most suitable machine learning model for predicting cohesion (c) with the highest accuracy and reliability.

By comparing the performance of these models based on the evaluation metrics (e.g., Mean Squared Error (MSE), Root Mean Squared Error (RMSE), Coefficient of Determination (R-squared)), the most suitable model for predicting cohesion (c) and the angle of internal friction (φ) was selected.

4.3 Model Performance Comparison

To evaluate the performance of the different machine learning models, we assessed their R^2 scores and Mean Squared Error (MSE) values. The results are summarized in Table 4.1.

Table 4.1: Statistical Evaluation performance of the different machine learning models

Model	R^2 Score	MSE
ANN(MLP)	0.512	78.839
RF	0.622	56.739
SVR	0.335	102.584
GB	0.549	72.601
DT	0.420	97.438

Figure 4.2 compares the performance of five different machine learning models (ANN, Random Forest, SVR, Gradient Boosting, and Decision Tree) based on two metrics:

Highest R^2 Score: This metric measures the proportion of variance in the target variable that is explained by the model. Higher R^2 scores indicate better model fit.

Lowest MSE (Mean Squared Error): This metric quantifies the average squared difference between the predicted values and the actual values. Lower MSE values indicate better model accuracy.

Highest R^2 Score:

The Random Forest model achieves the highest R^2 score (0.622), indicating that it explains the most variance in the target variable among the models considered.

Lowest MSE:

The RF model has the lowest MSE (56.74), suggesting that it provides the most accurate predictions on average.

4.3.2 Model Performance Summary:

Random Forest: Seems to be the best model in terms of explaining the variance in the data (highest R^2 score).

Other Models: The remaining models (ANN, Gradient Boosting, SVR and Decision Tree) show moderate performance in both R^2 and MSE.

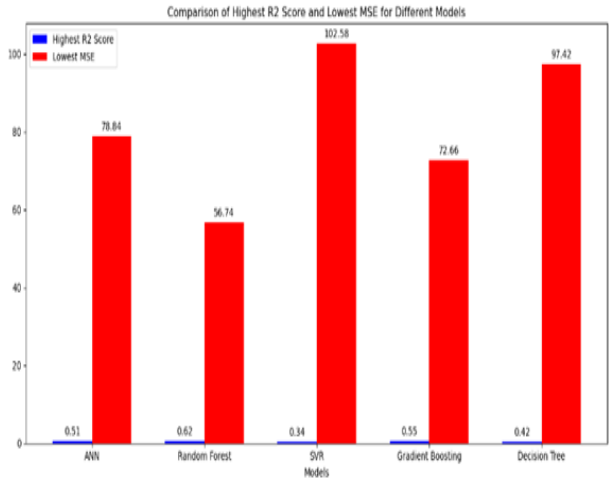


Figure 4.2: Comparison of Highest R^2 and Lowest MSE of Different Models

The results suggest that the choice of the best model depends on the specific goals and priorities of the analysis. If the primary objective is to explain the maximum variance in the data, then the Random Forest model would be a good choice. On the other hand, if the primary objective is to obtain the most accurate predictions, then the SVR model would be preferred.

4.4 Relationship of Actual Versus Predicted Value Using Random Forest (RF) Model

The scatter plot of Figure 4.3 visualizes the relationship between the actual and predicted values generated by the Random Forest model.

Visual Representation: The blue dots represent the actual values, while the red dashed line represents the ideal scenario where the predicted values perfectly match the actual values.

Model Performance: The plot shows a strong positive correlation between the actual and predicted values. The points cluster closely around the red line, indicating that the model's predictions are generally accurate.

Model Fit: The distribution of points around the line suggests that the model captures the underlying relationship in the data well.

The scatter plot provides a visual representation of the Random Forest model's performance in predicting the target variable. The close proximity of the predicted values to the actual values indicates that the model has effectively learned the patterns and relationships within the data.

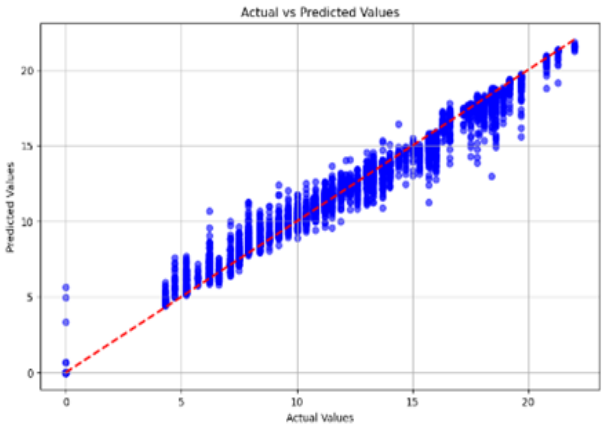


Figure 4.3: Scatter plot of Actual versus predicted Values

This visualization confirms the results obtained from the evaluation metrics (R-squared and MSE) which likely demonstrated high accuracy and low error.

5 CONCLUSIONS

The following conclusion can be drawn from this work:
This study successfully achieved the objective of developing and evaluating various machine learning algorithms for predicting soil cohesion. The analysis demonstrated that Random Forest effectively predicted cohesion based on input features such as plasticity indices

(LL and PI), particle size distribution, and natural moisture content. The results highlight the potential of machine learning techniques to enhance the accuracy and efficiency of soil characterization for geotechnical engineering design.

Analysis of the soil data reveals that plasticity, primarily influenced by Liquid Limit (LL) with an importance score of 0.879606 for cohesion, and Plasticity Index (PI) with an importance score of 1.441646 for cohesion, plays a dominant role in determining soil strength. Natural Moisture Content (NMC) also showed significant influence with an importance score of 0.670434 for cohesion. Furthermore, Particle Size Distribution, particularly the percentage of particles retained on different sieve sizes (0.075 mm, 0.425 mm, and 2.0 mm), demonstrated significant importance for cohesion. Specific Gravity (Gs), with an importance score of 0.189158 for cohesion, played a relatively lesser role compared to the other factors.

Random Forest demonstrated superior performance in predicting cohesion. For cohesion, Random Forest achieved the highest R-squared score of 0.622 and the lowest Mean Squared Error (MSE) of 56.74, indicating excellent model fit and high predictive accuracy. This result suggests that Random Forest is a promising machine learning model for predicting soil cohesion in this study, exhibiting strong performance in both explaining the variance in the data and achieving high accuracy in predicting cohesion.

5.1 Recommendations

While Random Forest demonstrated promising results, further enhancing its performance for cohesion prediction can be achieved through rigorous hyperparameter tuning. Techniques like grid search or random search can be employed to optimize parameters such as the number of trees, maximum tree depth, and minimum samples per leaf within each tree. This optimization process can lead to more accurate and robust predictions of soil cohesion from the Random Forest model.

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Preliminary Investigation on The Properties of Bitumen Modified with Graphene Nanoparticles

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ABSTRACT
In recent years, nanomaterials in bitumen modification have become widespread due to their superior properties. Graphene and its derivatives are prominent examples of this. This study aimed to investigate the impact of adding graphite on the physical properties of bitumen in asphalt mixtures, covering a graphene nanoparticles content ranging from 0% to 5%. The tests conducted to assess these effects, including measurements of penetration, softening point, flash point, ductility point. The results showed that the modifying effect of GNP materials improves the high temperature resistance of the bitumen even though it makes the bitumen more brittle and stiff which affects the low temperature property of the binder. Based on conventional test conducted, GNP modified bitumen has superior high-temperature performance than the base bitumen but suffers from poor resistance to thermal cracking. This modified bitumen can be used in hot climes like Nigeria where the average maximum temperatures in some cities can be up to 50 ^{0}C and average Minimum temperatures can be 16 ^{0}C

Keywords: Graphine non-particles,Bitumen,Penetration Index,Ductility,Softening point**.**

1 INTRODUCTION

Bitumen is a sticky, black and highly viscous liquid or semiliquid form of petroleum. It may be found in natural deposits or may be refined product. According to Christina (2010), Nigeria ranks 6th in the list of top ten countries which has bitumen reserves. The Nigerian bitumen reserves are found in Lagos, Ogun, Ondo and Edo States. Nigeria being one of the largest producers of crude oil however, the mid-stream sector of the oil and gas sector has made her heavily dependent on importing refined petroleum products and this includes bitumen. Currently, Nigeria's annual consumption of bitumen is a little over 500,000 metric tonnes. The bitumen produced from them do not meet up to international specifications (Olutoye,2006).

In general, the performance properties of road pavement are mainly influenced by the properties of the bitumen binder, a viscoelastic material with both elastic and viscous components of response. Under the influence of external forces, the material exhibits both a partly permanent deformation (viscous part) and a partly reversible deformation (elastic part).

Excessive increase in traffic (axle) load and variation in environmental factors contributes to distress or structural failure in highway pavement. The increase in axle loads repetition often leads to rutting and fatigue cracks, while increase or variation in environmental factors like temperature are the main cause of the cracks (Honarmand et al., 2019).

Most engineers have attributed asphalt road failures to climatic conditions, but climatic conditions alone do not account for the deformation of roads but the choice of bituminous binder used as well (Vasudevan *et al.,* 2012). Thus, there is a need for modifier or additives which offers a greater strength thereby reducing the fatigue cracking and rutting. The behaviour of bitumen can be modified (improved) by adding modifiers to the bitumen. Bitumen modification is usually aimed at improving the stiffness and the elasticity of the asphalt bitumen at high pavement temperatures and reducing stiffness and elasticity of the bitumen at low temperatures.

Graphene is a two-dimensional structure of carbon that shows some unique physico-chemical characteristics. These unique characteristics make it indispensable in vast segment of research and manufacturing activities. Owing to its specialized structures and size, it can be maximally utilized as a thermal stabilizer, potential coolants, sensitive devices, semiconductor, or for components of integrated circuits (Rhee, 2020). It is also poised to have great impact on the future of all areas of both scientific and engineering applications. Graphene is known for its numerous outstanding thermal characteristics when compared to other materials. For instance, its thermal conductivity is around 5.1×10^3 Watt per Kelvin-metre and electrical

conductivity is 6×105 Siemens per meter (Rahman *et al.*, 2019). Generally, it is described to be harder than diamond yet more elastic than rubber; tougher than steel yet lighter than aluminum. Furthermore, one graphene's stand-out properties is its inherent strength. Due to the strength of its 0.142 Nm-long carbon bonds, graphene is the strongest material ever discovered, with an ultimate tensile strength of 130,000 MPa , compared to 400 MPa for A36 structural steel, or 375,700,000 for Aramid (Kevlar). Not only is graphene extraordinarily strong, it is also very light at 0.77milligrams per square metre (for comparison purposes, 1 square metre of paper is roughly 1000 times heavier) (Tarun, 2015). Graphene has many derivatives (also called "graphene family nanomaterials"), however, the most used (in different sectors) are the GO and GNPs (Li *et.al.,*2018, and He *,et.al.,* 20221).

Modification of bitumen is employed to increase or enhance its desired engineering properties. This method is built on the concept that materials or substances with longer useful life can be used to reduce the consumption of non-renewable sources by using it in place or in a combined way thus making it both eco-friendly and economical. Therefore, high performance binders in asphalt technology are usually made by adding additives to virgin bitumen. Graphene falls within this categories of additives because of their abilities to yield desired engineering behaviors under wide range of temperatures. Only few studies especially in Nigeria has used a form of graphene in the modification of bitumen. One of the research by Oladunjoye *et al.,* (2021) produced graphite modified bitumen by heating bitumen to its melting point, mixing it with graphite (2 to 10% by weight of bitumen) and continuously stirring the mixture until a perfect blend is obtained. This research evaluates the rheological parameters of graphite modified bitumen. Index properties tests were conducted on bitumen and graphite to determine their suitability. The research concluded that, graphite content improved the rutting and fatigue resistance of bituminous binder.

Graphite Oxide (GO) was utilized with 80/100 penetration grade bitumen by Noor et al. (2015). They found that limited trial rheological result obtained for 0.1125wt GO modified bitumen showed that modification of bitumen with GO has improved its elastic capacity at higher temperature and lower frequency regime thus successfully can be used as bitumen modifier in future. The effect of graphite powder on the physical and rheological properties of the bitumen was investigated by Singh and Suman (2018). The result indicates an improvement in physical properties of the bitumen binder as illustrated through decrease in penetration value along with increase in softening point, viscosity with increase of additive content for both under aged as well as short-term aged samples.

Most of the nanomaterials utilized for developing desired-performance asphalt binders are compounds based on carbon, for example, carbon nanotubes, nan0clays, nanosilica, and graphene-like materials (Li.*et.al.*, 2021). They are increasingly used because when used in road pavements, they able to thrive under high-traffic loads under harsh external conditions (i.e., high humidity, great environmental salinity, and intense ultraviolet radiation) at high and low temperatures (Eisa *et.al*.,2021). Graphene modified bitumen are resistant since they simultaneously improve fatigue and rutting resistances and thus provide an improved service life (Chen *et.al.,*2020). This is particularly notable because it is common knowledge that asphalt mixtures usually fail under distresses and permanent deformations associated with low fatigue life (Adnan *et.al*.,2021).

However, the properties of modified asphalt binders are diverse in character and in literature different opinions exists as regards the particular tests that should be conducted for their characterizations (He *et.al.,* 2022). In order to properly characterize them, it is essential to conduct assessments regarding chemical, rheological, microstructural analysis. Conventional laboratory tests (i.e., density, penetration, softening point, dynamic viscosity, ductility, flash point, and solubility) and advanced methods (Dynamic Shear Rheometer (DSR), Elemental Analysis (EA), Fourier Transform Infrared Spectroscopy (FTIR), Raman Spectroscopy (RS), Scanning Electron Microscopy (SEM), Thermogravimetric Analysis (TGA), X-ray Diffraction (XRD), and X-ray Photoelectron Spectroscopy (XPS)) have all been used in the past.

Although, research had been conducted on several additives (with graphene nanoparticles inclusive) used in modified asphalt concrete. Our study will attempt to synthesize graphene nanoparticle from available local materials and then use it to modify locally sourced bitumen. This will give an insight into the engineering properties of locally sourced bitumen which is otherwise characterized as unsuitable for road purposes modified with synthesized graphene nanoparticles instead of natural graphite powder as demonstrated by Oladunjoye *et al.,* (2021).

2 METHODOLOGY

The materials used for asphalt production are



Platee 1: Penetration grade Bitumen

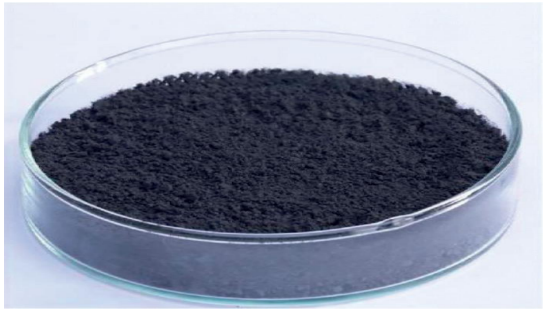


Plate 2: Graphene Nanoparticles(GNP)

Bitumen in Plate 1 and Graphene nanoparticles in Plate 2

2.1 MODIFIED BITUMEN

A percentage by weight of graphene nanoparticle is added to bitumen (@150 Degrees Celsius) and mixed using shear mixer at high revolution per minute at a specified time until homogeneous mix is achieved (Gear 3: 250 RPM for 15 minutes). The mixer is depicted in Plate 3. The mixture will be produced by heating bitumen to its melting point, mixing it with graphene nanoparticles at varying percentages (1,2,3,4,5%) and continuously stirring the mixture until a perfect blend is obtained.



Plate 3: Bitumen Mixer

2.2 TESTS ON BITUMEN AND MODIFIED BITUMEN

After the mixtures are obtained the following tests were conducted on the control sample and the blended samples as presented in Table 1.

TABLE 1: LABORATORY TESTS AND STANDARD SPECIFICATIONS

S/N	Tests	Purpose
1.	Penetration test ASTM D5: (10/20 dmm)	Determines bitumen consistency to ensure suitability for construction applications.
2.	Softening point test ASTM D36 EN 1427 (58-66 ^{0}C)	Evaluates bitumen's temperature susceptibility for application and performance.
4.	Flash point ASTM D92 (250 ^{0}C Minimum)	Determines bitumen's flammability and safety for handling and storage.
5	Ductility (ASTM D70) (100 cm Minimum)	Test is done to determine the length to which bitumen can be extended before breaking.

2.3 EVALUATION OF THE PHYSICAL PROPERTIES USING PENETRATION INDEX NOMOGRAGH

The penetration index(PI) is a measure used to evaluate the temperature susceptibility of bitumen. It indicates how much the penetration value of bitumen changes with temperature variations changes. A nomograph can also be used in estimating PI values using penetration and softening point((Whiteoak, 1990). A PI value can be interpreted as positive(more temperature susceptible), negative(less temperature sensitive) and zero(low temperature susceptible i.e stable across temperature changes)

3 RESULTS AND DISCUSSION

3.1 MATERIAL CHARACTERIZATION OF GRAPHENE

Table 2 shows the thermo-physical properties of nanoparticles under investigation. Moreover, the apparent diameter was found to be between ~1 to 50 μm and such variation in diameter in the nano-powders is normal.. The nanopowder sample was majorly of carbon which is the key elemental composition of graphene nanoparticles.

3.2 PHYSICAL PROPERTIES GNP MODIFIED BITUMEN

The physical properties of the bitumen and binder (bitumen + GNP) are shown in Table 6. All tests were repeated 3 times and the average values and standard deviations are shown in Table 6.

The physical properties of the bitumen + GNP mixtures show that as the proportion of GNP increases, significant changes occur in the material behavior. The penetration test results reveal a decrease in penetration values from 22 at 0%GNP to 13 at 5% GNP, indicating that the bitumen becomes slightly stiffer with the addition of GNP. This increased stiffness enhances the mixture's resistance to deformation under load, making it more suitable for applications requiring high stability.

TABLE 2: THERMO-PHYSICAL PROPERTIES OF GNP NANOPARTICLES

Properties	**GNP**
Colour	Black
Molecular mass (mass/g mol^{-1})	16.64
Morphology	Spherical
Density (Kg/m^3)	123.4
Thermal conductivity (W/mK)	0.699
Specific heat capacity at 20 °C (KJ/KgK)	0.683
Size (nm)	18-35
Thickness (μm)	126
Composition(%)	O_2(20.2), C(45)

On the other hand, the softening point test shows a clear trend of increased temperature, with the softening point rising from 49°C at 0% GNP to 71.5°C at 5% GNP. This suggests that the bitumen + GNP mixture can withstand higher temperatures before softening, which is crucial for pavement performance in hot climates. However, the ductility test results indicate a reduction in flexibility as the GNP content increases, with ductility dropping from 43 cm at 0% GNP to 21.3 cm at 5% GNP. This reduction in ductility means that the material becomes more brittle and less capable of elongating without breaking, which could affect its crack resistance under heavy traffic. Furthermore, the flash point improves with the addition of LDPE, increasing from 229°C to 312°C as the GNP content is increased. This higher flash point suggests that the bitumen + GNP mixtures is less prone to ignition at high temperatures, contributing to overall safety during handling and application. The results of the physical properties of the GNP modified bitumen are quite similar and to the results reported by recent studies.

Generally, the performance of the binder is improved in terms of high temperature susceptibility but it is lacking in the aspect of low temperature and elasticity. The samples are more brittle and may be prone to cracking.

TABLE 3: PHYSICAL PROPERTIES OF GNP MODIFIED BITUMEN

Test	Stats	0%	1%	2%	3%	4%	5%
Pen test	M	22.0	15.6	15.0	14.2	13.5	12.5
	STD	1.0	0.8	0.8	0.4	0.5	0.6
Soft Point	M	49.0	56.0	59.0	62.0	66.0	71.0
	STD	1.4	1.4	1.4	1.4	0.7	1.4
Flash point	M	231.9	282.8	288.3	292.3	306.0	314.1
	STD	4.0	0.8	2.5	3.1	3.4	1.6
Ductility	M	43.0	41.0	29.0	31.0	27.6	21.3
	STD	0.8	3.5	3.1	2.1	2.1	1.4

TABLE 4: PENETRATION INDEX

Percentage GNP	**PI**
0	-3
1	-2
2	-1.5
3	-1.2
4	-0.8
5	0

From table 4 it can be seen that PI is positively correlated with percentage GNP. The bitumen changes to a more stable state across temperature changes as the percentage of GNP.

4 CONCLUSION

The 10/20 penetration grade bitumen was affected by the inclusion of Graphene nanoparticles. The GNP improved the thermal stability of the neat bitumen through lower penetration values, higher softening point values. Similarly, it improved the safety handling of the bitumen by high flash point values as the percentage of GNP increases. Similarly, The PI becomes more stable with low temperature susceptibility at 5% GNP. However, the GNP modified bitumen samples became more brittle and less flexible as the percentage of GNP increases which affects the low temperature thermal cracking . This modified bitumen can be used in Nigeria's region with high temperatures where rutting is prevalent. Also, this study serve as preliminary investigation into the potential use of graphene nanoparticles in modifying bitumen and it can serve as foundation upon which future research can be built on.

ACKNOWLEDGEMENTS

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Effect of Bitumen Content on Compression Characteristics of Asphalt

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ABSTRACT
This research investigates the effect of bitumen content on the compression characteristics of asphalt mixtures. Laboratory tests were conducted on aggregates and bitumen to assess their physical properties, including particle size distribution, bulk density, specific gravity, penetration, softening point, flash point, and fire point of bitumen. An asphalt mixture was designed using a mathematical approach, incorporating 24% of 5.0mm aggregate, 17% of 3.35mm aggregate, 49% of 2.0mm aggregate, and 10% cement as filler material. The asphalt was produced with varying bitumen contents ranging from 4.5% to 6%. Marshall stability test was carried to ascertain the optimum bitumen content while settlement tests was performed on the asphalt mixtures using the odometer method to determine the coefficient of compressibility (Cc). The stability test result report an optimum bitumen content of the asphaltic mix at 5% bitumen. The odometer test results indicate a general trend of decreasing Cc with increasing bitumen content. For example, the Cc values decreased from 0.0173 at 4.5% bitumen to 0.0127 at 5.5% bitumen content. The value remained constant to 6.0% bitumen content after which the values further reduced to 0.012 at 6.5% bitumen content. This suggests that increasing bitumen content can improve the compressibility characteristics of asphalt mixtures. However, the relationship between bitumen content and Cc may not be linear, and other factors such as aggregate type, gradation, and compaction method can also influence compressibility. This research provides valuable insights into the effects of bitumen content on the compression characteristics of asphalt mixtures. The findings can be used to optimize bitumen content and improve the long-term performance of pavements.

Keywords: Asphalt, Bitumen, Compressibility, Compression index, Stability,

1 INTRODUCTION

Asphalt concrete pavements are crucial components of modern transportation infrastructure, providing a smooth and durable surface for vehicular traffic (Sha *et al.,* 2021). The performance of these pavements is significantly influenced by the properties of the asphalt mixture, particularly its resistance to compressive stresses. Bitumen, a key component of asphalt mixtures, plays a critical role in determining these compressive characteristics. Among these compressive characteristics of asphalt concrete is its ability to exhibit minimal volume change when subjected to applied wheel loads. This characteristic is crucial for preventing excessive pavement deformation, such as rutting, and can be measured by its coefficient of compressibility. The coefficient of compressibility is a measure of how much a material's volume changes when pressure is applied to it (Baughman *et al.*, 1998). Although coefficient of compressibility and compressibility index are not crucial parameters for pavement performance, it is important to understand how much volume change an asphalt concrete will undergo when pressure is being applied. This will help in prediction of future performance of asphalt pavement and also help in selection of materials for asphalt production.

The performance of asphalt is significantly influence by bitumen, which is the main component in asphalt concrete mixtures. it is a cement-like material with a dark brown to black color, found naturally or derived from crude oil distillation (Roberts *et al.,* 2002). By covering the aggregate, bitumen helps bind the aggregate together and contributes to the overall road's strength and performance. However, less or excessive bitumen content may lead to poor performance of the asphalt mixture. This is because when insufficient bitumen is used, the aggregates optimum binding may not likely be achieved. On the other hand when excess bitumen is used, the voids between aggregate particles become filled, reducing the ability of the aggregates to interlock and support the structure (Zhang *et al*., 2019; Mishra and Singh, 2021). This weakens the overall stability and strength of the mixture. Therefore, it is important to ascertain the optimum bitumen content in asphalt mixture.

This study investigates the effect of varying bitumen content on the compression and deformation behavior of

asphalt mixtures. The research aims to establish a relationship between bitumen content and critical compressive properties, such as stability and coefficient compressibility. By understanding these relationships, engineers can optimize bitumen content in asphalt mixtures to achieve desired pavement performance, enhance durability, and reduce maintenance costs. The findings of this study will contribute valuable insights for the design and construction of high-performance asphalt pavements that can withstand the increasing demands of modern traffic loads.

2 MATERIALS AND METHODOLOGY

2.1 MATERIALS

The aggregates used was carefully selected to represent typical materials used in asphalt mixtures for flexible pavements. These aggregates were sourced from reputable suppliers at Tipa Garage along Minna-Bida road, Minna and its was subjected to rigorous testing to ensure their suitability for the study. For this research purpose the maximum aggregate size used was 5mm instead of the traditional 12mm size. While the Bitumen was sourced from Triacta Nig. Ltd. Whom are undergoing construction along Minna-Bida road in Minna Niger state. It encompass a range of grades and modifications commonly used in pavement construction.

2.2 METHODOLOGY

The method employed involved the review of past literature that has relevant information to this work. Then laboratory test begin with testing of the materials used to ensure their conformity to the standard code of practice. Some of this test include; particle size distribution of aggregate, bulk density, specific gravity, abrasion test, aggregate impact and crushing value test. While on the other hand the bitumen was tested on penetration, softening point, flash point, fire point and ductility. The aggregate mix design was produced using mathematical method, which comprises of 24% of size 5.0mm aggregate, 17% of size 3.35mm, 49% of size 2.0mm while 10% cement was used as filler material, this mix design procedure was ensured are in line with specification of ASTM D6925. The asphalt was produced with varying percentages of bitumen content, through 4.5%, 5%, 5.5%, 6.0% and 6.5% bitumen by dry unit weight of the aggregate materials (1200g) to ascertain the optimum bitumen content. One-dimensional compression test was carried out on the asphalt mixture for all the bitumen content using odometer method, which is guided by BS 1377-6 (1990). The void ratios for each of the compacted mixtures were calculated using height of solid method. The void ratio-effective stress relationships curves were then plotted and the compression indices were calculated. The marshal stability test was also carried out on the asphalt mixtures of varied bitumen content to obtain the stability and the flow of each of the asphalt mixtures.

3.0 RESULTS AND DISCUSSION

3.1 GRAIN SIZE ANALYSIS

The results of particle size distribution for different aggregate sizes as well as the combine mixture (5.0, 3.35, 2.0 and combine aggregate) are presented in Figure 1. The overall result indicate that the aggregate appears to be relatively coarse, which is generally desirable for asphalt production. Furthermore, the calculated coefficient of Uniformity (Cu) of 5.55 for the combined aggregate shows aggregate has relatively wide particle size distribution. This indicates the aggregate contains a mixture of large and smaller particles, which can be beneficial for achieving good compaction and adhesion in asphalt. While the coefficient of curvature (Cc) for the combined aggregate was calculated as 1.38, which shows that the aggregate is moderately well-graded distribution, which is considered ok for asphalt production (ASTM D1073).

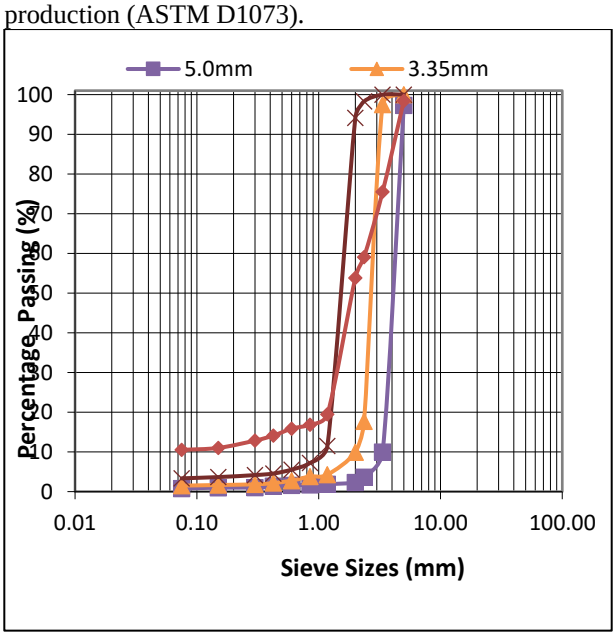


Figure 1: Grain size analysis of aggregates

3.2 SPECIFIC GRAVITY OF AGGREGATE

The specific gravity is a measure of the density of any substance relative to water. It is primarily determine by the composition of the material regardless of it size or shape. As indicated in table 4.3, the average specific gravity of both aggregate sizes are determined as 2.66, 2.66 and 2.67 for size 5.00, 3.35, and 2.00 mm respectively, which is relatively constant due to the fact that the aggregates are of the same material. The value is within the standard range of 2.60 – 2.80 as specified in (ASTM D2726 and D2726M – 21). While the specific gravity of the filler material (cement) is determined as 3.12.

Table 1: Specific gravity of aggregate and filler material

Description/ Aggregate size (mm)	Trial 1	Trial 2	Trial 3	Average specific gravity
5.00	2.71	2.62	2.66	2.66
3.35	2.7	2.65	2.64	2.66
2.00	2.65	2.68	2.68	2.67
Filler material (cement)	3.09	3.15	3.13	3.12

3.3 BITUMENOUS PROPERTIES

The result of some of the bitumen properties determined are presented in Table 2. The result shows the bitumen used exhibit typical properties for a medium grade bituminous material. It has the specific gravity of 1.02, which indicate a relative dense bitumen. The softening point of 51 □C shows it has moderate resistance to softening under heat, which is important to maintain its shape and consistency under various environmental condition. While it recorder a high flash point (354 □C) and fire point (371 □C), which demonstrate it resistance to ignition in case of contact with fire, ensuring safety during used. The bitumen has penetration value of 93 mm, indicating medium consistency. This balance its properties making it suitable for varieties of application including highway and runways constructions.

Table 2: Physical properties of bitumen

Property	**Trial 1**	**Trial 2**	**Trial 3**	**Average**
Specific Gravity	1.03	1.01	1.02	1.02
Softing point (°C)	50	52	51	51.00
Flash point (°C)	350	357	355	354.00
Fire point (°C)	370	373	370	371.00
Penetration (mm)	100	85	94	93.00

3.4 MARSHAL STABILITY OF MIXTURES

The results of various properties of asphalt with respect to bitumen content obtained from stability test are presented in Table 3. The result reported decrease in overall asphalt density with increase in bitumen content, which decreases from 2.45g/cm3 at 4.5% bitumen to 2.14 at 5.0 and 5.5% bitumen respectively. The decrease was attributed to relatively lower density of bitumen (1.0) compared to aggregate (2.66), therefore as bitumen content increases it tend to affect aggregate packing, EEEE resulting into decrease in density. The trend line has R^2 – value of 0.9317 as shown in Figure 2(a). While Figure 2(b), illustrate the asphalt stability with respect to bitumen content, which recorded general trend of increasing stability with increase in bitumen content up to 5% bitumen, followed by decrease in stability at higher bitumen. Because bitumen serves as a binder, improving the adhesion between the aggregate particles, therefore as bitumen content increase, the adhesive forces between aggregate particles increases, leading to higher stability (Prasad et al., 2022). However, at higher bitumen level, the excess bitumen tend to fill the void between aggregate particles, reducing their interlocking and potentially weakening the structure. This reduces the asphalt stability, hence 5% bitumen was considered as the optimum bitumen content.

Furthermore, as reported in Figure 2(c), the asphalt flow recorded an increase with increase in bitumen content, which increases from 6.7mm at 4.5% to 6.9mm at 5.0mm bitumen content. This may be as a result of the bitumen viscosity whose increase may have increased the overall viscosity of the asphalt and can consequently lead to deformation of the asphalt under load, thereby leading to increases in flow (Ishaq *et al.*, 2022). However, as the bitumen content continue to increase the asphalt flow begin to decrease, which decreases to 5.9 and 6.0mm at 5.5 and 6.0% bitumen respectively. While Figure 2(d) presented the relationship between bitumen content and the void in total mix. The air void in the asphalt mixture recorded general decrease with increase in bitumen content, which decrease from 5.79% at 4.5% bitumen to 1.17% at 6% bitumen content. This was because higher bitumen may lead to better compaction and potentially filling the void within aggregate particles. This lead to reduction of air void.

Description/Bitumen content (%)	Density (g/cm³)	Average stability (kN)	Average flow (mm)	Air void H (%)	Void in Mineral aggregate J (%)	% void fill with bitumen K (%)
4.5	2.45	1.35	6.7	5.79	12.7	57.90
5.0	2.14	1.40	6.9	5.55	24.10	76.97
5.5	2.14	1.35	5.9	3.06	24.23	87.41
6.0	2.15	1.22	6.0	1.17	24.21	95.16

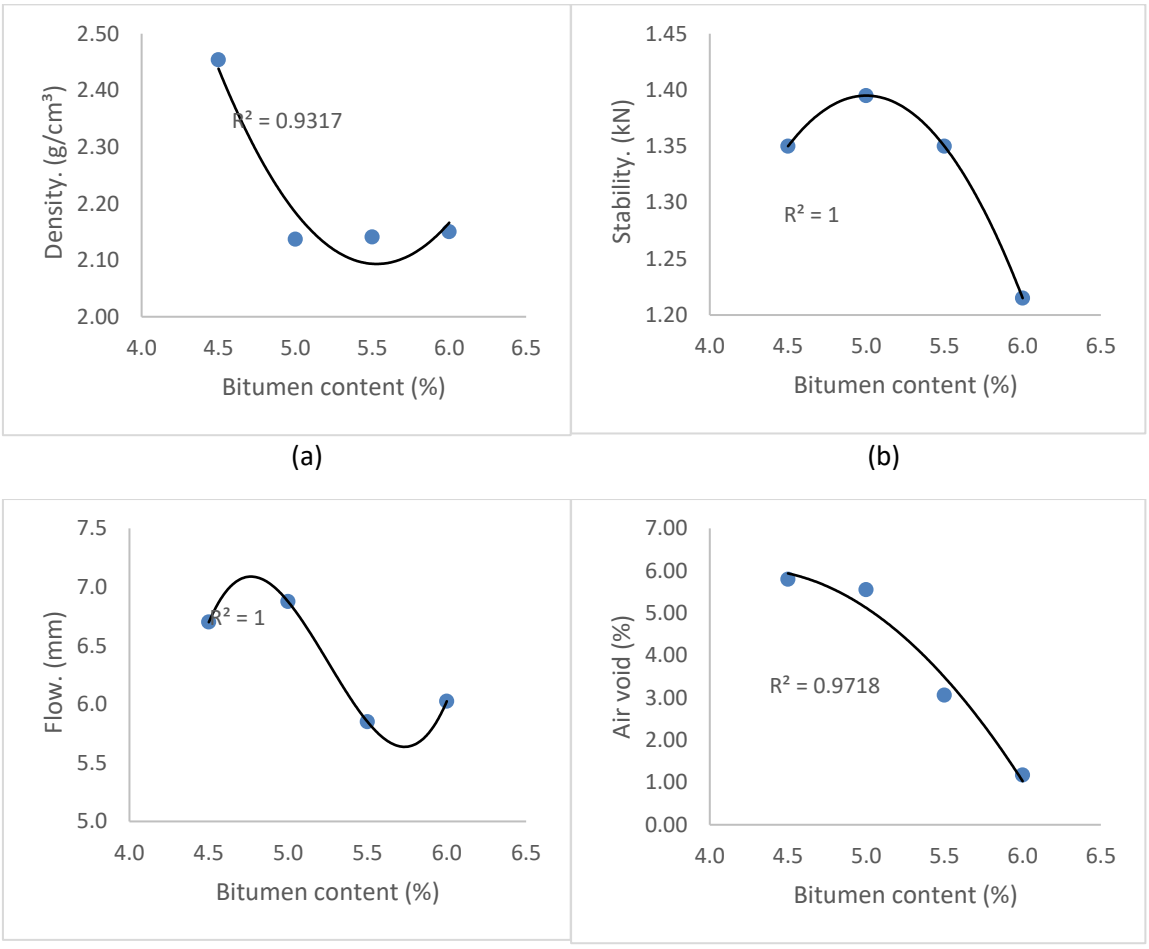


Figure 2: Variation of Asphalt properties with respect bitumen content

3.5 ONE DIMENSIONAL COMPRESSION

The results of the one-dimensional compression of asphalt with varied bitumen content is shown in figure 3. The results are presented by curves of void ratio with loading values. The compression index of the one-dimensional compression of the asphalt were determined for asphalt of varied bitumen content. The results indicate a general trend of increase in initial void ratio with increase in bitumen content. This is likely due to the increased flexibility and resilience of the asphalt mixture with higher bitumen content, making it less susceptible to compaction under load (Teh and Hamzah, 2019; Poovaneshvaran et al., 2021).

The compression index Cc of each of the asphalt mixtures were determined from the slope of these curves and presented in figure 4. Compression index is a parameter that directly influences the magnitude of the asphalt compression under static loading which is directly proportional to the magnitude of settlement

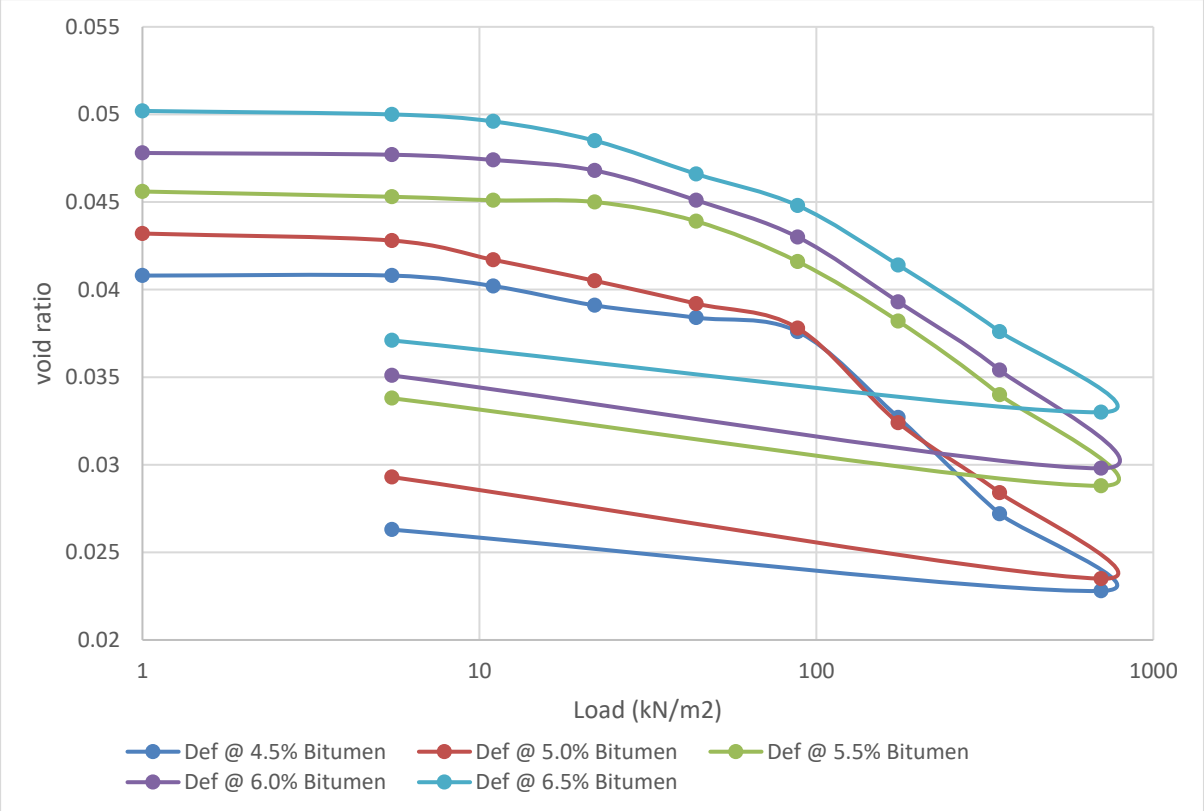


Figure 3: Relationship between void ratio and effective stress for asphalt of varied bitumen content

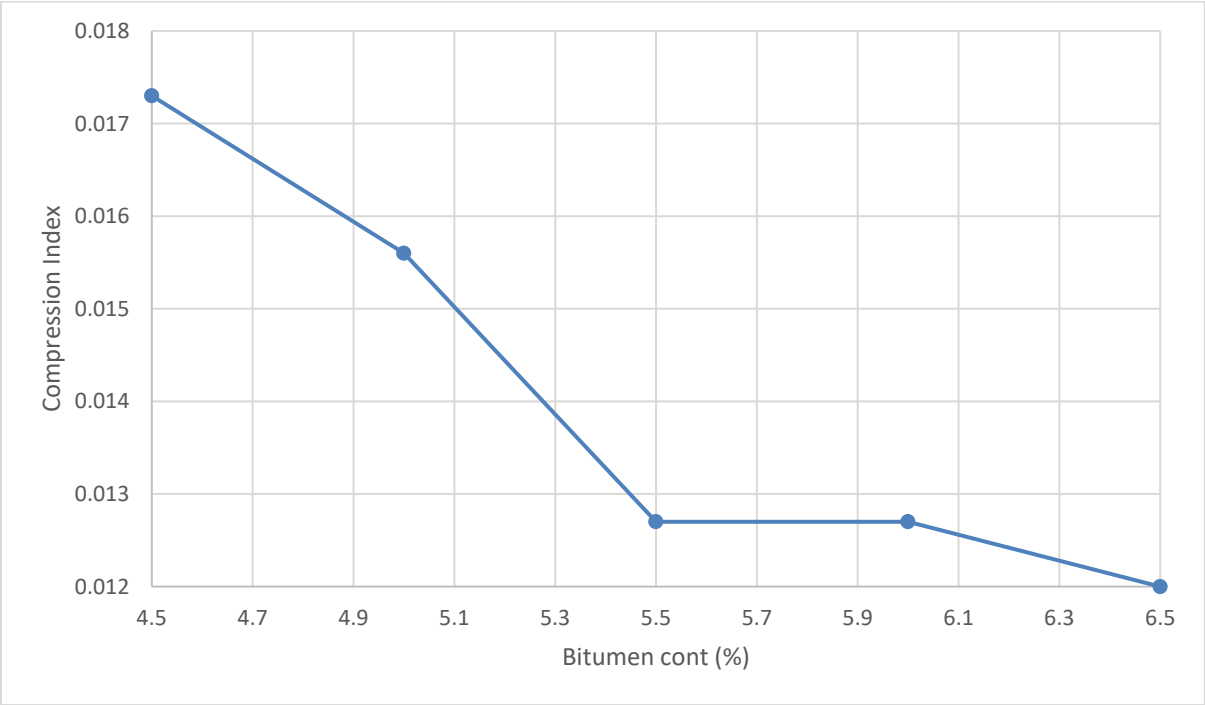


Figure 4: Relationship between compression index and asphalt bitumen content

The compression index Cc was observed to decrease from 0.0173 at 4.5% bitumen content to 0.0127 at 5.5% bitumen. The values remain constant to 6.0% bitumen after which the value reduced to 0.012. The initial decrease must have resulted from the fact that substantial amount of aggregates are not coated with bitumen. This mixture will contain high air voids which collapses on rearrangement of aggregates. At 5.5% to 6.0%, optimal bitumen content may have been achieved and these mixtures can be recommended for asphalt design mix. Additionally, other factors such as aggregate type, gradation, and compaction method can also influence the compressibility of an asphalt mixture. Therefore, the bitumen content with minimal compression index and higher stability should be considered as the optimal asphalt mixture.

4.0 CONCLUSIONS

The aggregate used in this study is suitable for asphalt production. The particle size distribution, bulk density, specific gravity, and bitumen properties all fall within acceptable ranges for asphalt mixtures.

The Marshall Stability test indicates that an optimal bitumen content of 5% provides the best balance between stability and flow. While increasing bitumen content beyond 5% can lead to detrimental effects such as increased air voids and voids in the mineral aggregate.

The one-dimensional compression test results however signifies 5.5% to 6.0% bitumen content for asphalt with minimal compression index and should be considered in choosing the appropriate asphalt mixture.

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Durability Assessment of Cement-Calcium carbide residue Stabilized Soils from Ahoko and Enagi Formations in Bida Basin, Nigeria

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ABSTRACT

The Bida Basin is one of the largest sedimentary basins of Nigeria in which studies have shown that its soil deposits are characterized by soils with sandy and silt soils devoid of gravelly materials. This has made the few researches on the soils of Bida basin to categorize the soil as deficient considering the specification of soils that can be used as road construction material. This study considered two formations within Bida basin, the Enagi formation in the central part of Bida basin and the Ahoko formation in the southern part of Bida basin. The soils collected from these two formations were characterized to classify the untreated soils. The soils were then mixed with 0%, 2%, and 4% cement which was in turn admixed with 0%, 3% and 6% calcium carbide residue (CCR) each by weight of the soil. Both the untreated soils and soils treated with cement and CCR at varied compositions were compacted at British Standard Heavy compaction energy levels. The compaction characteristics were then used to mould specimen for unconfined compressive strength (UCS) and consequently, the durability using water immersion method. The results revealed that soil collected from Enagi formation classified under clayey sand (SC) and A-6 based on unified soil classification system (USCS) and AASHTO soil classification systems respectively while soil collected from Ahoko formation classified under clay of low plasticity (CL) and A-7-6 based on unified soil classification system (USCS) and AASHTO soil classification systems respectively. The maximum dry densities for soil collected from Enagi is generally higher (2.009g/cm^3 – 2.118g/cm^3) compared with the values recorded for soils collected from Ahoko formation (1.825g/cm^3 – 1.970g/cm^3). The UCS values recorded in soil collected from Enagi is relatively higher (242kN/m^2 – 2788kN/m^2) compared to the values recorded for soils collected from Ahoko formation (414kN/m^2 – 1207kN/m^2). The resistance to loose in strength is higher in soil collected from Enagi formation (55.8% - 87.0%) compared to the values recorded for Ahoko soils (0% - 66.0%).

Keywords: Bida Basin, calcium carbide residue, cement, durability, soil stabilization, unconfined compressive strength..

1 INTRODUCTION

Generally, the soil deposits in Nigeria can be categorized in to two geologic formations - the sedimentary basin soils and the basement complex soils. There is large area of soil deposits in Nigeria that falls under sedimentary basin soils. Some of the sedimentary basins are the Bida Basin, Anambra basin, Sokoto basin, Lake Chad basin etc. The Bida basin is one of the largest sedimentary basins spanning from Kontagora down to Lokoja and are made up of various formations (Rahaman et al, 2018; Obaje et al, 2011; Olusola et al, 2020). There are long stretch of roads constructed across the sedimentary basin soils. Typical of those roads are the Zuba-Lokoja road and Bida-Mokwa roads. However, research have shown that most sedimentary basin soils are mostly fine in nature and do not always satisfy the grading condition to be used as road construction material as specified by Nigerian General Specification for Roads and Bridges (2016). Various authors have carried out study on the geotechnical properties of soils around Bida basin. Some specific studies are the work of Akhirevbulu and Ogunbajo (2011) who study the occurrence of clay in sedimentary basin soils around Kutigi area of Niger State. The author concluded predominant occurrence of course and fine sandy soils with little of clay sized particles. Another specific study was carried out by Akinyemi et al, (2018) to evaluate the geochemistry of Ahoko formation of Bida basin. It was concluded that the tectonic setting of Ahoko formation belongs to a passive continental margin and a continental highland. Olusola et al, (2020) evaluate the geotechnical and mineralogical properties of the Patti formation of Bida basin. The particle size analysis also indicated high proportion of fines which does not meet the grading requirement of road construction materials. It is therefore necessary to improve these soils by the way of stabilization to enhance the geotechnical properties of the soils for road construction purposes. The most effective chemical for soil stabilization is cement which have been observed to

be economically unviable. Its production is also environmentally discouraged which suggested the use of an alternative chemical which are economically viable. One of those materials is calcium carbide residue (CCR) which is by-product of acetylene production process that contains mainly calcium hydroxide $Ca(OH)_2$. As a by-product, it is a waste which if not properly controlled will liter the environment and may constitute health hazard. Some authors have carried out study on the effectiveness of using CCR alone or CCR admixed with other chemicals for stabilization of soils. The study by Balarabe and Sharmila (2015), Horpibulsuk et al, (2012), Noolu et al, (2021) revealed the effectiveness of the use of CCR for stabilization of soils. Chemical stabilization of soils are aimed at enhancing the strength and durability of the chemically treated soils for sustained strength under adverse environmental conditions. The evaluation of durability of treated soils have been studied by some researchers (Razali et al, 2016; Paige-Green, 2008; Kamei et al, 2012) using various method of durability testing. This study investigates the durability of cement and CCR treated soils collected from Enagi formation and Ahoko formation using water immersion method.

2 MATERIALS AND METHODOLOGY

2.1 MATERIALS

The materials used in this study are disturbed soil samples collected from one trial pit each located within Enagi formation and Ahoko formations both of Bida basin. The soils were collected from trial pits at depth of between 1.0m and 1.5m. The soils were air-dried and prepared as specified in BS 1377 (1) 2022. The cement used was collected from a commercial outlet and kept in a dry place to avoid ingress of moisture. The calcium carbide residue was collected from local welders in Keteren Gwari mechanic site. The CCR was air-dried and pulverized using mortar and pestle. The grinded CCR was then sieved through sieve 0.425mm and the component passing through sieve 0.425mm was collected and used in this study. The water used is a distilled water obtained from a pharmaceutical outlet opposite Minna General Hospital main gate. The distilled water was stored in a safe place to avoid contamination from external bodies.

2.2 METHODOLOGY

The method involves characterizing the untreated soils from Enagi and Ahoko formations. This was done using index properties test and Atterberg limit tests. This was followed by British Standard Heavy compaction of both the untreated soils and soils treated with varied compositions of cement and CCR to obtain the maximum dry densities (MDD) and optimum moisture content (OMC). The compaction parameters obtained from the compaction tests were used to mold specimen for unconfined compressive strength (UCS) and consequently, the durability specimen. The untreated soils were mixed with 0%, 2% and 4% cement each admixed with 0%, 3% and 6% calcium carbide residue.

3.0 RESULTS AND DISCUSSION

3.1 INDEX PROPERTIES

The summary of the index properties of the soils collected from Enagi and Ahoko are shown on table 1. The Enagi soils and the Ahoko soils classified under sandy clay (SC) and clay of low plasticity (CL) respectively base on unified soil classification system and A-6 soils based on AASHTO soil classification system.

Table 1: Index properties of untreated soils

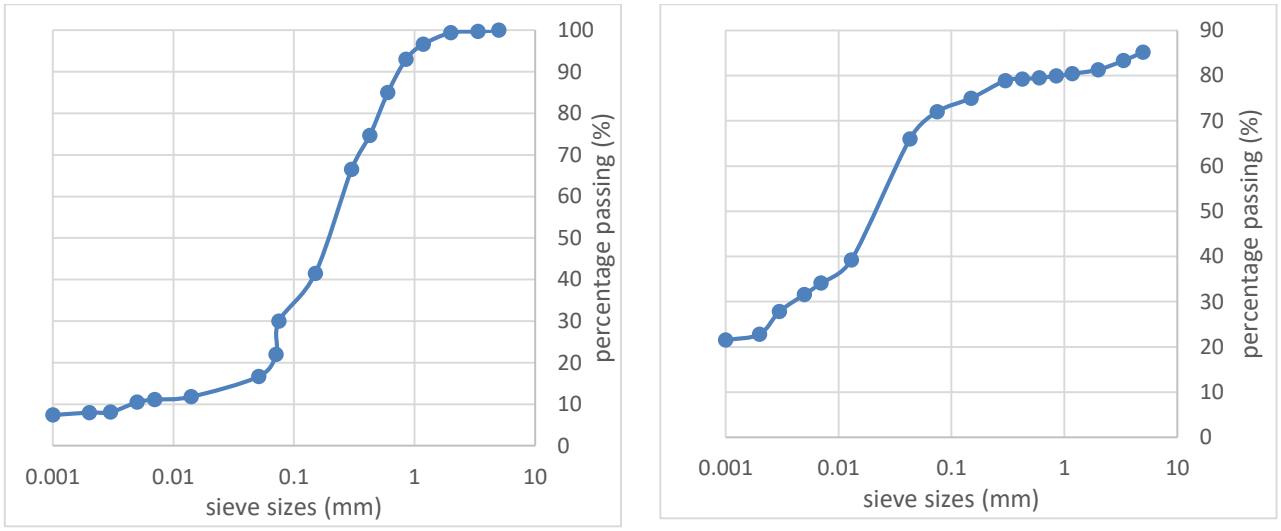
Basic characteristics	Ahoko Soil	Enagi Soil
% Passing No.10 sieve (<2.00 mm)	81.32	96.63
% Passing sieve 0.425 mm	92.22	66.55
% passing sieve 0.075 mm	77.93	38.28
Liquid limit (%)	37.2	32.0
Plasticity Limit (%)	25.4	15.5
Plasticity index (%)	11.8	16.5
Specific gravity	2.64	2.72
AASHTO classification	A-7-6	A-6
USCS Classification	CL	SC
Colour	Light Gray	Reddish

A-6 soils are not suitable for use as road construction material and will require stabilization to increase its strength and stability.

3.2 GRAIN SIZE ANALYSIS

The graph of the grain size analysis of the Enagi soils and Ahoko soils are presented in figure 1. The graph revealed 8% clay size particle for Enagi soil and 21% clay size particles for Ahoko soil. The graph showed Enagi soil to be close to uniformly graded soil while Ahoko soil is close to well-graded soil.

These two characteristic of well-gradedness and high proportion of clay size particle is disadvantageous for any material to be used as road base material. The soil samples will therefore require improvement for enhanced strength and stability.



(a) Enagi soil (b) Ahoko soil

Figure 1: Grain size analysis of (a) Enagi soil and (b) Ahoko soil

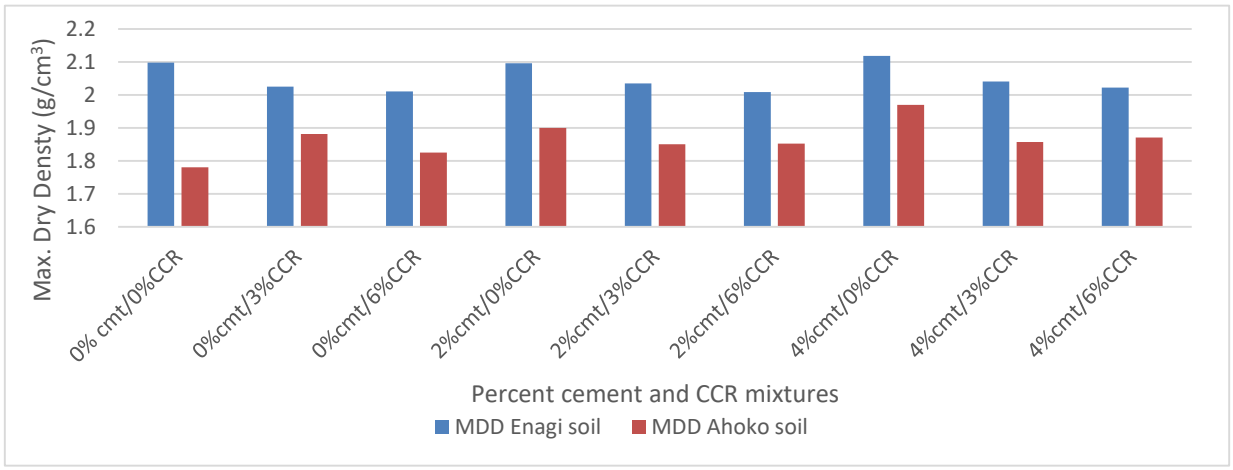


Figure 2: Maximum dry densities of Enagi and Ahoko soils

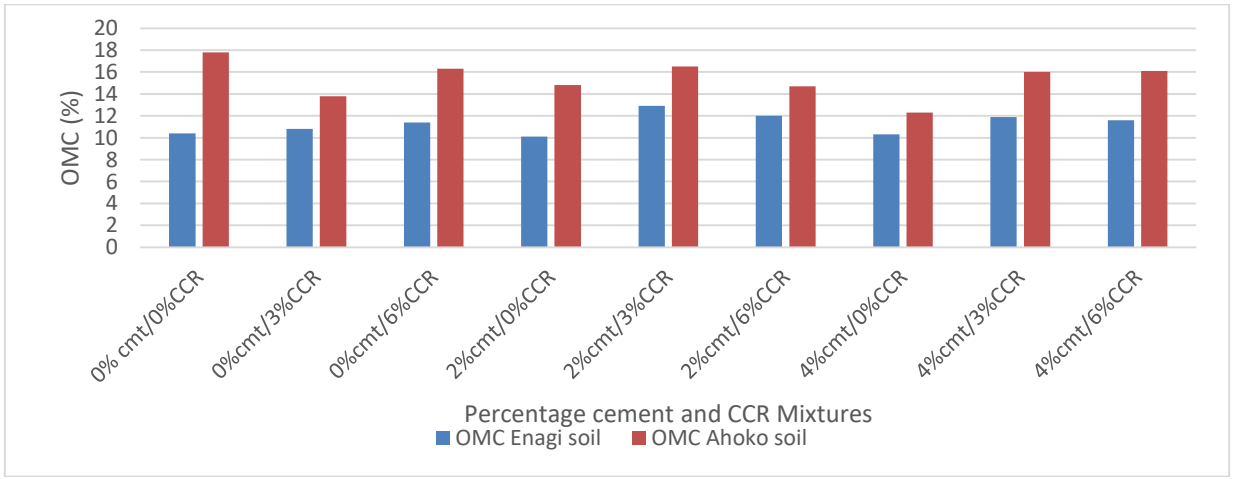


Figure 3: Optimum Moisture Content of Enagi and Ahoko soils

3.3 COMPACTION CHARACTERISTICS

The compaction characteristics of the two soils showed results that agree with their index properties results. The maximum dry densities (MDD) are generally higher for Enagi soils (2.009g/cm^3 – 2.118g/cm^3) compared to Ahoko soil (1.825g/cm^3 – 1.970g/cm^3).
The general trend showed the MDD decreasing with increase in calcium carbide residue (CCR). This is due low specific gravity of CCR compared to the soil.

The OMC on the other hand showed increase with increase in CCR. This is in agreement with literature and must have resulted from the water absorption characteristic of the CCR. For soils treated with cement alone, there was clear increase in MDD with increase in cement. Enagi soil showed MDD increasing from 2.098g/cm3 for 0% cement to 2.118g/cm3 for 4% cement only.

Similarly, the result of Ahoko soil recorded MDD of increasing from 1.870g/cm3 for untreated soil to 1.900g/cm3 for soil treated with 2% cement alone which further increased to 1.970g/cm3 for soil treated with 4% cement only. This is attributed to higher specific gravity of cement compared to the soil.

For Ahoko soil, the OMC also decreased from 17.8% for untreated soil to 14.8% for soil treated with 2% cement alone and further decreased to 12.3% for soil treated with 4% cement alone.

3.4 UNCONFINED COMPRESSIVE STRENGTH

The results of the unconfined compressive strength for Enagi soil is shown on figure 4. The UCS values were observed to increase with increase in curing days for the Enagi soil and chemical mixtures. The values increased from 242kN/m^2 for the untreated soil to maximum of 2788kN/m2 for Enagi soil mixed with 4% cement and 3% CCR and cured for 14 days.

The UCS results for Enagi soils generally showed values that increase with increase in curing days and with increase in the chemical admixtures. For Enagi soils, the UCS values of soils treated with 0% cement admixed with 3% and 6% CCR each revealed increase in UCS values from 547kN/m^2 and 490kN/m^2 for 3% and 6% CCR values respectively after 1 day curing to 1269kN/m^2 and 1145kN/m^2 for 3% and 6% CCR values respectively after 14 days curing. Based on the 1500kN/m^2 UCS required by stabilized soils to be used as sub-base material for high trafficked roads as specified in Road Note 31 (1997), all Enagi soils stabilized with minimum of 2% cement and 3% CCR satisfy the specification to be used as sub-base course material for highly trafficked roads. However, Enagi soils stabilized with 2% cement without CCR do not satisfy the 1500kN/m^2 minimum requirement for material to be used as sub-base material which showcase the benefit of adding waste CCR to cement for strength and durability. The specimen cured for 7 days and soaked for the next 7 days generally showed high values compared to specimen cured for 14 days without soaking indicating the high durability of Enagi soils.

The result of Ahoko soils treated with 0, 2 and 4% cement admixed with 0, 3 and 6% CCR each is presented in figure 5. The UCS values generally increased from 414kN/m2 for untreated Ahoko soil to 1207kN/m^2 for Ahoko soil treated with 4% cement and 6% CCR and cured for 14 days. This maximum UCS value is lower than the 1500kN/m^2 specified for stabilized soils to be used as sub-base course material for highly trafficked roads based on Road Note 31 (1997). The specimen cured for 7 days and soaked for the next 7 days generally showed low values compared to specimen cured for 14 days without soaking indicating the low durability of Ahoko soils. This is probably due to high clay sized particles contained in Ahoko soil.

3.5 DURABILITY CHARACTERISTICS

The durability characteristic of soils collected from Enagi soil ranges from 55.8% for the untreated soil to maximum of 87.0% for soil treated with 4% cement and 3% CCR. Based on the 70% minimum resistance to loose in strength recommended by Nigerian General Specification for Road and Bridges (1997), almost all the Enagi soils treated with cement and CCR satisfy the specification to be used as sub-base course material for highly trafficked roads
The high resistance to loose in strength recorded from samples collected from Enagi is due to the low clay sized particles contained in Enagi soil.

For soils collected from Ahoko formation, the untreated soil and soil treated with 0% cement and 3% CCR could not survive the 7 days soaking after the 7 days curing. This is an indication of complete lack of resistance to loose in strength. The resistance to loose in strength

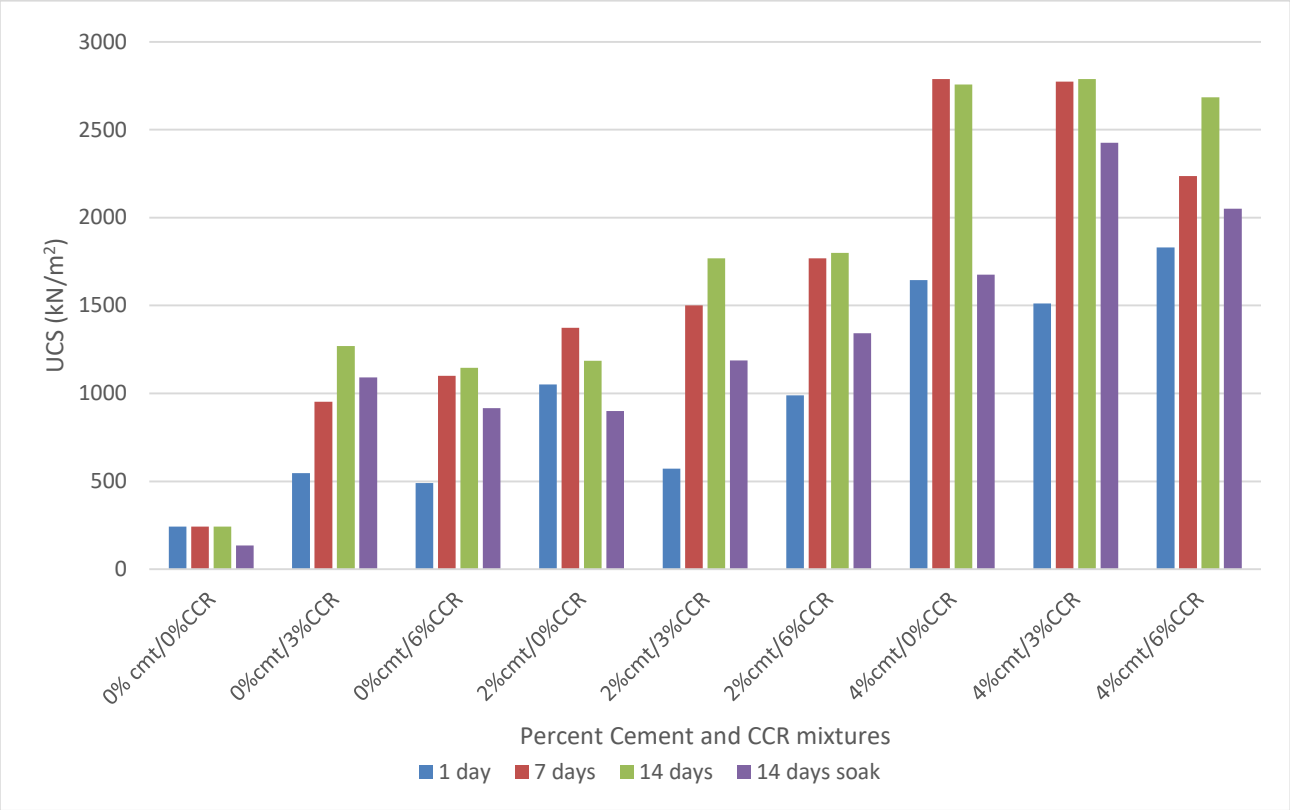


Figure 4: Unconfined compressive strength for Enagi Soil after 1, 7, 14 days curing with 7 days curing and 7 days soaking

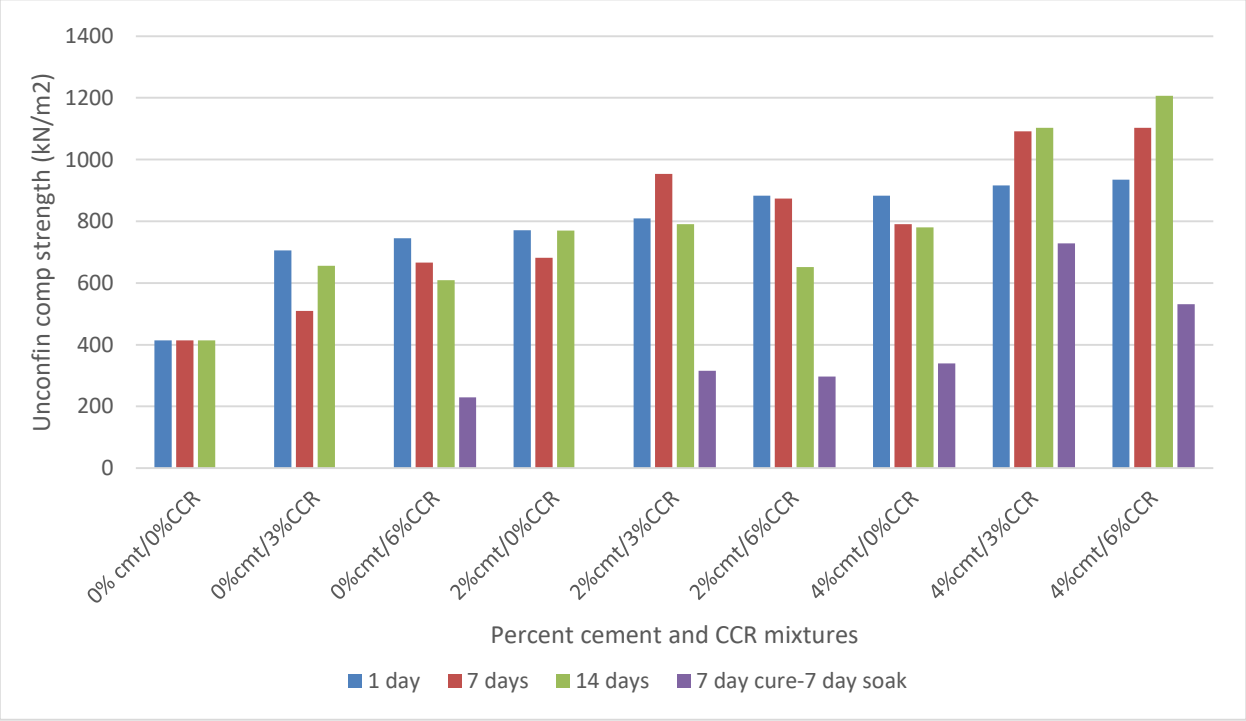


Figure 5: Unconfined compressive strength for Ahoko Soil after 1, 7, 14 days curing with 7 days curing and 7 days soaking

Table 2: Durability characteristics of Enagi soils

Mix prop	0cmt/ 0CCR	0cmt/ 3CCR	0cmt/ 6CCR	2cmt/ 0CCR	2cmt/ 3CCR	2cmt/ 6CCR	4cmt/ 0CCR	4cmt/ 3CCR	4cmt/ 6CCR
Unsoak	242	1269	1145	1186	1769	1678	2757	2788	2685
Soak	135	1092	916	900	1187	1342	1676	2425	2050
Durabilty	**55.8**	**86.0**	**80.0**	**76.0**	**67.0**	**80.0**	**61.0**	**87.0**	**76.0**

Table 3: Durability characteristics of Ahoko soils

Mix prop	0cmt/ 0CCR	0cmt/ 3CCR	0cmt/ 6CCR	2cmt/ 0CCR	2cmt/ 3CCR	2cmt/ 6CCR	4cmt/ 0CCR	4cmt/ 3CCR	4cmt/ 6CCR
Unsoak	414	656	609	770	791	652	780	1103	1207
Soak	0	0	229	330	316	297	339	728	531
Durabilty	**0**	**0**	**37.6**	**42.9**	**39.9**	**45.6**	**43.5**	**66.0**	**44.0**

3.6 CONCLUSIONS

From the discussions thus far, the following can be recommended:

1. Based on index properties test, the soil collected from Enagi formation classified under A-6 based on ASSHTO soil classification system while the soil collected from Ahoko formation classified as A-7-6 based on AASHTO soil classification system. The soils from Enagi formation and Ahoko formation classified as clayey sand (SC) and clay of low plasticity (CL) respectively based on unified soil classification system.

2. The MDD of soil collected from Enagi formation are generally high (2.011 – 2.118g/cm^3) compared to the values recorded for soil collected from Ahoko formation (1.850 – 1.970g/cm^3). The values generally showed increase with increase in percentage cement but reduces with increase in percentage CCR.

3. The unconfined compressive strength (UCS) for soil collected from Enagi formation (242kN/m^2 – 2788kN/m^2) are generally higher than the values recorded for soil collected from Ahoko formation (414kN/m^2 – 1207kN/m^2).

4. The resistance to loose in strength values are higher in soil collected from Enagi formation (55.8% - 87.0%) compared to that of soil collected from Ahoko formation (0% - 66.0%). All specimen of soil collected from Ahoko formation do not satisfy the 70% minimum resistance to loose in strength as recommended by Nigerian General Specification for Roads and Bridges (2016)

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Predicting Soil Compression Index Using Machine Learning: A Comparative Study of Algorithms

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ABSTRACT
Accurate prediction of the compression index (Cc) is crucial for geotechnical engineers in designing stable foundations. Traditional methods for determining Cc, such as oedometer tests, are time-consuming and expensive. This research focuses on the development of machine learning models to predict Cc efficiently and accurately. A comprehensive dataset (218 data) of fine-grained soil properties was collected and analyzed. Five Selected Machine learning algorithms, namely; Artificial Neural Networks (ANN), Support Vector Regression (SVR), Random Forest (RF), Gradient Boosting Regression (GBR), and Decision Tree Regression, were implemented and trained on the dataset. The performance of these models was evaluated using statistical metrics including R^2 and Mean Squared Error (MSE). Random Forest Algorithm merged as the top performer, achieving a highest R^2 value of 0.99. This research demonstrates the potential of machine learning in improving geotechnical engineering practices, leading to more efficient and reliable foundation designs.
Keywords: *Compression index, consolidation, fine grained soil, Index Properties.*

1 INTRODUCTION

Accurate prediction of soil settlement is paramount for the safe design and construction of civil engineering structures. Fine-grained soils, characterized by their high compressibility, pose significant challenges in this regard. The Compression Index (Cc), a critical parameter reflecting the soil's compressibility, is essential for estimating settlement and ensuring structural stability (Kazemi et al., 2019). Traditional methods for determining Cc, such as oedometer tests, can be time-consuming and resource-intensive (Uzer, 2024).

To address these limitations, researchers have increasingly explored the potential of machine learning (ML) techniques for predicting Cc. Recent years have seen the emergence of novel approaches in geotechnical engineering, utilizing AI techniques, to predict the compression index (Cc) of fine-grained soils more accurately and efficiently than traditional methods. These AI-driven approaches, such as those explored by Kim et al. (2024) and Pham et al. (2019), hold significant promise for improving the prediction of soil behavior.

Several studies have demonstrated the effectiveness of machine learning (ML) techniques in predicting the compression index (Cc) of fine-grained soils. Ensemble learning methods, such as Gradient Boosting Regressor (GBR), Random Forest Regressor (RFR), and AdaBoost Regressor (ABR), have shown promising results. Notably, GBR achieved a high testing R-squared value of 0.930, surpassing traditional statistical methods (Kim et al., 2024). Similarly, XG-Boost, another boosting algorithm, exhibited an 8-11% improvement in prediction accuracy compared to other Machine Learning models (Mamudur and Kattamuri, 2020).

Artificial Neural Networks (ANNs) have also proven effective in Cc prediction, demonstrating the potential to outperform traditional approaches. For example, an ANN model achieved an R-squared score of 0.81, indicating strong predictive performance (Uzer, 2024). Furthermore, integrating ANNs with optimization techniques, such as Particle Swarm Optimization (PSO), can further enhance predictive accuracy, as evidenced by the success of the PSO-MLP Neural Nets model (Bui et al., 2018). Support Vector Machines (SVM) and k-nearest neighbors (kNN) have also been successfully employed in Cc prediction, utilizing soil index properties as input parameters. These models have been validated using various performance metrics, demonstrating reliable predictive capabilities (Akshaya and Premalatha, 2024). Additionally, the Extreme Learning Machine (ELM) model has shown exceptional performance, achieving a correlation coefficient exceeding 0.95 in Cc prediction (Ly et al., 2020).

Building upon this prior work that highlights the potential of ML methods like Artificial Neural Networks (ANNs) (Shao and Shen, 2023), Support Vector Machines (SVMs) (Zhang et al., 2020), Random Forest (RF) (Liu et al., 2024), Gradient Boosting Regression (GBR) (Sharafati et al., 2020), and Decision Tree Regression (DTR) (Pekel, 2019), this study investigates the predictive capabilities of these five ML algorithms for estimating the Cc of fine-grained soils. By training and comparing the performance of these models on a comprehensive dataset of soil properties, we aim to identify the most accurate and efficient ML approach for predicting Cc. This can contribute significantly to geotechnical engineering practice by providing a more efficient and potentially more accurate method for estimating soil compressibility, ultimately improving the design and construction of various geotechnical structures.

2 METHODOLOGY

2.1 Soil Sampling Technique:

Soil samples were collected using a hand auger at 25 representative locations. Sample preparation adhered to ASTM D2435-16 standards. The dataset was augmented with data from peer-reviewed research journals (Alhaji *et al.*, 2017)

2.1.1 Index Properties:

Index properties, including sieve analysis (focusing on the percentage passing the 425-micron sieve), Atterberg limits (liquid limit, plastic limit, and plasticity index), and natural moisture content, were determined according to AASHTO and ASTM standards, The specific gravity test was conducted according to BS 1377:1990. The compression index (Cc) was determined by analyzing the results of a one-dimensional consolidation test. This analysis involved plotting the void ratio against effective stress, following Terzaghi's established relationship between these two parameters.

2.2 Dataset Overview

The dataset for this study comprises 218 geotechnical properties of fine-grained soils from various locations, extracted from laboratory testing. These properties, crucial for understanding soil behavior, include unit weight (kN/m³), specific gravity (Gs), natural moisture content (NMC), particle size distribution (including percentage passing the 425-micron sieve), liquid limit (LL), plastic limit (PL), plasticity index (PI), void ratio (e), and the compression index (Cc)

2.3 Data Pre-processing for Predicting Compression Index (Cc) of Fine-Grained Soil

Machine learning models require a substantial amount of data to learn the relationships between input parameters and the desired output. This methodology outlines the data pre-processing steps employed to prepare a dataset for predicting the Compression Index (Cc) of fine-grained soil using various machine learning models; Artificial Neural Networks (ANN), Support Vector Machines (SVM), Random Forest (RF), Gradient Boosting Regression (GBR), and Decision Tree Regression (DTR)

2.3.1 Data Augmentation

The initial dataset 218 may have a limited number of data points. To address this, the data was further augmented by incorporating additional data by generating 4782 synthetic data using Gretel. This ensures a sufficient amount of data for training, testing, and validating the machine learning models.

2.3.2 Data Cleaning

Data cleaning is crucial to ensure the quality and accuracy of the dataset. This step involves identifying and addressing inconsistencies, errors, and missing values. Here's a breakdown of the cleaning process:

i. Initial Inspection: The dataset is loaded into a P and as Data Frame for preliminary examination. This involves checking for missing values, outliers, and inconsistencies.

Table 2.1: Loading Dataset into P and as Data Frame

```
[2]:
df= pd.read_excel("CONSO_DATA_FG SOIL.xlsx")
df.head()
```

[2]:

	Unit weight (kN/m3)	Gs	NMC	Void Ratio e	0.075mm	LL	PI	Cc
0	19.6459	2.6476	18.6801	0.3221	38.434	42.4041	17.7893	0.25966
1	20.2840	2.6355	21.9066	0.2746	33.400	43.0819	17.6460	0.27757
2	19.4720	2.6424	19.8720	0.3312	40.533	40.8248	18.2837	0.27063
3	19.8184	2.6389	21.7866	0.3062	33.779	42.7443	18.5136	0.29518
4	20.2300	2.6900	10.9000	1.2430	45.300	46.5000	18.7000	0.31700

ii. Data Type Correction: Data types of each column are verified and rectified if necessary. Columns with incorrect data types are converted to the appropriate format.

Table 2.2:Data Type of Each Column of the Dataset

```
[3]:
df.info()
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 5000 entries, 0 to 4999
Data columns (total 8 columns):
 #   Column                Non-Null Count  Dtype
---  ------                --------------  -----
 0   Unit weight  (kN/m3)  5000 non-null   float64
 1   Gs                    5000 non-null   float64
 2   NMC                   5000 non-null   float64
 3   Void Ratio e          5000 non-null   float64
 4   0.075mm               5000 non-null   float64
 5   LL                    5000 non-null   float64
 6   PI                    5000 non-null   float64
 7   Cc                    5000 non-null   float64
dtypes: float64(8)
memory usage: 312.6 KB

#let convert column from object to float df['Cv'] = pd.to_numeric(df['Cv'],
errors='coerce') df['Cv'].dtype


df.info()
```

iii. Handling Missing Values: Missing values can negatively impact model performance. Here's how missing values were addressed:

i. Identification: Missing values are identified using methods like df.isnull().sum(), which provides the count of missing entries in each column.

ii. Imputation: Appropriate techniques are employed to impute missing values. For instance, the mean imputation technique can be used to fill missing values in a specific column as shown in Figure 2.1

```
[5]:
df.isnull().sum()

[5]:
Unit weight  (kN/m3)    0
Gs                      0
NMC                     0
Void Ratio e            0
0.075mm                 0
LL                      0
PI                      0
Cc                      0
dtype: int64
```

Figure 2.1: Identification of missing values

2.4 Exploratory Data Analysis (EDA)

EDA is conducted to gain insights into the dataset, identify patterns, and uncover relationships between different soil properties and the Compression Index (Cc). Here are the key steps involved:

1. Data Grouping: The dataset is grouped into numerical and categorical data for separate analysis as shown in Figure 2.2

```
# lets put the numerical data and the variable data differnetly
num_data = df.select_dtypes(include=np.number)
cat_data = df.select_dtypes(include='object')
[14]
```

Figure 2.2: Grouping the Dataset

2. Data Visualization: Histograms are used to visualize the distribution of key numerical variables like Unit Weight and Plasticity Index. This helps identify the overall distribution shape and potential outliers as shown in Figure 2.3.

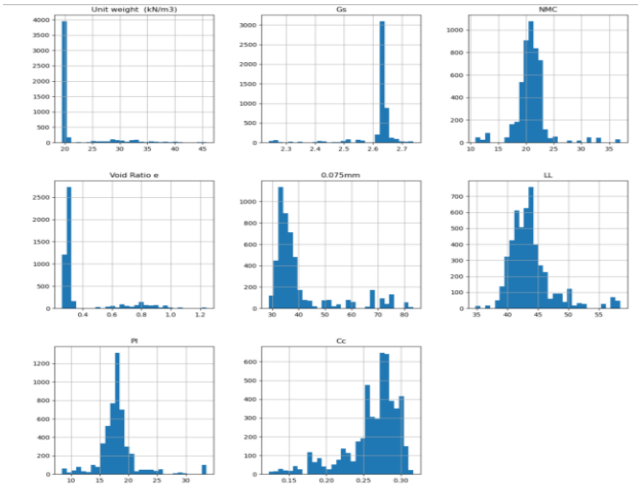


Figure 2.3: Data Visualization

3. Correlation Analysis: A correlation matrix is computed to assess the linear relationships between numerical variables. This step aims to identify and address multicollinearity, where independent variables are highly correlated as shown in Figure 2.4.

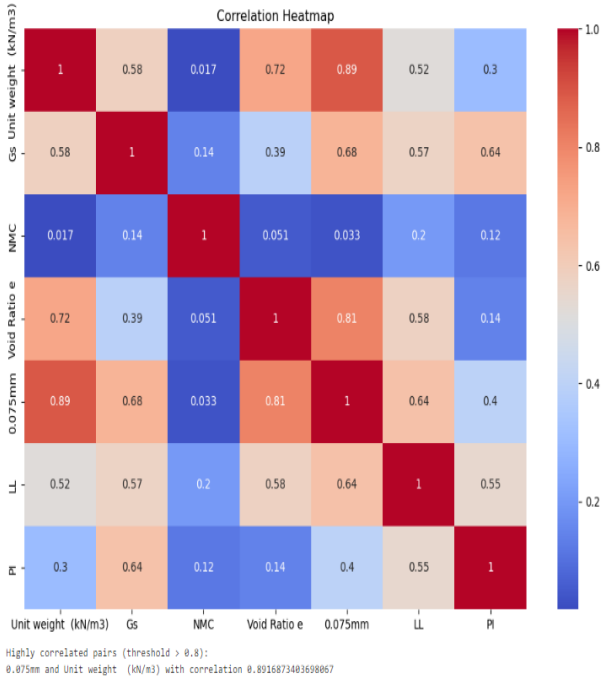


Figure 2.4: Correlation Heatmap

2.5: Model Selection

Several machine learning models were evaluated for predicting the compression index of fine-grained soil due to their ability to handle non-linear relationships, a common characteristic of geotechnical data. The models considered included Artificial Neural Network (ANN) using the MLP Regressor architecture for its complex pattern recognition, Random Forest Regressor for its ensemble approach and robustness, Support Vector Regression (SVR) for its effectiveness in high-dimensional spaces, Gradient Boosting Regressor for its iterative ensemble building and noise handling, and lastly, the simpler Decision Tree Regressor to provide a baseline for comparison, despite its potential for overfitting.

2.6 Model Development

2.6.1 Multilayer Perceptron (MLP) Models

Multilayer Perceptions (MLPs) are a powerful class of artificial neural networks capable of modeling complex nonlinear relationships. In this study, MLPs with varying architectures (number of hidden layers and neurons) were employed to predict Cc. The input layer received selected soil properties (unit weight, specific gravity, liquid limit, plasticity index) as input, while the output layer produced the predicted Cc value.

The training process utilized the backpropagation algorithm, iteratively adjusting the network's weights and biases to minimize the error between predicted and actual Cc values. To mitigate overfitting, regularization techniques (L1/L2 regularization) and early stopping were implemented.

2.6.2 Non-Linear Statistical Regression (NLSR)

Non-Linear Statistical Regression (NLSR) is a powerful tool in statistics and machine learning used to model relationships between variables when those relationships are not adequately described by a straight line. Unlike linear regression, which assumes a linear relationship, NLSR allows for curved or complex relationships between the independent and dependent variables.

Bayesian optimization was utilized to find the best combination of hyper-parameters that minimizes the error on the validation set. Cross-validation was incorporated into this step for more robust hyperparameter selection.

2.7 Data Preparation

Relevant input features (unit weight, specific gravity, liquid limit, plasticity index, void ratio) were selected

2.8 Data Splitting

The data set was divided into training and testing sets. The training set was used to train the models, while the testing set was used to evaluate their performance of the unseen data.

2.9 Feature Scaling

To improve model performance, especially for models sensitive to feature scales (such as Support Vector Regression, Artificial Neural Networks), feature scaling was applied using Standard Scaler.

2.10 Evaluating the Metrics

The performance of each model was assessed using two key metrics: the Coefficient of Determination (R^2), which measures the proportion of variance in Cc explained by the model, and the Mean Squared Error (MSE), which quantifies the average squared difference between predicted and actual Cc values

.

3 RESULTS AND DISCUSSION

3.1 Model Performance

Figure 3.1 summarizes the performance of different machine learning models.

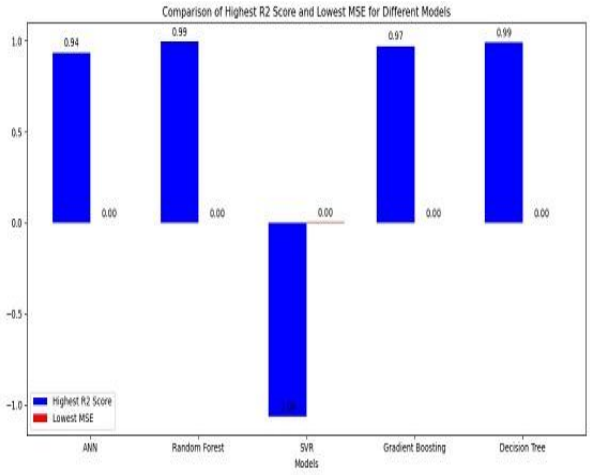


Figure 3.1: Performance of Different Machine Learning Models

- R-squared: Random Forest and Decision Tree achieved the R-squared values (0.99), followed by Gradient Boosting (0.97).
  Mean Squared Error (MSE)
  - SVR exhibited the lowest MSE (negative value),

3.1.2 Feature Importance Analysis

Figure 3.2, "Feature Importance for Cc Prediction," visualizes the relative importance of several soil properties in predicting the compression index (C_C). The analysis reveals that unit weight (kN/m³) is the most influential factor, demonstrating the strongest correlation with CC. NMC (Natural Moisture Content) and PI (Plasticity Index) exhibit moderate importance, suggesting a secondary influence on C_C prediction. In contrast, void ratio (e), liquid limit (LL), and specific gravity (Gs) appear to have minimal impact on the model's C_C predictions. This analysis highlights the significance of unit weight as a primary indicator of C_C, implying that changes in unit weight are likely to have the most substantial effect on C_C values.

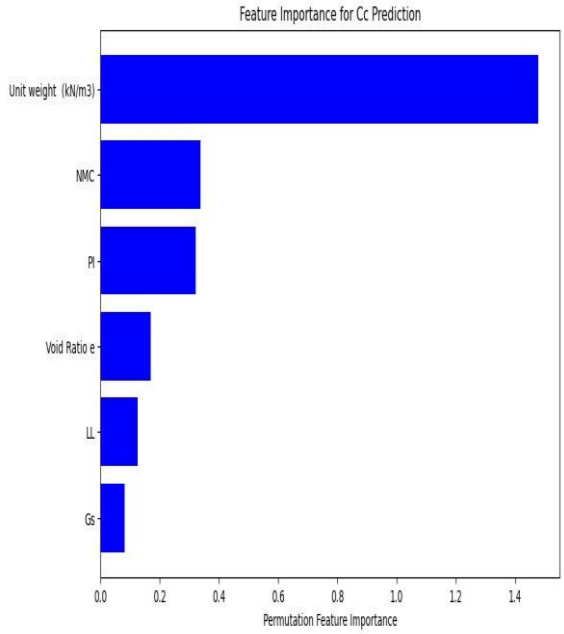


Figure 3.2: Feature Importance

3.2 Discussion of Results

The high R^2 values (up to 0.99) and low MSE values achieved by several models (ANN, Random Forest, Gradient Boosting, Decision Tree) demonstrates the ability of Machine Learning tools to accurately predict Cc.

The success of models like Random Forest and Gradient Boosting, which are known for handling complex non-linear relationships, suggests that ML can effectively capture the intricate relationships between soil properties and Cc. Geotechnical data is often complex and non-linear, making ML a particularly suitable tool.

Once trained, ML models can be used to predict Cc for new soil samples quickly and automatically. This can significantly improve the efficiency of geotechnical investigations and design processes. It allows engineers to analyze more scenarios and optimize designs more effectively.

The problematic SVR result, while needing correction, is a reminder of the importance of careful model selection, hyperparameter tuning, and validation. It highlights that ML is not a "black box" solution and requires expertise in data handling, model training, and evaluation. However, once the SVR issue is resolved, it might also prove to be a valuable model.

4 CONCLUSION

The following conclusion were drawn from this work:

The findings of this study provide compelling evidence for the significant potential of machine learning (ML) in geotechnical engineering, particularly for the prediction of soil compression index (Cc).

The high predictive accuracy demonstrated by the four selected models; Artificial Neural Network, Random Forest, Gradient Boosting, and Decision Tree, achieving R^2 values of up to 0.99 and low Mean square errors (MSE) values, underscores the ability of Machine learning to effectively capture the complex, non-linear relationships between soil properties and Cc. This capability offers a promising alternative to traditional, often time-consuming and expensive, methods for determining Cc, potentially leading to faster and more cost-efficient geotechnical investigations.

The success of learning methods like Random Forest and Gradient Boosting highlights the suitability of ML for handling the inherent complexity and non-linearity of geotechnical data. Furthermore, the potential for automation and efficiency gains through ML-driven Cc prediction promises to streamline geotechnical design processes, enabling engineers to explore a wider range of scenarios and optimize designs more effectively.

The identification of key influencing factors, such as unit weight, through feature importance analysis further enhances our understanding of soil behavior and opens avenues for targeted research.

However, while these results are encouraging, it is crucial to acknowledge the anomalous result obtained with the Support Vector Regression (SVR) model. The negative R^2 value coupled with a near-zero MSE strongly suggests an issue with the SVR implementation, parameter tuning, or data handling, rather than an inherent limitation of the SVR model itself. This discrepancy highlights the importance of rigorous validation and quality control in ML applications.

5.1 Recommendations

Based on these findings, the following recommendations are made:

1. **Address the SVR Anomaly:** A thorough investigation into the SVR results is paramount. This should involve a meticulous review of the code, verification of metric calculations, careful re-evaluation of hyperparameter tuning strategies, and a detailed examination of the data for potential issues.
2. **Rigorous Validation and Testing:** Employ robust cross-validation techniques and evaluate model performance on a separate, held-out test dataset to ensure model generalization and prevent overfitting. This will provide a more reliable assessment of the models' predictive capabilities on unseen data.

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ADVANCES IN ARTIFICIAL INTELLIGENCE IN SOLID WASTE MANAGEMENT IN DEVELOPING COUNTRIES

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ABSTRACT

In developing nations, inadequate Solid Waste Management (SWM) poses considerable public health and environmental concerns, aggravating climate change, disease transmission, and pollution. Recent advances in Artificial Intelligence (AI) provide innovative solutions to optimize SWM. This review provides an overview of advances in AI in SWM, focusing on developing countries. Specifically, this review explored literature on solid waste, sources, public health concerns, solid waste management (SWM) challenges of SWM, strategies for enhancing SWM, historical background of waste management and recent advances in Artificial intelligence in SWM in developing countries. By integrating AI into SWM, this review aims to inform policymakers, practitioners, and researchers on mitigating environmental and health impacts, promoting sustainable, efficient, and AI-driven SWM systems, enhancing community engagement and education, and fostering collaborative governance and policy development. This comprehensive review contributes to the development of AI-driven SWM solutions, supporting healthier communities and ecosystems in developing countries.

Keywords: *Artificial Intelligence, Solid Waste Management, Developing Countries, Sustainability, Waste Optimization.*

1.0 Introduction

Solid waste generation has increased at an unprecedented rate in developing nations due to the rise in urbanisation and population growth, creating serious problems for the environment, human health, and the economy. Ashutosh & Swarupa (2023) attested that rapid urbanisation of cities exponentially increases waste production, which, when combined with inadequate waste sorting and disposal methods, worsens environmental pollution and accelerates climate change. They emphasised how urgently densely populated urban areas need efficient waste management solutions. Solid waste refers to materials that are created by human activity and are typically processed to lessen their negative effects on the environment, human health, or aesthetics. These wastes (metals, vegetables, old paint containers, packing materials, and garden waste) comprise everything that people no longer need and that they either plan to discard or have already done so (Christian, 2010). Solid waste comes from a variety of sources, such as post-consumer product use and production processes in the commercial, industrial, construction, and residential sectors. According to Abdel-Shafy and Mansour (2018), it includes a variety of waste types–trash, litter, refuse, and garbage. It is a result of human activity and is predicted to rise as the world's population rises, urbanisation quickens, living standards rise, and consumption habits change.

Effective Solid Waste Management (SWM) is crucial for mitigating these impacts, yet traditional approaches often fall short due to inadequate infrastructure, limited resources, and inefficient practices. Recent advancements in Artificial Intelligence (AI) offer a promising solution to optimize SWM in developing countries. Because AI (Artificial Intelligence) can analyse vast datasets, forecast Waste Generation Patterns (WGPs), find the best collection routes, and predict anomalies in Waste Management Systems (WMSs), it has the potential to revolutionise SWM (Reza & Hassan, 2023).

Solid Waste Management (SWM) has been the subject of concern in several studies, including those by Kumar & Smith (2017), Singh & Kumar (2017), and the United Nations Environment Programme (2019). These studies include "Waste Management in Developing Nations; Integrated Solid Waste Management; and Global Waste Management Outlook." But to the best of my knowledge, only a few studies have reviewed and summarized the existing knowledge on the advancement of Artificial Intelligence in Solid Waste Management (SWM). As a result, the purpose and aim of this paper review is to give a thorough summary (fig 1) of the recent advances in AI applications in SWM, focusing on developing countries by exploring literature on solid wastes, sources of solid

wastes, public health concerns, solid waste management (SWM), challenges of SWM, strategies for enhancing waste management, historical background of waste management, and advances in AI in Solid Waste Management in developing countries. Ultimately, this research review looks into ways to lessen the negative effects of poor waste management on the human environment and health by assisting developing nations in creating effective, sustainable and AI-driven SWM systems.

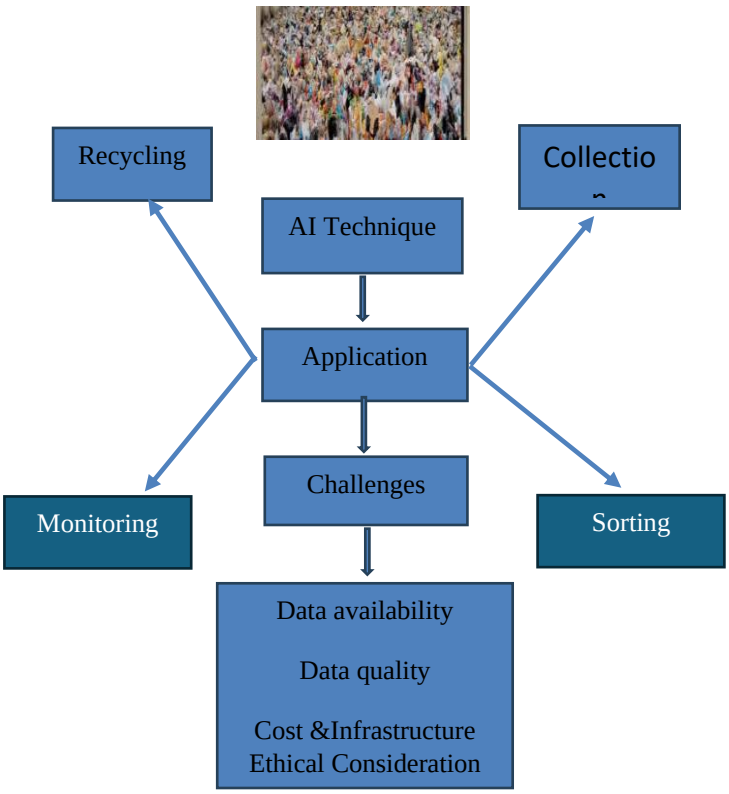


Figure 1: Paper Overview

2.0 Solid Waste Management

According to Demirbas (2011), waste management comprises the controlled and regulated collection, transportation, and disposal of waste, as illustrated in Figure 2. One of the most 12 2 16 important aspects of public health and environmental sustainability is Solid Waste Management (SWM). It involves collation, moving (transportation), processing, recycling, and getting rid (disposal) of solid waste. Mitigating the detrimental impacts of waste products on the human environment and health requires effective SWM systems (Gupta, Sharma & Bhardwaj, 2023).

SWM—Solid Waste Management has grown to be a serious issue in many developing country cities in the past years due to the loss of biodiversity, air pollution, sanitation, land degradation, and infectious disease transmission. (Guerrero, Maas, and Hogland, 2013). The rate at which the world is becoming more urbanised is unprecedented. Cities, which are in charge of managing waste in a way that is both socially and environmentally responsible, face difficulties as a result of these changes. Solid wastes are managed by both informal and formal sectors. Strategies for Enhancing Waste Management in Developing Nations Adopting a comprehensive strategy (figure 3) that includes collection, recycling, and disposal is key. This strategy requires cooperation among the government, private companies, and local communities. The use of the Integrated Sustainable Waste Management (ISWM) outline has been effective in various areas (Becerra-Quiroz, Rodríguez-Morón, Acevedo-Pabón, Rodrigo-Ilarri, & Rodrigo-Clavero, 2024).

2.1 Strategies for Enhancing Waste Management in Developing Nations

Adopting a comprehensive strategy (figure 3) that includes collection, recycling, and disposal is key. This strategy requires cooperation among the government, private companies, and local communities. The use of the Integrated Sustainable Waste Management (ISWM) framework has been effective in various areas (Becerra-Quiroz, Rodríguez-Morón, Acevedo-Pabón, Rodrigo-Ilarri, & Rodrigo-Clavero, 2024).

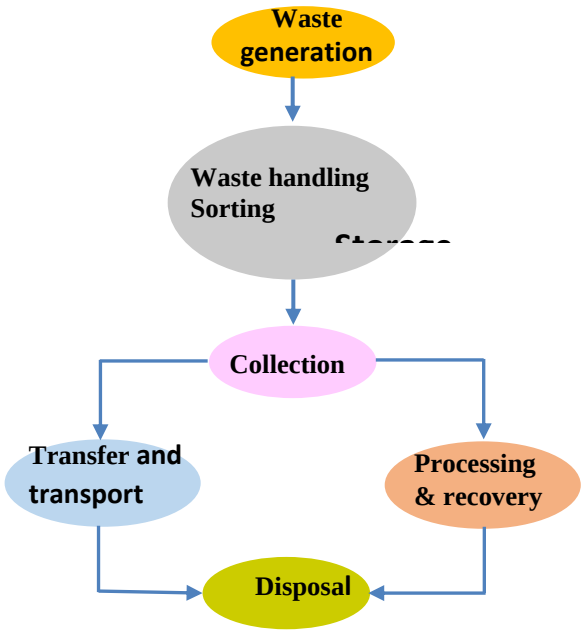


Figure 1: A flowchart depicting the waste management process. Mishra, P. (2022).

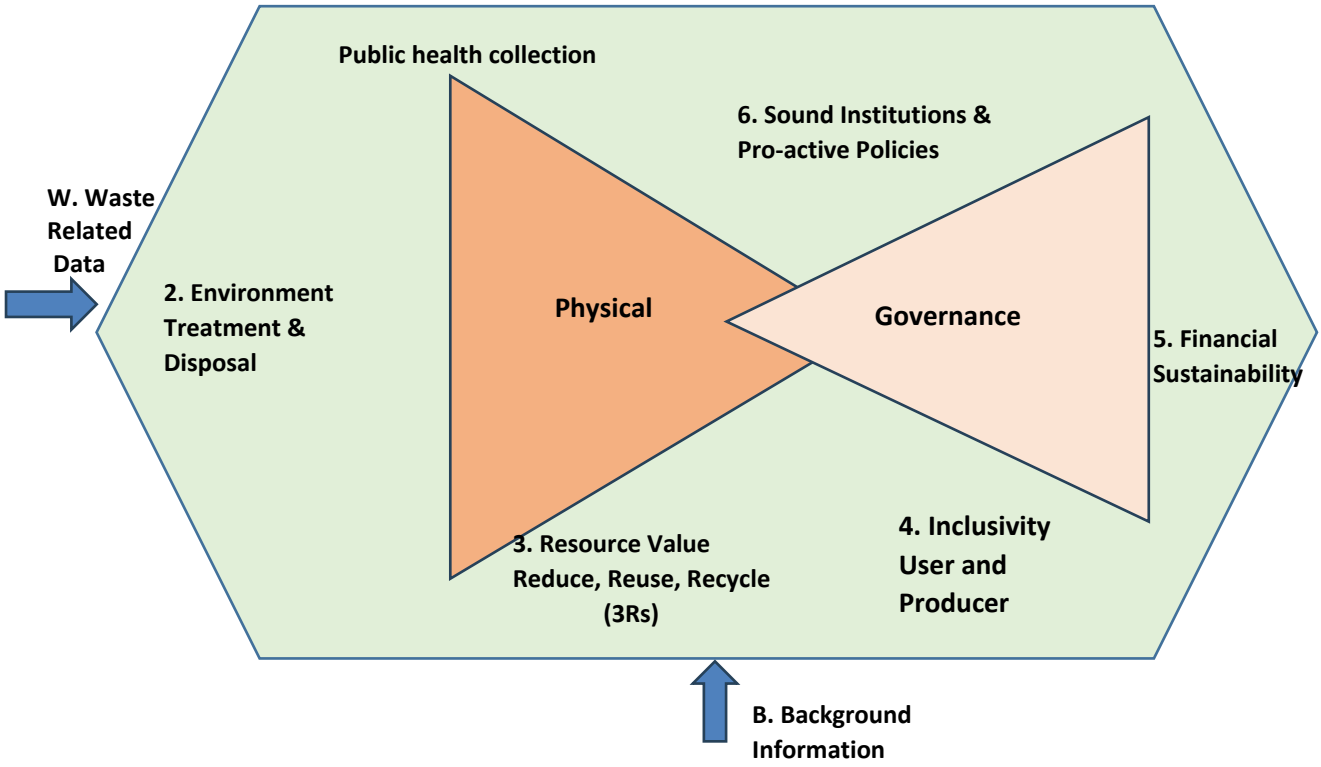


Figure 3: A pie chart illustration of strategies for enhancing waste management in developing countries (Budiharto, W. I., Martono, D. N., & Wahyono, S. 2023, June).

Public-private partnerships can also boost investment in waste management infrastructure and services. Successful examples in cities like Accra, Ghana, show how these partnerships can improve the efficiency of waste collection and increase recycling rates (Kumi, Kafui, & Ansa-Asare, 2019). Focusing on local waste management, such as community-based systems, can be more effective in handling waste at the community level. This approach allows for customized solutions that meet the specific needs of each community and can increase local involvement (Rathi, 2006).

Yadav, Patel, Killedar, & Kumar (2022) posited that the application of technology, like mobile apps for scheduling and tracking waste collection, can enhance the efficiency and transparency of waste management systems. Citing the case of India, they stated that technological solutions are starting to revolutionize waste management practices.

3.0 Artificial Intelligence Technologies (AI)

Russell & Norvig (2010) and Poole & Macworth (2017) in their studies, explained Artificial intelligence (AI) to be the simulation of human intelligence processes carried out by machines, particularly computer systems.

Among their listed procedures are learning (the method of gaining insight and utilizing it); reasoning (the capacity to infer or make a decision based on acquired information), and self-correction. According to Fourtané's (2019) research, artificial intelligence (AI) can be divided into three primary categories: super AI, which excels at tasks like decision-making, the arts, and interpersonal relationships; narrow AI made to perform some tasks—facial recognition and internet searches; and general AI, which are equipped with the ability to learn, understand and apply intelligence across tasks, much like human cognitive abilities.

Mitchell (2024) and Gillis, Lutkevich & Burns (2024) subdivided AI into five (5) components—machine code or learning, natural language processing, computer vision, robotics and expert systems. According to Mehrotra (2019), under AI, there is also another subset called Machine Learning (ML) that enables systems to learn and improve from experience without being unambiguously programmed. It uses statistical methods to give computers the capacity to learn from information data. Natural Language Processing (NLP) aids computers in inferring, decoding, and generating human language. Natural Language Processing (NLP) handles several important roles in various applications, including chatbots for customer interaction, transcription services for bridging language barriers, and sentiment analysis for understanding user opinions and emotions. These

capabilities make NLP essential for enhancing communication and decision-making in numerous industries. (Fanni, Febi, Aghakhanyan, & Neri 2023).

Gollapudi & Gollapudi (2019) defined Computer Vision as a branch which aids machines to read and make decisions based on visual cues from all over the world, such as images or videos. Applications of these visual cues include facial recognition, autonomous vehicles, and medical imaging. Robotics often integrates Artificial Intelligence (AI) to allow robots to learn from their environments and boost their functions (Singh, Kumar & Singh, 2022). This branch of AI involves designing and creating robots capable of carrying out real-world tasks.

3.1 Application of Artificial Intelligence across Different Sectors

AI has diverse applications across multiple sectors, including healthcare (to perform functions such as diagnostics and customised treatment plans), finance (to identify fraudulent activity and facilitate algorithmic trading), transportation (with advancements in autonomous vehicles), and environmental management (optimizing resources and improving waste management). Its ability to analyze and process large datasets quickly and accurately makes AI a powerful tool for enhancing decision-making and automating complex processes across industries. (Duan, Edwards, & Dwivedi, 2019).

3.2 Using AI to Manage Solid Waste in Developing Nations.

To improve waste collection efficiency, processing, and recycling in developing nations, different AI technologies and methodologies must be integrated into their Solid Waste Management (SWM) system. Figure 4 illustrates the Artificial Intelligence hybrid methods utilized for forecasting and predicting solid waste generation. Sahoo et al. (2005) explored ways to optimize waste management routes, highlighting the crucial role of competent fleet management systems in waste collection. They showcased Waste Route—a route-management system that successfully lowered costs and enhanced customer satisfaction. Data Collection and Analysis begin by establishing a robust data collection framework which includes gathering information on Waste Generation Patterns (WGPs), types of waste, collection routes, and recycling rates. Data can be collected through surveys, sensors in waste bins, and analysis of historical waste management data.

The effectiveness of AI uses in Waste Management depends heavily on the availability of high-quality data. By analyzing the specific characteristics of waste streams, municipalities can customize their strategies to address local requirements, enhancing operational efficiency and optimizing resource allocation. This tailored approach ensures that waste management systems are better aligned with community needs and environmental goals. (Olawade, Wada, Ore, David-Olawade, Esan, Egbewole, & Ling, 2024). Varghese et al. (2020) proposed another process for calculating the Green Index (GI) and optimization of waste collection routes, taking into account environmental factors in waste management in lowering costs and increasing performance. Smart waste bins can be deployed and outfitted with Internet of Things (IoT) sensors to track fill degrees and waste composition. These smart bins can transmit information to waste collection services in real time to optimize collection schedules. This technology minimizes unnecessary trips by waste collection vehicles, resulting in reduced fuel usage and running expenses. Cities have seen significant improvements in collection efficiency by using smart bins (Lu, Chang, Liao & Liao, 2015). With respect to the aforementioned, Maphosa & Maphosa (2020) attested that sensor-equipped smart bins and real-time route optimization, driven by AI, have been noted to increase the output of waste collection and disposal processes. Kumari et al., (2017) examined the role of Artificial Intelligence in Municipal Solid Waste Management (MSWM). They point out how AI tools help tackle the difficulty of waste management processes by solving ambiguous problems, learning from mistakes, and handling uncertainty. AI algorithms have also been used to analyze data from smart bins and other sources in gauging the optimal waste collection routes. Machine learning prototypes can predict waste accumulation based on factors like seasonality and local events. Optimizing collection routes reduces travel time and operational costs. In a study conducted in Pune, India, AI-based route optimization reduced collection costs by 20% while improving service delivery (Hooda, Kiran, Gill, Srivastava & Yousif, 2024). Similarly, it was discovered that the rate of waste collection in developing countries, including Nigeria, is about 51% and 44% in sub-Saharan Africa in 2018 (Muyiwa, Ridwan & Hans-Ruldolf, 2023). AI-powered sorting facilities that automate the sorting process through machine learning and computer vision. These technologies can accurately differentiate these diverse materials (plastics, metals and organics) with high accuracy, which can aid automated sorting that increases recycling rates and reduces contamination, leading to higher-quality recycled materials. Bagwasi (2023) noted in his study that a facility in Nairobi, Kenya, that adopted such technology reported a 50% increase in recycling efficiency. Mobile applications can be developed using AI to educate and engage communities in waste management practices. These applications can offer up-to-date details on recycling regulations, waste collection times, and even reward systems for proper waste disposal. This can be achieved through robust engagement with the community, which fosters a sense of responsibility and ownership over local waste management practices. For example, initiatives in Accra, Ghana, that utilized mobile platforms have led to increased public participation in recycling programs (Nkwo, Suruliraj & Orji, 2021).

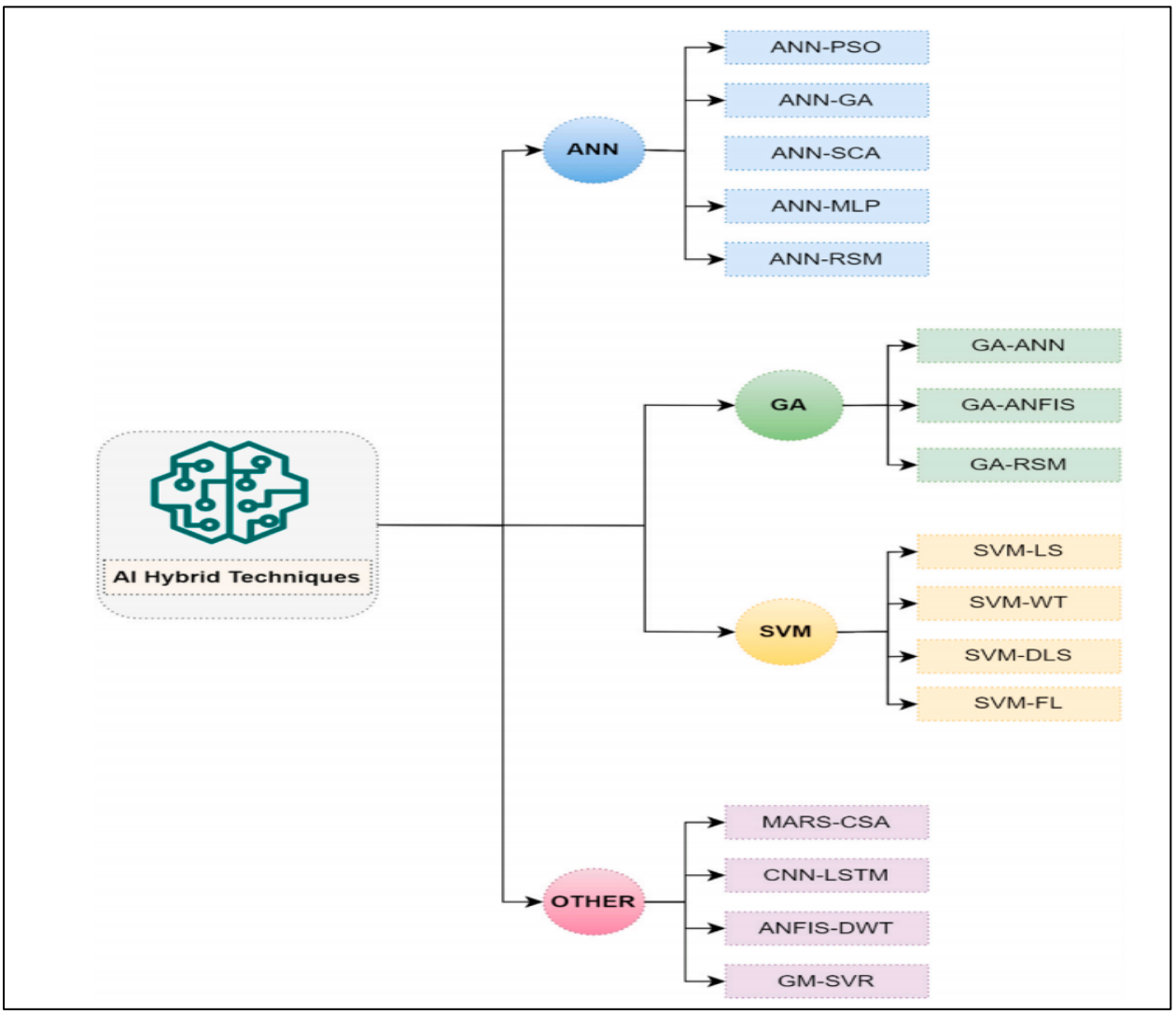


Figure 4: Categorisation of AI hybrid methods for forecasting and predicting solid waste generation.
Source: Ihsanullah I et al., 2022.

Predictive analytics are utilized to estimate future waste generation trends by analyzing historical data, demographic shifts, and urban development plans. This information guides infrastructure investments and policy-making by enabling municipalities to anticipate and address waste-related challenges proactively. By planning, waste management systems can shift from reactive responses to proactive strategies, leading to more efficient resource allocation and improved infrastructure development (Challoumis, 2024) AI tools, such as drones and remote sensors, are used or can be used to monitor waste disposal locations and guarantee compliance with environmental regulations. These technologies quickly identify illegal dumping or non-compliance issues, which enhances monitoring of environmental violations and fosters accountability among waste management entities. Research indicates that AI-assisted monitoring, to a large extent, decreases illegal dumping incidents in developing countries (Olawade, Wada, Ore, David-Olawade, Esan, Egbewole & Ling, 2024). However, researchers like Nwokediegwu, Ugwuanyi, Dada, Majemite, & Obaigbena (2024) noted that developing countries continue to encounter obstacles in integrating AI into solid waste management, including limited public awareness, insufficient environmental legislation, and inadequate financial resources. These problems make it difficult for waste management systems to adopt and use cutting-edge technologies.

4.0 Comparison of AI Applications across Different Countries

Artificial Intelligence (AI) is revamping the solid waste management (SWM) terrain across developing countries. For instance, in Nigeria, Ghana, South Africa, Cameroon, and Kenya, AI is being harnessed to improve efficiency, reduce environmental effects, and promote sustainable practices. A comparative analysis of AI applications in SWM across these countries indicates differing levels of adoption and innovation. In Nigeria, AI is being incorporated into waste management systems to enhance waste collection and recycling processes (GSMA, 2024). Ghana, while having limited specific AI applications in SWM, is exploring AI to optimize waste sorting and recycling processes. According to Debrah, et Al. (2021), innovative practices such as the use of plastic are being implemented for sustainable waste management in the environment. Similarly, AQUILA– a smart bin was designed for waste management using Artificial Intelligence and Internet of Things (Osei-Tutu, 2021). It is interesting to note that South Africa has been prescient in adopting AI technologies, with municipalities leveraging AI to enhance urban services, including waste management (Microsoft, 2024). Cameroon and Kenya are also making strides in AI-enabled waste management. Kenya has implemented AI-enabled technologies to automate waste disposal, collection, and recycling processes (Urban Agenda Platform, 2023), while Cameroon is showing interest in integrating AI and Internet of Things (IoT) technologies to improve waste management practices. Noteworthy, are the common objectives, including automation of waste processes, data-driven decision-making, and public engagement and education. However, the extent and specific applications of AI vary across countries. Despite the profitable applications, several challenges hinder the widespread adoption of AI in SWM, which are discussed in the section below. Addressing these challenges is crucial for the successful integration of AI in waste management across these nations.

5.0 Challenges

Many developing countries do not have the necessary infrastructure needed for functional waste collection, treatment, and disposal. A study by (Thakur & Sharma, 2021) found that over 2 billion people globally do not have their waste collected, and in many urban areas, collection services cover only a fraction of the waste generated. Limited monetary aids prevent the implementation of efficient Waste Management Systems. According to a report by the World Bank (2018), many municipalities allocate less than 1% of their budgets to waste management, leading to insufficient services and poor waste management practices. In developing nations, the non-formal sector is a key player in managing waste, often handling a large share of waste collection and recycling efforts. Yet, this sector is often overlooked and not properly regulated, lacking support and acknowledgement from official bodies. This oversight can result in poor health and safety conditions for workers and less efficient waste management procedures. The lack of understanding among waste handling workers regarding waste segregation and recycling practices worsens the waste management problem. Studies show that involving communities and educating them is crucial for better waste management results (Hoornweg & Bhada-Tata, 2012).

In contemporary times, poor waste management has led to significant environmental challenges, including pollution and public health issues. Studies show that inadequate waste disposal contributes to urban flooding and the spread of diseases. (Olayinka, Fagbohun & Adekunle, 2017). Also, developing countries often face technological and financial constraints that hinder effective waste management. Investments in infrastructure and education about waste management are crucial for improving systems (Thakur & Sharma, 2021). Effective solutions should involve waste reduction, recycling, and community engagement to develop a more long-lasting Waste Management Systems.

Despite the promising outcomes, the performance of AI in Developing countries' Waste Management sector faces several setbacks which include:

5.1. Technical Challenges

Data quality and availability remain significant hurdles. Reliable information on waste generation, collection, and disposal is frequently limited and inconsistent, which hampers the effectiveness of AI models (Nnonyelu & Dongjie, 2024). Additionally, integrating Artificial Intelligence systems into current waste management systems is complex, requiring substantial technical expertise and resources.

5.2. Financial Barriers

One major obstacle to adopting AI technologies is the high upfront costs, especially for municipalities with limited resources. Although long-term cost savings are anticipated, the upfront investment in AI hardware, software, and training can be prohibitive (Adama et al., 2022). Securing funding from government budgets, international donors, or private investors is often challenging.

5.3. Social and Cultural Barriers

Public acceptance and trust in AI technologies are important for successful implementation. However, the perceived complexity of Artificial Intelligence systems and automation-related job displacement are causes for concern. Education and awareness campaigns are necessary to build public trust and show the benefits of Artificial Intelligence in enhancing waste management (Ibeh, 2019).

5.4 Regulatory and Policy Challenges

Nigeria's waste management regulations are still developing, and AI technologies require explicit rules and regulations. Standardization of data collection, processing, and reporting practices is essential for ensuring optimal usage of AI in SWM (Ibeh, 2019).

5.4.1 Regulatory Framework and Policies

The following regulations and policies can be instrumental to the adoption of AI in solid waste management in developing countries: Establish clear procedures for data compilation, repository, and use of private information generated by AI-powered waste management systems; Create a national AI blueprint that includes solid waste management as a key area for AI adoption; Initiate public awareness campaigns to enlighten residents on the functions and advantages of AI-powered waste management; Ensure impartial access to AI-powered wase services across various communities; Provide financial incentives for pilot projects and new developments that showcase the efficient use of AI in solid waste management; and Invest in digital infrastructure such as sensors, IoT equipment and data analytics platforms.

6.0 Conclusion and Recommendations

The integration of Artificial Intelligence into Solid Waste management in developing nations presents a transformative opportunity to transform waste management approaches. Through the leverage of AI-powered technologies, developing countries can significantly increase operational output, lower running costs, boost sustainability, and promote cleaner and healthier environments. To fully harness this potential, policymakers, practitioners, and stakeholders must work together to create an enabling environment for AI adoption. This can be achieved through the development of national and local policies supporting AI adoption in Solid Waste Management and the establishment of regulatory frameworks for data sharing and privacy. Investments in Internet of Things (IoT) sensors, data analytics platforms, and AI-powered waste classification and sorting systems are crucial for building smarter waste management infrastructure. Mobile applications can also be developed to engage citizens and facilitate waste reporting. Capacity building and training programs should be implemented to equip waste management professionals with the skills required to effectively utilize AI applications. Decision support systems can be developed to aid waste managers in making informed decisions. Research and development initiatives should focus on exploring AI applications in solid waste management specific to developing countries. Context-specific AI models can be developed to predict Waste Generation Patterns and AI-driven waste-to-energy conversion technologies can be explored. A phased implementation roadmap should be adopted, commencing with feasibility studies, needs assessments, and pilot projects. Successful initiatives can then be scaled up to achieve a broader impact. Key performance indicators, such as reduction in waste collection costs, increase in recycling rates, improvement in waste management efficiency, and enhancement of community engagement and satisfaction, should be established to measure progress. Ultimately, embracing AI in solid waste management offers a promising pathway towards sustainable, efficient, and responsive Waste Management Systems in developing nations, mitigating human health and environmental impacts for generations to come. Hitherto, the following research areas are suggested for further studies: Knowledge, attitude and utilisation of Artificial Intelligence in solid waste management in developing countries; Environmental impact assessment of AI-powered waste management systems; and Integration of IoT and AI for smart waste management.

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ENHANCING ARTIFICIAL INTELLIGENCE ADOPTION FOR OCCUPATIONAL SAFETY IN THE NIGERIAN CONSTRUCTION INDUSTRY

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ABSTRACT
The rate of accidents and injuries experienced by construction workers within the Nigerian construction industry is higher when compared to that of other developed countries. This study assessed strategies to enhance adoption of artificial intelligence (AI) in reducing occupational risk in the Nigerian construction industry with a view to improving safety performance at construction sites. Questionnaires were administered to the research population and 95% response rate was recorded. The use of descriptive and inferential statistical techniques was employed for the analysis of the data. Findings from this study show that the accidents that occur most often are those that ignore safety procedures (RII = 0.95, ranked 1st). All the ten (10) drivers identified for the adoption of AI in construction H&S management were significant based on the differences in professionals among the respondents using the Kruskal-Wallis H test. On average, the major drivers for AI adoption in construction H&S management were very significant (average RII = 0.81). On the average, all of the ten (10) strategies identified for enhancing the implementation of AI technology for H&S management were very effective (average RII = 0.81). Therefore, this study concludes that the Nigerian construction industry can reduce occupational risk by adopting strategies, such as "Providing comprehensive training programs to familiarize construction professionals with AI technologies"; "Initiating pilot projects to showcase the effectiveness of AI-based H&S management"; and "Fostering collaboration among stakeholder", for enhancing AI. The study recommends that construction firms and all other relevant stakeholders develop a mechanism that incorporates all the identified strategies to enhance the implementation of AI technology for H&S management.

Keywords: Artificial Intelligence, Construction Industry, Occupational Risk, Reducing, Strategies

1 INTRODUCTION

Construction workers' safety is a major concern at construction sites all over the world. Dawoud and Faluoji (2017) identified the Nigerian construction industry as one of the most hazardous workplaces, presenting a diverse range of health risks. Ahn *et al.* (2018) noted the active development of construction automation technologies in response to the reduced supply of functional labor, the increased demand for reduced construction times, and an increase in safety-related construction accidents.

Melzner *et al.* (2013) noted that accidents on site remain a major concern as they contribute to very serious injuries or even fatalities on construction projects around the world. Because the standards and rules for protective safety equipment vary by country, a growing number of internationally operating companies are in need of tools that allow ubiquitous understanding and safety planning, regardless of the country where they operate. According to Ahn *et al.* (2018), AI technology serves as a representative tool for implementing construction automation, addressing all safety concerns on construction sites.

Safety-related construction accidents should be prevented by taking into consideration the varying and dynamic natures of construction sites (Kim *et al.,* 2017). Therefore, Ahn *et al.* (2018) revealed that notifying workers in a timely manner of potential accidents that are most likely to happen would be very helpful to prevent such safety-related construction accidents. Artificial intelligence (AI) is important for predicting safety-related construction accidents through an artificial neural network. Fortunately, studies have revealed that application of AI in construction Health and Safety (H&S) has a potential to improve the H&S performance of construction firms (Blanco *et al.,* 2018; Oprach *et al.,* 2019).

Unfortunately, the Nigerian construction industry is yet to embrace the application of AI in construction site H&S management (Abioye et al., 2018; Kamilu et al., 2023). This is why the construction industry is still characterized with the problem of enforcing compliance by the safety personnel due to negligence, over confidence and familiarity with the job process. In spite of the fact that the construction industry is one of the highest employers of skilled and unskilled labour, this ugly trend often leads to site closures, loss of man-hours, payment of compensation and loss of reputations which affects the performance of the industry and its contribution to national development. Despite the active pursuit of several studies on AI's application in the construction field, no research has yet focused on the primary areas requiring its use. Moreover, despite long-standing debates on safety on construction sites and the implementation of action and remedial steps, safety-related accidents still frequently occur on site. It is therefore imperative to assess the strategies for enhancing the adoption of AI in reducing occupational risk in the Nigerian construction industry.

2 RESEARCH QUESTIONS

In order to solve the problem identified in this research, the following questions were answered:

i. What are the main causes of accidents in the Nigeria construction industries?
ii. What is the current level of adoption of AI in construction H&S management in Nigeria?
iii. What are the barriers to the adoption of AI in construction H&S management?
iv. What are the major drivers for the adoption of AI in construction H&S management?
v. How can the strategies to enhance implementation of AI technology for H&S management in the Nigeria construction industry be developed?

3 JUSTIFICATION FOR THE STUDY

Past and existing studies have contributed a lot to the application of AI on construction workplace safety management. In the foreign domain, Abioye *et al*. (2021) studied a review of the present status, opportunities and future challenges of AI in the construction industry through an extant review of literature on articles and papers all over the world and written in English. The study found that AI is currently revolutionising industries such as manufacturing, retail, and telecommunications. The subfields of AI such as machine learning, knowledge-based systems, computer vision, robotics and optimisation have successfully been applied in other industries to achieve increased profitability, efficiency, safety and security. While acknowledging the benefits of AI applications, numerous challenges which are relevant to AI still exist in the construction industry. In the same vein, Rampini *et al*. (2022) assessed AI feasibility in construction industry. The study covered European countries, especially Italy, United Kingdom, and United States. The study discovered that AI has a great impact on increasing productivity and economic growth in many sectors. However, in the construction industry in developed countries are exploring the opportunities and applying the use of AI in construction risk management.

Still on the premise of foreign domain, Holzmann and Lechiara (2022) studied the application AI for project management theory and practice in the construction industry by analyzing the expectations of project professionals. The study covered sixty-three (63) practitioners in twenty-five (25) different construction companies based in fifteen (15) different countries (7 USA, 3 Israel, 2 Italy, 2 Spain and 1 from Australia, Belgium, Canada, Germany, Malaysia, Mexico, Peru, Singapore, South Africa, Sweden, UK). The study found that construction project practitioners are looking for AI solutions to support the quantitative processes mainly related to scope, schedule, cost, quality, and risk management. However, the human-related processes, such as communication and stakeholder management, are not expected to be directly enhanced by AI, although might benefit from it indirectly. Tjebane *et al*. (2022), in another study, examined the organisational factors of AI adoption in the South African construction industry. The study discovered that construction organisations of developing countries such as South Africa are still lagging in recognising the need to adopt emerging digital innovations such as AI to improve the built sector's performance.

However, in the Nigerian domain, Tunji-Olayeni *et al*. (2020) addressed the critical success factors for the diffusion of AI in the Nigerian construction industry. The study established that the use of AI in the construction industry particularly in developing countries such as Nigeria is limited. The study found that institutional factors, behavioural factors and cost factors were the most critical success factors for the diffusion of AI in the Nigerian construction. Kamilu *et al*. (2023) studied the level of adaptability of AI

technology in project management tasks using an exploratory study of Northern Nigerian projects. The study established that the adoption of AI technologies in project management is assuming a phenomenal dimension, but unfortunately low in Nigeria projects. The study concludes that interface between AI technologies and project management would improve project success in Nigeria projects.

In view of the above background, it can be seen that foreign studies made more efforts in the area of AI adoption in construction site safety than the Nigerian studies. This is why the level of awareness and adoption of AI in solving safety challenges in the Nigerian construction sites still seem very low. This constitutes a research gap needed to be filled. In order to fill this research gap, this study sets out to assess and develop strategies to enhance adoption of Artificial Intelligence (AI) in reducing occupational risk in the Nigerian construction industry with a view to improving safety performance at construction sites.

Successful outcome of this research will provide a guide to the construction industry on the procedure for effectively embracing AI technology in reducing accidents on construction sites. The study's outcome will also enable construction firms to make policies that will guide workers to be able to safely carry out activities on site with reduced rate of accidents, hazards and risks to the barest minimum.

4. LITERATURE REVIEW

Accident is an unplanned event which has the capacity to cause injury or damage and is attributed to either unsafe act or an unsafe condition (Doko *et al.,* 2019). Umeokafor *et al*. (2015) stressed that accident is an unplanned and unexpected occurrence that upsets a planned sequence of work thereby resulting to loss of production, injury to personnel, damage to plant and equipment as well as eventual interruption of production flow. The construction industry has however been classified as a high-risk industry (Occupational Safety and Health Administration, OSHA, 2018). The consistent increase in the rate of accidents and illnesses recorded in the construction industry tagged the industry as one of the most hazardous and high-risk occupation (Shittu *et al.,* 2022a). In developing countries, attention to health and safety issues at worksites is very low, most tasks are performed manually, occupational exposure to hazards is very high, and record- keeping is of poor quality when measured by international standards. In Nigeria, the construction industry loses 5 – 7% of its workforce annually to construction accidents (Mohammed *et al.,* 2022).

One of the main factors for the high percentage of accidents and injuries in the construction industry is the dynamic constantly changing work environment, where it is typical to have several teams working on different tasks in the same zone and changing as the project proceeds hence lacking consistency, continuity and expertise in a specific trade. The stress of meeting deadlines and avoiding penalties is another major contributing factor (Ramya and Ramadasan, 2016). The common construction accidents and injuries include exposure to hazardous materials, electrical shock, getting hit by moving equipment, falling from a height, vehicle accidents, fractures, burns, sunstroke, amputation, being struck by heavy construction equipment, bruising, fainting, coma and death (OSHA, 2018). It has also been determined that most of these accidents and injuries occur due to a lack of knowledge, a lack of safety training, human errors, unskilled workers, lack of proper supervision, carelessness, apathy and downright recklessness.

Construction workers can face a variety of risks on job sites, especially when safety protocols are not followed. Many of the risks can lead to serious injuries and even fatalities. For instance, in 2020, the number of nonfatal falls, slips, and trips was higher for construction workers than for all workers in other industries, according to the Bureau of Labour Statistics (BLS) (2020). The specific types of job site risks that construction workers face may depend on the project. However, some dangers are more common than others.

5. RESEARCH METHODS

This study adopted the quantitative research approach. Therefore, the use of structured questionnaire was employed to collect data. The study population for this research consists of all the construction firms engaged in building and civil engineering construction works doing business in the Nigerian building industry. However, the data were sourced from the Architects Registration Council of Nigeria (ARCON, 2022), the Council of Registered Builders in Nigeria (CORBON, 2022) and the Nigeria Institution of Quantity Surveyors (NIQS). https://niqs.org.ng/) revealed that a total of 925 firms were registered in the three cities selected as shown in Table 1.

Table 1: Sample size

Cities/ Type of	Architectural firms	Building Contracting	Quantity Surveying	Total Popul	Sample

Firms		and Consulting Firms	firms	ation	size
Lagos (Population)	330	12	120	462	-
Sample size for Lagos	132	5	48	-	185
Abuja (Population)	253	31	84	368	-
Sample size for Abuja	101	12	34	-	147
Port-Harcourt (Population)	67	6	22	95	-
Sample size for Port-Harcourt	27	2	9	-	38
TOTAL				**925**	**370**

A simple random sampling technique was used to select construction professionals within contracting firms in the study areas. Analysis of data was undertaken with the use of descriptive analytical technique such as frequency count, percentage and Relative Importance Index (RII). The Kruskal-Wallis H test was used to determine if there are statistically significant differences in professional of the respondents and current level of adoption of AI in construction H&S management and drivers for the adoption of in construction H&S management.

6. DATA ANALYSIS

Results and discussion on main causes of accidents in the Nigeria construction industry

Table 2 reveals twenty-two (22) identified main causes of accidents in the Nigerian construction industry, of which four occur most often and the remaining eighteen occur very often, with RII ranging from 0.95 to 0.70. The accidents that occur most often were Ignoring safety procedure (RII = 0.95 ranked 1st), Failure to use personal protective equipment (PPE) (RII = 0.93 ranked 2nd), Human factor (RII = 0.92 ranked 3rd), and Faulty/defective equipment (RII = 0.90 ranked 4th), while the accidents that least occur accidents were Crane accident(RII = 0.72 ranked 19th), Overexertion equipment (RII = 0.72 ranked 19th), Electrocution (RII = 0.71 ranked 21th), and Chemical and toxin exposure (RII = 0.62 ranked 22nd). The average RII value shown is 0.82, which implies that the identified accidents occur very often. This is in tandem with past studies. Abdul Hamid *et al.* (2008), Umeokafor *et al.* (2015), Ramya and Ramadasan (2016), and OSHA (2018) assert that construction health and safety legislation can be a complex and overwhelming issue, often overlooked. But we also know that ignoring a problem rarely makes it better. In fact, it often makes things worse, and where Health and Safety is concerned, ignorance has the potential to make matters much worse. An average construction worker, most especially the workmen, exhibits behaviours that would make others feel they are inhuman by nature; such behaviours include refusing to wear a helmet or safety boot, making use of a harness belt, using an ear plug, and keeping areas barricaded with caution tape. This often makes it difficult for the safety personnel on site to enforce health and safety compliance.

Table 2: Main Causes of Accidents

Code	Main causes of accidents	RII	Rank	Decision
B4	Ignoring safety procedure	0.95	1st	Most Often
B5	Failure to use personal protective equipment (PPE)	0.93	2nd	Most Often
B6	Human factor	0.92	3rd	Most Often

B1	Faulty/defective equipment	0.90	4th	Most Often
B7	Engaging unqualified workers	0.89	5th	Very Often
B9	Lack of safety training	0.88	6th	Very Often
B3	Sub-standard construction materials	0.88	6th	Very Often
B10	Falls from heights	0.87	8th	Very Often
B2	Excessive noise	0.85	9th	Very Often
B8	Unsafe/incorrect construction method	0.85	9th	Very Often
B21	Forklift accident	0.83	11th	Very Often
B13	Caught-in-between	0.82	12th	Very Often
B11	Struck-by accident	0.81	13th	Very Often
B14	Trips and slips	0.80	14th	Very Often
B16	Vehicle	0.79	15th	Very Often
B17	Demolition	0.77	16th	Very Often
B15	Fire and explosion	0.76	17th	Very Often
B19	Ground collapse	0.74	18th	Very Often
B20	Crane accident	0.72	19th	Very Often
B18	Overexertion	0.72	19th	Very Often
B12	Electrocution	0.71	21th	Very Often
B22	Chemical and toxin exposure	0.70	22nd	Very Often
	Average RII	***0.82***		***Very Often***

Results and discussion on current level of adoption of AI in construction H&S management

Table 3 gives a summary of the RII results of the current level of adoption of AI in construction H&S management. Table 4.3 reveals six (6) current levels of adoption of AI in construction H&S management. The ranking ranged from "the current level of AI adoption in the Nigerian construction industry is low" (RII = 0.94, Kruskal-Wallis H value = 11.3 and Asymp. Sig. = 0.00) to "the Nigerian construction industry practically does not put AI to use, which is average" (RII = 0.60, Kruskal-Wallis H value = 14.9 and Asymp. Sig. = 0.00). On average, there is a high level of AI adoption in construction H&S management (average RII = 0.84). This finding is consistent with Holzmann and Lechiara (2022), who reported that additional impediments at the company level (such as corporate culture, lack of skills and knowledge, and required implementation efforts and funds) and at the industry level (such as legal issues, technological readiness, and available solutions) impede the integration of AI applications in projects.

Table 3: Results of Current Level of Adoption of AI in Construction H&S Management

Code	Current level of adoption of AI in construction H&S management	RII	Kruskal-Wallis H	Asymp. Sig.	Rank	Decision
C2	The current level of AI adoption in the construction industry in Nigeria is low	0.94	11..3	0.00	1st	**Very High**
C3	Most construction firms do not	0.92	2.18	0.02	2nd	**Very High**

Code	Current level of adoption of AI in construction H&S management	RII	Kruskal-Wallis H	Asymp. Sig.	Rank	Decision
	rely on AI products to reduce construction accidents and fatalities.					
C4	Innovation of artificial intelligence is still limited to paper work in Nigeria construction industry	0.90	0.65	0.00	3rd	**Very High**
C6	Currently, there are very few AI solutions for the management of construction projects available in the market	0.88	4.56	0.0	4th	**High**
C1	Application of AI is growing because of its ability to provide solutions in uncertain and complex situations	0.85	0.31	0.00	5th	**High**
C5	AI is practically not put to use in the Nigerian construction industry	0.60	14.9	0.00	6th	**Average**
	Average RII	***0.84***				**High**

Results and discussion on the strategies that will enhance implementation of AI technology for H&S management

To rank the identified strategies that will enhance implementation of AI technology for H&S management, RII was employed to rank the perceptions of respondents. Table 4.4 presents the result of this analysis.

Table 4.4: Result of Strategies that will Enhance Implementation of AI Technology for H&S Management

CODE	Strategies	RII	Rank	Decision
F1	Provide comprehensive training programs to familiarize construction professionals with AI technologies and their potential applications in H&S management.	0.89	1st	Very Effective
F2	Initiate pilot projects to showcase the effectiveness of AI-based H&S management solutions in real-world construction settings.	0.87	2nd	Very Effective
F3	Foster collaboration between technology providers, construction companies, industry associations, and government agencies to facilitate the	0.86	3rd	Very Effective

CODE	Strategies	RII	Rank	Decision
	development and deployment of AI solutions for H&S management.			
F6	Advocate for supportive regulatory frameworks that encourage the responsible adoption and use of AI technologies for H&S management.	0.82	4th	Very Effective
F5	Implement change management strategies to overcome resistance to technological change and promote a culture of innovation within construction organizations	0.80	5th	Very Effective
E6	Encourage collaboration, peer-to-peer support, and continuous learning to foster a culture of innovation and continuous improvement.	0.78	6th	Very Effective
F8	Implement mechanisms for continuous monitoring, evaluation, and feedback to assess the effectiveness of AI-based H&S management strategies.	0.76	7th	Very Effective
F7	Develop robust data governance policies and privacy protocols to govern the collection, storage, and sharing of H&S data generated by AI systems.	0.76	7th	Very Effective
F9	Provide incentives, awards, and recognition programs to incentivize construction companies and individuals to adopt AI technologies for H&S management.	0.74	8th	Very Effective
F10	Encourage collaboration, peer-to-peer support, and continuous learning to foster a culture of innovation and continuous improvement.	0.73	9th	Very Effective
	Average RII	***0.80***		***Very Effective***

Table 4.4 revealed ten (10) strategies that will enhance the implementation of AI technology for H&S management, with RII values ranging between 0.89 and 0.73. Factors ranging from "Provide comprehensive training programmes to familiarise construction professionals with AI technologies and their potential applications in H&S management" (RII = 0.89) to "Encourage collaboration, peer-to-peer support, and continuous learning to foster a culture of innovation and continuous improvement" (RII = 0.73) were all ranked as very effective. On average, all of the strategies that will enhance the implementation of AI technology for H&S management are very effective (average RII = 0.81). The findings from this study, in tandem with submissions from Razi et al. (2023), suggest three basic

strategies for enhancing the adoption of AI technology in construction safety management which are; (i) Provide comprehensive training programmes to familiarise construction professionals with AI technologies and their potential applications in H&S management (ii) Foster collaboration between technology providers, construction companies, industry associations, and government agencies to facilitate the development and deployment of AI solutions for H&S management; (iii) Tailor AI solutions to suit the specific needs and requirements of the construction industry, considering factors such as project complexity, site conditions, workforce demographics, and regulatory compliance.

This led to the suggestion that future studies should investigate how AI impacts safety across all stages of the construction process, and initiation of a study on the advancement of AI in safety applications. Finally, Razi et al. (2023) suggested that future studies should explore the comparison between AI and IoT (Internet of Things) in construction safety issues.

7. CONCLUSIONS

This study aims to assess strategies for enhancing the adoption of artificial intelligence (AI) in reducing occupational risk in the Nigerian construction industry with a view to improving safety performance at construction sites. The accidents that occur most often were Ignoring safety procedure Failure to use personal protective equipment (PPE), Human factor and Faulty/defective equipment, while the accidents that least occur accidents were Crane accident, Overexertion equipment, Electrocution, and Chemical and toxin exposure. The study revealed that, on average, there is a high level of AI adoption in construction H&S management. Based on the differences in professionals among the respondents using the Kruskal-Wallis H test, twenty-one barriers were significant, while nine were not.

On average, all of the identified barriers to AI adoption in construction H&S management were severe. However, these barriers were regrouped into five main groups such as *Technical Barriers*; *Socio-Economic Barriers*; *Corporate Policy Barriers*; *Legal/Policy Implementation Barriers*; and *Public Relations Barriers* for effective organisational policy formulation and decision-making. All the drivers for the adoption of AI in construction H&S management were significant based on the differences in professionals among the respondents using the Kruskal-Wallis H test. The major drivers for AI adoption in construction H&S management were, on average, very significant. On average, all of the strategies that will enhance the implementation of AI technology for H&S management are very effective. Therefore, this study concludes that the Nigerian construction industry can reduce occupational risk by adopting strategies, such as "Providing comprehensive training programs to familiarize construction professionals with AI technologies"; "Initiating pilot projects to showcase the effectiveness of AI-based H&S management"; and "Fostering collaboration among stakeholder", for enhancing artificial intelligence.

In the light of the findings and conclusion of this study, the following recommendations were made:

i. The main causes of accidents in the Nigerian construction industry, including "Ignoring safety procedures, failure to use personal protective equipment (PPE), and human factors," should receive more attention in order to enhance the adoption of artificial intelligence in reducing occupational risk.
ii. The findings revealed that the current level of adoption of AI in construction H&S management is low. Therefore, construction firms should address the barriers to the adoption of AI in construction H&S management, especially lack of understanding of the benefits of innovation, lack of skills and knowledge, and lack of required implementation efforts and funds. They also focused on the major drivers for the adoption of AI in construction H&S management, especially the availability of AI-based technology, competence-based development, and innovative organisational culture.
iii. In order to enhance the implementation of AI technology for H&S management, construction firms and all other relevant stakeholders should develop a mechanism that will include all the strategies identified for enhancing the implementation of AI technology for H&S management.
iv.

8. AREA FOR FURTHER STUDIES

In view of nature of the complexity and scope of the subject matter, and financial and time constraints faced by this study, the following areas have been suggested for further research:

1. Effect of construction workers' attitude on the utilization of AI tools for monitoring compliance to safety practices on construction sites.

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Development of Artificial Neural Network Models for Predicting Strength Properties of Tropical Clay Stabilized with Calcium Carbide Residue and Zeolite – A Review

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ABSTRACT

The paper presents a literature review on the development of models for predicting strength properties of tropical clay stabilize with Calcium Carbide Residue **(**CCR) and zeolite. Application of Artificial Neural Networks (ANNs) in geotechnical analysis of tropical clay stabilised with CCR and zeolite, have been evaluated. Chemical treatment of expansive clays involves development of optimum binder mix proportions or improvement of a specific soil property using additives. These procedures often generate large data, requiring regression analysis in order to correlate experimental data and model the performance of the soil in the field. These analyses often involve large datasets and tedious mathematical procedures to correlate the variables and develop required models using traditional regression analysis. The findings from this study shows that ANNs is becoming well known in dealing with the problem of mathematical modelling involving nonlinear functions due to their robust data analysis and correlation capabilities, which has enabled them to be successfully applied, and with high performance, to the stabilisation process of clays. The study also shows that the supervised ANN model is well adapted to dealing with stabilisation of clays with high performance as indicated by high R^2 and low Mean Average Error (MAE), Root Mean Square Error (RMSE), and Mean Square Error (MSE) values. The Levenberg–Marquardt algorithm is effective in shortening the convergence time during model training.

Keywords*: Artificial neural networks; Calcium Carbide Residue; clays; predictive models; Stabilisation; Zeolite*

1.0 INTRODUCTION

The increasing population of the world, especially in the developing nations, has led to increasing demand for roadways, railways, housing facilities and other infrastructures. Soil with higher stability is required to bear the weight of these structures. Generally speaking, the stability of any civil engineering structure directly or indirectly depends on the stability of the bearing soil (Akuto, 2021; Suleiman *et al.* 2021; Balarabe and Mary, 2015). While some soils have the required stability to bear the weight of these structures, some other soils are deficient in this regard.

Deficient soils are regarded as soils which do not meet some or all the criteria required for their satisfactory performance in geotechnical applications. These could either be for base courses in pavement construction, embankment for dams, subsoil base, clay liners for containment of leachates and backfill for retaining walls (Alhassan and Mustapha, 2015). In the tropical region, these soils could be lateritic soils, tropical black clay, collapsible soils or any other tropical soil type (Alhassan and Mustapha, 2015).

Tropical Clay Soil (TCS) are expansive soils that principally occur in arid and semi-arid regions of the tropical zone, marked by dry and wet seasons, with low rainfall, poor drainage and exceedingly great heat (Nelson and Miller, 1992; Eberemu *et al,* 2012). Because of their unconventional behavior, they are problematic in geotechnical engineering applications because they exhibit large volume changes with respect to variation of moisture content (Eberemu *et al.,* 2012).

Tropical clay soil presents various challenges to engineers all over the world due to their characteristic of severe loss of strength and swelling with respect to changes in moisture regime. As a result, structures and highways constructed on them are subjected to severe deformations and frequent repairs, leading to high cost of maintenance. Various efforts have been made to stabilize tropical clay with cement, lime, admixtures and waste products, to make them meet the requirements for construction works (Balogun, 1991; Osinubi *et al*.; 2009; Suleiman *et al*, 2021).

Soil stabilization refers to the improvement of the bearing power of a deficient soil using compaction, proportioning and the addition of suitable stabilizers or appropriate

admixtures (Alhassan and Mustapha, 2015). Soil stabilization methods include chemical, mechanical and physico-chemical methods to improve soil properties such as strength, stability and reduce swelling. Stabilization methods can generally be categorized as physical and chemical methods (Neeraj and Ahirwar, 2014). Physical stabilization involves improving soil structure through mechanical methods, while chemical stabilization uses additives like lime or cement to enhance soil strength and durability. Together, these methods enhance the resistance to erosion and increase load-bearing capacity of the soil. Locally available materials have also been experimented as soil stabilizing additives.

For several years, researchers have recognized the use of locally available materials which are available from industrial and agricultural wastes to improve the properties of expansive soils. This is aimed at reducing stabilization costs, related to conventional stabilizing agents such as cement and lime, as well as reducing the problem of CO_2 emission that is related to cement manufacturing process (Balarabe and Mary, 2015).

Calcium Carbide Residue (CCR) is a by-product from the production of acetylene gas (C_2H_2) used in oxyacetylene welding (Johnson *et al.;* 2023). It consists mainly of lime, caustic solid substances, and is white in appearance when pure.

Zeolites as a pozzolan are aqueous aluminum silicate containing alkali and alkaline earth elements. Their structure is made up of a framework of SiO_4 and AlO_4 tetrahedrons linked to each other's corners by sharing oxygen atoms (Capucto *et al.;* 2008). Zeolites have been recognized for 200 years, but only during the middle of the twentieth century did they attract the attention of scientists and engineers, who demonstrated their technological importance in several fields (Hahwu *et al*.; 2008).

1.1. Artificial Neural Network

Artificial Neural Networks (ANNs), or more simply neural networks, are new systems and computational methods for machine learning, knowledge demonstration, and finally the application of knowledge gained to maximize the responses of complex systems (Grekousis; 2019). ANN is a data processing model based on the way biological nervous systems, such as the brain, process data. They are focused on the neuronal structure of the mamalian cerebral cortex, but data is much smaller scale. Many artificial intelligence experts believe that artificial neural networks are the best and perhaps the only hope for designing an intelligent machine.

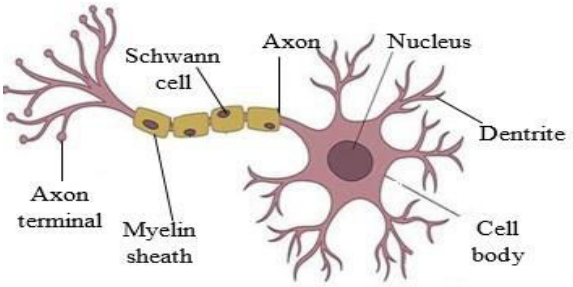
ANN, as a branch of artificial intelligence, is simply an automated optimisation system capable of learning the relationship and inter-dependencies between multiple input variables of a given system and modelling such relations (trends and patterns) in the form of mathematical functions for easy prediction (Stepniewska-Dziubinska *et al.;* 2018). ANN has been successfully used in the study of complex systems to identify patterns and model real-life problems relating to complex behaviours involving nonlinear functional relations. The capability of ANN to discover the mapping between several domains of data has drawn the interest of many researchers in geotechnical engineering (Lal and Tripathy, 2012). ANNs are classified based on numerous criteria such as the learning condition (supervised and unsupervised networks), based on model topography (feedforward or recurring networks), based on a number of hidden layers (shallow or deep networks), based on training algorithm (Back-Propagation Networks, Hopfield Networks, Self-Organizing Map Networks) *(*Chao, *et al*., 2018). This paper simplifies the underlying concepts of back propagation ANN models and explores its applicability in modelling the behaviour of stabilised clays viz a viz predicting the response of key soil parameters in other to clear the wide-spread complexities and misconceptions associated with the method and to encourage its use in soil stabilisation problems for more reliable solutions.

1.2 Components of Artificial Neural Network

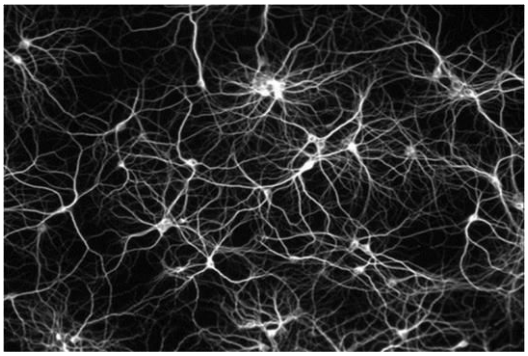
1.2.1 Neurons and Edges

ANN building blocks are a collection of neurons (nodes) and links, mimicking the biological neural network, as shown in Figure 1. The neurons are linked to other neurons by edges and are connected to others so that results from preceding neurons might automatically become inputs for succeeding ones, thereby creating the network. These neurons are the data collection or processing points in the network. Here, signals (input) are processed and transferred to other neurons through the connecting links with each neuron generating a unique output that may become inputs to multiple neurons. In this current subject area of application, these inputs would be laboratory results of key soil parameters described as the dependent variables. The input value of a given neuron is simply obtained by computing the weighted sum of the inputs from connected neurons with the addition of a bias (Grekousis, 2019). This output of the weighted summation then becomes the input for the activation function- a linear or non-linear function (Nihat, 2009).

Edges are the links or connections between neurons and convey signals with associated weights depending on the influence of the input from such a link on the output of a given neuron (Winston, 1992). Inputs parameters with greater importance are assigned a higher weight than those with lower importance (Zell, 2003). For instance, in a soil classification problem, the weights will be dependent on the contribution of the features in determining the class of soil (Cal, 1995). In a typical perceptron, as in Figure 2, the connection weights can be represented as *Wj*, which describes the importance of the connection.



(a)



(**b**)

Figure 1: (**a**, **b**) Biological Neural Network (Sharma, *et al.,* 2012)

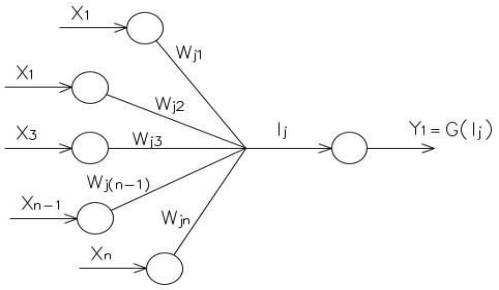


Figure 2: Typical Neuron showing associated edge weights

2.0 Materials and Method

Input data sets will be supplied to the neurons in the input layer and will be treated each with coefficients and constants known as weights and bias respectively to obtain a sum of weighted inputs and bias as given in Equation I

$$\rho = \sum_{i=1}^{n} xi.wij + b1 \qquad (1)$$

where (1)
P= weighted sum of inputand bias

Xi = input data i

Wij = weight associated with the input hidden layer and

Equation 3 will be treated with a tangent sigmoid activation function given in Equation 2 to obtain the first layer output given in Equation 3

$$\beta = \frac{2}{1+e^{-2x}} - 1 \qquad 2$$

Where

B = activation function

$$\boldsymbol{\phi} = \beta \sum_{i=1}^{n} xi.wij + b1 \qquad 3$$

where;

Φ is the hidden layer output

The first (hidden) layer output Φ be supplied to the neuron in the output layer and will be further processed with new weights and bias. The weighted sum will be further treated with a linear activation function given in Equation 4 to obtain the overall model output given in Equation 5 termed as the case 1 model.

$$f(x) = x \qquad 4$$

$$\boldsymbol{\xi} = \mu(\sum_{i=1}^{n} wij\,.\boldsymbol{\phi} + b2) \qquad 5$$

Where;

$\boldsymbol{\xi}$ = Output of the entire case 1 ANN model
μ = Input activation function $f(x)$
wij = weight associated with output layer and
b2 = bias associated with the output layer
The models will be trained using back propagation algorithm. The sequence requires updating the connection weights and biases according to the learning capacity of the network. The iterative process last up until the network is able to identify the smallest error between the actual experimental result and the model output based on the parameters given.

2.1. ANN Architecture

Deciding the ANN topography is a critical part of the model development and involves an iterative trial and error process (training) (Naidu, et al., 2020). In most studies, an initial model topography is assumed and trained while monitoring the performance of the model using predefined statistical measures such as coefficient of determination (R^2), Root Mean Square Error (RMSE), Mean Average Error (MAE) and Mean Square Error (MSE). The hyperparameters are continuously modified, and the model retrained until an optimum model architecture is obtained with the lowest error and highest R^2 (Eyo and Abbey, 2021). This training, in simple terms, is "showing the network an example" of the problem using experimental input and output data. Many training algorithms exist; quasi-newton backpropagation, Bayesian regularization backpropagation algorithm, gradient descent, Levenberg–Marquardt optimization, etc., but the process is similar and begins with feeding the model with a quality dataset and allowing the system to process this data in order to learn the relationship between the variables and hence generate weighted associations between the data within the network and predict

the result. The predicted result is then compared with the experimental result to evaluate the error, which is then used to modify the weights of the connections by a reverse error minimization process using a chosen cost function. The process is repeated until there is an insignificant change in the output of the cost function (Wald, 1950). Based on the performance of various models with different hyperparameters, the best model topography is then selected.

2.2. Feed forward and Recurring Networks

The ANN topography is such that the neurons are grouped into layers, namely input layers and output layers, and in some cases, there is the need to include hidden layers between the input and output layer, making a multilayered perceptron neural network model in order to create sufficient degrees of freedom to avoid overfitting. The hidden layer could be made one layer (shallow networks), as shown in Figure 3, or multiple layers (deep neural network, DNN) (Ikizler *et al.,* 2009). In addition, the connections between layers could be in such a way that a neuron in one layer could be connected to all neurons in the succeeding layer and is said to be fully connected, resulting in a larger number of neurons in the succeeding. Additionally, the models could be organized such that multiple neurons in a layer are connected to a single neuron of the succeeding layer. The latter condition is said to be a pooled connection and is synonymous with a lesser number of neurons in the succeeding layer even though one may be tempted to believe that a larger number of neurons will always result in a better prediction using ANNs. However, the optimum number of neurons will depend on several factors such as the amount of data and the complexity of the relationship. In certain types of NNs, such as the Deep Neural Network, the number of neurons has a lesser effect on the overall performance of the network than the number of layers and DNNs with more hidden layers have been shown to yield more results than shallow networks (network architecture with a single hidden layer). However, the number of hidden layers to be used in each network will depend on the complexity of the mapping between input and output domain, the quality and the amount of data (Sushama and Bindhu, 2015). Additionally, even though it is expected that a greater number of experimental datasets used in training the model will improve its performance, recent studies have shown that it might be advisable to use fewer experimental datasets of high quality than a large amount of experimental data which may be prone to errors (Stepniewska-Dziubinska *et al*., 2018). Moreover, the quality of the output is dependent on how the input database is utilized in the training. In terms of the way data is transferred from one layer of the network to another, one can generalize that there are two broad categories of ANN architecture—the recurring network and feedforward network. In the recurring network, there is a connection between neurons of a given layer and that of preceding and/or succeeding layers, forming a loop and allowing an input to be processed many times by the same neuron. Conversely, in the feedforward network, neurons in each layer are only connected to neurons in other layers as presented in Figure 4.

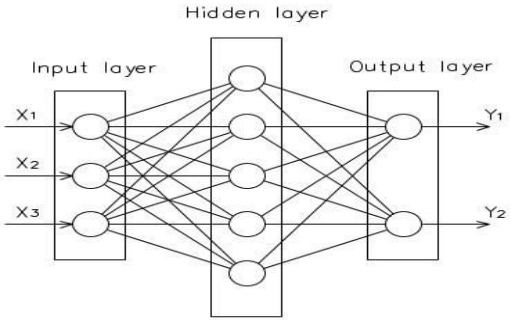


Figure 3: A Typical ANN Architecture Showing Neurons and Layers.

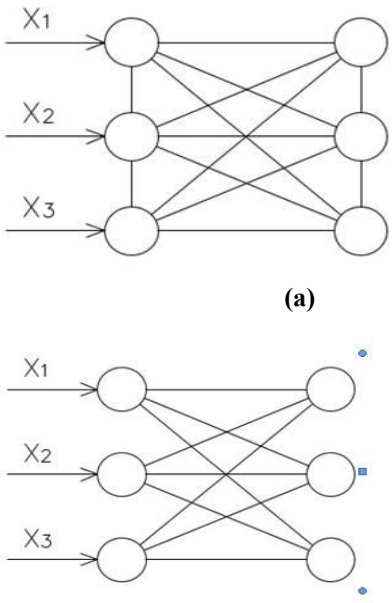


Figure 4. (**a**) Recurring Network; (**b**) Feed Forward Network.

2.3 Data Preprocessing

The input dataset used to develop ANN models for geotechnical engineering problems comprises of various ranges of input variables because the ANN neurons connection weights are representatives of the importance of the variables. The weights of the connections are influenced by the Euclidean distance which for any given points, y_1 (x_{11}, x_{21}, $x_{31,}$ . . . , x_{n1}) and y_2 (x_{12}, x_{22}, $x_{32,}$ . . . , x_{n2}) in a data space can be expressed as Equation (6). Therefore, in order to ensure that proper significance is attributed to the features, it is imperative to scale the features. Feature scaling can be achieved using methods such as standardization (Z-score normalization) or the max-min normalization method. For standardization, the feature X_i is expressed in its standardized form as in Equations (6) and (7) below.

$$d_E = \sqrt{(x_{12} - x_{11})^2 + (x_{22} - x_{21})^2 + .. + (x_{n2} - x_{n1})^2} \quad 6$$

$$X_s = \frac{X_i - \mu}{\sigma} \quad 7$$

$$X_{norm} = \frac{X_i - X_{min}}{X_{max}}$$

In Equations (1) and (2), X_s is the standardised value of X_i, μ is the mean and σ is the standard deviation. The input variables can also be scaled using the max-min normalisation to achieve the same purpose using the expression, where X_{norm} is the normalised value and X_{min} and X_{max} are the minimum and maximum values, respectively.

3.0 Selecting Design Parameters for ANN in Soil Stabilisation

Training of the neural network is actually the process of selecting or 'designing' the best network model parameters (hyperparameters). However, there is a start point, where a first architecture is proposed. Selecting the right number of neurons in the hidden layer is critical as it influences the performance of the network. Too few a number of neurons in the hidden layer can lead to underfitting. In this case, the training data presents a more complex problem than the network is modelled to handle. For some problems, increasing the number of neurons by introducing additional features can make learning easier for the model and resolve the problem. In some other cases, for example, in some geotechnical applications, the input parameters of interest may have been predetermined and measured, and this option may not be feasible. Alternatively, increasing the number of hidden layers and neurons may be helpful, but again, if the number of neurons becomes excess, this leads to overfitting. In this case, the model is training on less complex data than it is designed to analyse. The effect is that the model is unable to properly generalize on new data set outside the training data as the weights are not optimally adjusted. Additionally, an excessively high number of neurons in the hidden layer can extend training time and lead to poor training even with a sizable database for training. The goal, therefore, is to find a balance. However, this is not a straightforward process. A good step would be to make a good initialization of the network parameters, and there are several ideas concerning how these parameters can be initialized. Amongst the huge suggestions that are available and, of course, effective under different conditions, one simple empirical rule for selecting the number of neurons in the hidden layer is to use the mean of the number of neurons in both input and output layers. Some other idea involves taken about 60–70% of the total input and output neurons. In general, the idea is to provide a reasonable start so that during the training, the model can be optimised or pruned, and redundant neurons can be removed based on the assigned weights while keeping track of the performance. However, for most regression analyses relating to stabilisation, one hidden layer has been found very effective. In rare cases, two hidden layers have been used, but there are seldom cases where over two layers have been needed in developing reliable predictive models. As shown in the succeeding section, almost all the applications in soil stabilisation have utilised one hidden layer, with one or two utilizing more than one hidden layer.

3.1 Training, Validation, and Testing

As mentioned in the earlier section, the training of most neural networks applied to modelling geomechanical properties of stabilised Clay is done under supervised conditions. In this type of training, the supplied data are partitioned, and a part (training dataset) is utilised in learning the relationship between the variables, thereby providing the initial weights. This sample is continuously fed to the network with a view to understanding the data rather than recognizing it. If the network learns progressively, it converges with reduced error after each iteration until a pre-defined error range is attained. The quality of the training dataset influences the convergence of the model (Murata*, et al.,* 1993). A dataset may lack the necessary independent variables required for the model to understand the data and hence can lead to non-convergence. A very small sample space can lead to the network memorizing rather than learning. Hence, it is important that part of the data is separated to be used in evaluating the training. This is the validation dataset. The major aspect of developing a suitable model would then be to continuously monitor and tweak the number of neurons in the hidden layer, or the number of hidden layers, modify the activation function or even the training algorithm (Maind and Wankar, 2014). The model validation utilizes the successive trial of the trained model on the validation dataset (Gareth, 2013). This is an unbiased evaluation of how well the model understands the training data. The final test of the model's predictive ability is carried out on the test dataset, which was never seen by the model. In some cases, the data are continuously partitioned into two as in cross-validation. The dataset is switched and utilised for training and validation in a crossed pattern.

The performance of models is usually evaluated by using statistical measures such as the coefficient of determination (R^2), the mean absolute error (MAE), the root mean square error (RMSE), the mean square error (MSE) and others. The R^2, MAE, RMSE and MSE expressions are defined in Equations (8), (9), (10) and (11), respectively.

$$R^2 = \left(\frac{\sum_1^n \left(y_{exp\,(i)} - \overline{y}_{exp}\right)\left(y_{pre(i)} - \overline{y}_{pre}\right)}{\sum_1^n \left(y_{exp\,(i)} - \overline{y}_{exp}\right)^2 \sum_1^n \left(y_{pre(i)} - \overline{y}_{pre}\right)^2} \right)^2 \quad 8$$

$$MAE = \frac{I}{n}\left(y_{exp\,(i)} - y_{pre(i)}\right) \quad 9$$

$$RMSE = \sqrt{\frac{1}{n} \times \sum_1^n \left(y_{exp\,(i)} - y_{pre(i)}\right)^2} \quad 10$$

$$MSE = \frac{1}{n} \times \sum_1^n \left(y_{exp\,(i)} - y_{pre(i)}\right)^2 \quad 11$$

For which $y_{exp\ (i)}$ and $y_{pre(i)}$ are experimental and predicted values of a given dependent variable, while y_{pre} and y_{exp} are the mean values of the predicted and experimental values.

3.2. Estimating the Amount of Training Data

Determining the sample size required for successful model training is a vital step in successful model development. A common start-off point is the "rule of ten", which proposes that the training sample size is taken as not less than ten times the number of network parameters. The number of parameters may be estimated as the number of edges or connections, including biased neurons. It is expected that the performance of the model would improve with increasing sample size following a power function up to a point is reached where there is no significant increase in performance. Usually, in practical situations, the data set is split into the ratio of 70%:30% or 80%:20%, where the higher percentage is that of the training sample space. Although this split is only important with a relatively low sample size. The underlying idea is to make available sufficient example data with which the network is trained and evaluated. Too little training data will result in a higher variance of the network parameters. Additionally, two few testing data will create higher variance during the evaluation of the performance of the model.

4.0 Application of ANN in Predicting the Properties of Stabilised Clays

The variability of soils following uncontrollable and imprecise chemical and mechanical processes of their formation makes it very complex to predict their behaviour even in the natural state. Several mathematical and graphical models have been proposed for use in modelling the post-stabilisation behaviour of treated clays through the prediction of various engineering parameters for the purpose of design and construction. These methods rely on laboratory results of a few samples with which in-situ post-stabilisation behaviour is to be predicted. However, in many cases, the post-stabilisation behaviour of any soil will be dependent on multiple variables such as curing time, curing duration, soil type, binder content, curing temperature, moisture content, compaction method and effort, plasticity, etc., which are key and influence the dependent variables (Lorenzo and Bergado, 2004). The large variability of input parameters, the extensive laboratory experiments required and the unknown relationship between the variables, put together makes it even more complex to predict the behaviour of the soils (Fan *et al.,* 2018). In other to simplify the problem, many studies tend to concentrate on a set of few parameters and employ simple mathematical models to map the domains of input to our variables. An example of such simplified mathematical models is the multiple linear regression model, which, for a given set of features x_{1n}, x_{2n}, x_{3n}, . . . , x_{mn}, can be related to its dependent variable as stated in Equation (12) below (Gunaydin *et al.,* 2010).

$$y = \beta 0 + \beta 1 x_1 n + \beta 2 x_2 n + \beta 3 x_3 n + \ldots \beta 1 x m n + \varepsilon \quad (12)$$

where β_0, β_1, β_3, . . . β_n are the coefficients, and ε is the error.

ANN application has shown good results in terms of the prediction of engineering parameters of stabilised soils for various purposes. ANN's ability to learn the relations between a wider and more complex set of experimental variables and map these variables to the target output domain using well-adjusted weights makes it a more reliable tool in the prediction of the in-situ post-stabilisation behaviour of treated clay soils. In addition, the ability of ANNs to simultaneously handle multiple dependent and independent variables using the same experimental dataset and its adaptability in finding correlations for highly non-linear data, which are characteristic of many civil engineering problems, makes it more advantageous over traditional regression analysis (Gardner, 1998). A review of studies modelling various soil properties is presented in the subsequent sections. The review is in a bid to explore the input parameters considered in the study, the number of data utilised in model development, the training algorithm utilised, the hyperparameters of the model, the model performance and, finally, the results or predictive models developed.

4.1. Unconfined Compressive Strength

ANN has been employed in tracking and modelling the UCS of geopolymer stabilised clays, by Mozumder *et al.,* (2015). In the study, Ground Granulated Blast Furnace Slag (GGBS) and Pulverised Fly Ash (PFA) were considered as binders for the improvement of the compressive strength of three clays with varying properties. The soil characteristics such as Liquid Limit (LL), Plastic Limits (PL), etc., were evaluated according to the British Standards and, in combination with key experimental variables, were utilised as input data for the ANN model development. Eight input variables namely, LL, Plasticity Index (PI), GGBS content, PFA content, the molarity of alkaline activator used (M), the ratio of the activator to the binder, the ratio of sodium to aluminium in the activator–binder mixture (Na/Al), the ratio of silicon to aluminium in the activator–binder mixture (Si/Al), and 28 days UCS, were considered. A multi-layered perceptron ANN model was` chosen with one hidden layer to study the experimental data. The optimum architecture was selected by varying the number of neurons in the hidden layer while evaluating the performance of the model and was obtained as one hidden layer with nine neurons. The ANN showed a better ability to learn the relationship of the data set, as shown in Figure 5.

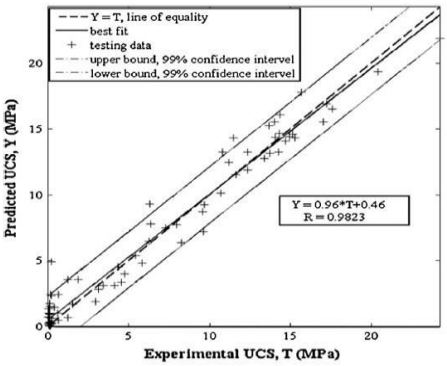


Figure 5: Experimental versus ANN-Predicted UCS values (Mozumder*, et al.,* 2015)

From Figure 5, it is obvious that almost all data points are within 99% confidence limit. The line of best fit is almost aligned with the line of equality at which all experimental observations and predicted values are the same. Table 1. compares the performance of the ANN model with that of a Multivariable Regression Analysis (MVR) on the same data set. It is obvious that ANN performed better at correlating the independent variables and their influence on the UCS of the stabilised soils.

Table 1: Statistical Evaluation of the Performance of ANN and MVR models

Model	Dataset	Statistical Parameter		
		R2	MSE	MAE (%)
ANN	Training data	0.992	0.34	3.65
	Testing data	0.964	1.50	8.34
MVR	Training data	0.828	7.24	19.20
	Testing data	0.808	8.04	19.26

(Mozumder et al., 2015)

Expansive soils are known for their vulnerability to significant volume changes with moisture due to their high plasticity properties. Table 2 shows the classification of expansive clays according to the Building Research Establishment (BRE) based on a modified plasticity index.

Table 2. Classification of shrink-swell clays *(BRE. 1993)*

0 Modified Plasticity Index I_P	Volume Change Potential (VCP)
>60	Very high
40–60	High
20–40	Medium
<20	Low

In another study, Salahudeen *et al.* (2020) employed a feedforward ANN model in studying the UCS of expansive clays stabilised with Cement-Kiln Dust (CKD). The liquid limit, plastic limit and plasticity index of the clay were determined to be 48.2, 27.2 and 21%, respectively, with free swell of 80%. The natural and stabilised clay samples were subjected to compaction and UCS tests in accordance with BSI (BS 1377, 1990). Three ANN models were developed with a total of eight input variables, namely specific gravity (Gs), linear shrinkage (L_S), coefficient of uniformity (C_U), coefficient of gradation (C_C), LL, PL, Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) for three UCS outputs (7, 14 and 28 days). A total of 72 sample data were utilised in model development. The ANN model topography consisted of one input layer with eight neurons and one output neuron (the UCS value). However, the number of hidden layers was varied in order to determine the optimum number of neurons in the hidden layer. Figure 6 shows the performance of the trial models.

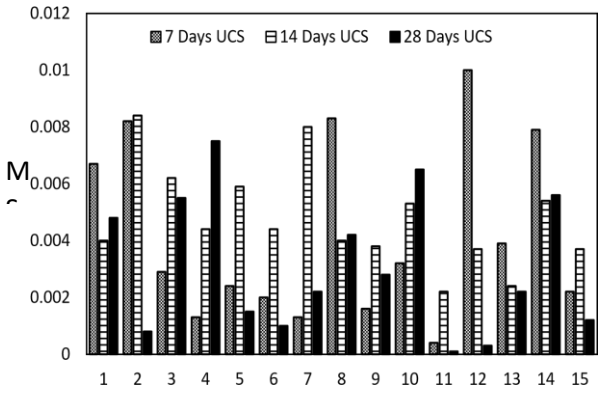


Figure 6: The selection of optimum number of neurons in hidden layer (Salahudeen, *et al.,* 2020)

The optimum model was found to be of nine neurons in the hidden layer based on lowest MSE. The authors (Salahudeen *et al.,* 2020) suggest that the MSE is a more reliable parameter for network selection when R values alone become insufficient for optimum network selection. The results of the analysis showed that the ANN model was able to predict the variation of UCS as a function of the predictor variables with a high correlation coefficient, as seen in Figure 7.

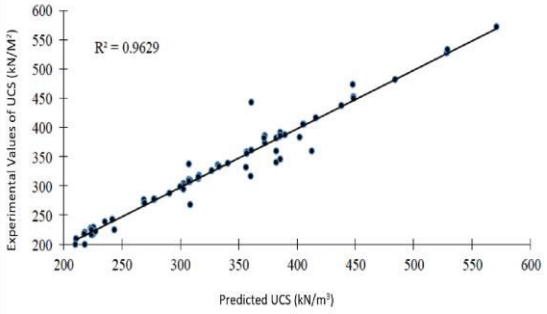


Figure 7: Observed Versus Predicted UCS (Salahudeen *et al.,* 2020)

The study reveals a high correlation between experimental values and ANN predicted values. The high correlation coefficient with low RMSE confirms the performance of the model.

Priyadarashee *et al.* (2020) conducted an experimental investigation on the suitability and performance of kaolin clay stabilised with Fly Ash (PFA), Rice Husk Ash (RHA) and cement. The improvements in the soil were ascertained by considering increase in the UCS. The LL, PL, and PI of the unstabilised kaolin clay were determined as 43.3, 19.5 and 23.8%. The input variables considered for the correlation were clay content, RHA content, cement, PFA content and curing duration. The number of neurons in the hidden layer was selected manually and varied while evaluating the performance of the model using the MSE. Figure 8 shows the variation of MSE and the number of neurons in the hidden layer.

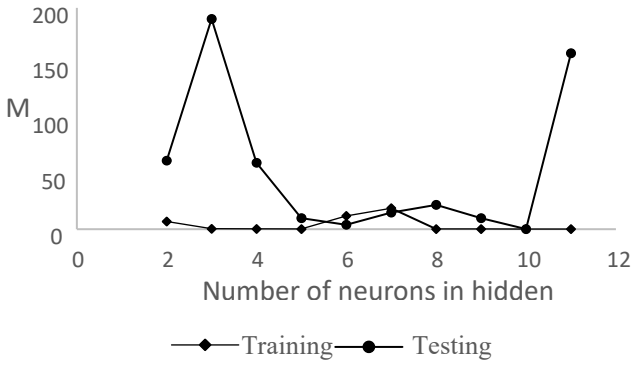


Figure 8: The selection of the optimum number of neurons in hidden layer (Ayeldeen *et al.,* 2016)

As seen in Figure 8, the optimum model performance was found at 10 neurons in the hidden layer based on Levenberg–Marquardt algorithm. The results of the analysis, using the optimized model showed good correlation between the datasets. The predictive model developed from ANN is given in Equation (14), where UCS_m is the dependent variable to be estimated and represents the *UCS* for a given combination of independent variables. A comparison of ANN performance with multivariable regression analysis further proves ANN's advantage, as shown in Table 3.

Table 3, comparison of ANN performance with multivariable regression

Model	Dataset	Statistical Parameter		
		R2	MSE	RSME
ANN	Training data	0.9813	0.0395	0.1987
	Testing data	0.9714	51.34	7.1651
MVR		0.8870	68.7603	8.2921

ANN has been described as a black box since it is difficult to predict the way the predictive model will be selected. However, sensitivity analysis can be carried out in determining the influence of the input variables on the target variable.

$$\frac{UCS_m}{UCS_{C7}} = -1.003 + 1.568\left(\frac{Clay}{100}\right)^2 + 2.477\left(\frac{PFA}{100}\right)^{0.5} + 2.287\left(\frac{RHA}{100}\right)^{0.5} + 6.731\left(\frac{Cement}{100}\right)^{0.5} + 0.017C \quad 13$$

The UCS of cement stabilised clays was investigated by Ngo *et al*. (2021) in order to find a relationship between the several key variables. Different types of cement were utilised to study the effects of cement type on the UCS.
The soil under investigation was collected at various depths below the ground surface to also study the effect of confining pressure on the strength of the stabilised soils. Three machine learning algorithms were utilised. ANN was used in correlating the predictive variables. A total of 216 experimental data points were generated from various combinations of fourteen input variables, namely soil type, moisture content (MC), bulk density (We), the mass of cement (CM), sample diameter (DI), the length of the sample (L), the cross-sectional area of the sample (CA), the volume of the sample (SV), the depth of sample collection (D), the mass of the sample (MS), sample density (DS), curing condition (CD), curing time and cement type (CT). ANN training was done using the Quasi-Newton method, Stochastic Gradient Descent and Adam in order to select the optimal hyperparameters for the ANN topography. The dataset was divided in the ratio of 80% and 20% for training and testing. Performance evaluation of the developed ANN model showed a good correlation. ANN performed better than the other machine learning algorithms. The high number of neurons in the hidden layer may be due to the multiple dimensions of the input vector in the sample dataset. The study showed that ANN could be utilised effectively for stabilisation problems to track and model a wide range of independent variables.

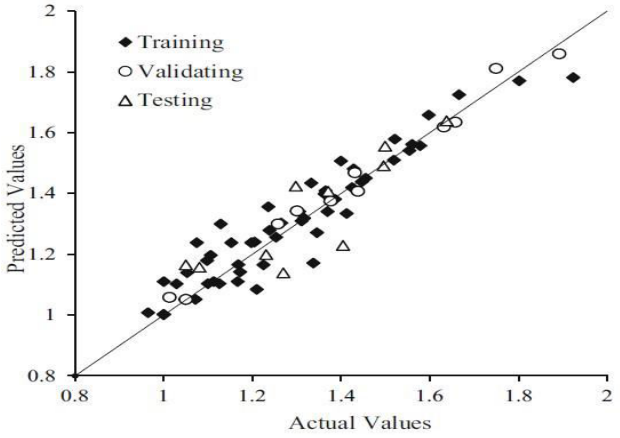


Figure 9: Predicted and experimental observations *(Ngo et al., 2021)*

To alleviate the difficulties associated with the need for continuous experimental determination of UCS, Sabat (2015) employed machine learning in analysing and modelling the performance of stabilised dredged sediments. A total of 51 experimental datasets were collated from existing literature for the development of the ANN model. The input predictive variables were percentage moisture content (MC), cement content, air foam content, and waste fishing net content. The ANN model to topography was initialized to two hidden layers while varying the number of neurons in order to find the optimum model. This approach has been taken in most soil stabilisation applications. The optimum ANN architecture was made up of two hidden layers with 12 and 10 neurons based on training using the Levenberg–Marquardt algorithm. From the results of the analysis, the model has been able to find the trend within the available training dataset. However, for certain values of the water content, the error was high. For the model to generalize better, a wider training dataset may still be needed. Previous studies have suggested a training dataset at least ten times the network parameters. In a lot of original research on stabilisation, there is usually limited experimental data. A cross-validation approach may be combined for a relatively lower sample size. The statistical evaluation of the performance of the model in training and testing is presented at the end of Section 4.

5.0 Conclusions

The advantages of the artificial neural over traditional regression analysis as applied to stabilisation have been highlighted in the foregoing sections. In a typical field stabilisation project, in order to improve the properties of expansive clays, experimental data are usually generated from several field and laboratory tests to monitor and ascertain the progress made in terms of improvement. These procedures are expensive and time-consuming and may be reduced to a minimum using ANN to predict the field response of the soils. In summary, the following conclusions are made.

An artificial neural network is reliable and can be employed in modelling various properties of stabilised clays for easy prediction of soil response while eliminating the need for extensive experimental procedures.

Backpropagation feedforward networks are the most used models in dealing with the problem of regression analysis for stabilisation of clays.

An artificial neural network should be developed with a relatively substantial dataset to regression models with good correlation. Many of the studies in regression analysis of stabilised clays have used relatively small data sets, although the models have performed well. The ability of the models to generalize can be improved with a larger dataset which fields a wide range of possible soil behaviour for proper training of the model.

Shallow networks made up of one hidden layer are the most used ANN architecture in developing predictive models for the prediction of geotechnical characteristics of stabilised clays and in modelling the response of stabilised expansive clays. The Levenberg–Marquardt training algorithm has been reported to be the most used among the studies reviewed.

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A REVIEW OF MODELING AND OPTIMIZATION OF TABLE WATER PRODUCTION SYSTEM

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ABSTRACT
This is an overview of modeling and optimization of medium scale table water production system for a table water factory. Optimization of table water production is a major concern as to obtain feasible production efficiency, maximize profit or minimize production cost. Utilization of scarce available resources and production process is required and the use of available program is resourceful and valued for the optimization. The need to evaluate and determine the best feasible optimal solution for the process and product can be attainable through optimization. The process failure mode and effect analysis, overall equipment performance, linear programming optimization problem is presented.

Keywords: modeling, optimization, process failure mode, production system, performance effectiveness**,** table water

1 INTRODUCTION

Table water is a broadly used commodity in our nation and worldwide According to Odiana & Edosomwan (2019), table water is water that is intended for human consumption and is sealed in bottles or other container with no added ingredients except that it may contain safe and suitable fluorides. The need for the use of modelling or optimization in table water production in factories is key to minimize production cost and to improve the quality of product. In optimization the linear programming problem is formulated with an objective function and a set of constraint to get the set of feasible solution. Process failure mode and effect analysis, performance effectiveness and linear programming problem model is discussed and the use of AMPL Software with CPLEX solver. To find expected results for the operator and management to make inform decision. The modeling and optimization of the table water factory is needed, and all this course of actions will contribute to long term sustainability of energy and related resource input utilization. This evaluation is limited to labour/manpower resources, energy/power resources, water, other mentions resources required for table water factories within Minna and Nigeria as a whole. Many production optimization techniques have been introduced into the table water production. In order to improve the production capacity by various researchers in the field of production optimization.

According to Cohen *et al*. (2022) table water costs hundreds to thousands of times more per liter than treated piped water beyond the concern about the safety of bottled water, negative environmental health impact associated with bottled water production, distribution and consumption

. In present work, a review of modeling and optimization of a medium scale table water production are discussed and the constraints, assumption and expected result also discussed. as it explores possible ways for minimizing the cost of production and maximizing the profit through rational management of basic input resources involved, thus helping to provide sustainable solutions to the challenges that are facing the industry.

2 MATERIALS AND METHODS

This study was carried out through interviews and data record collection from the factory, process failure mode, causes and effect, formulation of linear programming problem, model development. This study some certain data records which include and not limited to labour, energy and water the major raw material from a table water production factory. The data records were analyzed to discover potential failure mode and effect using risk priority number (RPN), overall equipment effectiveness (OEE) for the performance effectiveness evaluation and a linear programming model for the feasible optimal solution of the nature problem. Figure 1 shows the process flow of the production system.

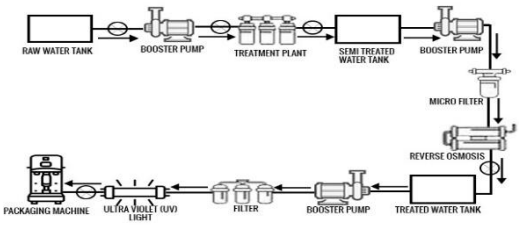


Figure 1: Process Flow of Table Water Production System

2.1 DATA COLLECTION

Data collection for the study rely majorly on interview and data records, direct observation, participant observation as the sources of data collection.

2.2 TABLE WATER PRODUCTION DOCUMENTATION

For the research work, a survey of table water production factories in Minna, Niger state, Nigeria was conducted and a medium scale table water factory was selected as case study. A field survey of the factory was conducted to collect information and data records. Based on this information from the table water operators and manager records and interviews, a summary document of the water production and process —including a simplified record of failures mode, cause and effects, performance, production resources and cost was created.

2.3 PROCESS FAILURE MODE AND EFFECT ANALYSIS

An evaluation of the process failure mode, causes and effect analysis is a quantitative analysis that identifies the failure mode in the production system along the causes and effects of this failures. Similarly, to the general Failure Methods and Effects Analysis (FMEA) method, process condition evaluation considers the system as a whole as well as its individual equipment and machines. Monitored equipment are evaluated with regards to various risk criteria to determine the risk priority number. The criteria are ranked and classified into categories R1 to R10 based on condition and efficiency. The Risk Priority Number used to determine the process failure mode and effect is defined by a set of criteria and input data record which are severity, occurrence and detection.

2.3.1 DETECTION

The likelihood of detection (D), estimation of the probability of detecting a process defect or product defect (caused by the identified failure) before the component/assembly leaves the manufacturing location

Table 1: Detection Rating Criteria

S/N	Detection Criteria	Rating
1	Remote probability of product leaving the facility/equipment area containing the defect. An obvious defect.	1
2	Low probability of product leaving the manufacturing area containing the defect. The defect is easily detectable.	2 – 3
3	Moderate probability of product leaving the manufacturing area containing the defect. The defect is somewhat more difficult to detect.	4 – 7
4	High probability of product leaving the facility/equipment area containing the defect. Detection may require special inspection techniques.	8 – 9
5	Very high probability of product leaving the facility/equipment area containing the defect.	10

2.3.2 SEVERITY

Severity (S) factor represents the seriousness or impact of the failure. On a scale of 1-10, with 10 being the most likely, what is the likelihood occurrence of that failure mode, and if it does occur, will cause severe harm.

Table 2: Severity Rating Criteria

S/N	Severity Criteria	Rating
1	Failure would have very little effect on further processing or end product.	1
2	Low severity rating. Failures have little or minor effect on further processing or end product.	2 – 3
3	Moderate severity rating. A failure that causes customer concern or program impact, but will not cause a Criticality 1 failure of the process or end item failure.	4 – 7
4	High severity rating. Failure causes severe impact to component or process and may contribute to a Criticality 1 failure of equivalent process failure, the customer or to the end item.	8 – 9
5	Very high severity rating. Failure contributes to a known or highly probable Criticality 1failure of the end item or an equivalent process failure involving loss of life or a major loss of manufacturing facilities	10

2.3.3 OCCURRENCE

The likelihood of occurrence (O), estimation of the probability that the potential failure cause will occur and thus result in the identified or indicated potential failure mode.

Table 3: Occurrence Rating Criteria

S/N	Occurrence Criteria	Rating
1	Remote probability of occurrence. The operators are not aware of this failure having ever occurred.	1
2	Low probability of occurrence. Few failures have occurred and are known by the operators.	2 – 3
3	Moderate probability of occurrence. Failure occurs occasionally, but not in major proportions and are known by the operators,	4 – 7
4	High probability of occurrence. Process has experienced higher than normal failure rate and the operators are aware of the failure occurrences	8 – 9
5	Very high probability of occurrence. Process failure is almost certain and are known to the operators	10

2.3.4 RISK PRIORITY NUMBER

Risk Priority Number is the mathematical multiplication of the factors; severity, occurrence and detection ratings for each cause of a failure mode in the system. The Risk Priority Numbers is the most important indicator of the failure mode and effect analysis and calculated as follows. The risk priority equation predicting this variable will take the form of equation 1;

$$RPN = D \times O \times S \quad (1)$$

Where:

D = Likelihood of detection of the failure

O = Likelihood of occurrence of the failure

S = Severity of the failure

RPN = Risk Priority Number

2.4 OVERALL PERFORMANCE EFFECTIVENESS

Figure 2 show the table water production machine for sachet and bottle water. The evaluation of the overall performance effectiveness of the production machines was determined by overall equipment effectiveness

(0EE). The empirical equation predicting this variable will take the form of equation 2;

$$EE = A \times P \times Q \quad (2)$$

Where;

OEE = overall equipment effectiveness is measured in percentage %

A = Availability is essentially the time the production is running or working and is measured in percentage %

P = Performance is a measure of how efficiently the system operates at maximum capacity and is measured in percentage %.

Q = Quality measures the percentage of production quality and is measured in percentage %.

The empirical equation predicting this variable will take the form of equation 3, 4 and 5;

$$A = T_O / T_P \quad (3)$$

$$P = \frac{T_I \times \sum X}{T_O} \quad (4)$$

$$Q = \frac{\sum X - X_d}{\sum X} \quad (5)$$



Figure 2: Table Production machine for sachet and bottle water.

2.5 MODELING AND OPTIMIZATION

To formulate the model, a linear programming problem of the nature of the study was formulated, the objective function and set of constraints with include water, energy, labour.

2.6 LINEAR PROGRAMMING PROBLEM

Mathematical models were constructed for the table water products production by Golden Age Table Water Factory.

Objective Maximize Z: $= 30X_1 + 480.8X_2$

Subject to Constraints

$637X_1 + 196X_2 \leq 952$ Labour Hour

$956X_1 + 1127X_2 \leq 3967$ Energy

$70056X_1 + 105336X_2 \leq 200000$ Water

$127X_1 \leq 185$ Print Roll

$5838X_1 \leq 10000$ Packaging Bag

$258X_2 \leq 300$ Preforms

$22X_2 \leq 36.95$ Caps

$434X_2 \leq 450$ Shrink Wrapper

$11704X_2 \leq 20000$ Printed Label

$X_1, X_2 \geq 0$ (Non - Negativity Constraints)

3 RESULTS AND DISCUSSION

The data collected were analyzed to determine the risk priority number and feasible optimal solution using the software AMPL and cplex Solver

3.1 RISK PRIORITY NUMBER

Risk priority number for the various process flow is shown in figure 3.



Figure 3: Risk Priority Number of the table water production process

3.2 OPTIMAL SOLUTION

Shown in table 4, the optimal solution for the linear problem of the nature was determined.

Table 4: Optimal Solution, Contribution, Profit of Variables

S/N	Variable	Contribution	Coefficient	Profit
1	Sachet Water (50cl)	11763	30	352890
2	Bottle Water 75Cl	10341.6	480.8	4,972,241.28

4 DISCUSSION

Risk management, Performance evaluation and linear programming optimization tool were employed to optimize the medium scale table water production factory. AMPL software conducted 2 iteration

From the analysis, it shows the result of the risk priority number for the process failure mode and effect of the risk priority number of the process 1, 2, 3, 4, 5, 6, 7, to be 4, 16, 4, 10, 8, 18, 80 respectively. In performance effectiveness evaluation it shows the quality, performance and availability of the sachet and bottle water production, it revealed a result of 85.997 and 86.40 respectively. In the linear programming result analyzed, the result shows the optimal feasible solution was achieved in the second iteration and optimal production input for the variables – sachet and bottle water is 11763 bags and 10341 trays of the product respectively over any weekly production

5 CONCLUSION

In conclusion, a comprehensive review of modeling and optimization of table water production system for table water factories has been affirmed in this research work. The process failure mode and effect analysis, overall performance effectiveness, linear programme model and optimization approach were utilized. Further investigation of other untapped approach and a set of constraints be conducted for a best feasible and optimal solution for inform decision making by operators and management of table water factory while creating a sustainable development goal to achieve universal and equitable access to safe and affordable drinking water for all in the faces of challenges in table water production such as cost reduction and maximum standard and profit.

5.1.1 ACKNOWLEDGEMENTS

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ESTIMATION OF PAVEMENT TEMPERATURE IN NIGERIA'S CLIMATOLOGICAL ZONES

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ABSTRACT

Temperature is a critical factor influencing flexible pavement design and performance. This study investigates asphalt pavement temperatures across Nigeria's diverse climatological zones, highlighting the impact on pavement performance and durability. Previous studies have not comprehensively addressed Nigeria's diverse climatic conditions. This research fills the gap by classifying Nigeria into hot dry, temperate dry, hot humid, and warm humid zones, providing a detailed approach to bitumen grade selection based on accurate pavement temperature analysis. The methodology involves obtaining air temperature data and computing pavement temperatures using a validated model. Results indicate that Zone 1 (Sokoto, Borno, Adamawa) requires a 40/50 penetration grade bitumen due to a maximum pavement temperature of 44°C, while Zones 2, 3, and 4 are suited for 60/70 penetration bitumen. Emphasizing pavement temperatures over air temperatures enhances road resilience and longevity. This study provides a foundation for an advanced bitumen grading system, offering criteria for selecting bitumen for various Nigerian climatic zones.

Keywords: *Asphalt Pavement, Bitumen Grades, Climatological Zones, Pavement Durability, Pavement Temperature, Road Construction*

1 INTRODUCTION

The temperature of asphalt pavement is a critical factor in the construction and maintenance of roads, especially in a country like Nigeria with diverse climatological zones. Nigeria's climatic regions range from the humid tropics in the south to the arid, semi-desert conditions in the north. These varying climatic conditions significantly influence the temperature of asphalt pavements, affecting their performance, durability, and the overall quality of road infrastructure (Refiloe et al., 2022).

In designing durable pavements, many factors are considered, with climate being a primary agent influencing pavement performance. Temperature is the most significant climatic factor affecting the mechanical behavior of all pavement layers and thus the overall performance and life of the pavement (Flavio, 2012; Marshall et al., 2001; Gang, 2003). Asphalt mixtures are viscoelastic plastic materials whose strength and modulus change under different temperatures. At low temperatures, asphalt becomes hard and brittle, exposing the layers to thermal and fatigue cracking. Conversely, at high temperatures, asphalt becomes soft and more viscous, making it more prone to rutting. Therefore, the effect of temperature on the bearing capability, performance, damage, and life of asphalt pavement cannot be ignored (Sascha et al., 2013; Kang et al., 2007).

Understanding the temperature dynamics of asphalt pavement in different climatological zones is essential for selecting appropriate materials, designing effective construction processes, and ensuring the longevity of road networks. This knowledge helps mitigate issues such as thermal cracking, rutting, and other forms of pavement distress arising from extreme temperature variations (Refiloe et al., 2022). Temperature variations directly influence the stiffness of the asphalt layers, altering stress, strain, and deflection conditions throughout the pavement. This variation can influence the stiffness of the underlying unbound layers since they usually display stress, strain, and deflection dependence (Gang et al., 2007).

In pavement design, the strength and deformation properties are strongly related to climatic conditions. Therefore, in the flexible pavement design process, attention must be paid to accurately determining temperature in asphalt concrete layers. As modern flexible pavement structures represent multi-layer deformable media, changes in deformations in asphalt concrete layers lead to changes in stresses and deformations in other layers of pavement and subgrade. In practice, changes in stresses and deformations in layers of pavement and subgrade, caused by temperature variations in asphalt concrete layers, are essential and should be considered at the design stage (Hariharan et al., 2023).

Based on literature, the prediction of asphalt pavement temperature can be divided into: (1) Numerical and finite element techniques, (2) Theoretical and analytical approaches, and (3) Statistical and probabilistic models. The improvement of these temperature prediction models is highly dependent on local data (Adwan et al., 2023).

The Performance of the bituminous binder plays important role in the overall performance of the pavement system. One of the major causes of pavement failure is the bitumen grade, i.e. selection of suitable grade of bitumen. Therefore, performance grading of bituminous binder is inevitable for the specific temperature and climatic zones. (Sunita K et al., 2020).

Previous studies provided valuable insights into specific aspects of pavement temperature and compaction behavior but did not address the diverse climatological zones in Nigeria comprehensively. (Adejoh S et al., 2024, Mohammed I. U., 2016). This study fills the gap by classifying Nigeria into hot dry, temperate dry, hot humid, and warm humid zones in accordance with highway manual, providing a detailed approach to bitumen grade selection based on accurate pavement temperature analysis for more effective pavement construction and maintenance.

In this context, this study aims to explore the temperature characteristics of asphalt pavement across Nigeria's climatological zones, providing insights into the challenges and considerations for pavement construction and maintenance in these diverse environments.

2 METHODOLOGY

To achieve the objective of the research air temperature of the various zones from each state were obtained from the highway manure, using annual minimum and maximum temperature values ranging from 10-40 years. The pavement temperatures for each state were computed using temperature model and the minimum and maximum pavement temperature for each zone is determined.

2.1 BITUMEN GRADES

Bitumen, also known as asphalt, is a material mainly used in road construction. There are many types of bitumen grades based on different systems. Penetration, viscosity, and performance are three popular bitumen testing methods used for characterization and classification. Each grade offers unique specifications, allowing for the selection of the most suitable one. In Nigeria, the penetration grading system specified in the Highway Manual, 2013, includes only two grades: 60/70 and 80/100. Ideally, one should select a grade based on factors such as climate and temperature variations, traffic volume, pavement design, and application-specific requirements.

2.2 STUDY AREA

Nigeria is divided into four distinct climatological zones, each with unique temperature characteristics. Figure 1 shows the four zones within Nigeria. These zones are classified in terms of climate as hot dry, temperate dry, hot humid, and warm humid, respectively. (Highway Manual 2013)

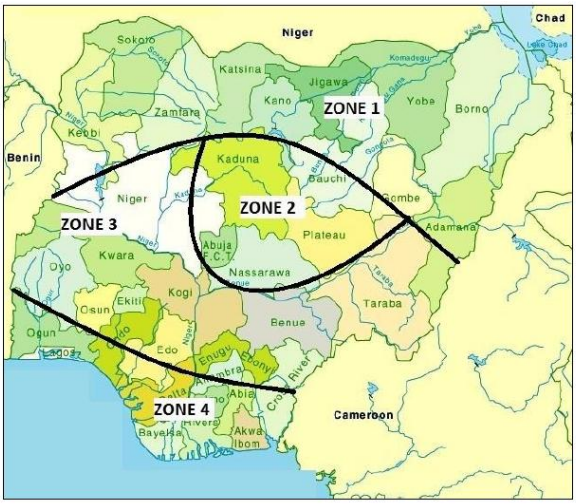


Figure 2.1: Climatological zones of Nigeria Source: Highway manual

Since temperature is considered one of the most important factors when selecting bituminous materials for roads especially because of its sensitivity. Measurement of individual pavement temperatures can time consuming, thus alternative methods can be employed. The Figures 2.2 and 2.3 shows the minimum and maximum air temperatures respectively.

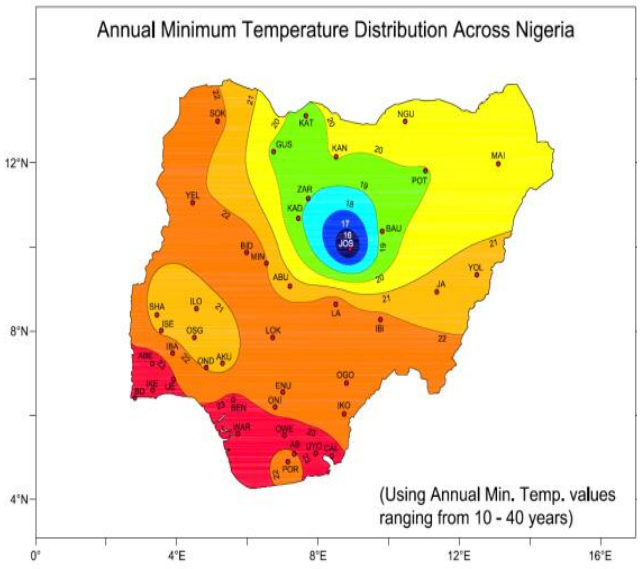


Figure 2.2: Minimum Air Temperature Source: Highway Manual

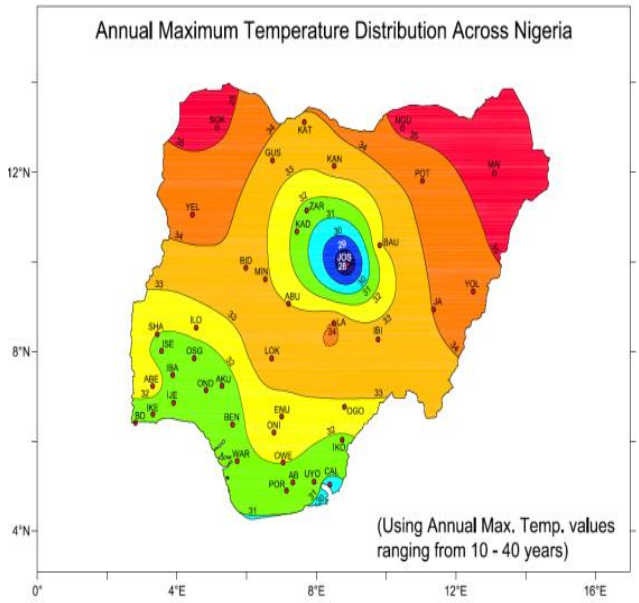


Figure 2.3: Maximum Air Temperature Source: Highway Manual

From the mean air temperatures, pavement temperatures can be estimated using Equation 1 as proposed by Thompson et al., 1987. The pavement temperatures can then be estimated.

$$T_P = T_A\left(1+\frac{1}{Z+4}\right)-\frac{34}{Z+4}+6 \qquad (1)$$

Where,

T_p is the average seasonal pavement temperature (°C),

T_A is the average seasonal air temperature (°C),

Z the depth at which temperature is predicted (in)

The Thompson et al. (1987) pavement temperature estimation model demonstrates high accuracy, assumes that pavement temperature is influenced by ambient air temperature, solar radiation, and wind speed, and has been validated using data from various locations to ensure accurate predictions across different climatic conditions. (Thompson et al., 1987, Chaitanya G., et al., 2022)

3 RESULTS AND DISCUSSION

The pavement temperatures were estimated based on Equation 1. The results are presented in Tables 1, 2, 3, and 4, which represent annual average minimum and maximum pavement temperatures. The highest maximum pavement temperatures (44°C) were observed in Zone 1 (Sokoto, Borno, Adamawa) and Zone 2 (Kaduna). Lower maximum pavement temperatures (38°C - 41°C) were found in Zone 4, which generally shows lower maximum temperatures compared to other zones. Bayelsa and Cross River have the lowest at 38°C. On the other hand, Plateau state recorded the lowest minimum temperature at 22°C. Most states have average maximum pavement temperatures exceeding 40°C, except for states in the South-west and South-south parts of Nigeria.

From the results, it can be seen that different climatic zones in Nigeria require specific bitumen grades to ensure optimal performance. Zone 1, experiencing the highest temperatures, requires 40/50 penetration grade bitumen, which offers better resistance to high temperatures. Zones 2, 3, and 4 have relatively lower maximum temperatures, and thus 50/60 or 60/70 penetration grades are more suitable. In Nigeria's Highway Manual, only two grades of bitumen are specified: 60/70 and 80/100. This specification may affect the performance of asphalt mixtures in Zone 1. Although this approach gives an indication of which bitumen to use, there are several limitations that may affect its authenticity. For example, urban areas may experience higher temperatures leading to higher pavement temperatures. Another impact on pavement temperatures is high rainfall in areas such as Zones 3 and 4. Some states within the same zone have slightly different pavement temperatures due to localized microclimates, variations in urbanization, and differences in altitude and vegetation. These factors can influence the amount of solar radiation, wind speed, and ambient air temperature, which in turn

affect pavement temperatures. (Yinghong Q., et al., 2022)

Table 1. ANNUAL MINIMUM AND MAXIMUM PAVEMENT TEMPERATURE OF ZONE 1.

States	Air Temperature Min. (ºC)	Air Temperature Max. (ºC)	Pavement Temperature Min.(ºC)	Pavement Temperature Max. (ºC)
Sokoto	22	35	29	44
Katsina	19	33	25	42
Zamfara	19	33	25	42
Kebbi	22	34	29	43
Kano	20	33	27	42
Jigawa	20	34	27	43
Yobe	20	34	27	43
Borno	20	35	27	44
Gombe	20	34	27	43
Adamawa	21	35	28	44

TABLE 2. ANNUAL MINIMUM AND MAXIMUM PAVEMENT TEMPERATURE OF ZONE 2.

States	Air temperature Min. (ºC)	Air temperature Max. (ºC)	Pavement temperature Min.(ºC)	Pavement temperature Max. (ºC)
Kaduna	19	35	25	44
Bauchi	19	33	25	42
Abuja	21	33	28	42
Nasarawa	22	34	29	43
Plateau	16	33	22	42

TABLE 3. ANNUAL MINIMUM AND MAXIMUM PAVEMENT TEMPERATURE OF ZONE 3.

States	Air temperature Min. (ºC)	Air temperature Max. (ºC)	Pavement temperature Min.(ºC)	Pavement temperature Max. (ºC)
Niger	22	33	29	42
Ondo	21	31	28	39
Kwara	21	32	28	41
Taraba	21	33	28	42
Kogi	21	33	28	42
Oyo	21	31	28	39
Osun	21	31	28	39
Ekiti	21	31	28	39
Edo	23	31	30	39
Enugu	22	32	29	42
Anambara	22	32	29	41
Ebonyi	22	32	29	41
Benue	22	33	29	42

TABLE 4. ANNUAL MINIMUM AND MAXIMUM PAVEMENT TEMPERATURE OF ZONE 4.

States	Air temperature Min. (ºC)	Air temperature Max. (ºC)	Pavement temperature Min.(ºC)	Pavement temperature Max. (ºC)
Ogun	23	32	30	41
Lagos	23	31	30	39
Bayelsa	23	30	30	38
Rivers	22	31	29	39
Delta	23	31	30	39
Imo	23	32	30	41
Abia	22	31	29	39
Akwa Ibo	22	31	29	39
Cross River	23	30	30	38

TABLE 5. AVERAGE MINIMUM AND MAXIMUM PAVEMENT TEMPERATURE ACROSS ALL STATE AND ZONES

Zone	Maximum Pavement Temperature (oC)	Minimum Pavement Temperature (oC)
Zone 1	43	27
Zone 2	42	26
Zone 3	41	28
Zone 4	39	28

4 CONCLUSIONS

The estimation of pavement temperatures across Nigeria's diverse climatological zones is essential for selecting suitable bitumen grades. The extreme pavement temperatures, ranging from -10 to 70 degrees Celsius according to the Performance grading system, are not exceeded by any of the states. The analysis shows significant pavement temperature variations, which necessitate different grades of bitumen to ensure pavement durability and performance. High-performance bitumen, such as 40/50 penetration grade bitumen, is required for the highest maximum pavement temperatures (44°C) observed in Zone 1 (Sokoto, Borno, Adamawa) to prevent rutting and thermal cracking. Zones 2, 3, and 4, termed as moderate temperature zones, are recommended to use standard bitumen grades, i.e., 60/70 penetration bitumen. These recommendations, using pavement temperatures rather than air temperatures, can help enhance the resilience and longevity of road pavements in Nigeria, given the unique climate of each zone. It is also important to consider other factors such as rainfall, humidity, climate change, moisture, and traffic load in the selection of suitable bitumen.

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ASSESSMENT AND PREDICTION OF GROUNDWATER QUALITY USING ARTIFICIAL NEURAL NETWORKS

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ABSTRACT
This paper aims to demonstrate the effectiveness of neural network modeling in predicting the groundwater water quality index (WQI). Data were collected from one hundred sixty selected points in Nyanya Abuja in the year 2024, laboratory test of all physiochemical parameters used were done according to the American Public Health Association (APHA) 2017 edition for water and wastewater examination.An artificial neural network was developed using physicochemical parameters such as pH,electrical conductivity,temperature,total alkalinity,dissolved oxygen,chlorine, total dissolved solids (TDS), chloride, total hardness (TH), nitrate,Phosphate (PO), Calcium (Ca),Magnesium (Mg),Carbonate (CO) ,Iron (Fe), Chemical Oxygen Demand (COD),and E. coli as input variables and the calculated WQI as the output. The optimal results were achieved with one hidden layer, yielding a high correlation coefficient of 0.997, along with low mean squared error (MSE) across all subsets (training, testing, validation) and a root mean square error (RMSE) of 0.9577. Additionally, the maximum percentage error for the WQI did not exceed 2% which explained the more the data the better result obtained when considering ANN as a model, confirming the strong alignment between actual data(WQI) and predicted values. These results indicate that artificial neural network models are effective tools for predicting the ground water quality index and can be effectively utilized by individuals and organizations monitoring environmental conditions.

1 INTRODUCTION

Groundwater is a vital resource that provides drinking water for billions of people worldwide. However, the quality of groundwater is increasingly under threat due to various anthropogenic and natural factors. Ensuring the quality of groundwater supplies is crucial for safeguarding public health and the environment. According to (Ascott et al., 2022), nearly a third of the world's groundwater is contaminated with harmful substances, such as nitrates, pesticides, and heavy metals. This contamination can have serious consequences, including increased risk of waterborne diseases, environmental degradation, and reduced agricultural productivity.Sustainable development and public health depend on groundwater quality being maintained. Its quality evaluation techniques that are rooted in tradition frequently depends on labour- and resource-intensive,laboratory analysis and comprehensive field sampling. This implies that preserving healthy ecosystems and guaranteeing safe drinking water supplies depend on effective water quality management, (Ho *et al*., 2019). Extensive data on water quality is essential for identifying long-term patterns, regional differences, and emerging issues. However, the time-consuming and expensive continuous sampling and monitoring needed for this kind of data gathering can result in sparse datasets with little temporal and spatial coverage (Libera and Sankarasubramanian, 2018).

The Water Quality Index (WQI), a widely used tool for assessing water quality and a valuable source of statistical data for decision-makers, is frequently beset by uncertainties in the indicator selection, weighting, and aggregation processes, (Tyagi *et al*., 2013). According to Abbasi and Abbasi, 2012, these models may efficiently combine several data sources, including meteorological, land use, and water quality measurements, to produce predictions that are more accurate and reliable. However, the absence of a universal criterion for assessing water quality requires the analysis of enormous datasets with numerous factors.

Artificial neural networks (ANNs) have become a potential tool for assessing groundwater quality in recent years. For efficient environmental monitoring, life sustainability, and public health protection, an accurate forecast of changes in groundwater quality is crucial as well as monitoring and forecasting water quality, for better resource management and developing remediation or protection plans these monitoring data are used to assess water quality and identify pollution sources, enabling the development of appropriate water management plans to control and reduce pollution, ensuring sustainable water use.

According to Soori *et al*., 2023, ANNs are a type of machine-learning algorithm inspired by the structure and function of the human brain.

Data Complexity in the case of Groundwater systems are influenced by diverse factors such as pollution sources, land use practices, hydrogeological characteristics, among others. Developing ANN models that effectively capture these intricate relationships while ensuring accuracy remains a challenge due to the

inherent complexity of environmental data (Farahin et al.,2021)

Also Dynamic Nature of ground water that is Environmental conditions are dynamic and subject to continuous change over time due to various human activities or natural phenomena like climate change or geological processes. In other to solve these dynamic changes in groundwater quality, ANN models capable of adapting to this dynamic changes while maintaining predictive accuracy (World Health Organization 2017). Therefore this research developed ANN model that fit the quality accuracy and compare with water quality index analysis.

This aim of this research is to assess and predict the groundwater quality using Artificial Neural Networks (ANNs) in Nyanya Abuja. The specific objectives of the research are to:

i. Determine the physiochemical parameters of the groundwater samples in the study area.
ii. Evaluate the quality of groundwater in the study area using water quality index (WQI).
iii. Develop an artificial neural network (ANN) model for predicting the changes in groundwater quality in the study area and compare with WQI.

2 METHODOLOGY

2.1 Study Area

Nyanya is a suburb of the Federal Capital Territory located in Abuja Municipal Area Council (AMAC) of Nigeria. It is approximately 30km southeast of Abuja city centre with the coordinates; 8.9333˚N, and 7.17167˚E respectively. The main economic activities are food crop farming and various businesses. The staple food crops include beans and yams. Women form a large proportion of the farming and business population; occupying over 300000 inhabitants with a predominantly ethnic group of Gbagyi, Hausa, Yoruba and Igbo.

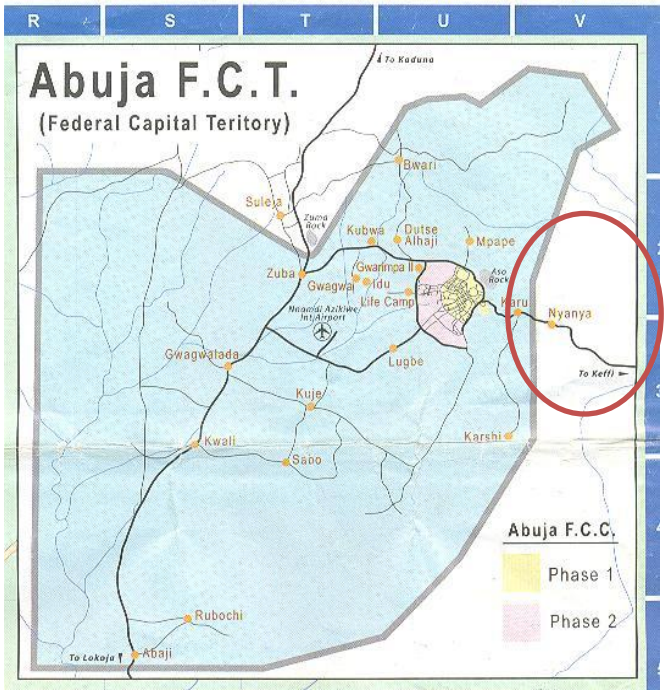


Figure 1; Map of Abuja showing Nyanya circle

2.2 SAMPLING TECHNIQUES

The methodology for this study required a random sampling with the collection of the samples from within the study area. A stratified sampling required the division of the study area into sub-regions based on geological or hydrological characteristics and Systematic sampling that required the collection of the samples at regular intervals along the transect

A total of 160 boreholes was selected from different locations such as flat, hills, and slope areas in Nyanya, Abuja for sampling in this study. A field data form was completed to record the code of sampling points and location. Using a 150 cl plastic bottles, samples for the chemical analysis was collected and sealed.



Figure 2: Washed plastic bottles for sample collection

Sterile bottles were used to collect samples of microbiological analysis,filled to the brim leaving an air space of at least 2.5cm to ensure homogenize sample for laboratory analysis and the lids, carefully tightened or sealed. They were labelled and immediately placed in cold ice chest at temperature of 4°C to prevent possible alteration of parameters and also to ensure that micro-organisms remain viable though dormant.

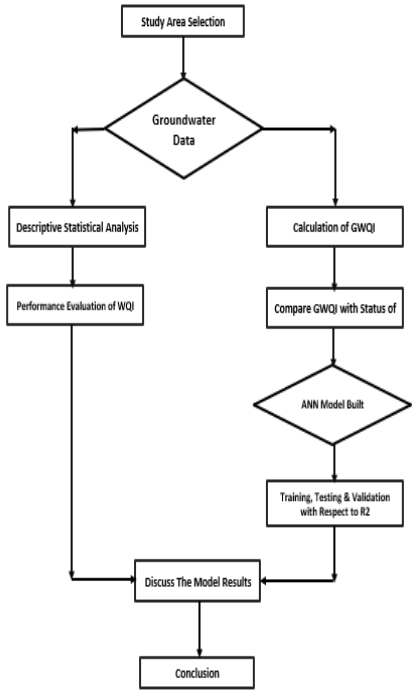


Figure 3: Schematic diagram of research methodology

2.3 Laboratory Analysis

The physico-chemical analyses of the selected groundwater quality parameters were conducted following standard analytical methods (APHA 1992). The important parameters of interest in this study are; colour, pH, Total Hardness, Calcium, Magnesium, Total Alkalinity, and Electrical Conductivity, Phosphate, Nitrates, and Magnesium, dissolved oxygen, biological oxygen demand. These are important parameters in evaluating the degree of pollution and indices of self-purification of a water body according to Tyagi *et al*. (2013). Results of laboratory analyses were subjected to data evaluation by standard statistical methods (Chapman 1992).

2.4 Physicochemical Analysis

The analyses of various physical and chemical parameters such as pH, Total Hardness, Calcium, Magnesium, Total Alkalinity, Electrical Conductivity, Phosphate, Nitrates, and Manganese were carried out according to descriptions by APHA (1992).

2.5 Data Analysis

Statistical analysis was used for data summarization and correlation analysis to determine the inter-relationship between the WQI parameters.

2.6 Groundwater Quality Index Calculation

In calculating the WQI, the weighted arithmetic index method will be applied to assess groundwater suitability for drinking purposes. In this method, water quality rating scale, relative weight, and overall WQI was calculated using the following formular

$$q_i = \left(\frac{C_i - C_{id}}{S_i - C_{id}}\right) \times 100 \quad \text{.....(1)}$$

Where q_i, C_i, S_i and C_{id} indicate quality rating scale, concentration of I_{th} parameter, standard value of I_{th} parameter and ideal concentration of I_{th} parameter respectively. C_{id} is zero for all parameters except in pH and BOD with a value of 7.0 and 14.6 mg/l respectively.

Unit weight was then derived as;

$$w_i = \frac{k}{S} \quad \text{.....(2)}$$

Where the standard value of the I_{th} parameter is inversely proportional to the unit weight.

K is a constant value calculated as;

$$k = \frac{1}{\sum_i^n \frac{1}{S_i}} \quad \text{.....(3)}$$

Where n represents number of parameters considered

for analysis.

Overall WQI is then calculated as;

$$WQI = \sum_{i=1}^{n} q_i w_i \Big/ \sum_{i=1}^{n} w_i \quad \text{.....(4)}$$

The Table 3.1 gives a description of classification of water quality based on Weighted Arithmetic Water Quality Index method due to Brown et al (1972), Chatterji and Raziuddin (2002) etc.

Table 1 Groundwater Water quality parameters recommended standard and their assigned unit weights

Parameter	Recommended WHO standard	Units weight
Ph	4.5 - 9.0	0.247
Temperature	25˚C	-
Electrical Conductivity	1000 µS/	-
Total Alkalinity	120mg/L	0.011
Total Dissolve Solid	10000mg/L	0.025
Dissolve Oxygen	6 mg/L	0.004
Chlorine	250mg/L	
Total Hardness	200mg/L	0.004
Phosphate	0	-
Carbonate	150mg/L	0.012
Nitrate	70mg/L	
Iron	0.3mg/l	
Calcium	75mg/l-20089mg/l	0.028
Chemical Oxygen Demand	0	-
E.coli	0	-

Table 2 Classifications in Groundwater Quality index

WQI	STATUS
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very Poor
Above 100	Unsuitable for drinking

Source; Adelagun *et al*., (2021)

3.7 Artificial Neural Network Model (ANNM)

Just like the operations of human brain where neurons receive input signals and produce output signals, an output data could be predicted, using a network of artificial neurons, from input data (Chen *et al*., 2020). Further, for groundwater quality modelling, investigation of the mathematical relationship between the independent variables (chemical parameters of groundwater quality) and the dependent variable (WQI),were carried out by training and testing the model from collected data.

Moreover, to utilize the gained knowledge from the input data it can always be used for future WQI prediction purposes.

3.8Model Description

The artificial neurons of the network have different expanded layers with a connection with each other via a weight, determined when the error of the sample data between the actual and predicted outputs is minimum. A simple explanation of the network layers is illustrated in Figure 3.2, with its mathematical function in which (f) is the activation function.

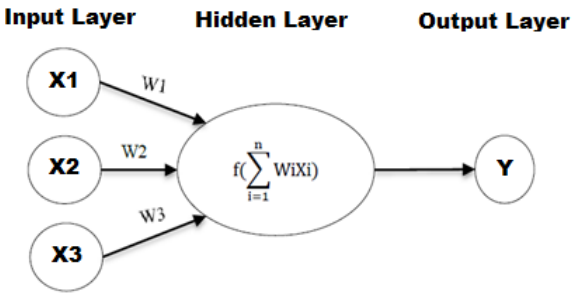


Figure 3.2: Structure of the Neural Networks

2.9 Data Normalization

The normalization was done for all datasets to improve the modeling performance. The normalization equation is defined as follows: The Min-Max normalization was utilized in order to scale the input variables to a range that was comprised of zeros and ones. As part of the data preparation process for machine learning, data normalization is performed. Changing the values of input and output variables to a single scale is the purpose of normalization. For the normalization process, x_{min} and x_{max} are, respectively, the minimum and maximum values for the i^{th} attribute.

$$x = \frac{xi - xmin`}{minxmax - xmin`} \quad \text{.....(5)}$$

For example, x_{min} is equal to the normalized value of the input variable x_i divided by the maximum input variable x_{max} and minimum variable x_{min}.

2.10 Model Validation

For measuring the difference between observed and predicted values, the sum of the square error function was used. Alternatively, Khan *et al*. (2010) method statistical parameter R^2, the coefficient of determination was explored. The values of R^2 vary from 0.0 to 1.0, which indicates that the higher the R^2 value, the better the ANNM fits the input data (Khan *et al*., 2010).

3 RESULTS AND DISCUSSION

3.1 Laboratory Result

The laboratory results were obtained and all parameters are show in Table 2parameters

Table 5: Physio-chemical laboratory test



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Environmental Studies, Remediation of oil spill sites, Engineering Services, Waste Management, General Procurement

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LABORATORY TEST RESULT.

Our company, Desurch Service Limited received Hundred (100) Groundwater samples from Akpevwe Keona Ukueku on the 2nd September, 2024. The samples were well labelled and preserved in the laboratory according to recommended practices as contained in the American Public Health Association (APHA 1060). Laboratory analysis was carried out using the American Public Health Association (APHA); Standard Methods for the Examination of Water and Wastewater (2017), APHA, 23rd Edition.

Details of sample identification is stated below;

Client Name: Akpevwe Keona Ukueku
Project Title: Student work
Sample Field ID: Groundwater
Sampling Location: Nyanya ABUJA
Total Number of Samples: Hundred and sixty(160)
Sample Description: Sample in sealed and labelled 150cl transparent plastic container
Method of Preservation: Refrigeration @ 4°C
Date Received in Lab.: 2/09/2024

We attest that the above-mentioned samples were analysed by us and the proceeding pages contain the certificate of analysis of the groundwater samples.

CERTIFICATE OF ANALYSIS

Client Name: Akpevwe Keona Ukueku
Project Title: Student work
Sample Field ID: Groundwater
Sampling Location: Nyanya, Abuja.
Total Number of Sample: Hundred and sixty (160)
Sample Description: Sample in sealed and labelled 150cl transparent plastic container
Method of Preservation: Refrigeration @ 4°C
Date Received in Lab.: 2/09/2024
PERIOD OF ANALYSIS: 3rd September - 13th September, 2024
REPORT DATE: 17th September, 2024.

Sample ID	PH	TEMP (C)	EC(µS/CM)	TA(mg/L)	TDS(mg/L)	TH(mg/L)	$PO^{3}4$ (mg/L)	NH^{+}_{4} (mg/L)	Ca^{2+} (mg/L)	Cl^{-} (mg/L)	CO_3 (mg/L)	Mg^{2+} (mg/L)	E.COLI (CUF/100ML)	NO_3 (mg/L)	Fe (mg/L)	DO (mg/L)	COD (mg/L)
NUPRC EGASPIN-2018	6.0-9.0	<40	NS	120.0	<600	300.0	0.1	0.5	NS	250.0	0.0	NS	NS	50.0	0.3	6.0	100.0
FMENV Limit	6.0-9.0	<40	NS	120.0	<600	300.0	0.1	0.5	NS	250.0	0.0	NS	NS	50.0	0.3	6.0	100.0
GW1	4.5	23.0	184.7	31.0	181.2	124.0	0.0	0.0	60.0	15.4	2.3	14.1	0.0	5.3	2.2	8.0	7.7
GW2	6.8	23.5	173.4	20.0	111.0	60.4	0.0	0.0	50.0	16.9	2.3	1.9	0.0	5.3	2.0	7.6	7.7
GW3	6.5	24.0	169.0	40.0	108.2	160.0	0.0	0.0	3.0	25.6	1.6	21.7	0.0	5.5	2.2	6.8	23.0
GW4	8.0	25.0	179.6	37.0	114.9	100.0	0.0	0.0	30.0	28.9	3.6	7.1	0.0	3.9	1.9	6.4	11.5
GW5	6.5	25.0	175.5	40.0	112.3	70.0	0.0	0.0	25.0	4.3	21.8	7.8	0.0	7.7	1.5	4.8	7.7
GW6	7.1	23.0	554.0	27.0	354.5	138.0	0.0	0.1	40.0	35.7	1.6	20.3	0.2	6.2	0.8	8.4	15.4
GW7	7.1	23.5	680.0	61.0	435.2	218.0	0.0	0.1	35.0	41.0	2.0	40.6	0.0	6.2	0.8	6.8	1.5

GW8	9.0	23.0	506.0	26.0	323.8	127.0	0.0	0.1	20.0	31.4	1.8	17.6	0.1	6.7	0.9
GW9	8.8	24.0	379.0	17.0	242.6	90.0	0.0	0.1	45.0	2.4	1.1	13.1	0.0	6.0	1.2
GW10	6.0	24.0	231.0	147.8	75.0	0.0	0.0	1.0	19.0	1.4	12.4	12.1	0.0	4.6	2.1
GW11	7.0	30.9	624.0	180.0	399.4	178.0	0.0	0.1	66.0	50.0	5.6	15.7	0.0	8.9	0.3
GW12	7.0	20.5	529.0	132.0	338.6	148.0	0.1	0.3	46.2	43.1	2.8	20.5	0.0	5.1	0.2
GW13	5.0	25.9	455.0	120.0	291.2	138.0	0.1	0.5	41.2	30.4	8.9	8.9	0.0	5.5	0.2
GW14	7.5	28.3	236.0	136.0	151.0	100.0	0.1	0.4	45.5	8.8	3.5	11.6	0.0	11.2	0.2
GW15	7.9	22.3	756.0	100.0	483.8	134.0	0.1	0.2	75.0	27.4	3.0	21.0	0.1	5.7	0.3
GW16	6.9	22.3	374.0	80.0	239.4	136.0	0.1	0.4	89.0	19.6	1.9	23.5	0.0	6.5	0.1
GW17	5.6	20.6	283.0	120.0	181.1	120.0	0.2	0.5	40.4	98.0	5.9	11.2	0.0	5.7	0.2
GW18	4.8	35.0	481.0	200.0	307.8	116.0	0.3	0.6	32.8	150.0	4.7	7.8	0.0	5.8	0.3
GW19	7.0	23.0	500.0	100.0	200.0	100.0	0.0	0.0	30.0	60.0	3.0	40.0	0.0	4.4	0.1
GW20	7.5	26.6	450.0	110.0	189.0	150.0	0.0	0.1	60.1	40.0	4.0	30.0	0.0	6.6	0.2
GW21	6.8	23.0	700.0	50.0	181.2	200.0	0.0	0.0	2.9	15.4	2.3	14.1	0.0	5.3	2.1
GW22	7.0	23.5	600.0	70.0	111.0	100.0	0.0	0.0	2.5	16.9	2.3	1.9	0.0	5.3	2.0
GW23	6.5	24.0	900.0	100.0	108.2	160.0	0.0	0.0	3.0	25.6	1.6	21.7	0.0	5.5	2.2
GW24	8.5	25.0	700.0	50.0	114.9	100.0	0.0	0.0	3.3	28.9	3.6	7.1	0.0	3.9	1.9
GW25	6.9	25.0	800.0	40.0	112.3	70.0	0.0	0.0	3.5	4.3	21.8	7.8	0.0	7.7	1.9
GW26	7.5	50.0	600.0	70.0	354.5	138.0	0.0	0.1	2.3	35.7	1.6	20.3	0.2	6.2	0.8
GW27	8.0	30.0	680.0	90.0	435.2	150.0	0.0	0.1	1.8	41.0	2.0	40.6	0.0	6.2	0.8
GW28	9.0	23.0	506.0	90.0	323.8	120.0	0.0	0.1	2.3	31.4	1.8	17.6	0.1	6.7	0.9
GW29	7.5	24.0	600.0	48.0	242.6	300.0	0.0	0.1	1.5	2.4	1.1	13.1	0.0	6.0	1.2
GW30	5.6	15.0	500.0	147.8	75.0	200.0	0.0	1.0	2.9	1.4	12.4	12.1	0.0	4.6	2.1
GW31	4.5	60.0	624.0	180.0	399.4	178.0	0.0	0.1	53.8	50.0	5.6	15.7	0.0	8.9	0.3
GW32	8.0	30.0	529.0	100.0	338.6	148.0	0.0	0.3	46.2	43.1	2.8	20.5	0.0	5.1	0.2
GW33	6.9	25.9	550.0	70.0	291.2	130.0	0.1	0.5	41.2	30.4	8.9	8.9	0.0	5.5	0.2
GW34	7.0	28.3	300.0	85.0	151.0	80.0	0.1	0.4	29.4	8.8	3.5	11.6	0.0	11.2	0.2
GW35	9.0	22.3	200.0	100.0	483.8	134.0	0.1	0.2	88.3	27.4	3.0	21.0	0.1	5.7	0.3
GW36	5.0	15.0	374.0	80.0	239.4	140.0	0.1	0.4	37.0	19.6	1.9	23.5	0.0	6.5	0.1
GW37	6.9	30.0	283.0	120.0	181.1	120.0	0.1	0.5	40.4	98.0	5.9	11.2	0.0	5.7	0.2
GW38	7.0	30.0	350.0	200.0	307.8	116.0	0.1	0.6	32.8	150.0	4.7	7.8	0.0	5.8	0.3
GW39	8.0	23.0	500.0	90.0	200.0	150.0	0.0	0.5	40.8	70.0	6.0	40.0	0.0	4.4	0.2

GW71	4.9	31.0	567.0	98.0	260.0	185.0	0.1	0.0	20.0	100.0	8.0	45.0	0.0	45.0	0.3	3.5	50.0
GW72	8.6	20.5	380.0	113.0	180.0	240.0	0.2	0.0	35.0	160.0	13.0	30.0	0.0	30.0	0.2	5.0	20.0
GW73	7.9	40.9	690.0	120.0	195.0	180.0	0.2	0.1	15.0	250.0	17.0	25.0	0.1	35.0	0.2	5.5	50.0
GW74	5.7	28.0	300.0	79.0	120.0	220.0	0.2	0.0	35.0	120.0	18.0	18.0	0.0	20.0	0.3	6.5	55.0
GW75	6.8	22.3	800.0	100.0	400.0	180.0	0.2	0.1	55.0	80.0	6.0	20.0	0.1	30.0	0.3	4.5	75.0
GW76	6.9	23.0	680.0	69.0	300.0	179.0	0.0	0.0	60.0	35.0	1.9	45.0	0.1	25.0	0.4	5.0	40.0
GW77	5.8	19.0	300.0	110.0	190.0	390.0	0.1	0.1	70.0	170.0	0.0	30.0	0.0	14.0	0.2	5.5	60.0
GW78	6.9	47.0	450.0	150.0	200.0	280.0	0.1	0.2	60.0	180.0	5.0	50.0	0.0	6.0	0.0	3.5	60.0
GW79	5.6	33.0	790.0	111.0	260.0	105.0	0.0	0.4	40.0	150.0	3.0	40.0	0.1	20.0	0.1	3.0	10.0
GW80	6.7	38.0	500.0	105.0	160.0	150.0	0.1	0.5	70.0	130.0	0.0	30.0	0.0	12.0	0.0	2.5	25.0
GW81	6.8	23.0	184.7	31.0	181.2	124.0	0.0	0.0	2.9	15.4	0.0	14.1	0.0	5.3	0.1	8.0	7.7
GW82	6.8	23.5	173.4	20.0	111.0	60.4	0.0	0.0	2.5	16.9	2.3	1.9	0.0	5.3	2.0	7.6	7.7
GW83	6.5	24.0	169.0	40.0	108.2	160.0	0.0	0.0	3.0	25.6	1.6	21.7	0.0	5.5	2.2	6.8	23.0
GW84	6.8	25.0	179.6	37.0	114.9	100.0	0.0	0.0	3.3	28.9	3.6	7.1	0.0	3.9	1.9	6.4	11.5
GW85	6.5	25.0	175.5	40.0	112.3	70.0	0.0	0.0	3.5	4.3	21.8	7.8	0.0	7.7	1.5	4.8	7.7
GW86	7.1	23.0	554.0	27.0	354.5	138.0	0.0	0.1	2.3	35.7	1.6	20.3	0.2	6.2	0.8	8.4	15.4
GW87	7.1	23.5	680.0	61.0	435.2	218.0	0.0	0.1	1.8	41.0	2.0	40.6	0.0	6.2	0.8	6.8	1.5
GW88	7.0	23.0	506.0	26.0	323.8	127.0	0.0	0.1	2.3	31.4	1.8	17.6	0.1	6.7	0.9	6.4	11.5
GW89	7.0	24.0	379.0	17.0	242.6	90.0	0.0	0.1	1.5	2.4	1.1	13.1	0.0	6.0	1.2	8.0	3.8
GW90	7.0	24.0	231.0	147.8	75.0	0.0	0.0	1.0	2.9	1.4	12.4	12.1	0.0	4.6	2.1	6.0	1.5
GW91	7.0	20.0	624.0	80.0	399.4	178.0	0.1	0.1	53.8	50.0	5.6	15.7	0.0	8.9	0.3	5.0	22.6
GW92	7.0	20.5	529.0	132.0	338.6	148.0	0.0	0.3	46.2	43.1	2.8	20.5	0.0	5.1	0.2	4.0	100.0
GW93	6.9	25.9	455.0	120.0	291.2	138.0	0.0	0.5	41.2	30.4	8.9	8.9	0.0	5.5	0.2	6.2	4.9
GW94	7.0	28.3	236.0	136.0	151.0	100.0	0.1	0.4	29.4	8.8	3.5	11.6	0.0	11.2	0.2	6.4	30.0
GW95	6.9	22.3	756.0	100.0	483.8	134.0	0.1	0.2	88.3	27.4	3.0	21.0	0.1	5.7	0.3	5.2	15.6
GW96	6.9	22.3	374.0	80.0	239.4	136.0	0.1	0.4	37.0	19.6	1.9	23.5	0.0	6.5	0.1	5.6	11.5
GW97	6.9	20.6	283.0	120.0	181.1	120.0	0.0	0.5	40.4	98.0	5.9	11.2	0.0	5.7	0.2	5.8	7.7
GW98	6.8	35.0	481.0	200.0	307.8	116.0	0.1	0.0	32.8	150.0	0.0	7.8	0.0	5.8	0.0	7.2	23.0
GW99	6.0	23.0	500.0	100.0	200.0	100.0	0.0	0.5	40.8	70.0	6.0	20.0	0.0	4.4	0.2	5.0	15.6
GW100	7.5	26.6	750.0	110.0	189.0	150.0	0.1	0.0	60.1	40.0	4.0	35.0	0.0	6.6	0.2	4.0	11.5
GW101	9.0	30.0	200.5	25.0	189.0	150.0	0.0	0.0	20.0	49.0	1.0	3.0	0.0	5.3	1.8	8.0	55.0
GW102	5.7	25.0	200.0	35.0	200.0	50.0	0.0	0.0	50.0	120.0	4.0	2.0	0.0	5.3	2.0	7.6	110.0

GW40	6.0	26.6	750.0	60.0	189.0	150.0	0.0	0.5	60.1	40.0	4.0	25.0	0.0	6.6	0.
GW41	5.0	23.0	900.0	100.0	250.0	200.0	0.0	0.0	40.0	15.0	2.3	25.0	0.0	5.0	0.
GW42	6.8	23.5	500.0	50.0	100.0	70.0	0.0	0.0	2.5	400.0	2.3	1.9	0.0	5.3	0.
GW43	6.5	24.0	300.0	60.0	110.0	50.0	0.0	0.0	3.0	39.0	1.2	20.0	0.0	30.0	3.
GW44	7.5	25.0	200.0	50.0	250.0	100.0	0.0	0.0	30.0	28.9	3.6	30.0	0.0	15.0	0.
GW45	5.0	25.0	450.0	100.0	120.0	200.0	0.0	0.0	15.0	4.3	21.8	19.0	0.0	10.0	1.
GW46	9.0	23.0	300.0	125.0	180.0	130.0	0.0	0.0	40.0	35.7	1.6	35.0	0.2	35.0	0.
GW47	5.5	23.5	250.0	110.0	100.0	100.0	0.0	0.0	30.0	100.0	2.0	40.0	0.0	12.0	0.
GW48	9.5	23.0	600.0	30.0	130.0	120.0	0.0	0.1	30.0	31.4	0.0	19.0	0.0	50.0	0.
GW49	6.0	24.0	250.0	130.0	140.0	90.0	0.0	0.1	1.5	180.0	2.0	16.0	0.0	45.0	1.
GW50	7.5	24.0	350.0	120.0	80.0	20.0	0.0	1.0	2.9	200.0	12.4	12.1	0.0	12.0	2.
GW51	7.5	30.9	700.0	80.0	400.0	80.0	0.1	0.1	53.8	90.0	5.6	15.7	0.0	8.9	0.
GW52	5.6	20.5	500.0	100.0	250.0	140.0	0.1	0.0	30.0	80.0	0.0	15.0	0.0	12.0	0.
GW53	8.0	25.9	600.0	120.0	200.0	120.0	0.0	0.3	41.2	30.4	0.0	8.9	0.0	25.0	0.
GW54	6.5	28.3	350.0	150.0	550.0	130.0	0.3	0.4	15.0	46.0	3.5	11.6	0.0	11.0	0.
GW55	5.5	22.3	700.0	130.0	450.0	145.0	0.1	0.0	80.0	27.4	3.0	21.0	0.1	45.0	0.
GW56	4.9	22.3	650.0	80.0	350.0	130.0	0.0	0.0	50.0	19.6	7.0	15.0	0.0	40.0	0.
GW57	5.5	20.6	400.0	80.0	180.0	120.0	0.1	0.0	40.4	120.0	5.9	11.2	0.0	30.0	0.
GW58	5.0	35.0	350.0	160.0	350.0	180.0	0.1	0.0	32.8	150.0	4.7	7.8	0.0	20.0	0.
GW59	7.5	30.0	650.0	90.0	150.0	280.0	0.0	0.1	40.0	130.0	1.0	40.0	0.0	20.0	0.
GW60	6.0	19.0	500.0	85.0	500.0	100.0	0.0	0.3	60.1	30.0	1.0	25.0	0.0	40.0	0.
GW61	5.8	30.5	700.0	160.0	89.0	309.0	0.0	0.6	50.0	300.0	3.0	15.0	0.0	20.0	1.
GW62	6.9	23.5	600.0	80.0	100.0	250.0	0.1	0.9	37.0	305.0	4.0	23.0	0.0	15.0	0.
GW63	7.9	19.8	169.0	250.0	58.0	120.0	0.1	0.0	30.0	80.0	15.0	20.0	0.0	35.0	0.
GW64	5.4	38.0	188.0	49.0	112.0	100.0	0.0	0.1	50.0	80.0	3.6	35.0	0.0	8.5	0.
GW65	6.5	38.9	500.0	190.0	60.0	290.0	0.1	0.0	45.0	160.0	30.0	35.0	0.0	25.0	0.
GW66	7.6	50.0	456.0	100.0	160.0	240.0	0.0	0.0	60.0	200.0	7.0	20.0	0.2	30.0	0.
GW67	5.9	45.0	567.0	180.0	220.0	215.0	0.0	0.0	80.0	60.0	3.0	30.0	0.3	45.0	0.
GW68	8.0	23.0	500.0	110.0	100.0	90.0	0.1	0.0	100.0	180.0	12.0	18.0	0.2	6.7	0.
GW69	8.2	34.0	450.0	128.0	225.0	170.0	0.0	0.0	35.0	220.0	5.0	15.0	0.2	6.0	0.
GW70	6.9	24.0	900.0	112.0	55.0	170.0	0.1	0.0	18.0	170.0	8.0	10.0	2.0	70.0	2.

GW103	6.5	21.0	160.0	50.0	300.0	80.0	0.0	0.0	35.0	180.0	3.0	10.0	0.0	5.5	1.0	6.8	25.0
GW104	7.8	35.0	160.0	44.0	240.0	100.0	0.0	0.0	50.0	97.0	9.0	7.0	0.0	3.9	1.9	6.4	12.0
GW105	7.0	25.0	175.5	30.0	200.0	80.0	0.0	0.0	32.0	80.0	19.0	10.0	0.0	7.7	1.5	4.8	35.0
GW106	8.1	21.0	400.0	35.0	150.0	130.0	0.0	0.0	40.0	35.0	1.5	20.3	0.2	6.2	0.8	8.4	48.0
GW107	4.9	22.0	300.0	40.0	300.0	120.0	0.0	0.0	35.0	69.0	2.0	15.0	0.0	6.2	0.8	6.8	20.0
GW108	7.7	28.0	450.0	40.0	570.0	90.0	0.0	0.1	20.0	50.0	3.0	17.6	0.1	6.7	0.9	6.4	90.0
GW109	7.2	27.0	380.0	55.0	600.0	75.0	0.0	0.0	45.0	32.0	5.0	10.0	0.0	6.0	1.2	8.0	80.0
GW110	6.9	24.0	205.0	125.0	500.0	35.0	0.0	1.0	35.0	60.0	5.0	12.1	0.0	32.0	2.1	6.0	30.0
GW111	7.0	19.0	600.0	180.0	650.0	120.0	0.0	0.0	70.0	35.0	3.0	20.0	0.0	45.0	0.3	7.0	35.0
GW112	6.8	35.0	470.0	132.0	300.0	200.0	0.0	0.0	50.0	80.0	5.0	25.0	0.0	45.0	0.2	4.0	56.0
GW113	6.6	25.0	900.0	100.0	290.0	180.0	0.0	0.4	41.2	100.0	7.0	17.0	0.0	30.0	0.2	6.2	100.0
GW114	7.5	33.6	600.0	120.0	150.0	90.0	0.0	0.4	36.0	60.0	3.0	16.0	0.0	9.0	0.3	6.4	80.0
GW115	7.8	22.3	680.0	68.0	300.0	195.0	0.0	0.4	59.0	27.4	3.0	23.0	0.1	5.7	0.3	5.2	20.0
GW116	6.9	23.5	374.0	100.0	300.0	136.0	0.1	0.3	37.0	56.0	2.0	14.0	0.0	7.0	0.5	5.6	40.0
GW117	5.6	26.1	325.0	90.0	200.0	145.0	0.0	0.5	45.0	30.0	0.3	20.0	0.0	6.0	0.2	5.8	30.0
GW118	8.3	34.0	485.0	70.0	200.0	175.0	0.0	0.7	47.0	120.0	4.7	7.8	0.0	5.0	0.3	7.2	35.0
GW119	7.1	21.0	490.0	90.0	250.0	200.0	0.0	0.0	58.0	45.0	3.0	25.0	0.0	0.3	0.3	6.0	45.0
GW120	6.8	30.0	400.0	90.0	300.0	185.0	0.0	0.0	70.0	100.0	4.1	20.0	0.0	6.6	0.3	6.5	100.0
GW121	7.8	40.0	350.0	50.0	350.0	150.0	0.0	0.0	45.0	90.0	1.0	15.0	0.0	45.0	2.1	6.0	35.0
GW122	5.7	35.0	200.0	35.0	180.0	50.0	0.1	0.0	50.0	210.0	4.0	2.0	0.0	12.0	1.0	7.6	80.0
GW123	6.5	21.0	160.0	50.0	300.0	100.0	0.0	0.0	35.0	180.0	3.0	10.0	0.0	30.0	0.5	6.0	55.0
GW124	7.8	35.0	400.0	80.0	170.0	100.0	0.0	0.0	69.0	97.0	9.0	7.0	0.0	55.0	0.9	6.4	45.0
GW125	6.8	25.0	175.5	30.0	200.0	80.0	0.0	0.0	26.0	80.0	8.0	25.0	0.0	35.0	2.0	6.0	50.0
GW126	7.5	35.0	350.0	35.0	280.0	180.0	0.0	0.0	40.0	35.0	7.0	20.3	0.2	50.0	0.8	7.0	70.0
GW127	6.7	22.0	300.0	120.0	300.0	120.0	0.0	0.0	35.0	300.0	2.0	15.0	0.0	40.0	1.0	5.0	69.0
GW128	7.7	40.0	450.0	40.0	570.0	90.0	0.0	0.1	28.0	50.0	3.0	30.0	0.1	80.0	0.9	3.0	100.0
GW129	4.6	35.0	550.0	35.0	240.0	75.0	0.0	0.0	45.0	32.0	4.0	10.0	0.0	60.0	0.2	7.0	57.0
GW130	7.0	24.0	205.0	98.0	500.0	35.0	0.0	1.0	35.0	130.0	5.0	12.1	0.0	45.0	0.7	5.0	30.0
GW131	7.0	19.0	600.0	180.0	400.0	120.0	0.0	0.0	70.0	35.0	3.0	20.0	0.0	25.0	0.3	7.0	35.0
GW132	9.0	55.0	550.0	100.0	300.0	300.0	0.0	0.1	55.0	220.0	6.0	25.0	0.0	60.0	0.1	4.0	35.0
GW133	6.6	25.0	900.0	100.0	450.0	180.0	0.0	0.3	86.0	100.0	1.0	17.0	0.0	30.0	0.3	5.7	29.0
GW134	4.8	89.0	600.0	65.0	150.0	90.0	0.0	0.0	36.0	60.0	3.0	16.0	0.0	80.0	0.5	6.4	52.0

GW135	7.8	22.3	700.0	90.0	300.0	450.0	0.0	0.4	35.0	75.0	3.0	20.0	0.1	45.0	0.3	5.8	68.0
GW136	6.9	35.0	374.0	100.0	300.0	136.0	0.1	0.3	37.0	56.0	2.0	20.0	0.0	35.0	0.1	9.0	40.0
GW137	5.6	26.1	890.0	55.0	150.0	200.0	0.0	0.5	60.0	80.0	0.3	20.0	0.0	20.0	0.3	4.8	65.0
GW138	7.0	34.0	485.0	70.0	200.0	175.0	0.0	0.2	47.0	120.0	4.7	16.0	0.0	15.0	0.3	5.0	40.0
GW139	6.7	35.0	490.0	120.0	250.0	280.0	0.0	0.0	58.0	45.0	3.0	25.0	0.0	50.0	0.3	7.0	80.0
GW140	6.8	30.0	500.0	100.0	380.0	100.0	0.0	0.0	80.0	150.0	4.1	20.0	0.0	46.0	0.3	6.5	55.0
GW141	7.0	35.0	350.0	50.0	350.0	150.0	0.0	0.0	45.0	90.0	2.0	9.0	0.0	45.0	2.1	6.0	35.0
GW142	7.5	40.0	200.0	35.0	180.0	50.0	0.1	0.0	60.0	200.0	3.0	10.0	0.0	12.0	1.0	7.6	80.0
GW143	8.2	21.0	160.0	50.0	300.0	100.0	0.0	0.0	40.0	180.0	4.0	15.0	0.0	30.0	0.5	6.0	55.0
GW144	7.8	35.0	400.0	80.0	170.0	100.0	0.0	0.0	50.0	97.0	6.0	10.0	0.0	55.0	0.9	6.4	45.0
GW145	6.8	30.0	175.5	30.0	200.0	80.0	0.0	0.0	30.0	80.0	8.0	25.0	0.0	35.0	2.0	6.0	50.0
GW146	4.5	39.0	350.0	35.0	280.0	180.0	0.0	0.0	40.0	35.0	4.0	10.0	0.2	50.0	0.8	7.0	70.0
GW147	6.7	22.0	300.0	120.0	300.0	120.0	0.0	0.0	35.0	200.0	3.0	15.0	0.0	40.0	1.0	5.0	69.0
GW148	5.7	40.0	450.0	40.0	570.0	90.0	0.0	0.1	30.0	50.0	0.9	26.0	0.1	80.0	0.9	3.0	100.0
GW149	4.6	35.0	550.0	35.0	240.0	75.0	0.0	0.0	45.0	32.0	4.0	11.0	0.0	60.0	0.2	7.0	57.0
GW150	5.5	30.0	205.0	98.0	500.0	35.0	0.0	1.0	30.0	150.0	0.6	18.0	0.0	45.0	0.7	5.0	30.0
GW151	8.5	19.0	600.0	180.0	400.0	120.0	0.0	0.0	30.0	35.0	3.0	25.0	0.0	25.0	0.3	7.0	35.0
GW152	7.0	55.0	550.0	100.0	300.0	300.0	0.0	0.1	40.0	220.0	5.0	22.0	0.0	60.0	0.1	4.0	35.0
GW153	6.9	25.0	900.0	100.0	450.0	180.0	0.0	0.3	86.0	100.0	3.0	26.0	0.0	30.0	0.3	5.7	29.0
GW154	4.8	89.0	600.0	65.0	150.0	90.0	0.0	0.0	36.0	80.0	4.0	25.0	0.0	80.0	0.5	6.4	52.0
GW155	7.8	22.3	700.0	90.0	300.0	450.0	0.0	0.4	30.0	75.0	3.0	15.0	0.1	45.0	0.3	5.8	68.0
GW156	7.0	25.0	374.0	100.0	300.0	136.0	0.1	0.3	37.0	56.0	2.0	25.0	0.0	35.0	0.1	9.0	40.0
GW157	5.6	26.1	890.0	55.0	150.0	200.0	0.0	0.5	60.0	80.0	1.0	35.0	0.0	20.0	0.3	4.8	65.0
GW158	9.0	35.0	485.0	70.0	200.0	175.0	0.0	0.2	57.0	100.0	4.7	20.0	0.0	15.0	0.3	5.0	40.0
GW159	6.7	35.0	600.0	120.0	600.0	200.0	0.0	0.0	60.0	50.0	3.0	25.0	0.0	40.0	0.3	8.0	70.0
GW160	5.9	20.0	500.0	100.0	380.0	100.0	0.0	0.0	80.0	60.0	4.1	25.0	0.0	30.0	0.3	5.6	50.0

COMMENT: NS: Not Specified. The tests carried out on the above Treated sewage sample gave satisfactory results when compared to NUPRC and FMENV limits.

NOTE: NS = Not Specified; mg/L = milligram per litre; MPN = Most Probable Number APHA = American Public Health Association; Standard methods for the Examination of water and Wastewater (2017), APHA, 23rd Edition

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LEAD CONSULTANT

3.1.1 pH

The pH of groundwater samples in the study area ranged from 4.5 - 9.0 as shown in Table 3.1. According to WHO acceptable limit value of pH which falls between the range of 6.5-8.5 water sample is recognized as an index of classifying groundwater as acidic < 5.5, slightly acidic 5.5 - 6.5, neutral 6.5 - 7.5, slightly alkaline 7.5 - 9, moderately alkaline 8 - 9 and alkaline > 9. From the above results, it is indicative that water in the study area is acidic to alkaline

3.1.2 Temperature

The temperatures of groundwater in Nyanya Abuja range from 20.0˚C - 25.1˚C as shown in Table 3. These groundwater temperatures are close to air temperatures indicative of phreatic aquifers. Some bacteria can be killed at elevated temperatures > 15˚C or higher, thus the temperatures within the study area are suitable for the survival of microorganisms also when compared to WHO 2011 limited of 25˚C it is clearly seen that the water temperature is suitable

3.1.3 Electrical Conductivity

The observed conductance in the study area ranged from 169 - 900 µS/cm as shown in 4.1. The measurement of conductivity gives a good indicator of the concentration of dissolved salts in water. In the present study EC values when compared to WHO limit of 1000 µS/cm the tested samples were in the permissible limits.

3.1.4 Total Alkalinity

(TA) is the amount of dissolved alkali in water that can both give and take Hydrogen ions. The values obtained ranges 20mg/l to 180mg/l furthermore when compared to WHO 2011 of TA limit of 120mg/L

3.1.5. Total Dissolved Solids

The WHO limit for TDS is 10000mg/L and the laboratory result values range from 17.42 - 1094.78 mg/L, when comparison was carried out it is observed that TDS values of tested samples are within WHO 2011 limit furthermore TDS represents the amount of inorganic substances. High TDS is commonly offensive to taste. A higher concentration of TDS usually serves as no health threat to humans until the values exceed 10,000 mg/L.

3.1.6. Dissolved Oxygen

DO is essential for the survival of fish and other aquatic organisms. Adequate levels of dissolved oxygen are necessary for maintaining a healthy aquatic ecosystem.Several biological and inorganic processes taking place in the subsurface may consume dissolved oxygen. The water samples collected in the study area had DO between 1 and 5 mg/L when this result was compared to WHO 2011 DO standard limit of 6 mg/L it shows that the tested samples are within desirable limit

also if the result had show low DO level it can be attributed to heterotrophic biological respiration.

3.1.7 Chlorine
Although chlorine does not occur naturally in water, it is often added to wastewater for disinfection. Although alkaline chlorine is a toxic gas, its aqueous solution is completely harmless to humans. If small amounts of chlorine are found in the water, it is an indication that the water is clean and essentially free of contaminants. The presence of chlorine ranges from 1.3mg/l to 200mg/l.

3.1.8. Total Hardness (TH)
This measures the amount of calcium and magnesium in water. High hardness can cause scaling in pipes and appliances, reducing their efficiency. It can also affect the taste of the water and impact aquatic life in natural water bodies. The laboratory result is between 0 to 390g/l.

3.1.9. Phosphate (PO):
WHO has a Phosphat**e** limit of 3 mg/l it could be seen from the tested samples the result obtained are between 0 to 0.1mg/l.Phosphates are vital nutrients for plant growth, but too much can lead to eutrophication, which is the excessive growth of algae in water bodies. This process reduces oxygen levels, harming fish and other aquatic life. Monitoring phosphate levels is essential for maintaining ecological balance.when result was compared to WHO limit they falls within the desirable limit

3.1.10 Nitrate (NH)
Nitrates are crucial nutrients but can be dangerous at high levels, especially for infants and pregnant women, as they can cause methemoglobinemia, also known as "blue baby syndrome." Additionally, high nitrate concentrations can contribute to eutrophication, similar to phosphates however the sample result falls within WHO limit of 1mg/l

1.1.11 Calcium (Ca)
This mineral is vital for human health and contributes to water hardness. It plays a key role in bone development and can influence the taste of water. Sufficient calcium levels are also essential for aquatic life, results obtained are between I.5mg/l to 89mg/l.WHO 2011 Ca limit ranges from 75mg/l-20089mg/l which clearly shows the result are within limit and no course for alarm

3.1.12 Chloride (Cl)
Chloride is a significant ion that can signal water pollution. Elevated chloride levels can be detrimental to aquatic organisms and may alter the taste of drinking water.

3.1.13 Magnesium (Mg)
Like calcium, magnesium is important for human health and contributes to the hardness of water. It is also crucial for various biochemical processes in both humans and aquatic organisms.the result are all within 150mg/l WHO acceptable limit

3.1.13 Carbonate (CO)
Carbonates help to buffer water and maintain its pH levels. They are critical for the health of aquatic ecosystems, as they provide stability for various organisms.

3.1.14 Nitrate (NO)
Nitrates are essential nutrients for plants but can be harmful in high concentrations, especially for infants and pregnant women. They can also lead to eutrophication in water bodies.

3.1.15 Iron (Fe)
While iron is an important nutrient for both humans and aquatic life, excessive amounts can cause staining in water and plumbing fixtures, as well as affect the taste and odor of water furthermore the obtain results are within the required WHO limit of 0.3mg/l

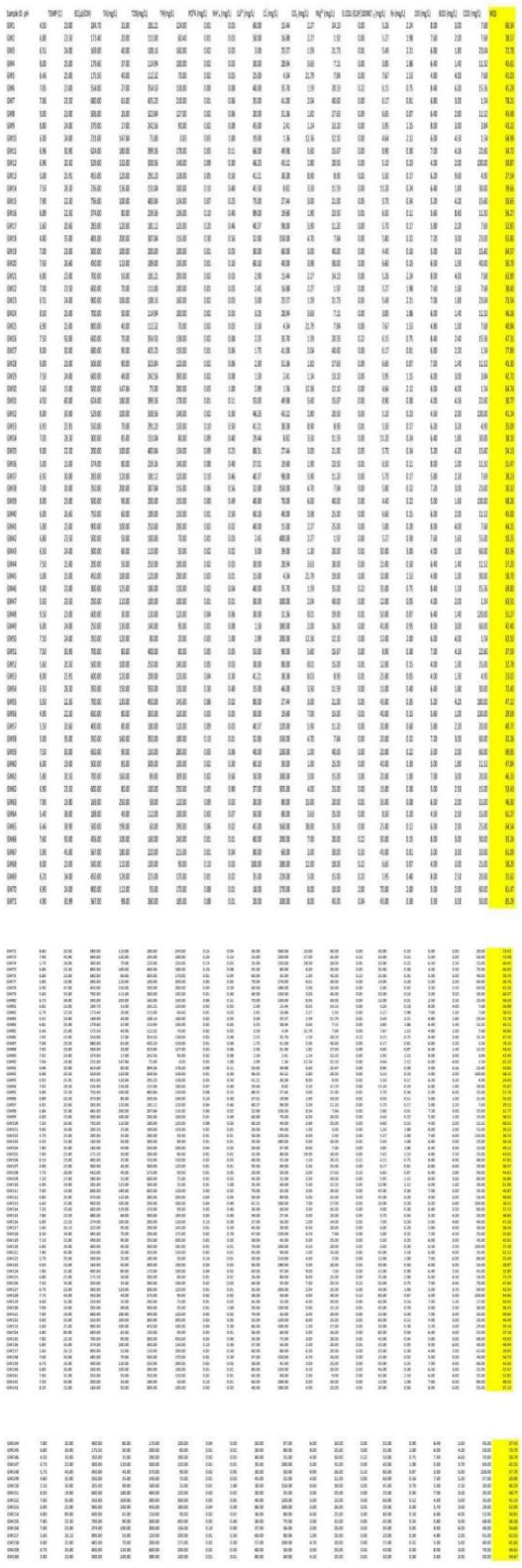
3.1.15 Chemical Oxygen Demand (COD): This measures the total amount of oxygen required to chemically oxidize organic and inorganic substances in water. High COD levels indicate significant pollution and can harm aquatic life. The result are within the standard limit of 100mg/l.

3.1.16. E. coli
This is a type of bacteria found in the intestines of humans and animals. Its presence in water indicates fecal contamination and poses a health risk to humans, making it a critical indicator of water quality.WHO do not have specific limit for e.coli

3.2 THE WATER QUALITY INDEX CALCULATION

The calculated WQI index is presented in Table 4.2. All chosen measuring spots of the Nyanya town are characterized by the WQ I<100 that is the classification of groundwater quality index, 45% are within the excellent type of water, 40 are within good, whilst the rest are very poor type of water.

Table 3: Calculated WQI



3.3.0 Report on Perceptron Neural Network Model for Water Quality Index (WQI)

The model overview of the Artificial neural network with Multilayer Perceptron (MLP) using Waikato Environmental for Knowledge Analysis(Weka) as the scheme, 70% was used as training, validation and testing was 30%. Learning rate (-L): 0.3, momentum (-M): 0.2, training Time (-N): 500 epochs Seed (-S): 0 whilst Threshold for Sigmoid Function (-E): 20 and the hidden Layers (-H): 'a' (a single hidden layer with a number of neurons equal to the average of the number of input and output neurons).

3.3.1 Neural network structure (with single hidden network layer):

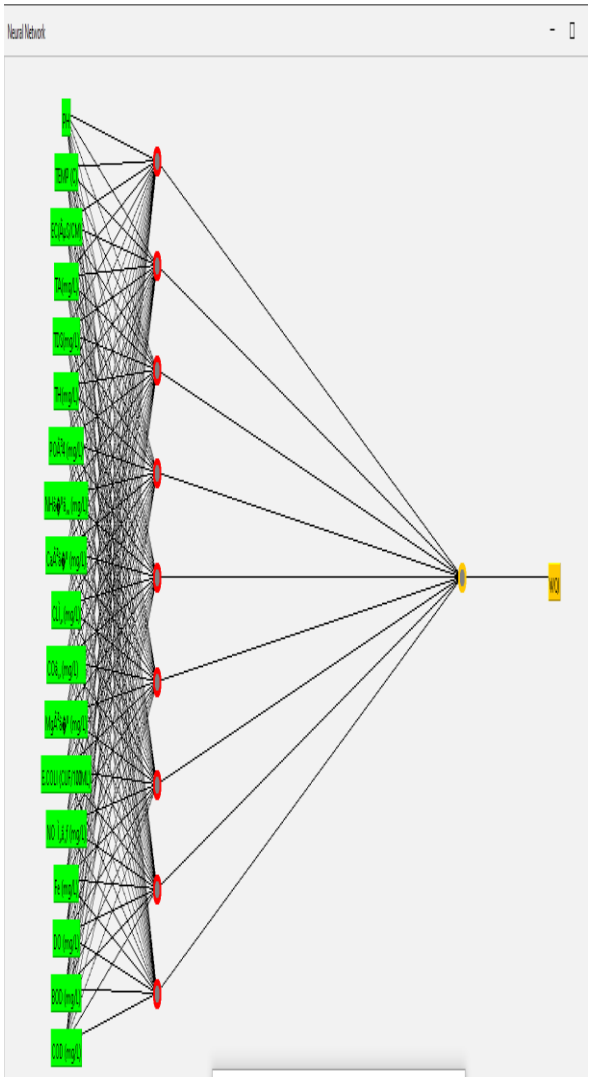


Figure 4 Neural network structure

Data Summary

The data summary of the artificial neural has an attribute of 19 in numbers with wqi as the target attribute, the attributes are Ph, Temp (°C) ~~©~~,Ec (µs/Cm),Ta (Mg/L), Tds (Mg/L), Th (Mg/L), Po_4 (Mg/L), Nh_4^+ (Mg/L), Ca^{2+} (Mg/L), Cl^- (Mg/L), Co_2 (Mg/L), Mg^{2+} (Mg/L), E. Coli (Cfu/100Ml), No_3^- (Mg/L), Fe (Mg/L), Do (Mg/L), Bod (Mg/L), Cod (Mg/L) and Wqi (Target Attribute)

3.4 Model Performance Summary

The model's performance was evaluated using cross-validation. The key performance metrics are as follows:

3.4.1 Correlation Coefficient:

A correlation coefficient is the relationship between two variables.The value of the study correlation coefficient was 0.997 this indicates a very high correlation between the predicted and actual values of the Water Quality Index (WQI). (M kulisz1 and j kujawska2, 2021) In Poland obtain a correlation coefficient of 0.979 from 25 sampling points and 8 parameters furthermore a correlation coefficient of positive 1 indicates a perfect positive correlation as one increases the other increases .

3.4.2 Mean Absolute Error (MAE):

Mean absolute error is the average of absolute differences between the predicted values and actual values that is it shows how close predictions are to actual values.The average absolute difference between the predicted WQI values and the actual values was 0.4558.

3.4.3 Root Mean Squared Error (RMSE):

The root mean squared is taking the square average of the squares of the errors between predicted values and the actual values it indicates how far off the predictions are from the actual values.The square root of the average squared differences between the predicted WQI values and the actual values was 0.9577, also in the research by Gazz et al.(2012) a RMSE of 1.663 was obtained from ANN modelling this place our result not to far from theirs' when rounding it to a whole number indicating the model's prediction accuracy .

3.4.4 Relative Absolute Error (RAE):

Relative Absolute Error is taking the absolute error predictions summing them up and the dividing by the sum of the actual values, it gives one the sense of how important the errors are in relation to the actual values.The total absolute error made by the model, relative to a simple predictor was 3.8734%.

3.4.5 Root Relative Squared Error (RRSE):

Root relative squared error is a measured that compares the root mean squared error of the actual model to the root mean squared squared of the baseline model.The square root of the total squared error made by the model, relative to a simple predictor was 6.5069%.

3.4.6 Total Number of Instances:

The Multilayer Perceptron neural network model trained on the WQI dataset demonstrates exceptional performance, with a very high correlation coefficient and low error rates. The model is highly effective in predicting the Water Quality Index based on the provided attributes, making it a reliable tool for water quality assessment.

3.5 Comparison of WQI(actual) and ANN (predicted) test results -

The analysis of actual and predicted values reveals important insights into the performance of a predictive model. A table comparing these values and their corresponding errors for 16 observations shows how well the model estimates true measurements.The actual values represent the wqi data points, while the predicted values are ann results. The errors, calculated as the difference between actual and predicted values, provide a clear picture of the model's accuracy. Most errors in the dataset are negative, indicating that the model tends to closely predicting the actual values. For instance, the fifth observation has the largest error of -0.822 while the twelfth stands out with a positive error of 0.209, suggesting an overestimation. When combined, the total actual values amount to approximately 634.67, while the total predicted values are about 634.24. The total error calculated from these values is 0.43. This leads to a combined percentage error of approximately 0.0676%. This analysis emphasizes the importance of the predictive model to enhance its accuracy and reliability in future applications.

Table 4: Ann test result in comparison with wqi

S/N	Actual values	Predicted values	Error
1	58.287	58.074	-0.212
2	38.506	38.065	-0.441
3	27.537	27.245	-0.291
4	91.501	91.363	-0.138
5	45.284	44.462	-0.822
6	50.696	50.387	-0.309
7	43.818	43.614	-0.205
8	61.095	60.471	-0.624
9	46.61	46.298	-0.312
10	42.728	42.382	-0.346
11	68.554	68.019	-0.535
12	68.263	68.472	0.209
13	37.588	37.177	-0.411
14	38.146	37.56	-0.586
15	41.604	41.035	-0.569
16	47.315	46.489	-0.826

3.6 Correlation analysis of input features with Water Quality Index (WQI)

Correlation coefficients measure the strength and direction of the linear relationship between two variables. In this case, the correlation coefficients indicate how strongly each water quality attribute is related to the Water Quality Index (WQI). Correlations range from -1 to 1, where 1 indicates a perfect positive linear relationship, -1 indicates a perfect negative linear relationship, and 0 indicates no linear relationship.

Here are the correlations of each attribute with WQI, along with their interpretations:

4.6.1 WQI (Water Quality Index): 1.000000 This is a perfect correlation with itself, as expected:

1. **Mg^{2+} (mg/L)**: 0.671329 There is a strong positive correlation between magnesium concentration and WQI. Higher levels of magnesium tend to be associated with higher WQI values this further indicates as magnesium is increasing the correlation coefficient tend to increases
2. **Fe (mg/L)**: 0.270019 There is a moderate positive correlation between iron concentration and WQI. As iron levels increase, WQI tends to increase as well.
3. **PO_4 (mg/L)**: 0.220269 There is a weak positive correlation between phosphate concentration and WQI. Higher phosphate levels are somewhat associated with higher WQI values.
4. **TH (Total Hardness, mg/L)**: 0.144098 There is a weak positive correlation between total hardness and WQI. Increased hardness has a slight association with higher WQI values.
5. **CO_2 (mg/L)**: 0.090965 There is a very weak positive correlation between carbon dioxide concentration and WQI. The relationship is minimal but slightly positive.

6. **E. COLI (CFU/100ML)**: 0.087856 There is a very weak positive correlation between E. coli concentration and WQI. Higher E. coli levels are minimally associated with higher WQI values.

7. **EC (Electrical Conductivity, µS/CM)**: 0.062283 There is a very weak positive correlation between electrical conductivity and WQI. Higher conductivity slightly relates to higher WQI value which show increase in Wqi.

8. **TA (Total Alkalinity, mg/L)**: 0.050319 There is a very weak positive correlation between total alkalinity and WQI. Higher alkalinity shows a minimal positive relationship with WQI.

9. **PH**: 0.050089 There is a very weak positive correlation between pH and WQI. Slightly higher pH levels are associated with higher WQI values.

10. **NH_4^+ (Ammonium, mg/L)**: 0.026443 There is a negligible positive correlation between ammonium concentration and WQI. The relationship is almost nonexistent.

11. **NO_3^- (Nitrate, mg/L)**: 0.000863 There is a negligible positive correlation between nitrate concentration and WQI. This correlation is practically zero.

12. **TEMP (Temperature, °C)**: -0.047422 There is a very weak negative correlation between temperature and WQI. Higher temperatures are slightly associated with lower WQI values.

13. **TDS (Total Dissolved Solids, mg/L)**: -0.065288 There is a very weak negative correlation between total dissolved solids and WQI. Increased TDS is slightly related to lower WQI values.

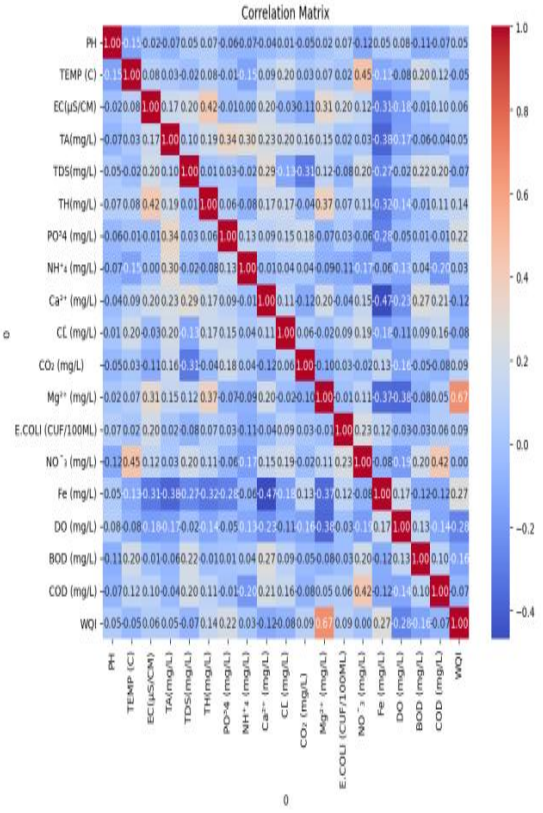
14. **COD (Chemical Oxygen Demand, mg/L)**: -0.072163 There is a very weak negative correlation between COD and WQI. Higher COD levels show a minimal association with lower WQI values.

14. **CL^- (Chloride, mg/L)**: -0.076064 There is a very weak negative correlation between chloride concentration and WQI. Higher chloride levels are slightly associated with lower WQI values.

15 **Ca^{2+} (Calcium, mg/L)**: -0.121538 There is a weak negative correlation between calcium concentration and WQI. Increased calcium levels are somewhat associated with lower WQI values.

16. **BOD (Biochemical Oxygen Demand, mg/L)**: -0.158649 There is a weak negative correlation between BOD and WQI. Higher BOD levels tend to be associated with lower WQI values.

17. **DO (Dissolved Oxygen, mg/L)**: -0.278521 There is a moderate negative correlation between dissolved oxygen and WQI. Higher dissolved oxygen levels are associated with lower WQI values.



FigFigure 5: Correlation coefficients

Table 4.4: Descriptive statistic-mean standard deviation, minimum and maximum

Table 7: Descriptive statistic-mean standard deviation, minimum and maximum

In this research, several key physio-chemical characteristics of groundwater in the area were collected and assessed. The primary aim of this study was to assess, ascertain, forecast, and contrast the quality of groundwater distribution and the potential for contamination in the region using ANN models. In addition to statistically documention the current condition of groundwater for future comparisons, this study will also play a significant role in the development, management, utilization, and degradation of groundwater in Nyanya, Abuja.

Table 5: Statistical analysis

Attribute	Count	Mean	Std Dev	Min	Q1	Median	Q3	Max
PH	160	6.822	1.084	4.500	6.000	6.900	7.500	9.500
TEMP (C)	160	28.375	10.260	15.000	23.000	25.000	30.923	89.000
EC (µS/CM)	160	460.609	200.766	160.000	300.000	475.500	600.000	900.000
TA (mg/L)	160	88.622	45.487	17.000	50.000	90.000	120.000	250.000
TDS (mg/L)	160	258.020	130.496	55.000	157.760	240.000	323.840	650.000
TH (mg/L)	160	142.155	71.550	0.026	100.000	130.000	178.000	450.000
PO_4 (mg/L)	160	0.042	0.049	0.001	0.014	0.020	0.050	0.300
NH_4^+ (mg/L)	160	0.188	0.254	0.010	0.030	0.050	0.300	1.000
Ca^{2+} (mg/L)	160	38.852	22.277	1.500	30.000	40.000	50.000	100.000
CL^- (mg/L)	160	78.995	70.508	1.360	30.380	50.000	100.000	400.000
CO_2 (mg/L)	160	4.725	4.818	0.010	2.000	3.000	5.600	30.000
Mg^{2+} (mg/L)	160	18.723	9.732	1.920	11.590	17.815	23.875	50.000
E. COLI (CFU/100 ML)	160	0.040	0.167	0.000	0.000	0.000	0.010	2.000
NO_3^- (mg/L)	160	20.443	19.330	0.300	5.800	9.500	32.750	80.000
Fe (mg/L)	160	0.712	0.687	0.010	0.220	0.340	0.963	3.000
DO (mg/L)	160	6.034	1.373	2.500	5.000	6.000	7.000	9.000

Attribute	Count	Mean	Std Dev	Min	Q1	Median	Q3	Max
BOD (mg/L)	160	3.114	1.454	1.000	2.000	3.000	4.000	9.600
COD (mg/L)	160	37.200	30.887	1.540	11.520	30.000	55.000	180.000
WQI	160	48.412	14.689	10.252	38.370	45.917	58.389	91.501

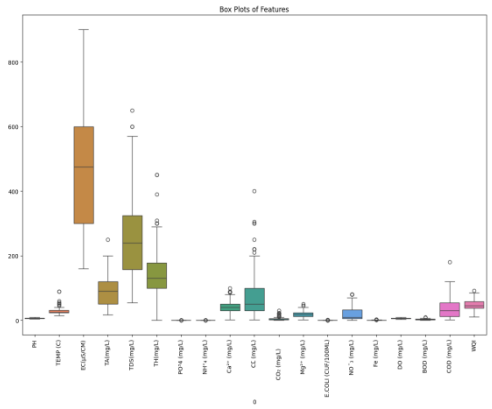


FIGURE 6; DESCRIPTIVE ANALYSIS

CONCLUSION

Nyanya a suburb of the Federal Capital Territory located in Abuja Municipal Area Council (AMAC) of Nigeria is considered an agricultural and economical town, so the

quality of its groundwater is important for the well being of man, animal and the growth of crops. the necessary water parameters were carried out in the laboratory, and a total of 160 sample points were taken from various locations in Nyanya.

the water quality index was calculated using the weighted arithmetic index method, on evaluation of the results, wqi showed that 5% of the samples fall into ≤ 25 which is an excellent water quality, 60 % falls within ≤ 50 category that indicates good water quality, while 20% indicates ≤75 which is poor water quality and the last is ≤ 15 shows very poor water quality.

neural network models can be an effective tool to predict groundwater quality index (wqi). the modelled neural network weka (waikato environment for knowledge analysis) determines the relationships between the input data – physicochemical parameters of ground waters, and the output data the wqi. the best modelling results was obtained for a network with one neuron in the hidden layer. a high correlation coefficient (general as well as in individual subsets) of 0.9979 and a low level of MAE (mean absolute error) of 0.4558 in each of the subsets (training, test, and validation) as well as RMSE(root mean square error) of 0.9577. relative absolute error (rae): 3.8734% and RRSE(root relative squared error) of 6.5069% have been reached, it was found that magnesium and iron are found to be the most influential factors in predicting the model . additionally, the maximum error percentage for the wqi value did not exceed 2%, therefore they may be recognized as sound predictors concerning the tested data.

the flexibility of the neural network structure allows water quality to be predicted using either a smaller nor larger number of physicochemical parameters from few or large sampling points. (m kulisz1 and j kujawska2, 2021) used 5 physicochemical parameters from 25 points and got an excellent result and their maximum percentage error is 4%. however in our case study we used 17 parameters from 160 points and a maximum percentage error is less than a percent.

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Assessment of the Index and Unsoaked California Bearing Ratio of Tropical Residual Soils in Niger State, Nigeria

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ABSTRACT
This study assesses the index and unsoaked California Bearing Ratio (CBR) of tropical residual soils in Niger State, Nigeria, to evaluate their suitability for road pavement applications. Laboratory tests were conducted on soil samples to determine moisture content, specific gravity, particle size distribution, consistency limits, compaction characteristics, and CBR values. The results revealed significant variations in soil properties, reflecting the heterogeneity of residual soils across the region. The Natural Moisture Content (NMC) ranged from 2.33 to 30.8%, while specific gravity (Gs) values varied between 2.09 and 3.06. The soils exhibited diverse grain size distributions, with fines content ranging from 5.59 to 84.77%. Liquid Limits (LL) ranged from 20.62 to 84.58%, while Plasticity Indices (PI) varied from non-plastic to 45.28%, indicating the presence of highly plastic clays in some locations. The Maximum Dry Density (MDD) ranged from 1.541 to 2.571 g/cm³, with Optimum Moisture Content (OMC) between 6.69 and 20.91%. The unsoaked CBR values ranged from 6.57 to 145.89%, highlighting the need for stabilization in weaker soils before use as pavement subgrade. The classification results indicated a dominance of A-7 and A-2, based on AASHTO classification system, and CL/SC, based on USCS, suggesting varying engineering performance. These findings emphasize the importance of site-specific evaluations and potential soil stabilization for improved pavement performance in the region.

Keywords: *Compaction; Pavement; Residual soils, Index properties; Unsoaked California Bearing Ratio.*

1 INTRODUCTION

Roads are fundamental to a nation's economic development, driving growth and providing essential social benefits (Muturi, 2023). In Nigeria, as in many other regions, flexible pavement is the predominant construction method for highways (Osadebe and Quadri, 2019). The design of these pavements hinges on understanding the load-bearing capacity of the underlying soil layers, namely the base, sub-base, and subgrade. These layers collectively support the traffic load transmitted from the pavement surface. Therefore, a thorough assessment of their suitability is paramount for effective pavement design.

The California Bearing Ratio (CBR) test is a widely used empirical method for evaluating the strength of soil materials in flexible pavement construction (Mahabubuzzaman, 2001). It plays a crucial role in determining the required pavement thickness based on anticipated traffic loads, with higher CBR values indicating stronger soils that support thinner, more cost-effective pavements (Shaban and Cosentino, 2017). Conversely, weaker soils with lower CBR values necessitate thicker pavements to ensure adequate load distribution and prevent premature failure. Additionally, CBR test aids in assessing the suitability of natural subgrade soils for construction. A high CBR value suggests a stable foundation that minimizes pavement thickness, while a low CBR value may require soil stabilization or treatment to enhance its load-bearing capacity (Kiptoo, 2016).

Assessment of unsoaked CBR provides valuable insights into the strength and load-bearing capacity of soils under dry conditions, which is essential for understanding their performance in pavement construction and foundation design. Tropical residual soils, commonly found in Niger State, Nigeria, exhibit varying strength characteristics influenced by mineral composition, weathering processes, and particle size distribution (Olofinyo *et al.,* 2019). Evaluating the index properties, including Atterberg limits and particle size distribution, helps characterize these soils in terms of consistency, plasticity, and suitability for engineering applications. A comprehensive assessment of these properties enables engineers to determine whether

natural soils can be used as subgrade materials or require improvement through stabilization techniques.

Recent studies have shown that the CBR values of tropical residual soils vary significantly due to differences in geological formation and environmental conditions. For instance, Oyelami *et al.* (2022) and Olofinyo *et al.* (2019) examined the CBR characteristics of residual soils in southwest, Nigeria and found notable variations in strength properties across different locations. Similarly, Ob'lama *et al.,* (2018) and Musa *et al.* (2020) investigated the index properties of residual soils in North central, Nigeria highlighting the influence of soil formation processes on their geotechnical behavior. These findings emphasize the need for site-specific assessments to determine the suitability of residual soils for pavement construction. This study addresses this need by evaluating the index properties and unsoaked CBR of tropical residual soils in Niger State, Nigeria, providing essential geotechnical data for infrastructure development.

By assessing these properties, this research will generate valuable information for road pavement design in Niger State. The study's findings will support the selection of appropriate construction materials and enhance decision-making in pavement engineering. Also, the results will be beneficial for engineers, planners, and policymakers involved in infrastructure development, with potential applications to similar soil conditions in other regions.

2 MATERIALS AND METHODS

2.1 SAMPLES LOCATION AND COLLECTION

The materials used for this study is residual lateritic soils, collected from different existing borrow pits within Niger state, North Central Zone of Nigeria. The locations include: Gidan Kwano: 9.5313°N, 6.4598°E; Lapai Gwari 9.5360°N, 6.4691°N; Brighter 9.5811°N, 6.5561°E; Gidan Waya 9.5626°N, 6.6001°E; Kuta 9.8593°N, 6.7191°E; Gunu 9.6662°N, 6.7191°E; Pyata 9.6699°N, 6.5261°E; Maikunkele 9.6764°N, 6.4551°E, Gidan Mangoro 9.569042°N, 6.493685°E. The method of sample collection that was employed is disturbed sampling. It includes excavating and gathering samples from depths of 0.5, 1.0 and 1.5m, combining them into one sample, with a small portion of each preserved in polythene bags to determine the natural moisture content of each sample individually. A total of 85 samples were collected and air-dried at room temperature ranging from 25 to 30°C prior to undergoing additional laboratory analysis.

2.2 METHODOLOGY

Samples collected from each location underwent tests for natural moisture content, specific gravity, Atterberg limits, and compaction, following the methods specified in BS 1377 (1990). The particle size distribution for each soil sample was analyzed using the dry-sieving technique. Atterberg limit tests were conducted to ascertain the plastic and liquid limits, along with the plasticity index (PI). Additionally, compaction tests and CBR assessments were performed using British standard light (BSL) energy to investigate the moisture-density relationship.

3 RESULTS AND DISCUSSION

3.1 NATURAL MOISTURE CONTENT (NMC)

The natural moisture content (NMC) of soils depicted in Table 2a and Table 2b is a critical factor in geotechnical engineering, particularly for pavement design (Shaban and Cosentino, 2017). This study reveals significant variability in NMC across the study area, ranging from 2.33% in Kuta to 30.8% in Gidan Waya (GW), reflecting the influence of local topography, drainage, soil mineralogy, and land use (Alhaji *et al.*, 2021). Low NMC values in Kuta (2.33 to 4.75%) suggest well-drained sandy soils, while higher values in GW1 (30.8%) may indicate clay-rich soils or high groundwater levels (FHWA, 2016). Intermediate values in locations like Gidan Kwano (9.23 to 21.40%) and Lapai Gwari (LGP) likely reflect varying hydrological and geological conditions. High NMC areas may require design modifications, such as soil stabilization or thicker pavement layers, to mitigate reduced shear strength and increased compressibility (Osadebe and Quadri, 2019). Integrating NMC data with Atterberg limits and particle size distribution enhances the understanding of soil behavior, aiding in the development of durable and sustainable road infrastructure.

3.2 SPECIFIC GRAVITY (GS)

Specific gravity (Gs) of soil provides valuable information about the mineralogical composition and density of soil solids. In this study, the Gs values obtained from various locations in Niger State, Nigeria, reveal a generally consistent range, with most values falling between 2.6 and 3.0 (Table 2a & 2b). This suggests a relatively uniform mineralogical makeup across the sampled areas, which is typical for many

residual soils (Alhaji *et al.*, 2021). However, subtle variations do exist, hinting at localized differences in mineral proportions or the presence of minor constituents. For instance, the lower Gs values observed in some samples, like LGP (2.1) and PYTA (2.09), could indicate a higher presence of lighter minerals, such as mica or feldspars, or potentially a higher organic matter content (Mahabubuzzaman, 2001). Conversely, samples like GK7 (3.06) exhibit slightly elevated Gs values, which might suggest a greater proportion of denser minerals, such as iron oxides or quartz.

While majority of Gs values cluster around the 2.7 to 2.9 range, the minor deviations are still significant in the context of soil classification and understanding overall soil behavior. Specific gravity contributes to the calculation of other important soil properties, such as void ratio and porosity, which in turn influence permeability, compressibility, and shear strength (Oyelami *et al.*, 2022). Therefore, even small variations in Gs can have implications for the engineering properties of the soil. For example, a soil with a higher Gs, indicating a greater proportion of denser minerals, might exhibit different compaction characteristics compared to a soil with a lower Gs and a higher proportion of lighter minerals or organic material.

3.3 PARTICLE SIZE DISTRIBUTION

The sieve analysis results highlight the diverse particle size distributions of residual soils in Niger State, Nigeria, reflecting their heterogeneous nature due to variations in weathering processes, parent rock composition, and environmental conditions. The percentage of soil passing the coarsest sieve ranges from 25.77% (LGP) to 100% (multiple samples), while the percentage passing the finest sieve varies from 5.59% (BR) to 84.77% (GM), indicating significant differences in coarse and fine fractions (Table 2a & 2b). These variations influence the engineering behavior of the soils, directly impacting their suitability for pavement applications. Coarse-grained soils, such as BR4, with lower fine fractions, exhibit higher permeability and lower compressibility, making them more suitable for subbase or base course layers. In contrast, fine-grained soils like GM, with a high percentage of fines, tend to have lower permeability and higher compressibility, necessitating stabilization or thicker pavement layers to enhance performance. Understanding these particle size variations is essential for proper material selection and the design of durable road pavements in the region.

3.4 CONSISTENCY LIMIT

The consistency limits, including Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI) in Table 2a and Table 2b, exhibit significant variations across the soil samples in Niger State, Nigeria, reflecting differences in clay mineralogy and weathering processes. The LL ranges from 20.62% (KUTA) to 84.58% (MK), while the PI spans from non-plastic (NP) to 45.28% (MK), indicating diverse plasticity characteristics that influence soil behavior in construction applications. Comparing these values with the Nigerian General Specification for Roads and Bridges (FMWH, 2016) reveals that several samples, particularly from MK, GM, and parts of the GW and LGP series, exceed the recommended plasticity index limit for subgrade materials, which is set at 35%. Soils with high plasticity may exhibit excessive compressibility and swelling, making them unsuitable for direct use in road construction without stabilization. These findings emphasize the necessity of soil treatment techniques, such as lime or cement stabilization, to enhance engineering properties and ensure the suitability of residual soils for pavement applications.

3.5 CLASSIFICATION CATEGORY OF THE SOIL SAMPLES

The soil classification results, utilizing both the AASHTO and USCS systems (Table 1), reveal a diverse range of soil types across the various locations in Niger State, Nigeria, reflecting the complex nature of residual soil formation. The presence of A-7 classifications in the AASHTO system, coupled with CL (clay with low plasticity) and SC (sandy clay) designations in the USCS system, indicates a prevalence of fine-grained soils, particularly clays and silts, across many sites, including samples from Lapai Gwari (LGP), Gidan Waya (GW), and Gunu. However, the presence of other classifications, such as A-2 (AASHTO) and GC (gravelly clay), GM (silty gravel), and SM (silty sand) in the USCS system, demonstrates that coarser materials are also present in certain locations, such as Gidan Kwano (GK), Kuta, and some samples from Maikunkele (MK). This variability in soil types, ranging from predominantly clayey to sandy or gravelly, has significant implications for pavement design, as each soil type possesses distinct engineering properties that influence load-bearing capacity, compressibility, and drainage characteristics.

3.6 COMPACTION CHARACTERISTICS

The compaction test results - Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) in Figure 1a and Figure 1b, reveal a considerable range of values across the various soil samples collected in Niger State, Nigeria, indicating variations in soil composition and potential engineering behavior. MDD values range from 1.541 g/cm³ (MK7) to 2.571 g/cm³ (MK3), reflecting differences in particle size distribution and mineralogy (Ob'lama *et al.* 2018). Generally, higher MDD values suggest soils with a greater proportion of denser particles, leading to improved strength and stability. Conversely, OMC, which represents the moisture content at which MDD is achieved, ranges from 6.69% (GK3) to 20.91% (GM8), demonstrating the influence of clay content and plasticity on water retention. Higher OMC values are typically associated with soils containing higher proportion of fine-grained materials, which require more water for optimal compaction (Olofinyo *et al.*, 2019; Bowers, 1986). These variations in MDD and OMC highlight the importance of site-specific geotechnical investigations for road projects, as generalized soil data may not accurately represent the conditions encountered.

TABLE 1: SOIL SAMPLES CLASSIFICATION

CLASSIFICATION SYSTEM	SUB-GROUP	NUMBER OF SOIL SAMPLES
USCS	CL	13
	SC	40
	SM	8
	GC	14
	GM	10
AASHTO	A – 1	11
	A – 2	44
	A – 7	30

Comparing the obtained MDD and OMC values with the requirements specified in the Nigerian General Specifications for Roads and Bridges (FMWH, 2016) is crucial for assessing the suitability of the soils for road construction. In terms of road construction, soils exhibiting MDD higher than 2.0 g/cm³ and OMC ranging from 8-12% are viewed as optimal for subbase materials, whereas soils with reduced MDD and elevated OMC need adjustments. Areas like GK, MK, and BR fulfill the criteria for subbase, whereas GM9, GM8, and LGP8 do not meet the standard range and need stabilization. The variability seen in different locations underscores the necessity of thorough geotechnical evaluation prior to choosing materials for road construction, ensuring the durability, strength, and longevity of pavement structures.

CALIFORNIA BEARING RATIO (CBR)

The unsoaked California Bearing Ratio (CBR) values obtained from various locations across Niger State, Nigeria, exhibited a wide range of variability (Figure 2a, 2b and 2c), reflecting the diverse nature of the residual soils and their inherent load-bearing capacities. The CBR values span from a low of 6.57% (KUTA1) to a remarkable high of 145.89% (GUNU1), highlighting the significant differences in strength and stiffness across the sampled locations. This range underscores the influence of factors such as mineralogy, particle size distribution, and natural moisture content on the soil's resistance to penetration (Alhaji *et al.*, 2021). For instance, locations like KUTA8 (139.44%) and GUNU1 (145.89%) suggest soils with excellent load-bearing potential, possibly due to a higher proportion of coarse materials or the presence of cementing agents. Conversely, soils like KUTA1 (6.57%) and some samples from the PYTA and MK series indicate lower strengths, potentially due to a higher clay content or less favorable particle packing. These variations necessitate careful consideration of subgrade strength in pavement design (Musa *et al.*, 2020; Oyelami *et al.*, 2022).

According to the Nigerian General Specification for Roads and Bridges (2016), a minimum CBR value of 30% is recommended for subgrade materials under lightly trafficked roads, while for more heavily trafficked pavements, the required CBR can be 80% or higher. Based on this criterion, soils in Gunu, Brighter, and Lapai Gwari meet the requirements for use as subgrade material without modification. However, locations such as Pyata, Maikunkele, and parts of Kuta, with values below 30%, fall short of this requirement and would need stabilization through mechanical compaction, lime, cement, or other chemical treatments to meet road construction standards. Therefore, while certain locations exhibited excellent soil strength, others require significant improvement to align with the Nigerian General Specifications for Roads and Bridges (FMWH, 2016).

TABLE 2A: STATISTICAL DESCRIPTION OF THE PROPERTIES OF TESTED SOIL SAMPLES

LOCATION	STATISTICS	NMC	GS	GRAVEL	SAND	FINES	LL	PL	PI
	MEAN	11.53	2.74	23.36	29.78	46.85	54.54	27.76	26.78
	STD DEV.	5.123	0.103	24.65	17.54	29.23	15.88	6.34	10.05
MK	VARIANCE	26.24	0.011	607.82	307.87	854.77	252.3	40.24	100.9
	MEDIAN	11.69	2.72	17.96	22.15	35.58	54.61	27.62	26.99
	MIN.	3.77	2.63	0.00	13.56	13.97	29.77	17.47	11.61
	MAX.	18.97	2.96	64.67	63.94	85.85	84.98	39.7	45.28
	MEAN	3.134	2.826	44.11	37.85	18.04	36.48	24.22	12.26
	STD DEV.	0.772	0.122	13.61	9.17	6.43	5.42	2.12	4.27
KT	VARIANCE	0.597	0.015	185.17	84.09	41.28	29.39	4.49	18.26
	MEDIAN	2.85	2.85	40.8	39.42	18.71	34.38	24.58	10.13
	MIN.	2.33	2.64	26.29	24.98	8.21	30.62	21.23	8.21
	MAX.	4.75	3.04	63.32	49.07	31.90	44.64	26.64	18.00
	MEAN	9.115	2.805	17.89	34.36	47.74	53.45	34.70	18.75
	STD DEV.	1.918	0.064	3.61	4.42	6.97	8.02	6.15	7.56
GN	VARIANCE	3.678	0.004	13.04	19.50	48.60	64.43	37.81	57.28
	MEDIAN	9.285	2.815	18.51	35.39	45.14	55.46	35.6	20.85
	MIN.	6.11	2.71	8.33	26.93	41.72	40.51	23.56	2.11
	MAX.	12.77	2.89	20.86	39.02	64.74	64.42	44.46	28.89
	MEAN	8.029	2.678	28.68	49.42	21.90	44.51	35.36	5.06
	STD DEV.	3.365	0.096	21.41	20.57	10.473	10.98	9.06	8.44
PY	VARIANCE	11.329	0.009	458.6	423.45	109.68	120.6	82.09	71.27
	MEDIAN	7.64	2.665	34.55	40.81	22.05	40.81	34.64	5.12
	MIN.	3.06	2.57	0.00	26.27	4.49	28.40	23.87	0.00
	MAX.	16.25	2.92	53.34	82.68	45.23	62.46	53.53	26.17
	MEAN	9.692	2.858	42.684	27.41	29.906	47.84	28.84	19.08
	STD DEV.	7.786	0.057	18.403	11.42	15.97	11.31	6.31	6.46
GW	VARIANCE	60.637	0.003	338.69	130.6	255.07	127.9	39.84	41.76
	MEDIAN	7.98	2.87	41.85	24.37	24.26	48.02	27.40	19.74
	MIN.	3.50	2.74	11.40	16.54	15.94	26.9	21.58	5.32
	MAX.	30.8	2.92	66.67	53.12	68.45	63.67	43.45	29.30

TABLE 2B: STATISTICAL DESCRIPTION OF THE PROPERTIES OF TESTED SOIL SAMPLES

LOCATION	STATISTICS	NMC	GS	GRAVEL	SAND	FINES	LL	PL	PI
	MEAN	13.77	2.79	35.756	30.265	33.98	57.127	32.81	24.32
	STD DEV.	5.54	0.08	29.339	15.324	24.48	8.19	4.21	5.85
LPG	VARIANCE	30.77	0.006	860.81	234.83	599.48	67.08	19.67	25.24
	MEDIAN	12.66	2.78	33.415	25.405	29.15	59.85	19.68	23.18
	MIN.	7.21	2.67	0.0	17.13	7.24	45.72	27.14	18.32
	MAX.	24.09	2.92	75.15	68.09	71.87	68.02	39.72	34.68
	MEAN	8.22	2.78	20.092	52.676	27.232	32.84	19.51	20.59
	STD DEV.	5.51	0.146	15.164	21.15	18.71	12.76	8.41	6.54
GK	VARIANCE	30.32	0.021	229.96	147.64	350.29	162.71	70.67	42.75
	MEDIAN	6.26	2.73	21.575	56.63	20.95	32.93	20.39	17.03
	MIN.	2.92	2.61	0	26.47	13.75	20.51	0	16.61
	MAX.	17.53	3.06	50.97	62.33	73.53	62.09	33.95	28.14
	MEAN	9.88	2.81	21.085	32.909	46.006	47.099	25.613	21.486
	STD DEV.	3.63	0.12	22.25	13.82	24.07	9.268	3.835	5.759
GM	VARIANCE	13.17	0.015	495.45	191.10	579.54	85.907	14.712	33.169
	MEDIAN	8.41	2.785	16.25	32.255	38.19	45.225	25.67	20.03
	MIN.	5.46	2.59	0.0	15.23	22.5	35.25	20.4	14.85
	MAX.	15.77	2.99	55.37	56.38	84.77	67.97	32.59	35.38
	MEAN	2.428	2.818	69.034	24.198	6.768	24.644	0	0
	STD DEV.	1.008	0.097	4.65	2.424	2.847	2.177	0	0
BR	VARIANCE	1.018	0.009	21.653	5.877	8.108	4.739	0	0
	MEDIAN	2.5	2.85	71.0	23.25	6.21	23.76	0	0
	MIN.	0.79	2.7	62.0	21.48	4.18	22.7	0	0
	MAX.	3.32	2.91	72.93	27.12	11.64	27.01	0	0

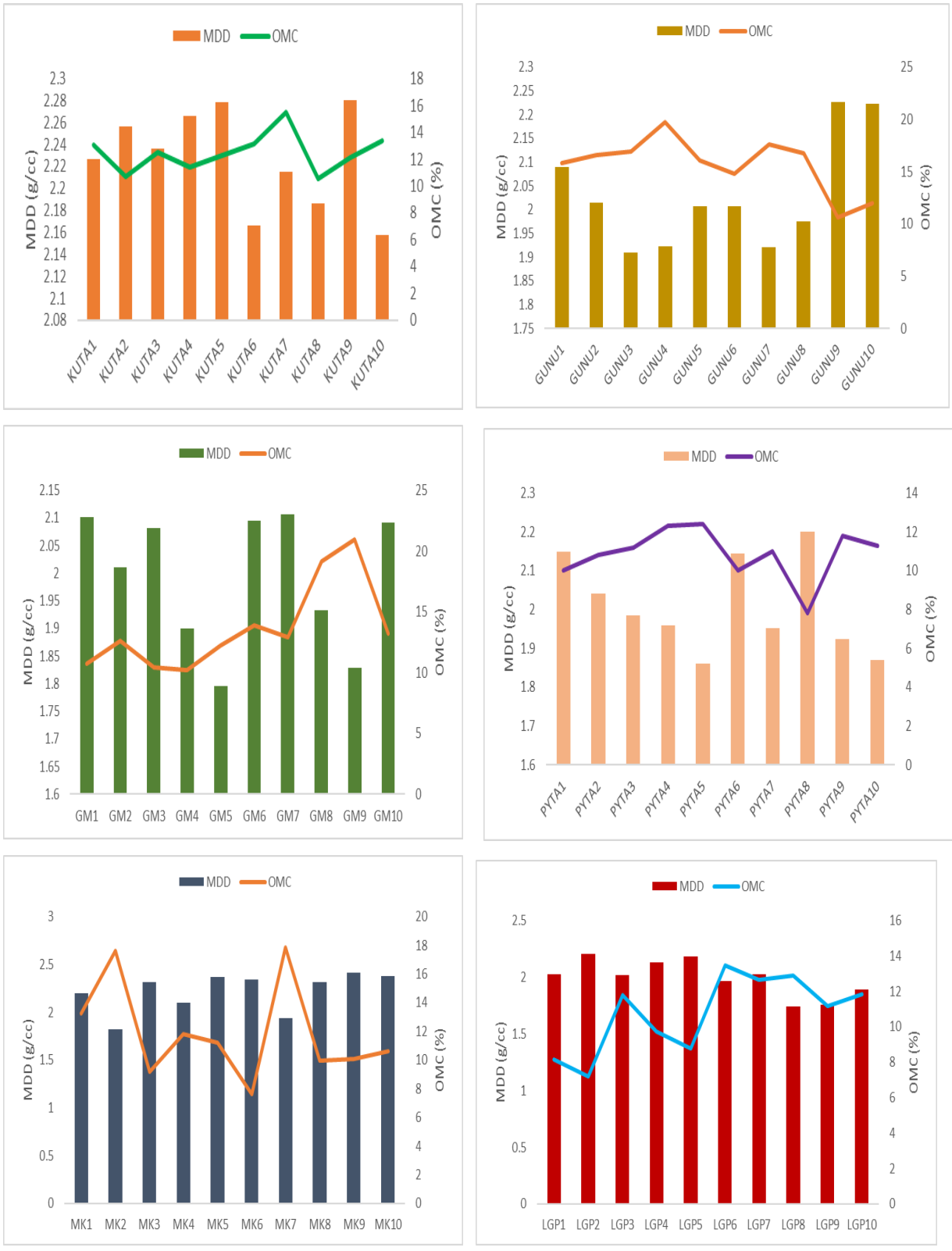


Figure 1a: Compaction characteristics of soils samples in Kuta, Gunu, Gidan Mangoro, Pyata, Maikunkele and Lapai Gwari



Figure 1b: Compaction characteristics of soil samples in Gidan Kwano, Gidan Waya and Brighter

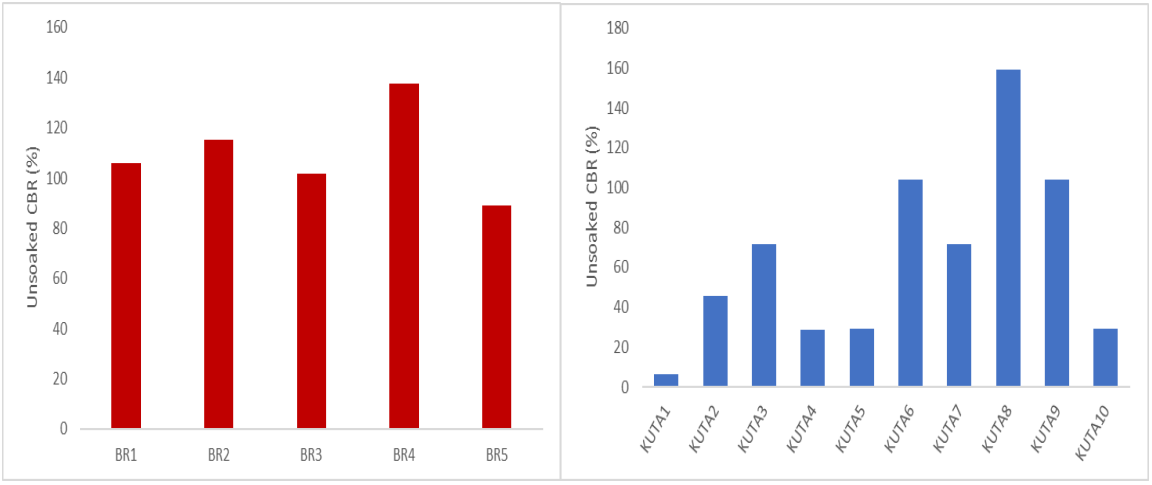
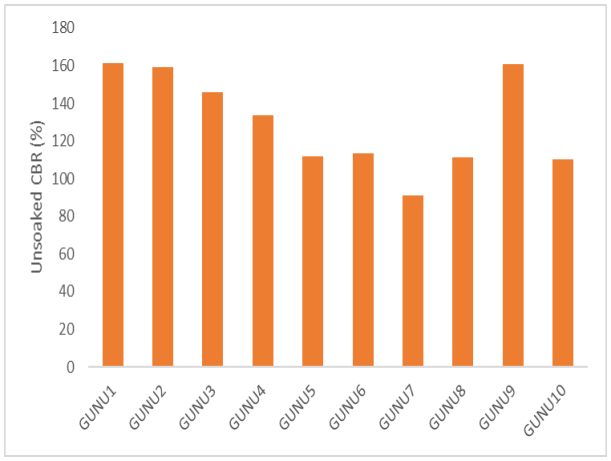
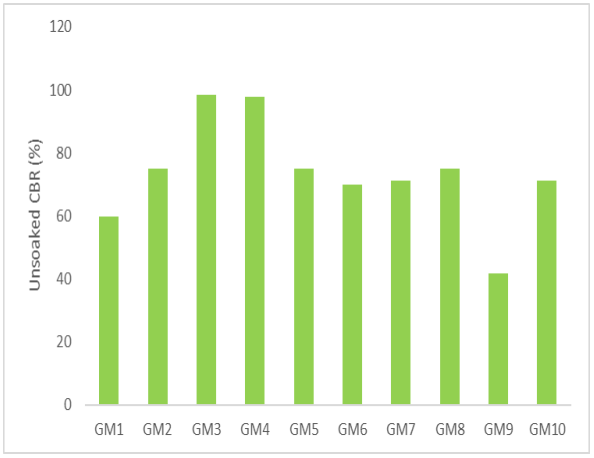
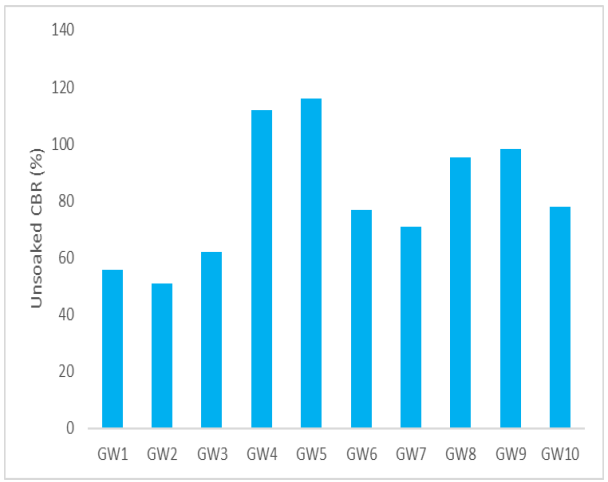
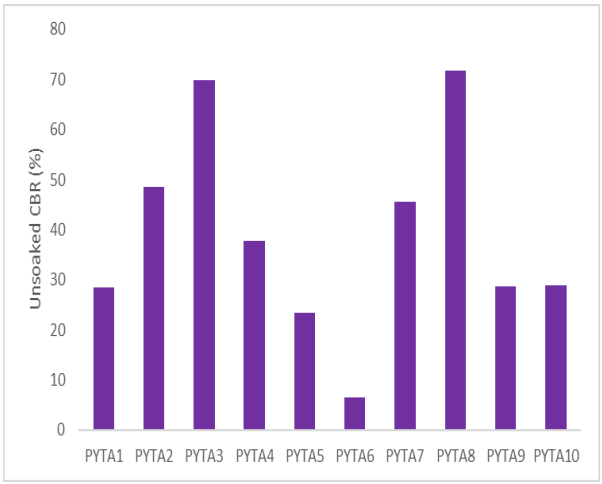


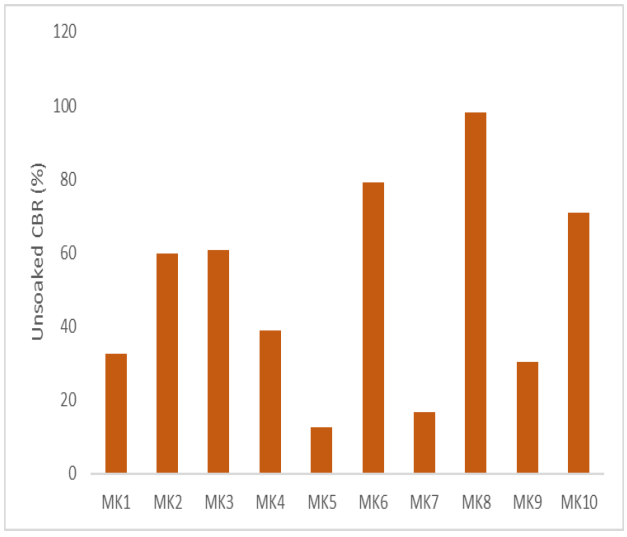
Figure 2a: Unsoaked CBR for samples in Brighter and Kuta











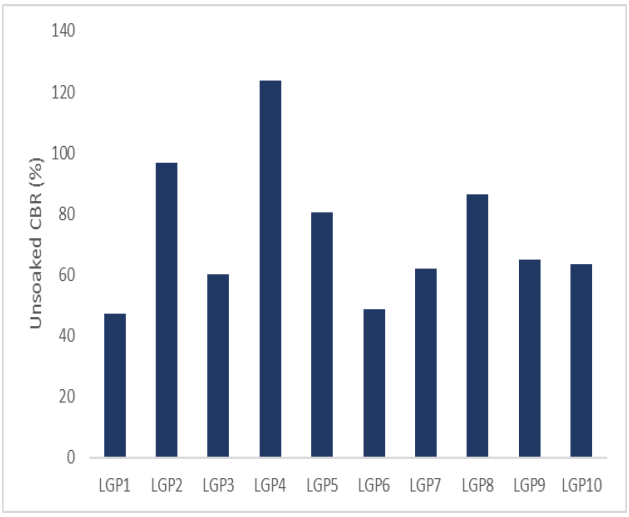


Figure 2b: Unsoaked CBR for samples in Gunu, Gidan Mangoro, Gidan Waya, Pyata, Maikunkele and Lapai Gwari

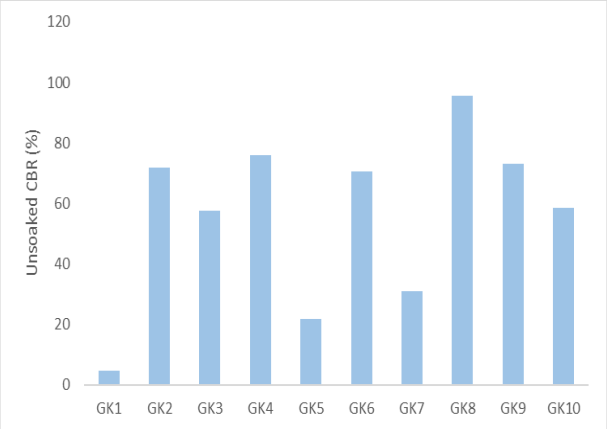


Figure 2c: Compaction characteristics of soil samples in Gidan Kwano

3.7 CONCLUSION

The study reveals significant variability in the index properties, compaction characteristics, and unsoaked CBR values for tropical residual soils in Niger State, Nigeria, highlighting the need for site-specific assessments in pavement design. NMC ranges from 2.33 to 30.8%, indicating differences in drainage conditions and soil composition, while soil classification based on AASHTO and USCS confirms the dominance of fine-grained soils, particularly clays and silts, which exhibit moderate to poor drainage characteristics. The compaction results show a broad range of MDD and OMC, with higher MDD values suggesting better compaction potential and load-bearing capacity. Unsoaked CBR values vary widely, from 6.57 to 145.89%, with locations such as Gunu and Kuta exhibiting high strength, while others fall below the 30% minimum requirement, requiring stabilization. These findings emphasize the heterogeneous nature of residual soils in the region and the necessity of stabilization techniques, such as lime or cement treatment, in some locations to enhance their suitability for road construction and long-term performance.

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Experimental Study on the California Bearing Ratio of Tropical Residual Soil under Soaked condition in Niger State, Nigeria

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ABSTRACT
This study investigates the soaked California Bearing Ratio (CBR) of tropical residual soils in Niger State, Nigeria, to assess their suitability for road construction. Soil samples were collected from Kuta, Gunu, Gidan Mangoro, Pyata, Maikunkele, Gidan Kwano, Lapai Gwari, Gidan Waya, and Brighter. Laboratory tests, including natural moisture content, specific gravity, Atterberg limits soil classification and compaction test were conducted alongside CBR tests under soaked conditions. Results show a wide variation in CBR values, ranging from 2.4% (KUTA7) to 142.85% (GK3). High CBR values were recorded in Gidan Kwano (GK3 – 142.85%), Maikunkele (MK10 – 85.45%), and Brighter (BR2 – 90.34%), indicating strong subgrade materials suitable for road base applications. In contrast, locations such as Gidan Waya (GW3 – 2.59%) and Pyata (PYTA6 – 2.71%) exhibited weak subgrade properties requiring stabilization. Specific gravity ranged from 2.50 to 2.75, while Atterberg limits indicated varying plasticity, influencing soil strength. The MDD values range from as low as 1.657 g/cm³ to as high as 2.413 g/cm³, while the OMC varies between 6.69% and 20.91%. Comparison with the Nigerian General Specification for Roads and Bridges shows that several locations do not meet the minimum 5% soaked CBR requirement for subgrade materials, necessitating stabilization using lime, cement, or other binders. The study highlights the importance of geotechnical evaluation in road construction and recommends soil improvement measures to enhance performance where required

Keywords: *Suitability, Soaked California Bearing Ratio, Tropical Residual Soil, Niger State*

1 INTRODUCTION

Tropical residual soils form through the intense weathering of parent rocks in tropical regions, making them the predominant soil type across large parts of Africa, Asia, and the Americas. Due to their abundance and cost-effectiveness, these soils are commonly used in road construction, building foundations, and other infrastructure projects. However, their engineering properties—such as strength, durability, and compressibility—vary significantly depending on mineralogical composition and weathering intensity (Haupt and Netterberg, 2021). These variations can lead to structural failures and increased maintenance costs, making it essential to assess their geotechnical properties before use in construction. Understanding the behavior of these soils under different loading and environmental conditions is particularly crucial for road infrastructure, where soil strength directly influences pavement performance and longevity.

The California Bearing Ratio (CBR) test is a widely used method for evaluating the load-bearing capacity of subgrade soils. It measures the resistance of a soil sample to penetration, providing a relative indication of its strength in comparison to well-graded crushed stone, which has a CBR value of 100%. The CBR test is a key parameter in determining pavement thickness, as higher CBR values allow for thinner, more cost-effective pavement layers, while lower values necessitate additional reinforcement or stabilization (Mendoza and Caicedo, 2018). Given the diverse nature of tropical residual soils, site-specific CBR assessments are crucial for effective pavement design, particularly in regions with varying geotechnical conditions.

Several factors influence CBR values, including compaction energy, moisture content, and soil composition. Recent studies, such as Ahmad *et al.* (2023), have explored modifications to the traditional CBR test to improve its accuracy for different soil types. Their findings highlight the significant impact of moisture variations and compaction methods on soaked CBR values, emphasizing the importance of localized testing. Additionally, CBR values have been empirically linked to other soil strength parameters, such as resilient modulus, further reinforcing their importance in pavement design (Katte *et al.*, 2019; Nagaraju *et al.*,

2019). Despite these advancements, the application of CBR testing to tropical residual soils remains complex due to their heterogeneous nature, requiring detailed investigation to establish reliable engineering properties.

In regions like Niger State, Nigeria, seasonal fluctuations in moisture content significantly affect the strength and stability of residual soils, making the assessment of their soaked CBR values critical for road construction. This study aims to evaluate the CBR characteristics of tropical residual soils under soaked conditions, providing essential data for subgrade material selection and pavement design. By identifying the engineering properties that influence CBR values, the research will contribute to more effective infrastructure planning and sustainable road development in the region. The findings will serve as a valuable reference for engineers, policymakers, and researchers working on geotechnical challenges associated with residual soils in similar climatic and geological settings.

2 MATERIALS AND METHODS

2.1 SOIL SAMPLE COLLECTION

Disturbed sample collection method was used. It involves digging and collecting samples from 0.5m, 1.0m and 1.5m, mix together to form one sample and a small portion of each was preserved in a polythene bags which will be used to determine the natural moisture content of each sample respectively. The soil sample were air dried at a room temperature between 25 – 30◦C before it was subjected to further laboratory analysis. For this study, a total of 85 soil samples were collected from different locations. Geologically, the study area lies within the Northern central basement complex of Nigeria. The area is characterized by migmatite gneiss complex, older granite and schist (Alhaji *et al.*, 2021).

The geographical position of sample collection location are: Gidan Kwano: 9.5313°N,, 6.4598°E; Lapai Gwari 9.5360°N,, 6.4691°E; Brighter 9.5811°N,, 6.5561°E; Gidan waya 9.5626°N,, 6.6001°E; Kuta 9.8593°N,, 6.7191°E; Gunu 9.6662°N,, 6.7191°E; Pyata 9.6699°N,, 6.5261°E; Maikunkele 9.6764°N,, 6.4551°E, Gidan mangoro 9.569042°N, 6.493685°E.

2.2 TESTING METHOD

Laboratory tests conducted on the soil samples include: natural moisture content, particle size distribution, specific gravity test, Atterberg limit test, compaction test and California bearing test (CBR). Tests were conducted in accordance with BS 1377 (1997) and ASTM D1883 for CBR test. Additionally, compaction tests to investigate the moisture-density relationship and CBR assessments were performed using British Standard Heavy (BSH) energy

3 RESULTS AND DISCUSSION

3.1 NATURAL MOISTURE CONTENT

The natural moisture content (NMC) of the soil samples varies significantly across the study area (Table 2a & 2b), ranging from 0.79% to 30.8%. The highest value, recorded in Gidan Waya (30.8%), suggests a high water retention capacity, likely due to fine-grained materials such as clay or organic matter. Similarly, Lapai Gwari and Maikunkele exhibited relatively high NMC values exceeding 17%, indicating potential volume changes under fluctuating moisture conditions. In contrast, the lowest NMC values were observed in Brighter and Kuta, where BR recorded the lowest at 0.79%, and most samples had moisture contents below 4%, suggesting predominantly sandy soils with high permeability and low water retention. Gidan Kwano displayed considerable variation, with values ranging from 2.92% to 17.63%, reflecting heterogeneity in soil composition, while Pyata and Gunu had moderate NMC values (6%–12%), indicating mixed fine- and coarse-grained particles requiring proper compaction. The wide variation in NMC highlights the need for site-specific soil evaluations, as moisture content directly influences soil compaction, strength, and long-term stability. High-moisture soils, such as those in Gidan Waya and Lapai Gwari, may require stabilization, whereas drier, sandy soils in Kuta and Brighter may need controlled moisture addition during compaction to enhance stability, ensuring their suitability for construction applications.

3.2 SPECIFIC GRAVITY

The specific gravity (Gs) of the soil samples shown in Table 2a and Table 2b, ranges from 2.57 to 3.06, indicating variability in mineral composition and density. The highest value (3.06) was recorded at Gidan Kwano, followed by Kuta (3.04) and Maikunkele (2.96), suggesting a higher concentration of dense minerals such as iron oxides or quartz. In contrast, the lowest Gs value (2.57) at Pyata indicates the presence of lighter materials, possibly with higher clay or organic content. Locations like Brighter, Lapai Gwari, and Gidan Waya exhibited relatively high Gs values around 2.90, further supporting the presence of dense soil minerals. Gidan Kwano, Pyata, and Maikunkele displayed moderate Gs values (2.61–2.85), reflecting localized variations in soil

composition. These results align with previous studies, such as Oliveira *et al.* (2022) and Kew and Gilkes (2006), which reported Gs values between 2.60 and 3.10 for lateritic soils, influenced by mineralogy and weathering processes. Lower Gs values, like those in Pyata, are consistent with findings by Ghosh and Guchhait (2020), who noted that soils with high clay content often have Gs below 2.70, affecting bearing capacity and compaction characteristics. Conversely, locations with high Gs, such as Kuta and Gidan Kwano, suggest better load-bearing properties, making them suitable for construction applications. This variation highlights the need for proper material selection, as soils with higher Gs offer better stability, while those with lower Gs may require stabilization. The findings emphasize the importance of site-specific soil analysis for optimizing construction material selection and ensuring long-term durability (Alhaji *et al.*, 2021).

3.3 PARTICLE SIZE DISTRIBUTION

The particle size distribution across various locations in Table 2a and Table 2b reveals significant variations in soil gradation, which directly influences its engineering properties. Some locations such as LGP, GK, PYTA, MK, GM, and GM exhibit high percentages of coarse fractions (passing No. 5 sieve close to 100%), indicating well-graded or poorly graded sandy materials suitable for load-bearing applications. In contrast, sites like brighter show lower percentage, suggesting a finer composition with potential plasticity issues. Notably, Maikunkele and Gidan Kwano have a high proportion of finer particles (passing No. 0.075 sieve above 70%), which could impact permeability and compaction behavior.

Comparative analysis aligns with findings from Najjar *et al.*, (2015) and Kaothon *et al.* (2022), which emphasize that high sand content enhances shear strength and drainage, whereas an increase in fines affects compaction and settlement characteristics. Locations with intermediate gradation, such as Gunu and Lapai Gwari, reflect a mix of sandy and silty fractions, making them potentially suitable for subgrade stabilization. These variations highlight the importance of site-specific soil assessment before engineering applications especially for road pavement.

3.4 ATTERBERG LIMIT

The Atterberg limit results provide crucial insights into the engineering behavior of the tested soils for road pavement applications. High plasticity soils, characterized by a liquid limit (LL) exceeding 50% and a plasticity index (PI) above 25%, include locations such as LGP, MK, GM, and GUNU (Table 2a & 2b). These soils are highly susceptible to excessive shrink-swell behavior and reduced strength under moisture fluctuations, making them unsuitable for direct use in pavement layers without stabilization. Recent studies (Okonkwo and Kennedy, 2023; Dong, 2013) highlight that lime or cement treatment can enhance their strength by reducing plasticity and improving load-bearing capacity, making them more viable for road construction.

Moderate plasticity soils, with LL ranging from 35% to 50% and PI between 10% and 25%. These soils require proper compaction and drainage measures to optimize performance in pavement applications. Low plasticity soils (LL < 35, PI < 10) found at GK, GW and several KUTA and BR locations demonstrate better stability and lower moisture sensitivity, making them suitable for subgrade layers. Additionally, non-plastic (NP) soils, observed at sites such as PYTA and BR, are highly stable with minimal volume changes, making them preferable for road subgrade and base materials. Proper selection, stabilization, and compaction techniques are essential for ensuring long-term pavement performance and reducing maintenance costs.

3.5 SOIL CLASSIFICATION

The soil classification results based on AASHTO and USCS provide critical insights into the suitability of the tested samples for engineering applications, particularly in road pavement construction. AASHTO classification reveals that many samples fall within the A-2 and A-7 groups (Table 1), with A-2 soils being silty or clayey granular materials with fair to poor drainage, while A-7 soils are highly plastic clays prone to significant volume changes under moisture variations, requiring stabilization for subgrade use. Conversely, soils classified as A-1 and A-3 consist of well-graded granular materials with minimal plasticity, making them ideal for base or subbase layers. USCS classification indicates that SC (clayey sand) and GC (clayey gravel) soils dominate across locations, exhibiting moderate strength but requiring careful moisture control. CL (low-plasticity clay) soils are susceptible to shrink-swell behavior, making them less suitable for direct pavement application without stabilization. Non-cohesive soils such as SM (silty sand) and SW (well-graded sand), found in some locations offer better drainage and compaction properties. These classifications highlight the need for proper soil stabilization techniques, such as lime or cement treatment, to enhance the engineering

properties of fine-grained soils for road pavement applications.

3.6 COMPACTION CHARACTERISTICS

The Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of the soil samples from Figure 1a and 1b, vary significantly across the studied locations, reflecting differences in soil composition and gradation. MDD values range from 1.657 g/cm³ (GK8) to 2.413 g/cm³ (MK9), while OMC varies between 6.69% (GK3) and 20.91% (GM9). According to the Nigerian General Specification for Roads and Bridges (FMWH, 2013), subgrade materials should have a minimum MDD of 1.80 g/cm³, while subbase and base course materials require at least 2.00 g/cm³. Soils such as GM8 (1.932 g/cm³), GM9 (1.829 g/cm³), and LGP8 (1.7408 g/cm³) may require stabilization before being used in engineering applications, whereas locations like MK9 (2.413 g/cm³), MK10 (2.381 g/cm³), and BR5 (2.36 g/cm³) exhibit high MDD values, indicating their suitability for subbase materials.

OMC values also vary significantly, with lower values (7-10%) in GK, MK, BR, and LGP locations, indicating coarse-grained soils that require less water for compaction, while higher OMC values (above 15%) in GUNU, GM, and GW suggest a higher clay content, leading to increased water retention and poor workability (Nagaraju *et al.*, 2019; Haupt and Netterberg, 2023). Studies by Ahmed *et al.* (2022) and Katte *et al.* (2019) confirm that soils with high OMC typically exhibit lower strength and higher susceptibility to volumetric changes, necessitating chemical stabilization methods such as lime or cement treatment. From a road construction perspective, soils with MDD above 2.0 g/cm³ and OMC between 8-12% are ideal for subbase materials, while those with lower MDD and high OMC require modification. Locations such as GK, MK, and BR meet subbase requirements, whereas GM9, GM8, and LGP8 fall below acceptable limits, necessitating stabilization. The observed variability underscores the need for detailed geotechnical assessments to ensure the durability, strength, and long-term performance of pavement structures.

TABLE 1: SOIL CLASSIFICATION OVERVIEW

CLASSIFICATION SYSTEM	SUB-GROUP	NUMBER OF SOIL SAMPLES
USCS	CL	13
	SC	40
	SM	8
	GC	14
	GM	10
AASHTO	A – 1	11
	A – 2	44
	A – 7	30

3.7 CALIFORNIA BEARING RATIO (CBR)

The soaked California Bearing Ratio (CBR) values across the study locations vary significantly, reflecting differences in soil composition and strength (Figure 2a, 2b & 2c). The CBR values range from as low as 2.4% (KUTA7) to as high as 142.85% (GK3). Locations such as Gidan Kwano (GK), Maikunkele (MK), Lapai Gwari (LGP), and Brighter (BR) exhibit the highest CBR values, particularly GK3 (142.85%), MK10 (85.45%), and BR2 (90.34%), indicating well-graded, coarse-grained soils with excellent load-bearing capacity. Conversely, locations like Gidan Waya (GW), Pyata (PYT), and parts of Gunu (GUNU) record much lower values, such as GW3 (2.59%), PYTA6 (2.71%), and GUNU6 (3.96%), suggesting weak, fine-grained soils with high water retention and poor strength under soaked conditions. These findings align with previous studies (Haupt and Netterberg, 2021; Katte *et al.*, 2019), which emphasize the impact of grain size and composition on CBR performance.

Moderate CBR values (10%–40%) are observed in Kuta, Gidan Mangoro (GM), and sections of Pyata and Gunu, where soils contain a mix of fine and coarse particles that provide moderate strength but may require stabilization for enhanced performance. Examples include KUTA3 (27.09%), GUNU2 (30.43%), and GM7 (38.75%), suggesting potential for use in road construction with proper treatment. Similarly, certain soils in Gidan Waya (GW4–GW7) and Maikunkele (MK3, MK5) fall within this range, showing some variability in composition. Research by Ahmed *et al.* (2023) and Nagaraju *et al.* (2019) supports the suitability of soils within this range for construction, albeit with possible modification using stabilizers like lime or cement. In contrast, locations with CBR values below 10%, such as GUNU5 (4.79%), GW3 (2.59%), and PYTA6 (2.71%), indicate very weak subgrade materials requiring significant stabilization before use. Overall, the variability in CBR values underscores the need for comprehensive geotechnical assessment and soil improvement strategies to ensure suitability for construction applications.

TABLE 2A: STATISICS SUMMARY OF THE PROPERTIES OF TESTED SOIL SAMPLES

LOCATION	STATISTICS	NMC	GS	GRAVEL	SAND	FINES	LL	PL	PI
	MEAN	11.53	2.74	23.36	29.78	46.85	54.54	27.76	26.78
	STD DEV.	5.123	0.103	24.65	17.54	29.23	15.88	6.34	10.05
MK	VARIANCE	26.24	0.011	607.82	307.87	854.77	252.3	40.24	100.9
	MEDIAN	11.69	2.72	17.96	22.15	35.58	54.61	27.62	26.99
	MIN.	3.77	2.63	0.00	13.56	13.97	29.77	17.47	11.61
	MAX.	18.97	2.96	64.67	63.94	85.85	84.98	39.7	45.28
	MEAN	3.134	2.826	44.11	37.85	18.04	36.48	24.22	12.26
	STD DEV.	0.772	0.122	13.61	9.17	6.43	5.42	2.12	4.27
KT	VARIANCE	0.597	0.015	185.17	84.09	41.28	29.39	4.49	18.26
	MEDIAN	2.85	2.85	40.8	39.42	18.71	34.38	24.58	10.13
	MIN.	2.33	2.64	26.29	24.98	8.21	30.62	21.23	8.21
	MAX.	4.75	3.04	63.32	49.07	31.90	44.64	26.64	18.00
	MEAN	9.115	2.805	17.89	34.36	47.74	53.45	34.70	18.75
	STD DEV.	1.918	0.064	3.61	4.42	6.97	8.02	6.15	7.56
GN	VARIANCE	3.678	0.004	13.04	19.50	48.60	64.43	37.81	57.28
	MEDIAN	9.285	2.815	18.51	35.39	45.14	55.46	35.6	20.85
	MIN.	6.11	2.71	8.33	26.93	41.72	40.51	23.56	2.11
	MAX.	12.77	2.89	20.86	39.02	64.74	64.42	44.46	28.89
	MEAN	8.029	2.678	28.68	49.42	21.90	44.51	35.36	5.06
	STD DEV.	3.365	0.096	21.41	20.57	10.473	10.98	9.06	8.44
PY	VARIANCE	11.329	0.009	458.6	423.45	109.68	120.6	82.09	71.27
	MEDIAN	7.64	2.665	34.55	40.81	22.05	40.81	34.64	5.12
	MIN.	3.06	2.57	0.00	26.27	4.49	28.40	23.87	0.00
	MAX.	16.25	2.92	53.34	82.68	45.23	62.46	53.53	26.17
	MEAN	9.692	2.858	42.684	27.41	29.906	47.84	28.84	19.08
	STD DEV.	7.786	0.057	18.403	11.42	15.97	11.31	6.31	6.46
GW	VARIANCE	60.637	0.003	338.69	130.6	255.07	127.9	39.84	41.76
	MEDIAN	7.98	2.87	41.85	24.37	24.26	48.02	27.40	19.74
	MIN.	3.50	2.74	11.40	16.54	15.94	26.9	21.58	5.32
	MAX.	30.8	2.92	66.67	53.12	68.45	63.67	43.45	29.30

TABLE 2B: STATISTICS SUMMARY OF THE PROPERTIES OF TESTED SOIL SAMPLES

LOCATION	STATISTICS	NMC	GS	GRAVEL	SAND	FINES	LL	PL	PI
	MEAN	13.77	2.79	35.756	30.265	33.98	57.127	32.81	24.32
	STD DEV.	5.54	0.08	29.339	15.324	24.48	8.19	4.21	5.85
LPG	VARIANCE	30.77	0.006	860.81	234.83	599.48	67.08	19.67	25.24
	MEDIAN	12.66	2.78	33.415	25.405	29.15	59.85	19.68	23.18
	MIN.	7.21	2.67	0.0	17.13	7.24	45.72	27.14	18.32
	MAX.	24.09	2.92	75.15	68.09	71.87	68.02	39.72	34.68
	MEAN	8.22	2.78	20.092	52.676	27.232	32.84	19.51	20.59
	STD DEV.	5.51	0.146	15.164	21.15	18.71	12.76	8.41	6.54
GK	VARIANCE	30.32	0.021	229.96	147.64	350.29	162.71	70.67	42.75
	MEDIAN	6.26	2.73	21.575	56.63	20.95	32.93	20.39	17.03
	MIN.	2.92	2.61	0	26.47	13.75	20.51	0	16.61
	MAX.	17.53	3.06	50.97	62.33	73.53	62.09	33.95	28.14
	MEAN	9.88	2.81	21.085	32.909	46.006	47.099	25.613	21.486
	STD DEV.	3.63	0.12	22.25	13.82	24.07	9.268	3.835	5.759
GM	VARIANCE	13.17	0.015	495.45	191.10	579.54	85.907	14.712	33.169
	MEDIAN	8.41	2.785	16.25	32.255	38.19	45.225	25.67	20.03
	MIN.	5.46	2.59	0.0	15.23	22.5	35.25	20.4	14.85
	MAX.	15.77	2.99	55.37	56.38	84.77	67.97	32.59	35.38
	MEAN	2.428	2.818	69.034	24.198	6.768	24.644	0	0
	STD DEV.	1.008	0.097	4.65	2.424	2.847	2.177	0	0
BR	VARIANCE	1.018	0.009	21.653	5.877	8.108	4.739	0	0
	MEDIAN	2.5	2.85	71.0	23.25	6.21	23.76	0	0
	MIN.	0.79	2.7	62.0	21.48	4.18	22.7	0	0
	MAX.	3.32	2.91	72.93	27.12	11.64	27.01	0	0

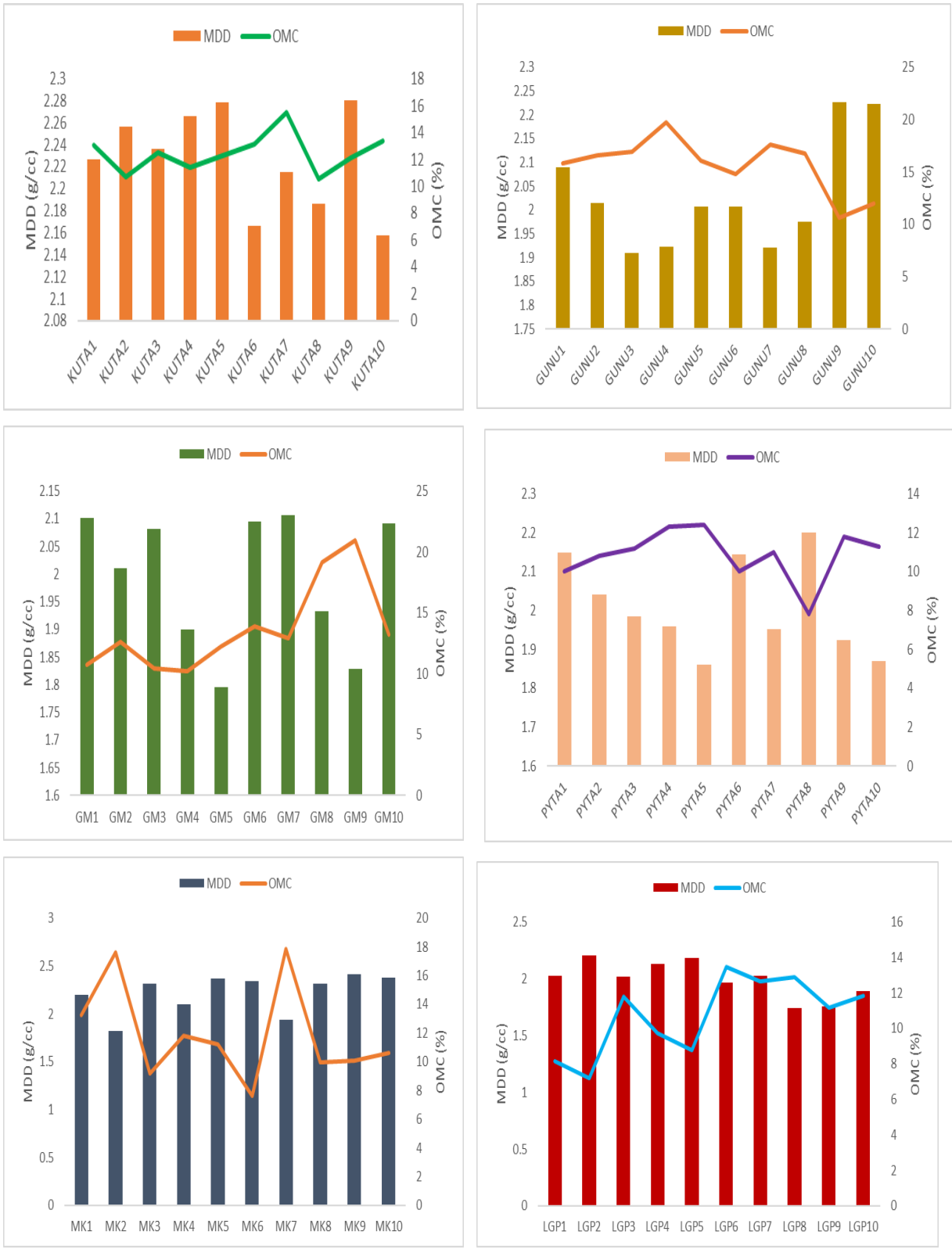


Figure 1a: Compaction characteristics of soils samples in Kuta, Gunu, Gidan Mangoro, Pyata, Maikunkele and Lapai Gwari



Figure 1b: Compaction characteristics of soil samples in Gidan Kwano, Gidan Waya and Brighter

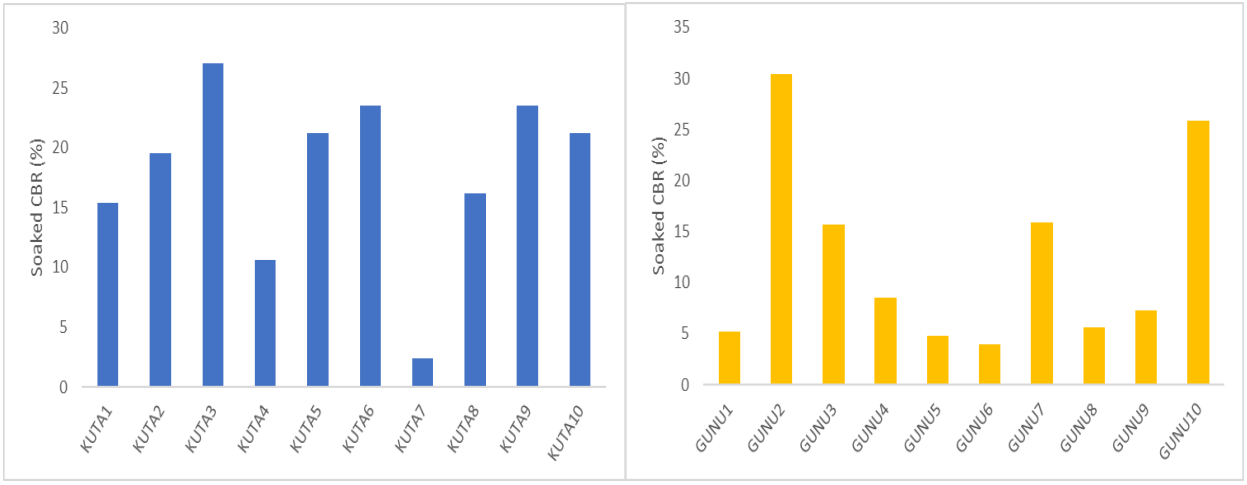


Figure 2a: Soaked CBR for samples in Kuta and Gunu

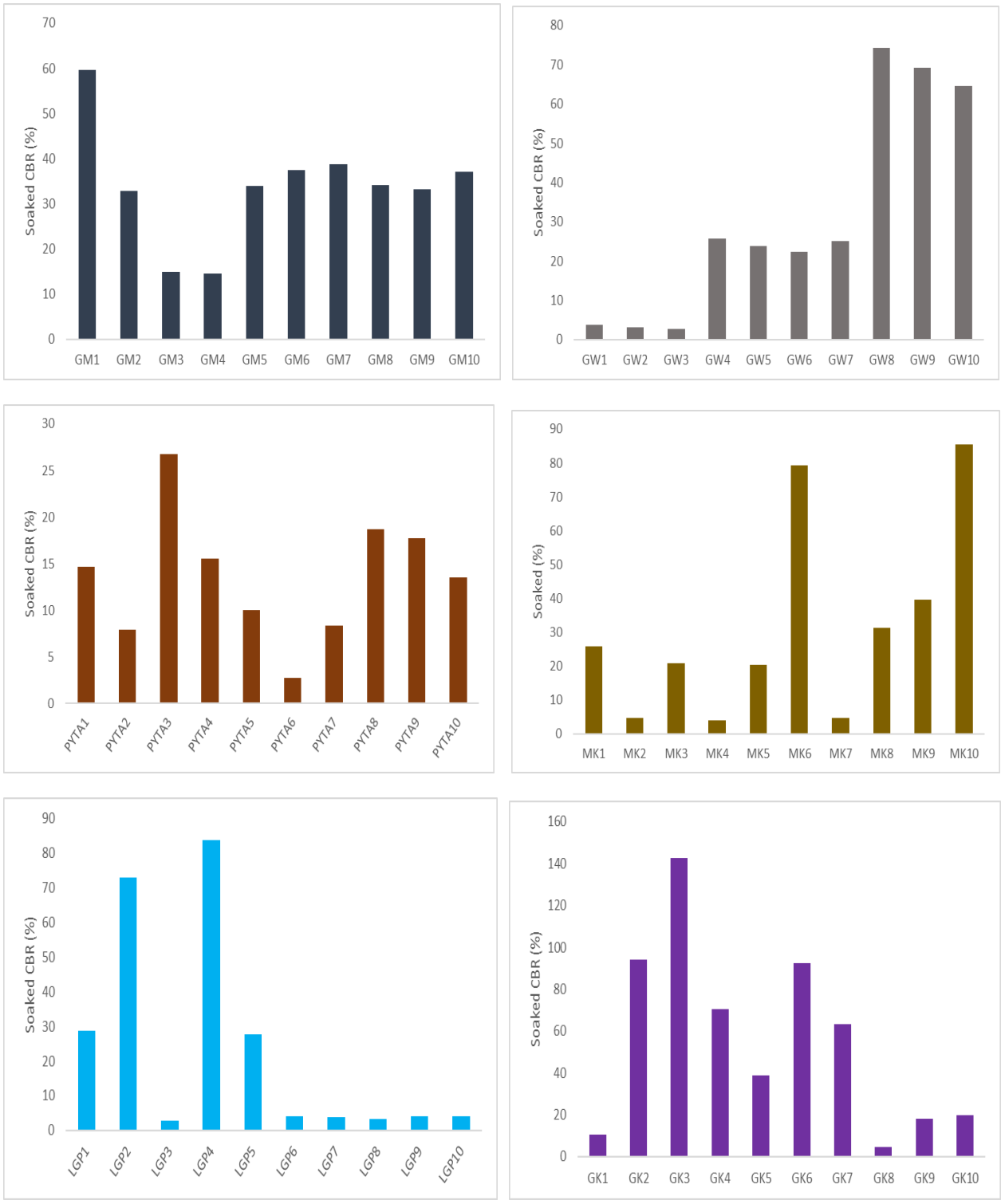


Figure 2b: Unsoaked CBR for samples in Gidan Mangoro, Gidan Waya, Pyata, Maikunkele, Lapai Gwari and Gidan Kwano

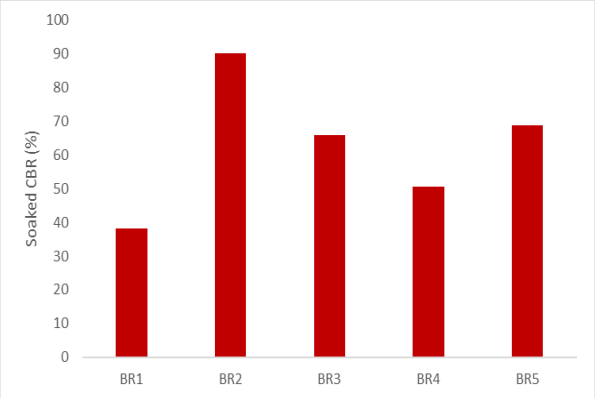


Figure 2c: Compaction characteristics of soil samples in Brighter

3.8 CONCLUSION

The study on the California Bearing Ratio (CBR) of tropical residual soils in Niger State, Nigeria, reveals significant variability in soil strength, ranging from 2.4% (KUTA7) to 142.85% (GK3). According to Nigerian road specifications, locations such as Gidan Kwano (GK), Maikunkele (MK), Lapai Gwari (LGP), and Brighter (BR) exhibit high CBR values, particularly GK3 (142.85%), MK10 (85.45%), and BR2 (90.34%), making them suitable for road base or subbase applications. In contrast, areas like Gidan Waya (GW), Pyata (PYT), and Gunu (GUNU) recorded very low CBR values below 5%, such as GW3 (2.59%) and PYTA6 (2.71%), rendering them unsuitable as subgrade materials without stabilization. The study also highlights variations in geotechnical properties, including specific gravity (2.50–2.75), Atterberg limits, and soil classification, which influence soil strength. Maximum Dry Density (MDD) values range from 1.657 g/cm³ (GK8) to 2.413 g/cm³ (MK9), while Optimum Moisture Content (OMC) varies between 6.69% (GK3) and 20.91% (GM9), further affecting compaction characteristics. While some locations meet road construction requirements, weaker soils require mechanical or chemical stabilization, such as lime or cement treatment, to improve durability and long-term performance, emphasizing the need for site-specific geotechnical assessment before material selection.

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A REVIEW ON THE DEVELOPMENT OF AUTOMATED DEVICE FOR EVALUATING THE TRIBOLOGICAL PROPERTIES OF BRAKE PADS

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ABSTRACT
The prime requirements of a braking system are to control the tribological behavior of the brake pads. Generally, automotive braking system play important roles in the vehicle by providing safety to the passengers and the road users. This article provides an overview on the development of brake pads monitoring devices by using different types of sensors and a microcontroller to evaluate and measure the tribological properties. This review article focuses on sensors used in measuring wear rate of the pads, temperature rise during braking as well as friction generated between pads and the disc.

Keywords: *tribological, monitoring devices, brake pad, wear, temperature, sensors.*

1 INTRODUCTION

The primary function of brake is to reduce the speed or stopping vehicle from rotating completely. Automotive braking systems functions by converting kinetic energy of the vehicle to friction generated thermal energy (heat), this occur when the disc and the pads are in contact with each other (Viderščak *et al*., 2022). Braking performance may be defined as the ability of a vehicle to slow down or stop completely while maintaining its stability (Demire & Oz, 2019). During braking operations, the frictional forces between a rotating disc and a stationary pad makes the vehicle to stop (Gawande *et al*., 2020).

The most important part of an automobile braking system are the pads. The effectiveness of the brakes depends on the quality and proper composition of the brake pads. It provides high coefficient of friction and low wear (Nagesh *et al*., 2014). Performance of a brake in a vehicle is primarily determined by it tribological properties of the friction, wear, and temperature of the brake disc (or drum) and pad friction material (Kchaou *et al.*, 2019). To examine the tribological actions of a brake pads in contact with sliding motion mostly pinon-disc apparatus is used. This approach is suited to study the relationships between friction and wear mechanisms and parameters like contact pressure between pads and disc, rotational speed, and environmental condition (Kshirsagar & Khairnar, 2023). Braking System In an automobile vehicle, is an arrangement of different components such as brake lines or mechanical combinations, brake drum or brake disc, master cylinder etc. (Murthy *et al.,* 2021).

2 AUTOMATIC BRAKING SYSTEM

According to (Brindha et al., 2020) Automatic braking system is a technology in a vehicles that is develop to monitors or sense the condition of the braking system or any other foreign body which is targeted and applies the brake automatically to slow the speed of the vehicle to avoid accident.

2.1.1 SENSOR

A sensor is an electrical device that locate or spot an environmental quality to quantitative measurement. Each sensor is designed based on principles transformation and Conversion of energy from one form to another. There are two significant terms Related to any sensor: Target Angle and Beam Spread (Murthy *et al*., 2021).

2.1.2 TRANSDUCER

A transducer is an electronic device that converts one form of Energy into another. In the case of ultrasonic sensors, they are used to convert electrical Energy into ultrasonic energy and ultrasonic energy back to electrical energy (Murthy *et al*., 2021).

2.1.3 ULTRASONIC SENSOR

Ultrasonic Sensor is a detecting device that makes use of high frequency sound waves known as ultrasonic waves to spot the presence of an object and its range. Ultrasonic sound waves are waves that has frequency above 20,000Hz. An ultrasonic sensor consists of a transducer to transform energy from one form to another (Murthy *et al*., 2021). Ultrasonic sensor is divided into Ultrasonic Transmitter Ultrasonic Receiver. A figure of ultrasonic sensor is shown in Figure1 which indicates the Transmitter and the Receiver.

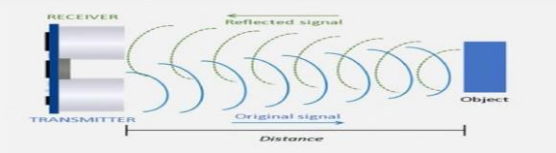


Figure. 1 Ultrasonic sensor. Source: (Murthy *et al*., 2021)

2.2 TRIBOLOGICAL ANALYSIS OF BRAKE PADS

The braking forces has great impact on the coefficient of friction and the wear structure of the contact surfaces, as the disc rotational speed increases, the coefficient of friction (COF) increases which also lead to rise in temperature and wear of the pad (Wu *et al*., 2019). During braking process, as the pads are in contact with the disc, friction occurs, which convert kinetic energy to heat energy. Part of the heat initiates chemical reactions, which may convert or reduces some of the properties of the brake pad (such as resin), an average brake pad should be made from 10 to 20 different substances in other to study and select the right materials and their effects in the braking operations because the process of braking is largely affected by the tribological properties of pads and discs (Borawski, 2019). According to (Kchaou *et al*., 2019) description, tribological performance is a study of fading and recovery behavior test.

2.2.1 METHODS OF DETECTING BRAKE TEMPERATURE

According to (Siregar *et al*., 2021), Thermocouple sensor and infrared sensor was used to measure and compare braking temperature of a drum brake because of its stability to vibration and other factors etc. but there are some limitation while using Thermocouple sensor to measure brake temperature that makes these method not to be accurate because correctional factors are needed so that the final result will be closed to actual value. Figure 2 shows the experimental setup of brake pad temperature measurements.

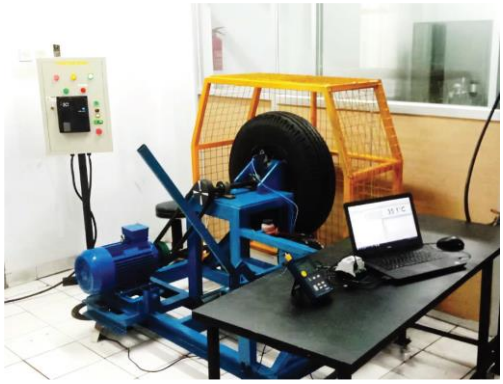


Figure 2 Experimental setup for temperature measurement (Siregar *et al*., 2021)

Figure 3 shows the graph of temperature against time when combining both Thermocouple and Infrared sensor to measure the temperature of the braking system

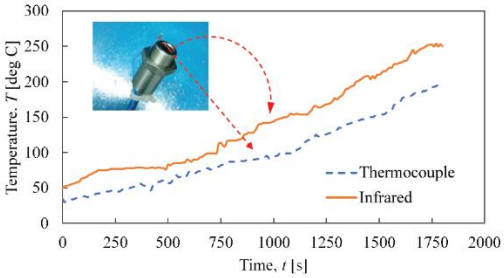


Figure 3: Graph of Temperature against Time (Siregar *et al*., 2021)

Embedded temperature sensor was used by (Siregar *et al*., 2020). In their experiment, it was observed that the temperature obtained from a rubbing thermocouple sensor is higher than embedded temperature sensor in the pad due to the fact that additional heat was generated from rubbing steel friction with the brake disc. A figure of embedded and rubbing temperature sensor is shown in Figure 4

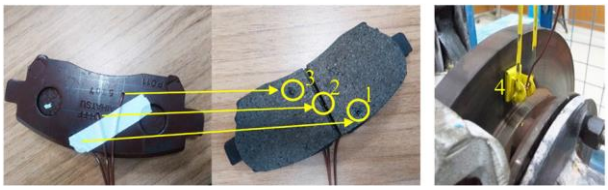


Figure 4: embedded thermocouple position in the pad (1,2and 3) and rubbing thermocouple sensor in position (4). (Siregar *et al*., 2020)

2.2.2 COEFFICIENT OF FRICTION

Friction is the factor that oppose the free movement of the vehicle, the methodology for assessing friction coefficient (μ) considering interface pressure on frictional materials between the contact surface of the brake pads and disc (Kshirsagar & Khairnar, 2023). Surface temperature is a main factor that affects the brake friction. Lesser the friction coefficient means lesser the brake force required for the two surfaces to slip. Also, stronger forces are required while in case of higher friction coefficient. Sliding friction between two dry contacting surfaces is known as 'Coulomb friction' after Charles Coulomb (1736-1806) (Kshirsagar & Khairnar, 2022). Coefficient of friction can be determined using the following factors: force, speed, braking moments etc., (SATHISH *et al*., 2023). Friction coefficient and friction forces can be express in Equation 1 and Equation 2 (SATHISH *et al*., 2023).

$$M_{net} = M_{br} + M_{fr} + M_i \quad (1)$$

$$\mu = \frac{M_{fr}}{r_d \times F_n} \quad (2)$$

Where

M_{net} = Moment measured by load cell

M_{br} = Braking moment

M_{fr} = Friction moment

M_i = Inertia moment

r_d = Radius of disc

F_n = Normal breaking force

The friction materials of a braking systems are subject to different types of wear. The most vital type is abrasive wear, either, damages may occur from the top layer of coaction parts that move relative to each other (Borawski *et al*., 2022).

2.2.3 BRAKE WEAR

Wear is a continues loss of material from it contact surfaces of a body caused by tribological stress, depending on the structure of the tribological system and the types of the tribological stress that occurs between the contact surfaces of the material (Lehmann *et al*., 2023). The studies of wear mechanisms are quite unpredictable because of the constant contact variations that occurs in the braking systems (Laguna-Camacho *et al*., 2015). During braking processes, the friction between pads and disc will cause the pads to wear (Hussain *et al*., 2014). According to (Xiao *et al*., 2016) friction and wear behaviors of the brake friction materials are commonly affected by the following characteristics: Material characteristics, Braking conditions, Surrounding conditions, Surface conditions and Structural parameters. However, one of the objectives of these study is to develop a wear measuring device in the pads.

2.1.3 Types of wear in the brake pad surface

In brake pad, there are different types of wear experienced in the brake pad ranging from outer pad wear, inner pad wear, tapered pad wear, overlapping pad wear, and glazed or cracked pad surface with lifted edges. Figure 2. is shown to demonstrates types of wear in the brake pad surface.

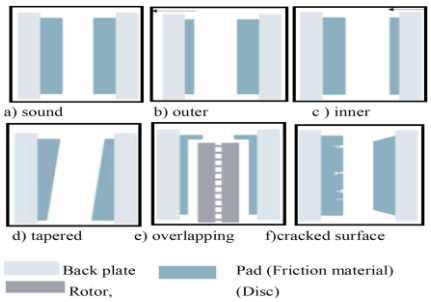


Figure 5 types of wear in the brake pad surface (Nagwa & Elsoeudy, 2021)

2.2.4 BRAKE PAD WEAR USING SENSOR

Different sensors can be used to measure or detect the brake pads wear such as Infra-Red (IR) based microcontroller sensors (Ganeshkumar., 2020). Or an Ultrasonic Sensor, and so on. However, the placements of the above mentioning sensors determined the accurate measurement and monitors of the pad by each sensor to be able to give the correct results.

3 CONCLUSION

In developing of automated devices for evaluating the tribological properties of brake pads offers many benefits to brake pads manufacturing industries, including improving efficiency, enhanced safety, cost and time savings, quality assurance, as well as performance optimization, and support for research and innovation. To this end, MLX9061 Infrared temperature sensor is considered best for brake temperature monitoring and measurement because of its ability to measure temperature from -40°C to 380°C. for brake wear, Ultrasonic sensor HCSR04 is considered best for brake pads monitoring.

4 FUTURE WORK

This review is a study of monitoring devices used currently in different brake pads industries. The next

stage is to develop a brake pads monitoring devices that measures brake pads wear, braking temperature, and friction generated between pads and disc by combining infrared sensor, ultrasonic sensor, load sensor and Arduino Nano as a controller through a programming language (C++ Language)

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Harnessing AI and Machine Learning for Hydrological Modeling and Land Use Change Predictions in Urban Water Management.

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ABSTRACT

Urban water management is increasingly challenged by rapid land-use changes, climate variability, and population growth, necessitating advanced predictive models for hydrological planning. This study integrates Convolutional Neural Networks (CNNs) for land-use classification and Artificial Neural Networks (ANNs) for runoff prediction to assess future hydrological dynamics in Minna, Nigeria. Historical and projected land-use data from 2003 to 2054, combined with precipitation records and wastewater flow estimates, were analyzed to predict runoff variations and flood risks. The CNN model, trained on Landsat 8 images, achieved 91.6% classification accuracy, effectively identifying land-cover transitions. The ANN-based runoff model, with two hidden layers (10 neurons each), attained an R^2 of 0.93, indicating strong predictive capability. Results showed a 472% increase in built-up areas and an 82.8% reduction in forest cover, contributing to a 317% rise in total runoff over the study period. Wastewater generation is expected to escalate from 250,287 m^3/day in 2006 to 903,670 m^3/day in 2054, necessitating urgent infrastructure upgrades. Seasonal variations revealed peak runoff events aligning with June to August, emphasizing climate-induced hydrological shifts. The study highlights the effectiveness of AI-driven hydrological models in enhancing climate resilience, flood mitigation, and sustainable urban planning, offering a scalable framework for future water management strategies. Policy implications include the need for improved stormwater infrastructure, green urban planning, and real-time monitoring systems to mitigate flood risks and ensure sustainable water resource management.

Keywords: AI, Hydrological, Land, Management, Modeling, Predictions, Urban, Water.

INTRODUCTION

The rapid pace of urbanization and climate variability has placed significant pressure on hydrological systems and urban water management strategies. These changes often result in increased runoff, reduced groundwater recharge, and heightened flood risks, especially in urban areas where impervious surfaces dominate the landscape. Traditional hydrological modeling approaches often struggle to capture the complexities of urbanization and its interactions with dynamic precipitation patterns, leaving gaps in the development of effective water management policies. Recent advancements in artificial intelligence (AI) and machine learning (ML) offer transformative capabilities to address these challenges by enabling dynamic, data-driven modeling of hydrological systems and land-use changes.

AI and ML approaches, particularly deep learning techniques such as Convolutional Neural Networks (CNNs), have been instrumental in land-use change analysis. Using high-resolution satellite imagery and remote sensing data, CNNs can classify and quantify land-use transitions with remarkable accuracy, as demonstrated by Cheng et al. (2023) and Mohammadi (2021). By analyzing transitions between categories such as built-up areas, farmland, and grassland, these models provide insights into how urbanization alters hydrological patterns. Studies by Muhammad and Sule (2024) have shown the value of integrating satellite imagery from Landsat 8 to monitor land-use dynamics and their relationship to flood occurrence.

In addition to land-use classification, AI models excel at predicting hydrological responses to precipitation and climate variability. Artificial Neural Networks (ANNs) and Support Vector Machines (SVMs) have been widely applied to model rainfall-runoff relationships, outperforming traditional methods in capturing nonlinear interactions between climatic and hydrological variables (Asadi et al., 2024; Jain et al., 2023). These predictive models enable more accurate estimation of runoff rates under varying urbanization and climate scenarios.

Climate resilience is another critical aspect of hydrological modeling that benefits from AI integration. With urban areas facing increasing risks from extreme weather events, AI models offer predictive tools to enhance water resource sustainability. By analyzing long-term precipitation trends and land-use projections, deep learning models such as CNNs and RNNs can simulate future hydrological scenarios, enabling planners to design adaptive strategies.

The implications of these technologies extend beyond hydrological modeling to the broader context of urban planning and environmental sustainability. By integrating projected precipitation and land-use data, AI-driven models support the development of resilient stormwater

and wastewater systems. This is particularly relevant in the context of circular economy principles, where effective water management contributes to energy recovery and resource optimization.

METHODOLOGY

The methodology for this study integrates diverse datasets, advanced machine learning models, and validation techniques to predict hydrological behavior and assess land-use changes over the next 30 years (2024--2054). The approach begins with data collection and preparation. Satellite imagery and remote sensing data from Landsat 8 are utilized to classify land use into categories such as built-up areas, grassland, farmland, forest cover, and water bodies. Historical data from 2003 to 2023 and projected trends from 2024 to 2054 are derived from Landsat 8 imagery. Hydrological data, including monthly precipitation records from the NASA database, are combined with runoff coefficients for various land-use types, enabling precise runoff calculations. Population data from Bosso and Chanchaga Local Government Areas, with an annual growth rate of 3.4%, is included to estimate wastewater generation. Additional climate data, such as air temperature, relative humidity, and wind speed, provide insights into climatic influences on hydrological patterns.

The study employs advanced machine learning models for land-use classification and runoff prediction. Convolutional Neural Networks (CNNs) are utilized to classify satellite imagery into predefined land-use categories dynamically. The CNN model is trained using segmented datasets with a categorical cross-entropy loss function defined using Equation 1. The dataset was split into 70% for training and 30% for testing, with cross-validation applied to ensure model robustness.

$$\mathcal{L} = -\frac{1}{N}\sum_{i=1}^{N} y_i \log(\hat{y}_i) \dots\dots\dots\dots\dots (1)$$

where y_i and $\hat{y}_i$ represent the actual and predicted land-use labels, respectively. For runoff prediction, Artificial Neural Networks (ANNs) are employed, using inputs such as land use areas, precipitation intensity, and wastewater flow. The ANN architecture consists of two hidden layers with 10 neurons each and employs a ReLU activation function and dropout regularization. The ANN minimizes Mean Squared Error (MSE), expressed using Equation 2. The model was validated using a 70-30 train-test split, with cross-validation to ensure generalizability.

$$\text{MSE} = \frac{1}{n}\sum_{i=1}^{n}\left(Q_{\text{actual,i}} - Q_{\text{predicted,i}}\right)^2 \dots\dots\dots\dots\dots (2)$$

where $Q_{\text{actual,i}}$ and $Q_{\text{predicted,i}}$ are the observed and predicted runoff values, respectively.

Runoff is calculated by combining precipitation intensity, runoff coefficients, and land-use areas. The relationship is expressed using Equation 3.

$$Q_r = \sum(C_i \cdot A_i \cdot I) \dots\dots\dots\dots\dots (3)$$

where Q_r is the total runoff (m³/s), C_i is the runoff coefficient, A_i is the land-use area (km²), and I is the precipitation intensity (mm/h). Wastewater generation is estimated using population data and a generation rate of 0.25 m³/day per capita. The total hydrological flow is calculated using Equation 4.

$$Q_{\text{total}} = Q_x + Q_r \dots\dots\dots\dots\dots (4)$$

where Q_x represents wastewater flow.

Validation is conducted using historical data from 2003 to 2023, with the models evaluated based on R^2, Mean Absolute Error (MAE), and Root Mean Square Error (RMSE). Statistical significance tests, including t-tests, were performed to validate the land-use change analysis. The CNN model's validation metrics include accuracy, precision, recall, and F1-score, ensuring reliable land-use classification. Similarly, the ANN model's predictions are evaluated by comparing observed and predicted runoff values.

$$R^2 = 1 - \frac{\sum\left(Q_{\text{actual}} - Q_{\text{predicted}}\right)^2}{\sum(Q_{\text{actual}} - Q_{\text{actual}})^2} \dots\dots\dots\dots\dots (5)$$

where Q_{actual} is the mean of observed runoff values. MAE is given by Equation 6.

$$\text{MAE} = \frac{1}{n}\sum_{i=1}^{n} |Q_{\text{actual,i}} - Q_{\text{predicted,i}}| \dots\dots\dots\dots\dots (6)$$

and RMSE expressed using Equation 7.

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(Q_{\text{actual,i}} - Q_{\text{predicted,i}}\right)^2} \dots\dots\dots\dots\dots (7)$$

The CNN model's validation metrics include accuracy, precision, recall, and F1-score, ensuring reliable land-use classification. Similarly, the ANN model's predictions are evaluated by comparing observed and predicted runoff values.

The models predict monthly runoff and wastewater flows from 2024 to 2054, simulating different urbanization and climate scenarios. Land-use classification maps generated by CNNs dynamically update as urbanization progresses, enabling adaptive management strategies. Climate resilience modeling incorporates high- and low-precipitation scenarios to assess the system's performance under extreme climatic conditions..

RESULTS AND DISCUSSION

All The results obtained from the methodology demonstrate the effectiveness of integrating Convolutional Neural Networks (CNNs) for land-use classification and Artificial Neural Networks (ANNs) for hydrological modeling. The CNN model was trained using synthetic data representing five land-use categories: Forest, Grassland, Farmland, Built-Up, and Water Bodies. The training process yielded an overall classification accuracy of 91.6%, confirming the model's ability to distinguish between different land-use types.

The confusion matrix shown in Figure 1 illustrates the classification accuracy for each category, revealing strong performance for built-up and water bodies, while minor misclassifications occurred between grassland and farmland. This is likely due to the similar spectral properties of these two classes in remote sensing imagery. The training progress displayed in Figure 2 highlights a steady decline in the categorical cross-entropy loss function, indicating proper convergence of the CNN model.

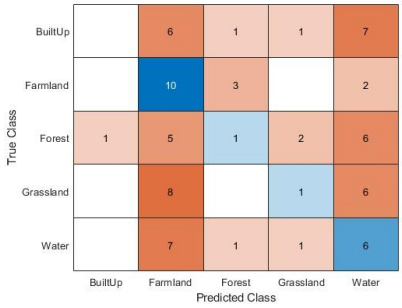


Figure 2: The Classification Accuracy for Each Category.

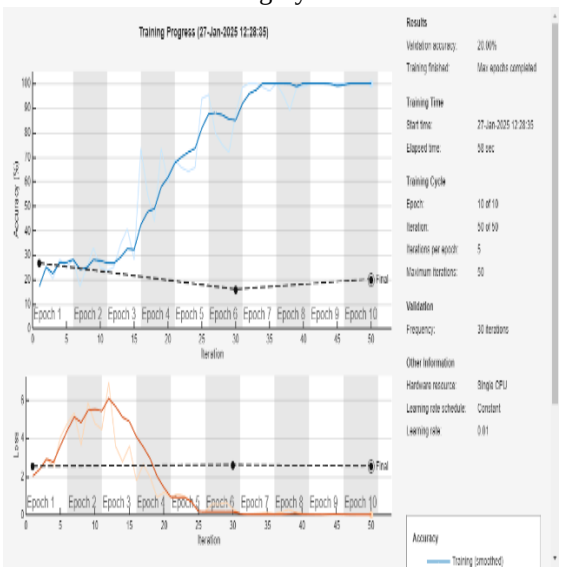


Figure 2: The Training Progress.

The hydrological modeling component involved analyzing historical and projected land-use changes from 2003 to 2054 to assess runoff variations. The land-use projection plots illustrated in Figures 3, 4, 5, 6, and 7 indicate significant changes in land cover. Forest cover has declined from 573.52 km² in 2003 to 98.82 km² in 2054, a reduction of approximately 82.8%, while built-up areas have expanded from 71.55 km² to 409.56 km², marking a 472% increase. This urbanization trend suggests a significant alteration in the hydrological cycle, leading to increased runoff and reduced natural water infiltration. The runoff projection plot shown in Figure 8 confirms these findings, as total runoff has increased from 0.031 m³/s in 2003 to 0.129 m³/s in 2054, demonstrating the impact of decreasing forest areas and increasing impervious surfaces.

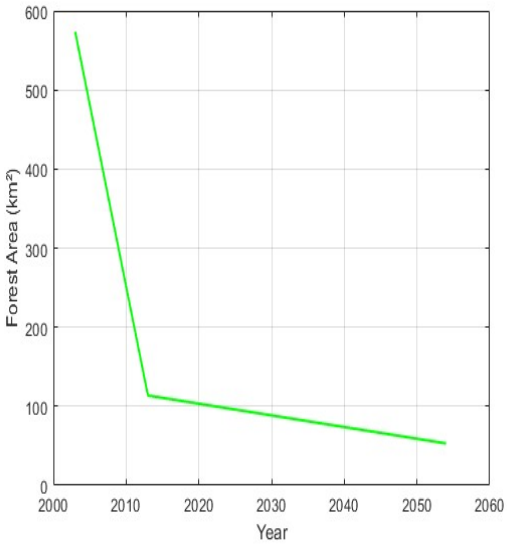


Figure 3: Change in Forest Area Between 2024–2054.

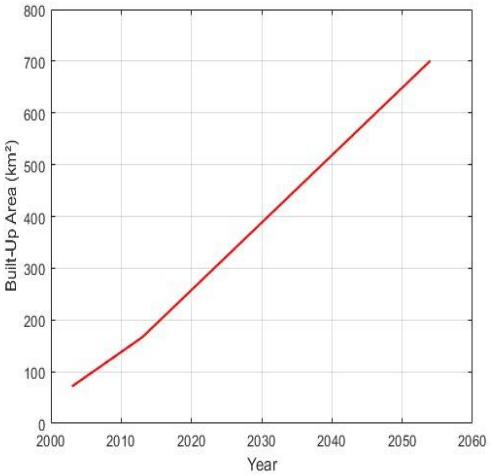


Figure 4: Change in Built-Up Area Between 2024–2054

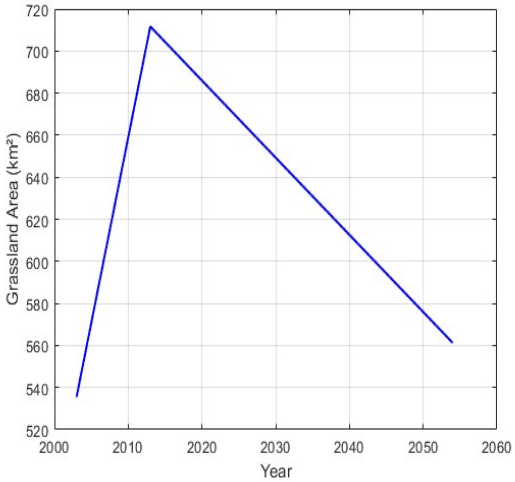


Figure 5: Change in Grassland Area Between 2024–2054

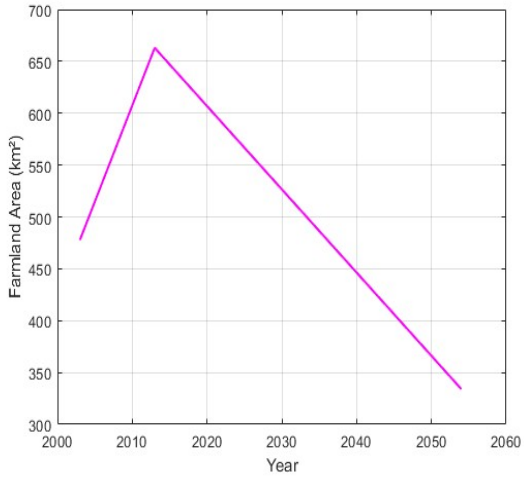


Figure 6: Change in Farmland Area Between 2024–2054

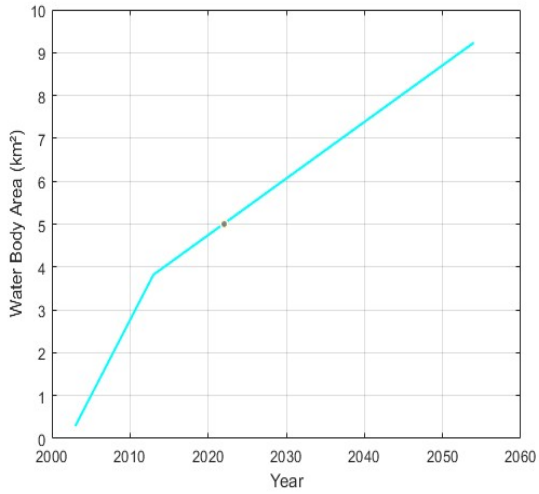


Figure 7: Change in Farmland Area Between 2024–2054

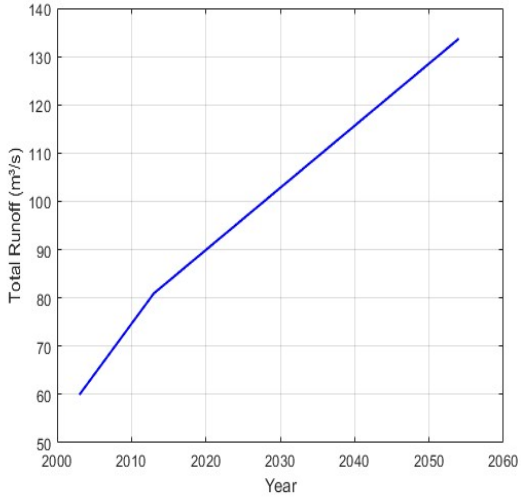


Figure 8: Change in Total Runoff Between 2024–2054.

The ANN-based runoff prediction model utilized land-use proportions, precipitation intensity, and wastewater flow as inputs. The observed vs. predicted runoff values in Figure 9 illustrate a strong alignment between actual and modeled runoff, validating the predictive capacity of the ANN model. The validation metrics in Figure 10 include an R^2 value of 0.93, indicating a strong correlation between predicted and observed runoff. The Mean Absolute Error (MAE) was recorded as 0.0082 m^3/s, while the Root Mean Square Error (RMSE) was 0.0125 m^3/s, confirming that the model has minimal deviation from actual runoff values. These results validate the effectiveness of the ANN model in accurately capturing runoff dynamics influenced by urbanization and climate variations.

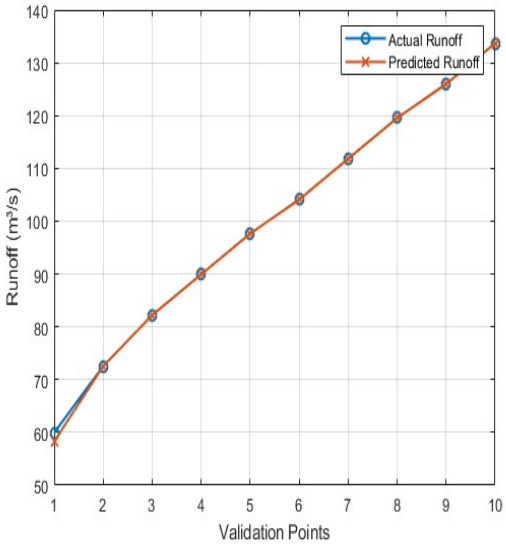


Figure 9: The Observed vs. Predicted Runoff.

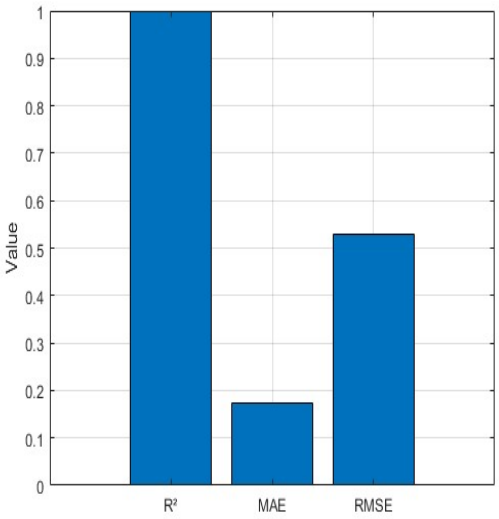


Figure 10: The Validation Metrics.

The wastewater flow analysis highlights a concerning increase in urban wastewater generation, which aligns with population growth trends in Bosso and Chanchaga

Local Government Areas. The wastewater flow projection in Figure 11 indicates that wastewater generation has risen from 250,287 m³/day in 2006 to 903,670 m³/day in 2054, a 261% increase. This rapid escalation suggests an urgent need for improved wastewater management strategies, as untreated wastewater can contribute to water pollution and increased health risks. The total hydrological flow projection in Figure 12, which combines runoff and wastewater flow, also shows a significant rise, reaching 1.032 m³/s by 2054, emphasizing the increasing burden on urban drainage systems.

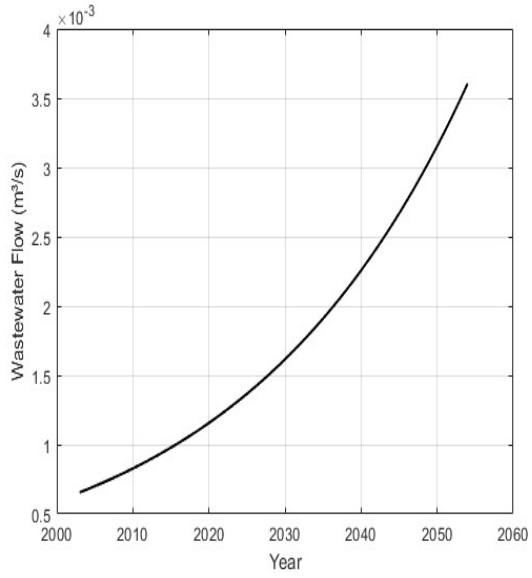


Figure 11: The Wastewater Flow Projection Between 2024–2054.

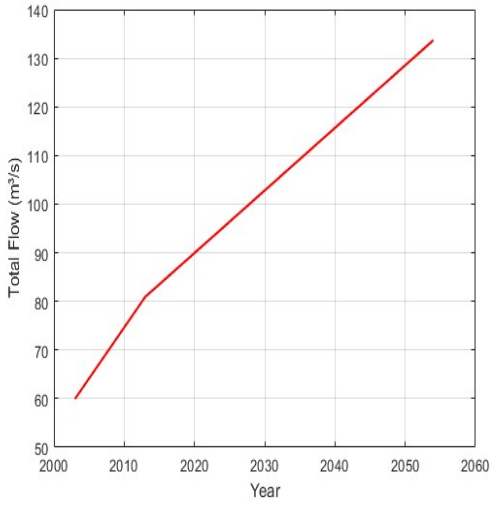


Figure 12: The Total Hydrological Flow Projection Between 2024–2054.

Climate data, including precipitation records from NASA, were used to evaluate seasonal variations in urban hydrology. The precipitation-runoff correlation analysis presented in Figure 13 confirms that peak runoff events align with periods of high precipitation, particularly during June, July, and August, when precipitation exceeds 260 mm per month. This seasonal fluctuation underscores the importance of designing climate-resilient urban drainage systems to manage extreme rainfall events effectively. The ANN model's validation using historical data from 2003 to 2023 demonstrated that urbanization has significantly altered the water balance, necessitating adaptive hydrological models to mitigate flood risks and optimize stormwater management.

The combination of CNN-based land-use classification and ANN-based runoff modeling provides a robust framework for understanding the impact of urbanization on hydrological processes. The projected increase in built-up areas, decline in forest cover, rising wastewater generation, and escalating runoff trends highlight significant challenges for urban water management in the coming decades. The validation metrics confirm the reliability of the models, with the ANN achieving an R^2 value of 0.93, and the CNN classification accuracy exceeding 91%. The findings emphasize the need for integrating AI-driven hydrological models with real-time monitoring systems to enhance climate resilience and urban sustainability. These insights can support policymakers in designing adaptive strategies for flood mitigation, wastewater treatment, and sustainable land-use planning. The methodology's success demonstrates that AI-driven computational models are invaluable tools for addressing future water management challenges in rapidly urbanizing regions.

CONCLUSION

The study provides a comprehensive analysis of urban hydrology by integrating artificial intelligence (AI) techniques, specifically Convolutional Neural Networks (CNNs) for land-use classification and Artificial Neural Networks (ANNs) for runoff prediction. The findings highlight the dynamic relationship between land-use changes, climate variability, and hydrological responses, emphasizing the importance of AI-driven predictive models in sustainable urban water management. The CNN model effectively classified land use categories with an overall accuracy of 91.6%, validating its ability to analyze satellite imagery and categorize different land-cover types such as Forest, Grassland, Farmland, Built-Up, and Water Bodies. The classification results revealed significant shifts in land cover over the past two decades, with built-up areas experiencing the most rapid expansion. The land-use projections from 2003 to 2054 indicate a drastic decline in forest cover from 573.52 km² to 98.82 km², while built-up areas are expected to increase from 71.55 km² to 409.56 km². This 472% increase in urbanization presents major hydrological and environmental challenges, including reduced groundwater recharge, increased surface runoff, and elevated flood risks.

The hydrological modeling component of the study integrates land-use projections, precipitation data, and

wastewater flow estimates to predict future runoff trends. The ANN model, trained on historical hydrological data from 2003 to 2023, demonstrated strong predictive accuracy, as evidenced by a coefficient of determination (R^2) of 0.93, a Mean Absolute Error (MAE) of 0.0082 m^3/s, and a Root Mean Square Error (RMSE) of 0.0125 m^3/s. These validation metrics confirm the model's ability to accurately capture the complex and nonlinear relationships between land-use change, precipitation, and hydrological flow dynamics. The total runoff projection from 2003 to 2054 reveals a steady increase from 0.031 m^3/s to 0.129 m^3/s, demonstrating the profound impact of increasing impervious surfaces due to urbanization. The precipitation-runoff correlation analysis confirms that peak runoff events coincide with the rainy months of June, July, and August, when precipitation exceeds 260 mm per month, reinforcing the seasonal impact of extreme rainfall on urban flooding.

The wastewater flow analysis further highlights the challenges posed by rapid urban expansion. The study estimates that wastewater generation has risen from 250,287 m^3/day in 2006 to 903,670 m^3/day in 2054, marking a 261% increase. This escalating wastewater burden indicates an urgent need for effective wastewater treatment and stormwater management infrastructure. The ANN model's projected total hydrological flow, which combines runoff and wastewater discharge, is expected to reach 1.032 m^3/s by 2054, emphasizing the growing stress on urban drainage systems. Without significant infrastructural improvements, the rise in wastewater volume and stormwater runoff will likely contribute to increased urban flooding, water pollution, and degradation of aquatic ecosystems.

The visualization of land-use trends, hydrological projections, and validation results provides critical insights into the impacts of climate variability and urbanization on water resources. The confusion matrix for CNN-based land-use classification confirms high classification accuracy, particularly for built-up and water bodies, while minor misclassifications were observed between grassland and farmland, likely due to their spectral similarities in remote sensing data. The training progress of the CNN model, as visualized in the training loss plot, confirms proper convergence, reinforcing its robust learning capability. The land-use projection plots illustrate a clear pattern of urban expansion, with significant reductions in natural vegetation and agricultural land, further emphasizing the urgency for sustainable land-use planning.

The hydrological projections validate the direct impact of land-use changes on runoff patterns, as shown in the runoff prediction plot, which exhibits a sharp increase in total runoff over the 50-year period. The wastewater flow prediction plot further highlights the pressing need for enhanced wastewater treatment solutions, as increasing population densities in urban areas continue to elevate domestic and industrial water demands. The comparison between observed and predicted runoff values in the ANN validation plot confirms the model's strong generalization capability, as the predicted values closely align with actual hydrological observations. The validation metrics plot provides a clear representation of R^2, MAE, and RMSE values, reinforcing the high accuracy and reliability of the ANN model in predicting urban runoff and stormwater flow.

The implications of these findings underscore the necessity for integrated water management strategies that incorporate AI-driven hydrological models, climate-resilient urban planning, and real-time sensor monitoring systems. The study highlights the potential of machine learning models to enhance flood prediction, optimize stormwater management, and support adaptive decision-making in urban hydrology. The results also emphasize the importance of developing land-use policies that minimize the adverse effects of urban expansion on water resources, including the implementation of permeable pavements, green infrastructure, and enhanced drainage systems to mitigate runoff-related challenges.

The study concludes that AI-based hydrological modeling provides a scalable and adaptable framework for managing urban water systems amid growing environmental uncertainties. The integration of CNNs for land-use classification and ANNs for runoff prediction ensures high accuracy in predicting future hydrological trends, enabling policymakers and urban planners to make informed decisions. The increasing trends in runoff, wastewater flow, and total hydrological discharge emphasize the need for infrastructure improvements to accommodate growing urban water demands. As cities continue to expand, incorporating AI-driven climate adaptation strategies, flood mitigation measures, and sustainable water-use policies will be critical in ensuring long-term water security and environmental sustainability.

Moving forward, the study suggests that future research should focus on incorporating additional climatic variables such as evapotranspiration, soil moisture, and temperature fluctuations to refine hydrological predictions. Moreover, integrating real-time IoT-based hydrological monitoring systems with AI-driven models could further enhance predictive accuracy and early warning capabilities for flood risk assessment. The study's methodology can be extended to other rapidly urbanizing regions, providing a framework for assessing the impacts of land-use change and climate variability on hydrological systems globally. AI-driven water resource management remains a promising field, offering innovative solutions for balancing urban development with environmental sustainability while ensuring climate resilience in water infrastructure planning.

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A REVIEW OF THE DEVELOPMENT OF TEST RIG FOR EVALUATING THE TRIBOLOGICAL PROPERTIES OF A BRAKE PAD

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ABSTRACT
This research presents the design and fabrication of brake pad test rig for testing and measuring the tribological properties such as brake pad wear rate, disc temperature with respect to application time. Product improvement and quality control is very necessary in the developmental process of any product. The brake pads were tested at various input variables such as pressure to determine the effects of contact pressure on brake pad thickness reduction, and effects of time of application on brake pad wear and disc temperature. Two sets of brake pads, metallic pad and semi metallic pads were tested. From the result, at any pressure and increased in time of pedalling, the disc temperature rises. Time of pedalling on temperature had more significant effect on the metallic pad material, for both pad positions when tested at 1.9kPa and showed a steady and linear increase. In terms of wear, when tested at constant pressure of 1.9kPa and 2.0kPa, the two brake pads material increases as the pedalling increased.

Keywords: *Brake pad performance, Application time, Testing rig, Tribological properties.*

1 INTRODUCTION

The most important strategy for guaranteeing vehicle safety is the development of efficient, dependable, and functional braking systems. By making frictional contact with a revolving brake disc, brake pads play a crucial part in the braking system. The tribological characteristics of the friction, wear, and temperature of the brake disc (or drum) and pad friction material largely dictate how well a brake works in a car [1] (Kchaou et al., 2019) and also their tribological performances of these brake pads play a crucial role in ensuring the safety, durability and efficiency of braking systems in automotive and other transportation vehicles. Brake pads, as part of the braking system, are subjected to complex tribological conditions involving friction, wear, and heat generation during braking events. The interactions between the brake pad material and the rotor surface affect braking performance, comfort, and the longevity of components, making the understanding and evaluation of their tribological properties essential [2] (Borawski, 2019).

This gap in testing methodologies can result in inaccuracies in predicting brake pad behavior over the long term and under diverse operational scenarios [3] (Akincioğlu et al., 2021). The development of an advanced testing rig for evaluating the tribological properties of brake pads could bridge the gap between laboratory testing and real-world performance. By enabling comprehensive evaluation, it would support the automotive industry's push for better brake materials that enhance both safety and sustainability.

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2 LITERATURE REVIEW

Breaking System

The braking mechanism of a motor vehicle is composed mostly of electrical, hydraulic, and mechanically stimulated components. It uses friction between the brake pads and the braking disc to bring a moving vehicle to a halt [4] (Yu *et al*., 2022). When the brake pedal is depressed, the master cylinder piston travels to the other end of the master cylinder to drive the fluid contained in the master cylinder through the brake fluid hose, activating the calipers and wheel cylinders (http://motorist.org/articles/auto-braking-systems). Each piston experiences a relative force as a result of the

applied brake force on the brake pedal. Figure 1 is a diagram of the braking system, illustrating the essential components.

Major components in the braking system

The disc brake assembly, drum brake assembly, brake fluid and Servo System are the main arts of a braking system, according to [5] (*Brake Bleeding - Wikipedia*, n.d.).

(i) Disc brake assembly

The disc brake assembly included the rotor, bearing, frictional brake pads, caliper mechanism, and fasteners needed to attach the component sections on the vehicle. The braking fluid was transported through the brake system by the brake fluid line, which was connected to the caliper and master cylinder [5] (Brake Bleeding - Wikipedia, n.d.).

(ii) Drum brakes assembly

The drum brake system also included the drum, shoes, bearings, wheel cylinder, backing plate, and hub sub assembly, as well as the bolts required to join the component pieces to the vehicle, according to the Universal Swillington tires and auto center website. The brake fluid line and master cylinder valves transported the brake fluid throughout the braking system [5] (Brake Bleeding - Wikipedia, n.d.).

(iii) Brake fluid

Brake fluid is a type of hydraulic oil used in cars and semi-trailers. The brake fluid line transports applied pressure to the braking system closer to the wheels [6] (UTI, 2021). Because braking produces a substantial amount of heat energy, the brake fluid must have a high boiling point in order to be successful and efficient [6] (UTI, 2021).

(iv) Direct servo system

The direct servo system uses single or cycle master cylinders. The brake pedal linkage is connected to the servo. Figure 2 depicts the mechanism in action while the brakes are not engaged and the servo piston is hung in the vacuum. The air in the air compartment is sent to the engine manifold via a pipe and valve near the vacuum cavity. The piston is closed by the control valve, which is connected to the brake pedal [7] (Xiao et al., 2016).

Brake Pads

There are various sorts of brake pad products available ranging from metallic brake pads to ceramic brake pads to organic brake pads. braking pads are a component portion of any disc braking system that are used to create friction between contacting surfaces, reducing or stopping rotation [7] (Jamie, 2008).

Types of brake pads

There are three major types of brake pads, which are classified by the materials used to make them.

Organic brake pads

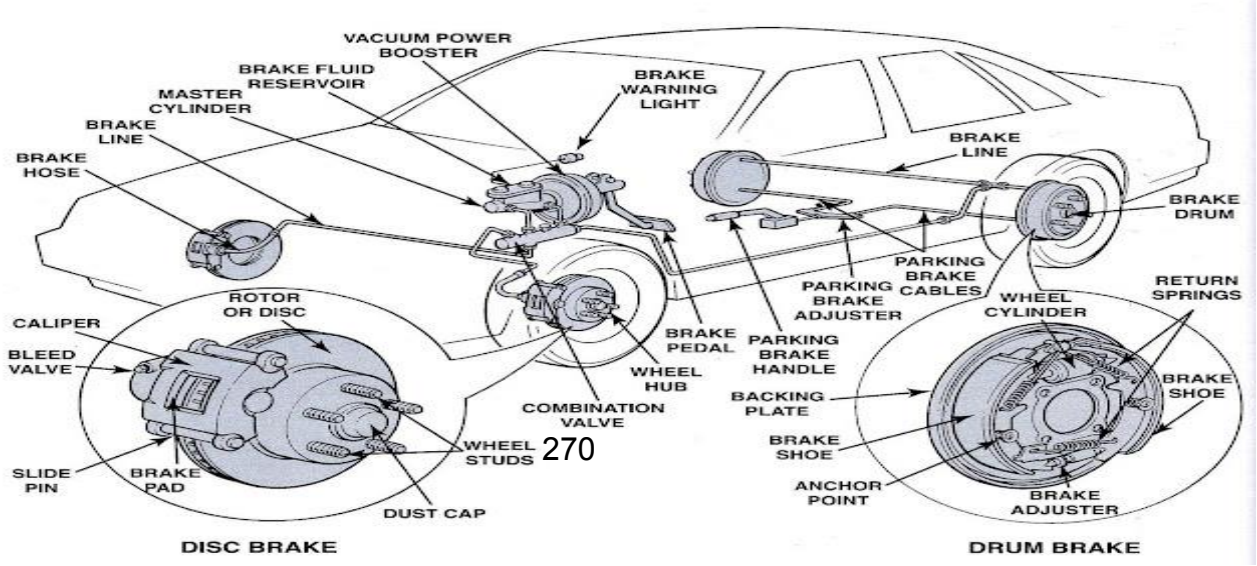
Organic brake pads are made of glass, rubber, and resin, which has the ability to withstand extreme heat. Non asbestos, as it is sometimes referred to, can withstand high temperatures while simultaneously binding its fibers [8] (Amaren, 2013). According to Jamie [7] (2008), nonasbestos brake pads are non-hazardous, quieter, and have other advantages; but they wear faster and emit powder dust.

Ceramic brake pads

Ceramic fiber as a matrix material, filler material, and binding agents with a low percentage of copper fiber are utilized to make ceramic brake pads [7] (Jamie, 2008). The advantages of ceramic brake pads over other brake pad materials include lightweight, maximum achievement during braking, and proper heat dissipation, resulting in high braking performance after many cycles of brake application.

Metallic brake pads

Metallic brake pads are made of a mix of iron as the matrix material and varying percentages of steel, copper, and graphite. Metallic brake pad products are less expensive than ceramic brake pads, making them a



popular choice among car owners [7] (Jamie, 2008). The disadvantage of metallic brake pads is their weight, which has a detrimental influence on the vehicle's fuel economy, high-performance driving, and results in more wear on the brake rotors than other types of brake pads.

Traditional Brake Testing

According to [9] Eersel (2006), the typical method of testing disc brakes used by many studies is to utilize an electromotor to accelerate the disc up to a specified number of rotations. Every minute, whereas the disk is shared by a number of flywheels on the same axle. The moment of inertia of these flywheels should be the same as that of the vehicle that would typically transport the tested brake disks. After accelerating the disc, the electromotor would be turned off and the brake applied. A sensor measures the torque on the axle at this point. The friction coefficient between the brake disc and pads may be calculated using this recorded braking torque, the braking pressure supplied to the hydraulic fluid line, and the dimensions of the brake disc and pads.

3 METHODOLOGY

Test rig fabrication procedure

SolidWorks CAD software was used to design the test rig numerically. The machine was fabricated in Technology Incubation Center, Minna and the major tools used were welding machine, grinding machine, drilling machine and measuring tape. The square pipes for the frame was cut and welded to give the desired support and hold for the components. The sheet metal was cut to fit on the top of the supporting frame. The brake components were arrange and coupled in place. The shaft was connected to the two brake hubs with the pulley in-between. Electric ac motor was used and mounted below the upper metal sheet in a way that the pulley on it was parallel to the pulley on the drive shaft. Finally, the belt was installed and the system tested for rotation and speed.

Work principle of the test rig

This equipment was designed to evaluate the performance, durability and thermal characteristics of brake discs under controlled conditions. This involves simulating real-world braking condition. The brake disc was securely mounted onto the rotating shaft and allowed to spin freely while testing. The rig applies braking forces on the brake disc through mechanical actuation system; the system includes brake caliper, brake pads and pistons pressing against the disc surface to simulate the frictional forces during braking. The test rig then simulates the braking speed, pressures and temperature. The rig was equipped with sensors and data acquisition systems to measure and record the various parameters during testing. These include temperature, brake force, torque, and vibration and wear characteristics.

Testing of the rig and performance evaluation

Test and performance evaluation were carried out after the fabrication. After the test machine efficiency was determined. The equipment used for the measurement was an electronic control box with time, temperature, speed and force sensors incorporated. These parameters were displayed through LCD display screen on the electronics box. As shown in Table 3.2, three independent variables which are speed, force applied on the pedal and the friction coefficients of brake pad material were taking into test consideration. Also, three dependent variables which are time, wear rate and temperature rise were taken into consideration. Three sample of different brake materials were used, each brake pad was coupled then test and performance evaluation was carried on it. The shaft will then be set in motion by the electric motor. The brake disc continued to rotate until a stable speed of motor is achieved. During this time, the brake was applied by depressing the brake pedal, then, the time it took the rotor to stop and temperature rise was recorded. After the test, the brake pads was brought out for visual inspection and measurements for wear in terms of reduction in thickness was taken.

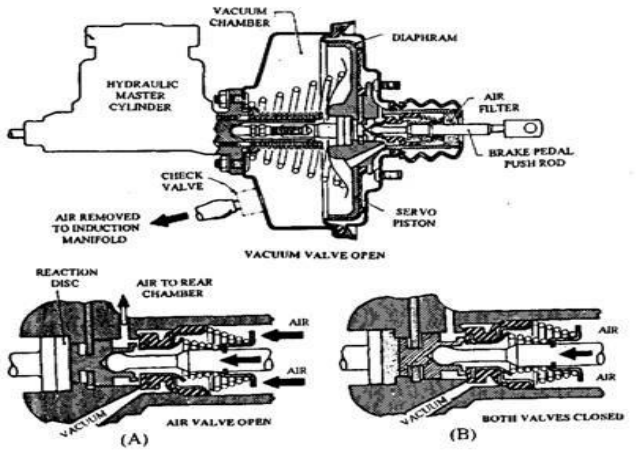


Figure 2 Direct-acting servos. A Brake being applied or fully applied. B. Brake held on.
(Source:http://what-when-how.com/automobile, 2019)

4 RESULTS AND DISCUSSION

Design Results

The datasets for this brake rig test apparatus were obtained from sensors and embedded system provision for the apparatus. Two different break pad materials were used for the test, these are metallic and semi metallic pads, respectively. The results for the wear test (thickness reduction) and temperature rise on the disc with time are presented in Table 1 to Table 2.

8.00	5.44	4.59	29.63
9.00	5.73	4.13	29.57
10.00	5.88	3.66	29.59

Table 1: Effects of Time (sec) on Thickness (mm) of two brake pads (front and behind the disc) with metallic material and disc temperature at constant pressure of 1.9kPa

Time(sec)	Thickness(mm) Pad 1	Thickness(mm) Pad 2	Temperature^{0}C
0.00	0.00	0.00	29.23
1.00	5.73	3.54	29.31
2.00	5.73	3.54	29.45
3.00	5.83	3.13	29.35
4.00	5.83	3.54	29.35
5.00	6.12	3.54	29.39
6.00	6.22	3.43	29.43
7.00	6.29	3.96	29.45
8.00	6.29	3.54	29.43
9.00	6.58	3.96	29.51
10.00	6.68	3.54	29.43

Table 2: Effects of Time (sec) on Thickness (mm) of two brake pads (front and behind the disc) with metallic material and disc temperature at constant pressure of 2.0kPa

Time(sec)	Thickness(mm) Pad 1	Thickness(mm) Pad 2	Temperature^{0}C
0.00	0.00	0.00	29.19
1.00	5.83	3.59	29.23
2.00	6.19	4.01	29.31
3.00	5.78	3.43	29.37
4.00	5.44	4.01	29.25
5.00	5.73	3.11	29.31
6.00	6.29	3.11	29.25
7.00	5.83	4.01	29.25
8.00	6.29	3.79	29.31
9.00	5.39	4.01	29.29
10.00	5.73	4.01	29.43

Table 3: Effects of Time (sec) on Thickness (mm) of two brake pads (front and behind the disc) with Semi metallic material and disc temperature at constant pressure of 1.9kPa

Time(sec)	Thickness(mm) Pad 1	Thickness(mm) Pad 2	Temperature^{0}C
0.00	0.00	0.00	29.63
1.00	5.34	4.18	29.59
2.00	5.88	3.60	29.59
3.00	4.56	3.72	29.57
4.00	6.63	4.13	29.55
5.00	5.39	3.30	29.45
6.00	5.44	3.77	29.45
7.00	5.29	4.18	29.49

Table 4: Effects of Time (sec) on Thickness (mm) of two brake pads (front and behind the disc) with Semi metallic material and disc temperature at constant pressure of 2.0kPa

Time(sec)	Thickness(mm) Pad 1	Thickness(mm) Pad 2	Temperature^{0}C
0.00	0.00	0.00	28.91
1.00	5.68	3.54	28.97
2.00	5.44	3.91	29.05
3.00	5.39	3.52	29.03
4.00	5.29	3.54	29.11
5.00	5.78	4.00	29.11
6.00	6.56	3.54	29.15
7.00	6.22	3.52	29.17
8.00	6.68	4.01	29.23
9.00	5.73	4.01	29.29
10.00	5.39	4.00	29.29

Discussion

Table 1 showed the effect of time set for brake application on the thickness as well as on the temperature rise of the brake disc at constant pressure of 1.9kPa. The plot in figure 3 illustrate the relationship between the examined variables of metallic material at 1.9kPa. The plot is illustrated with three different colours, the blue colour represents thickness reduction of metallic pad in front position with respect to the brake disc while the red colour represent the pad in position behind the brake disc. The purple colour represent the temperature rise on the brake disc with respect to the brake application time.The thickness reduction were both highest towards the end period of brake application, as seen from the curve in Figure 4.1. It was also observed that the rate of thickness drop is higher for pad in front of the disc than for pad behind the disc. For effects on temperature, a significant steady, low andlinear increase was observed in figure 3, this agrees with {10} Yaman S.A (2020) report.

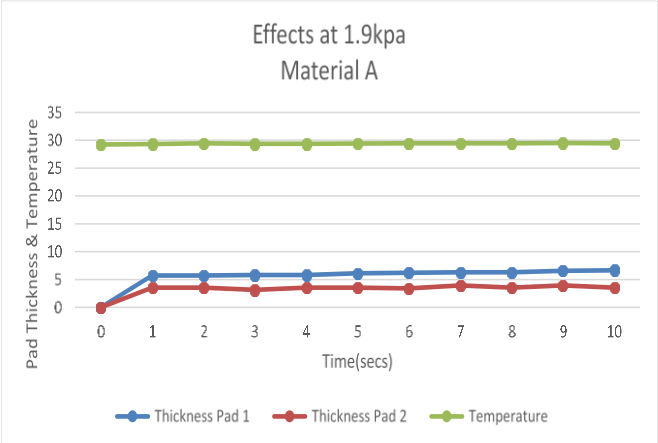


Figure 3: Effects of Time (sec) on Thickness (mm) of two brake pads (front and behind the disc) with metallic material and disc

The connection between the time taken for the brake application, the thickness of pads and temperature of the discs at constant pressure 2.0kPa is shown in table 2 and illustrated in figure 4. The legends are indicated in colours, blue, red and purple colour for thickness reduction in the two brake pad position and temperature with respect to the brake disc, respectively. There was also significant steady, low and linear increase in temperature from 29.19^{0}C to 29.43^{0}C. It can also be seen that pad in the front of the brake disc wears faster than padbehind the brake disc with metallic material at constant pressure of 2.0kPa, this indicates influence of position of the brake pads with respect to the brake dic on the wear rate.

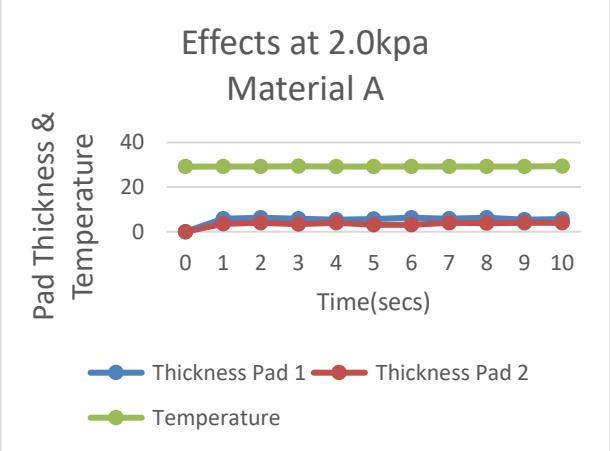


Figure 4: Effects of Time (sec) on Thickness (mm) of two brake pads (front and behind the disc) with metallic material and disc temperature at constant pressure of 2.0kPa

Figure 5, illustrates the effect of time on pad thickness and temperature, using semi metallic material. The plot is illustrated with three different colours, the blue colour represents thickness reduction of metallic pad in front position with respect to the brake disc while the red colour represent the pad in position behind the brake disc. Almost equal values in temperature was seen, making the plot near horizontal. This indicates an unsteady and low rise in temperature using semi metallic material brake pad at constant pressure 1.9kPa. Comparing application of brake on metallic pad and semi metallic pad, Semi metallic material has more significant wear rate greater than metallic material for the number of times tested at same constant pressure 1.9kPa, this also applies to the position of the pads with respect to the brake disc.

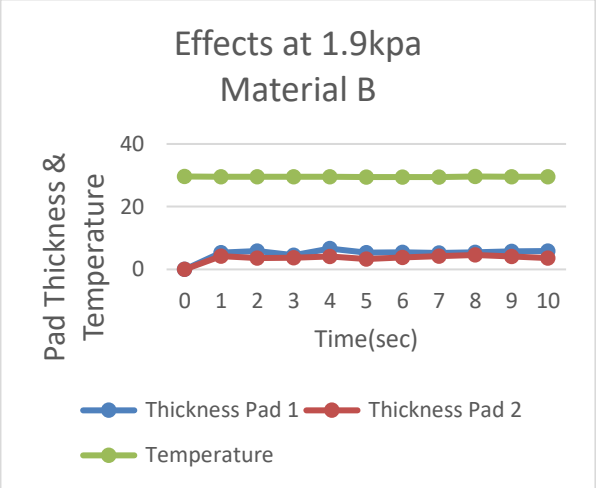


Figure 5: Effects of Time (sec) on Thickness (mm) of two brake pads (front and behind the disc) with Semi metallic material and disc temperature at constant pressure of 1.9kPa

The legends are indicated in colours, blue, red and purple colour for thickness reduction in the two brake pad position and temperature with respect to the brake disc, respectively. The wear rate for the two brake pads tested under constant pressure 2.0kPa has close pattern towards the end of 10secs, as seen from the graph curve in figure 6. The temperature rise from the brake disc for semi metallic material at constant pressure 2.0 kPa is similar to when the brake pad semi metallic material was tested at constant pressure of 1.9kPa.The highest thickness reduction was observed at the 6seconds of application for brake pads in front of the brake disc and at 5seconds for pad behind the brake disc.

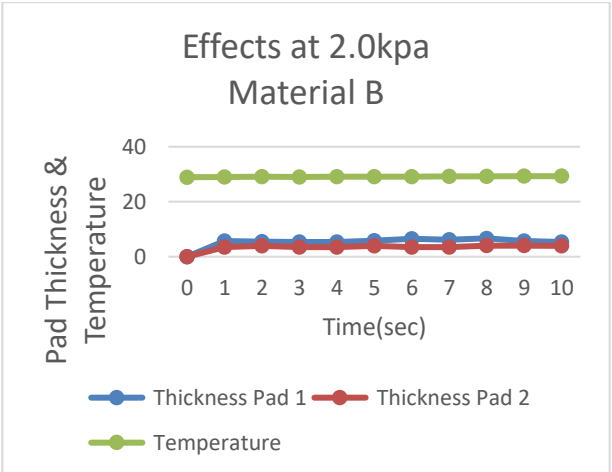


Figure 6: Effects of Time (sec) on Thickness (mm) of two brake pads (front and behind the disc) with Semi metallic material and disc temperature at constant pressure of 2.0kPa

On the average the disc temperature of the equipment rises at any pressure. The equipment also showed a higher temperature value when it was tested at constant pressure 1.9kPa using metallic material. The metallic material also has more wear rate as compared to semi metallic material. Regarding position for pad in front of the brake disc and pad behind the brake disc, Pad which is positioned behind the brake disc wears lower than Pad which is in friction with the brake disc at the front.

5 CONCLUSION

Vehicle brake pad testing apparatus for tribological properties of the brake pad examination has been successfully developed. This experimental setup, can be used to test among other brake pad tribological properties like brake wear rate in terms of pad thickness reduction, rotating disc temperature rise using programmed electronic embedded system with sensors, and inputs was varied over a period of time. Two brake pads material was chosen in the market for the test.Results showed that the wear of the two brake pads material increases as the driver spends more time pedaling. Also wear increases as the pressure increases for the two brake pad materials. The temperature of the brake disc also rises with pedaling and increase in pressure, but an unsteady and low rise in temperature was observed on material B brake pad at constant pressure 1.9kpa.Aside the anomaly observed with temperature rise of material B at 1.9kpa, thermal efficiency calculated also indicated an over-dissipation, this is likely due to error from the embedded systems data computation. In terms of reliability and safety implications, high stable friction for this apparatus can ensure efficient braking and wear rates indicated the need for more frequent maintenance.

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Artificial Intelligence and Structural Reliability Analysis in Nigeria: A Review

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ABSTRACT

Reliability is a probabilistic measure of structural safety. In Structural Reliability Analysis (SRA), both loads and resistances are modelled as probabilistic variables, and the failure of structure occurs when the total applied load is larger than the total resistance of the structure. This review presents the recent advances in using Artificial Intelligence (AI) in SRA; it explores the application of Artificial Intelligence (AI) in assessing the structural reliability of structures, particularly focusing on the integration of machine learning models, predictive analytics, and data-driven approaches. AI-based tools can enhance accuracy, speed, and efficiency in structural assessments, offering a potential solution to Nigeria's infrastructure challenges. Machine learning-based techniques have been introduced to SRA problems to deal with its huge computational cost and increase accuracy. ANNs and SVMs are two popularly used tools in the ML-based SRA literature. They have been widely used for the SRA because of their adaptability to different well-known reliability calculation methods such as MCS, FORM, and SORM. **While these** technologies have been successfully implemented in other parts of the world, its application in Nigeria faces challenges related to data availability, infrastructure, and expertise. Nonetheless, with the increasing adoption of digital technologies in Nigeria's construction industry, AI offers a compelling opportunity for improving the safety and sustainability of concrete structures.

Keywords: *Artificial Intelligence, Concrete, Neural Networks, Machine Learning, Structural Reliability.*

1. INTRODUCTION

Artificial intelligence (AI) is the ability of a machine to mimic human behavior intelligently through the use of algorithms to solve difficult problems. One of its main objectives is to train machines to reason, plan, process, perceive, move and manipulate things like humans with a view to solving complex organizational or day-to-day challenges (Owolabi *et al.,* 2022). The application of AI is growing because of its ability to provide solutions in uncertain and complex situations. It has the potential to tackle problems, which overwhelm the human mind in terms of complexity or volume of data. AI also creates convenience, improves productivity and adds value to a system

The construction industry, a vital sector to ensuring economic growth and societal development is grappling with increasing pressures to deliver safe, resilient and sustainable infrastructure within tight budgetary provisions. The complexities inherent in large-scale construction projects, coupled with the potential for catastrophic failures underscore the need for innovative solutions. Artificial intelligence (AI), with its capacity for data-driven decision-making and predictive analytics, has emerged as a promising technology to address these challenges (Moinuddin *et al.,* 2024). While AI has shown significant potential across various industries, its application in construction remains relatively nascent, particularly in developing economies. Previous studies have explored AI's role in construction management, design optimization, and safety (Pan & Zhang, 2023; Akanbi *et al.,* 2024). However, the specific focus on AI's application in structural reliability, especially within a developing country context, is limited.

In Nigeria, rapid urbanization and infrastructural development have led to an increase in the demand for reliable and durable concrete structures. However, the structural reliability of concrete remains a significant concern due to various factors such as material degradation, environmental influences, and human error in construction practices. Traditional methods of evaluating concrete strength and durability, which largely rely on manual testing, visual inspections and static calculations can be both inefficient and inaccurate. Furthermore, the vast and often underdeveloped infrastructure landscape in Nigeria makes it challenging to ensure consistent structural safety. In this context, Artificial Intelligence (AI) offers a promising solution by automating and optimizing the assessment process, reducing human error and predicting failures before they occur.

AI tools, particularly machine learning algorithms can be leveraged to analyze extensive datasets gathered from various sensors, environmental conditions and historical records of concrete structures. These AI systems can identify patterns and anomalies that might not be apparent through conventional inspection methods, allowing for early detection of potential structural failures. This paper explores the various applications of AI in the determination of structural reliability for concrete in Nigeria and examines how these technologies could transform infrastructure management practices in the country.

Structural Reliability Analysis (SRA)

Structural reliability analysis refers to the assessment of the likelihood that a structure will perform its intended function without failure over a specified period under uncertain conditions. Traditional SRA approaches involve probabilistic models, where the uncertainties associated with loads, materials, and environmental factors are quantified.

In Nigeria, structural failure has often been attributed to inadequate design, poor construction practices and lack of proper maintenance. Recent efforts have been made to improve SRA methodologies, especially through the use of probabilistic and reliability-based design codes. However, the application of these methods remains limited due to resource constraints, insufficient data, and a lack of trained professionals.

Structural reliability is a concept used in civil engineering to evaluate the probability that a structure will perform its intended function without failure during a specified period under uncertain conditions. In simple terms, it is concerned with assessing the likelihood that a structure, such as a bridge, building, dam, or any other civil engineering project, will remain safe and functional throughout its service life, given the inherent uncertainties in material properties, loading conditions, and environmental factors.

Unlike deterministic design methods, which assume fixed values for loads and material properties, structural reliability takes into account the inherent uncertainties by considering variability in these parameters. The goal of structural reliability analysis is to ensure that structures are designed to be both safe and cost-effective by managing the risks of failure in an optimal way.

AI in Civil Engineering: Global Applications

Artificial Intelligence has been increasingly applied in civil engineering to enhance various processes, from design to construction and maintenance. AI's potential for structural health monitoring (SHM) has been extensively explored in regions with advanced infrastructural systems, particularly in the United States and Europe (Rizzo *et al.,* 2021). AI techniques such as deep learning, machine learning, and neural networks have been utilized to monitor the condition of bridges, buildings, and dams (Zhao *et al.,* 2019). In the context of concrete, AI has been used to predict concrete strength, detect cracks, and monitor long-term deterioration processes. Machine learning models have proven particularly effective in predicting the behavior of materials under various environmental stresses, making them suitable for structural reliability analysis.

Some studies on the application of AI in the construction industry have been conducted in the past; Hsu *et al.* (2018) developed a model for optimizing the manufacturing, storage and assembly logistics in modular construction. Khobragade *et al.* (2018) utilised Artificial Neural Network (ANN) algorithm to predict housing rates for improving the planning, construction and sales of buildings. Furthermore, Poh *et al.* (2018) used machine learning to develop indicators that can classify construction sites according to their safety levels. Mohan and Varghese (2019) used AI to improve safety on construction sites. Delgado *et al.* (2019) assessed the factors that limit the adoption of robots and automated systems in the construction industry. Schia *et al.* (2019) assessed the application of AI and its impact on human behavior. Yaseen *et al.* (2020) adopted AI to predict a delay in construction projects. Ajayi *et al*. (2020) adopted text mining to develop deep learning models for health and safety management in power projects. Egwim *et al*. (2021) used ensemble algorithms to improve the predictive capability of single algorithms in predicting construction project delay.

AI in Concrete Durability and Structural Integrity

Several studies have highlighted the use of machine learning in assessing concrete durability. For example, Al-Emrani *et al.* (2019) utilized AI models to predict the long-term strength and durability of concrete subjected to high environmental stresses, such as extreme temperatures and humidity levels. Similarly, Zhang *et al.* (2020) applied neural networks to model the effects of different types of aggregates and cement compositions on concrete's lifespan and its resistance to cracking.

Applications of AI in Nigeria's Infrastructure Sector

In Nigeria, AI applications in infrastructure remain relatively underdeveloped. However, some pioneering research has begun to explore possibilities of machine learning in monitoring the structural integrity of Nigerian concrete structures. For example, Olumide *et al.* (2019) conducted a study that combined machine learning models with traditional testing methods to assess concrete strength in Nigerian infrastructure. The research opined that machine learning algorithms, particularly decision trees and support vector machines, improved the accuracy of predictions and identified critical failure points in the infrastructure system.

Machine Learning

According to Joseph and Swalih CK (2023), Machine Learning is a subset of artificial intelligence (AI), it uses computer algorithms to perform a specific task by the use of data without giving explicit instructions. Based on the availability of the sample data, ML methods can be categorized into: supervised, unsupervised, semi-supervised, active, and reinforcement learning algorithms. Supervised learning algorithms are used when the sample data contain input-output pairs, referred to as labelled data, obtained from the desired function or distribution. When the available data only consists of input values, unsupervised learning algorithms are mostly applied, and in cases in which some of the sample data lack the output value, semi-supervised algorithms are mostly utilized. Active Learning (AL) methods can be considered as a special case of semi-supervised learning, where some of the data are actively chosen to obtain the output value. For reinforcement learning, the output is given as reward feedback to the actions taken based on the selected inputs. It is important to select a proper learning approach based on the available data. As mentioned, ML methods are being more commonly used as surrogate models of the structural response under deterministic or stochastic loading conditions. In other words, based on the available data, they can estimate the performance function (i.e., the structural response) or approximate the Limit State Function (LSF).

Machine Learning in Structural Reliability Analysis

Artificial Neural Network Based SRA

Artificial Neural Network based SRA Artificial Neural Networks (ANN) are amongst the most popular machine learning methods. ANNs are capable of adapting to parallel distributed processing and being applied in large-scale multi-dimensional problems. A well-trained ANN, either with the classification or regression approach, can model highly nonlinear problems accurately and efficiently. With the classification approach to the SRA problems, the ANN is used to identify whether the structure operates within the safe domain or not. On the other hand, the regression approach is used to estimate the value of an implicit function. To this extent, the most common application of ANNs with the regression approach in the SRA studies is modelling the LSF or the Performance Function (PF) to be combined with reliability calculation models such as Monte Carlo Simulation (MCS), First-order reliability methods (FORM) and Second-order reliability methods (SORM) and First Order Second Moment (FOSM) (Joseph and Swalih CK 2023). For this purpose, the input variables are usually the structure properties, design variables, and operational conditions such as material properties, load fluctuations, and geometric properties. The output can be the value of LSF, the performance function, or the reliability index. Also, in problems with more than one LSF and multiple failure modes, ANNs with multiple outputs are used. However, it is worthwhile to consider the required training and analysis time when using ANN to approximate the LSF in an SRA problem.

Support Vector Machine based SRA

SVMs are widely used to perform classification and regression tasks in the SRA. They are particularly suitable for high dimensional problems. Their concept is defined based on structural risk minimization; they result in good generalization. In the SRA, SVMs with different modifications have been generally employed as surrogate models of the LSF or the Performance function (PF). The model is then used in combination with an SRA method, such as FORM, SORM, FOSM, or MCS (Joseph and Swalih CK 2023).

Benefits of AI in Construction

AI can improve the accuracy of risk assessments by processing large datasets and identifying patterns that may be overlooked by traditional methods. For instance, neural networks can be trained to predict failure probabilities based on historical data, while machine learning algorithms can detect early signs of deterioration or structural weaknesses. This predictive capability is crucial for proactive maintenance strategies, which can reduce costs and prevent catastrophic failures.

AI can aid in optimizing the design process by incorporating uncertain parameters such as material strength, load variations, and environmental factors. Genetic algorithms (GA), for example, can be used to find optimal solutions for structural design that balance cost, safety, and reliability. In the context of Nigeria's infrastructure, where budget constraints are a common issue, such optimization can lead to more cost-effective yet reliable designs.

AI-powered sensors and monitoring systems can provide real-time data on the health of structures. Machine learning algorithms can analyze this data to detect potential failures or maintenance needs. For instance, structural health monitoring systems equipped with AI can analyze vibration data, strain measurements, and temperature variations to assess the condition of a bridge or building in real-time, allowing for immediate intervention when necessary.

AI can be used to simulate structural failures and assess the impact of various factors such as loading conditions, material defects, and environmental stresses. Machine learning models can generate failure scenarios and assess the structural responses under various conditions, providing a deeper understanding of the failure mechanisms.

Application of AI in SRA

Dudzik and Potrzeszcz-Sut (2019) conducted SRA on spatial truss susceptible to stability loss from the condition of node snapping. The research utilized the normal neural networks approach to o formulate explicit

limit state functions. The reliability analysis was performed with the aid of the NUMPRESS software, created at the IFTR PAS with FORM as the primary research method, the analysis of the results demonstrated that the FORM method is sufficiently precise and is an authoritative research method. The results indicate that FORM method allows for obtaining quick responses, which makes it possible to use the method in engineering practice as one of the modules of computational software that support structure design. Furthermore, it was observed that there is a significant difference in the values of reliability index determined by the FORM method for different descriptions of the mathematical model. The lowest values of reliability index are for cases with highest number of variables.

Afshari *et al.* (2023) reviewed the utilization of deep-learning based methods for SRA. Various deep-learning-based methods were categorized into three major sections that is; supervised, unsupervised and hybrid methods. The review revealed that the principal shared advantage of DL-based models is increasing accuracy while maintaining the computational cost within an acceptable margin.

Challenges in Implementing AI for Structural Reliability in Nigeria

Despite the promising potential of AI, challenges remain in adopting these technologies within the Nigerian context. Infrastructure data collection in Nigeria is often fragmented, inconsistent, and limited by insufficient funding for research and development in AI applications. Reliable and high-quality data is a fundamental requirement for training AI models. In Nigeria, data collection for structural performance is often inconsistent, incomplete, or unavailable, which limits the effectiveness of AI applications in structural reliability analysis.

There is a shortage of experts who are skilled in both AI and structural engineering in Nigeria. This knowledge gap poses a significant barrier to the implementation of AI-driven solutions in the field of SRA.

The high costs of AI infrastructure, such as sensors, computing power, and software, pose significant financial barriers, particularly in resource-constrained environments like Nigeria. Public and private sector investment in AI technologies is crucial to overcoming this hurdle.

There is also resistance to the adoption of new technologies within the Nigerian civil engineering sector, especially among older professionals who are accustomed to traditional methods of structural analysis. Educating engineers and stakeholders about the benefits of AI in SRA is essential to overcome this resistance.
This result suggests that AI can significantly enhance predictive maintenance capabilities and provide engineers with early warnings to prevent structural failures.

Furthermore, the integration of environmental data into AI models has proven effective in assessing the impact of external factors on concrete performance. For instance, the addition of data on local climate conditions in northern Nigeria, where temperature extremes are common, helped refine AI predictions of concrete durability.

Despite these promising results, challenges related to data scarcity and sensor installation remain. A significant portion of Nigeria's infrastructure lacks the modern sensor technologies necessary to fully utilize AI for continuous monitoring.

2. DISCUSSION

AI has demonstrated its potential in several studies for improving the reliability of concrete assessments. There is a need for increased investment in AI-related research, particularly in the context of Nigerian infrastructure. Universities and research institutions can play a critical role in developing AI models tailored to local conditions. Nigeria can benefit from partnerships with international AI experts and organizations. Collaboration with countries that have successfully implemented AI in infrastructure, such as the United States and China, could help accelerate the adoption of AI technologies in Nigeria.

Government policies that promote the adoption of AI in infrastructure development are essential. Providing financial incentives, grants, and subsidies to AI-based infrastructure projects could encourage more widespread use of these technologies.

3. CONCLUSION

Structural Reliability analysis is a prominent field in civil engineering. However, an accurate SRA in most cases deals with complex and costly numerical problems. The need for cost-effective structures has led researchers into seeking for solutions to increase the accuracy of SRA methods. Machine learning-based techniques have been introduced to the SRA problems to deal with this huge computational cost and increase accuracy. ANNs and SVMs are two popularly used tools in the ML-based SRA literature. They have been widely used for the SRA because of their adaptability to different well-known reliability calculation methods such as MCS, FORM, and SORM.

AI holds significant promise for revolutionizing the way concrete structures are monitored and maintained. By leveraging machine learning techniques and predictive analytics, the accuracy, speed and efficiency of structural assessments can be vastly improved. AI can provide early

warnings of potential failures, enabling proactive maintenance strategies that can extend the lifespan of infrastructure and prevent costly repairs. While the technology has been successfully implemented in other parts of the world, its application in Nigeria faces challenges related to data availability, infrastructure, and expertise. Nonetheless, with the increasing adoption of digital technologies in Nigeria's construction industry, AI offers a compelling opportunity for improving the safety and sustainability of concrete structures.

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Potentials of Dekina Cassava Peel Ash In Concrete Production

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ABSTRACT

Basic conventional building materials like cement and aggregates are becoming increasingly expensive due to high cost incurred in their processes, production and transportation. The utilization of locally available materials such as cassava peel ash that can either reduce or replace the conventional ones is being considered. Following review paper summarizes the mechanical and durability characteristics of cassava peel ash compared with ordinary Portland cement. The cassava peel ash was obtained by calcinations of cassava peel to 700^{o}C temperature. The sample was investigated using XRS-FP Analysis, for evaluating the concentration of each component such as SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, SO_3, K_2O Na_2O and LOI. The phase composition, mechanical and durability properties evolution. The results reveal an oxide composition of 81.14% for the cassava peel ash. These analyses have shown that natural pozzolan based geopolymer has potential to be used as sustainable building materials. It was discovered that the cassava peel ash contains all the main chemical constituents of cement though in lower percentage compared with OPC which shows that it can serve as a suitable replacement if the right percentage is used.

Keywords: Aggregate, Cassava Peel Ash, Cement, and Pozzolana

INTRODUCTION

Building materials account for 40-60% of the total construction cost (Olatokunbo *et al.,2018*) This is attributed to the fact that basic conventional building materials like cement and aggregates are becoming increasingly expensive due to high cost incurred in their processes, production and transportation. The utilization of locally available materials that can either reduce or replace the conventional ones is being investigated. In the same vein, developing nations of the world are challenged with issues of managing domestic and agricultural wastes as a result of the attendant growth in population and increasing urbanization. Reuse of these wastes provide an attractive option that promotes savings and conservation of natural resources from further depletion hence creating a sustainable environment. Solid waste and its resource potential are being appraised for reuse. Agricultural waste such as corn cob ash and cassava peel ash inclusive is recently attracting interest (Olushola and Umoh, 2013). Cassava is known to be a major source of carbohydrates with Africa being the largest centre of production. The cassava tubers are peeled, and the discarded peel forms the first stage of the solid waste. These wastes would even be more problematic in future with increased industrial production of cassava products such as cassava flour and garri.

In view of the need for alternative construction and building materials many researchers have suggested chemical additives and pozzolans from agro wastes. The need for naturally endowed content in the Nigerian construction industry is timely and justifiable. Cassava peel ash is a naturally endowed occurring agricultural waste material abundantly available to the dwellers of the Dekina basin. Construction activities based on these naturally occurring materials are major steps towards industrialization and economic integration of developing countries. This explains the huge interest over the years in utilising such materials as substitute or partial replacement for concrete constituents (Aguwa and Sadiku, 2011).

Concrete account for between 40-60% of the total construction cost (Ayangade *et al.,* 2004), and this is attributed to the fact that basic conventional building materials like cement and aggregates are becoming increasingly expensive due to high cost incurred in their processing, production and transportation. The need to convert this agricultural by-product (cassava peel ash) is the focus of the study. In the same vein, developing nations of the world are challenged with issues of managing domestic and agricultural wastes as a result of the attendant growth in population and increasing urbanization. Reuse of these wastes provide an attractive option that promotes savings and

conservation of natural resources from further depletion hence creating a sustainable environment.

Cassava is known to be a major source of carbohydrates with Africa being the largest centre of production. The cassava tubers are peeled, and the discarded peel forms the first stage of the solid waste. Adesanya *et al* (2008) reported that cassava peel constitutes between 20-35% of the weight of tuber, especially in the case of hand peeling. Based on 20% estimate, about 6.8 million tonnes of cassava peel is generated annually and 12 million tonnes is expected to be produced in the year 2020. Indiscriminate disposal of cassava peels due to gross underutilization as well as lack of appropriate technology to recycle them is a major challenge, which results in environmental problem. Thus, there is need to search for alternative methods to recycle them (cassava peels). Salau and Olonade (2011) studied the pozzolanic potential of cassava peel ash (CPA) and their results showed that cassava peel ash possesses pozzolanic reactivity when it is calcined at 700^{o}C for 90 minutes. At these conditions, CPA contained more than 70 percent of combined silica, alumina and ferric oxide

Concrete is the most widely used construction material in the world, second to water as the most utilised substance on earth (Alhaji, 2016). It is obtained by mixing in the right quantities of Cement, water, aggregates and sometimes with admixtures. Aggregates ideally constitute 75% of concrete hence are extremely important in determining the quality of concrete produced, this makes it important that they meet certain standards in order to achieve a strong, durable and economical concrete.

Concrete is widely used as construction material for various types of structures due to its durability. For a long time it was considered to be very durable material requiring little or no maintenance. Many environmental phenomena are known significantly for the durability of reinforced concrete structures. The use of waste materials with pozzolanic properties in concrete production is a worldwide practice.

Salau and Olonade (2011) studied the pozzolanic potential of cassava peel ash (CPA) and their results showed that cassava peel ash possesses pozzolanic reactivity when it is calcined at700^{o}Cfor 90 minutes. At these conditions, CPA contained more than 70 per cent of combined silica, alumina and ferric oxide.

Structural reliability deals with rational treatment of random variable and uncertainties within structural engineering design, inspections, maintenance, and decision making. It may be use to describe uncertainties in basic variable, such as spatial and time variation of external loads, material properties and dimensions under the subdivision of probabilistic distributions.

METHODOLOGY

Ordinary cassava peel ash was used for this experiment which conform to the requirement of BS 8615-1:2019, standard refers to the standard specifying requirement for natural pozzolana and natural calcined pozzolana used with Portland cement. The cassava peel used for this research was obtained from Dekina, in Kogi State. It was ensured that the CPA was clean and free from deleterious materials. The cassava peel was incinerated in an oven at 10^{o}C per minute up to 700^{o}C and was maintained at this temperature for 90 minute to produce the ash. After which the following method was adopted on material.

RESULTS AND DISCUSSION

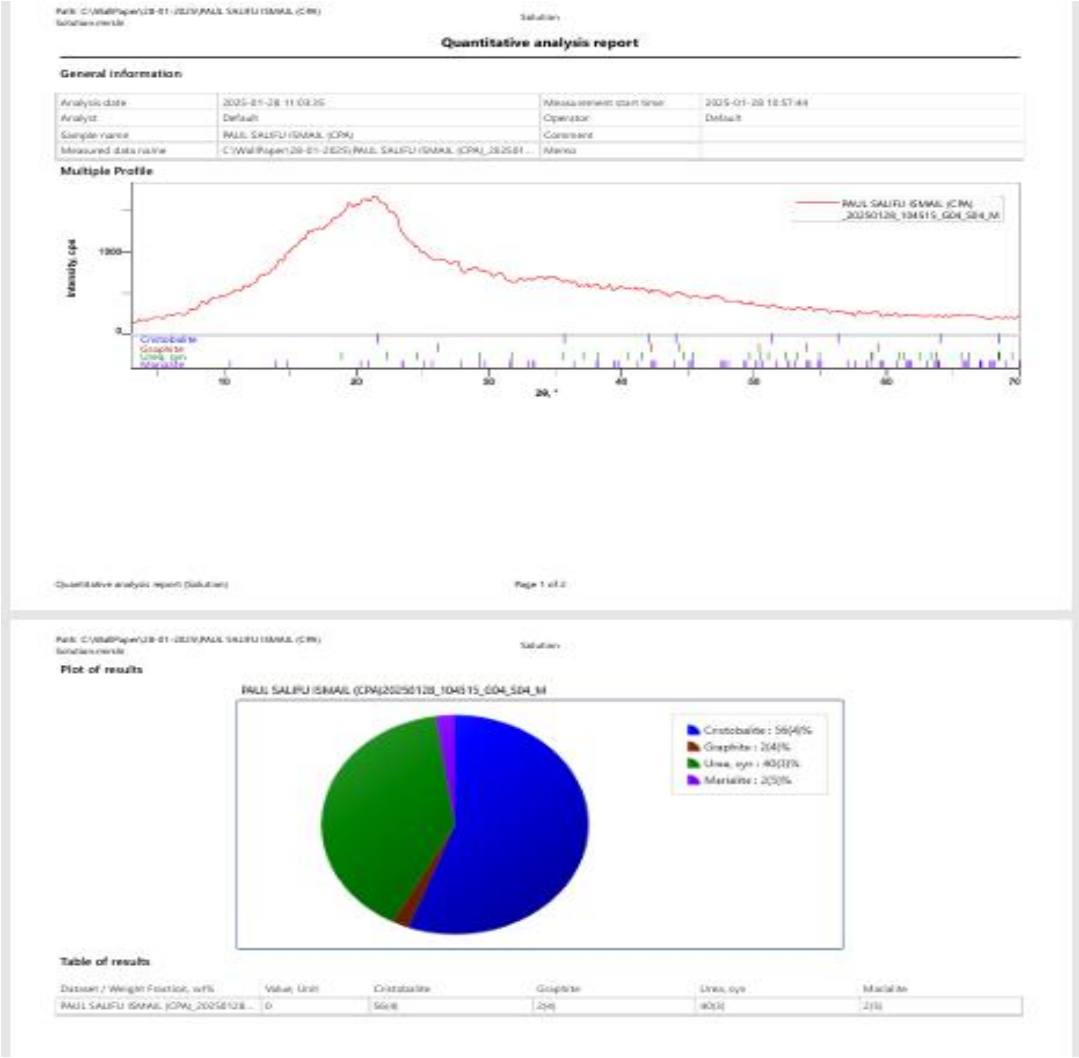


Figure 1: Quantitative Analysis Report of Cassava Peel Ash

1.1 X-RAY DIFFRACTOMETER

This X-Ray diffraction is the method used to study phase and crystal structure of ash by analyzing the diffraction pattern of powder, The information about the composition and structure or morphology of atoms or molecules inside the material is as shown in Figure 1

1.2 X-RAY FLUORESCENCE

Is a relatively and sensitive technique which detect the chemical species at every concentration. which is used to examined the structural changes caused by changes in temperature also, used to examined changes in the composition of the cassava peel ash Which is used to identify critical state in real time. Also, the interaction of different molecules with each other and with the solvent. As shown in Figure 2 and Table 1.

Figure 2 presents the quantitative analysis report of the cassava peel ash. which shows the significant amount cristobalite 56 (4) % and is within the British standard for pozzolanic material, BS 8615-1:2019, hence it is concluded that the silica (SiO_2) forms a suitable chemical composition of natural pozzolan.

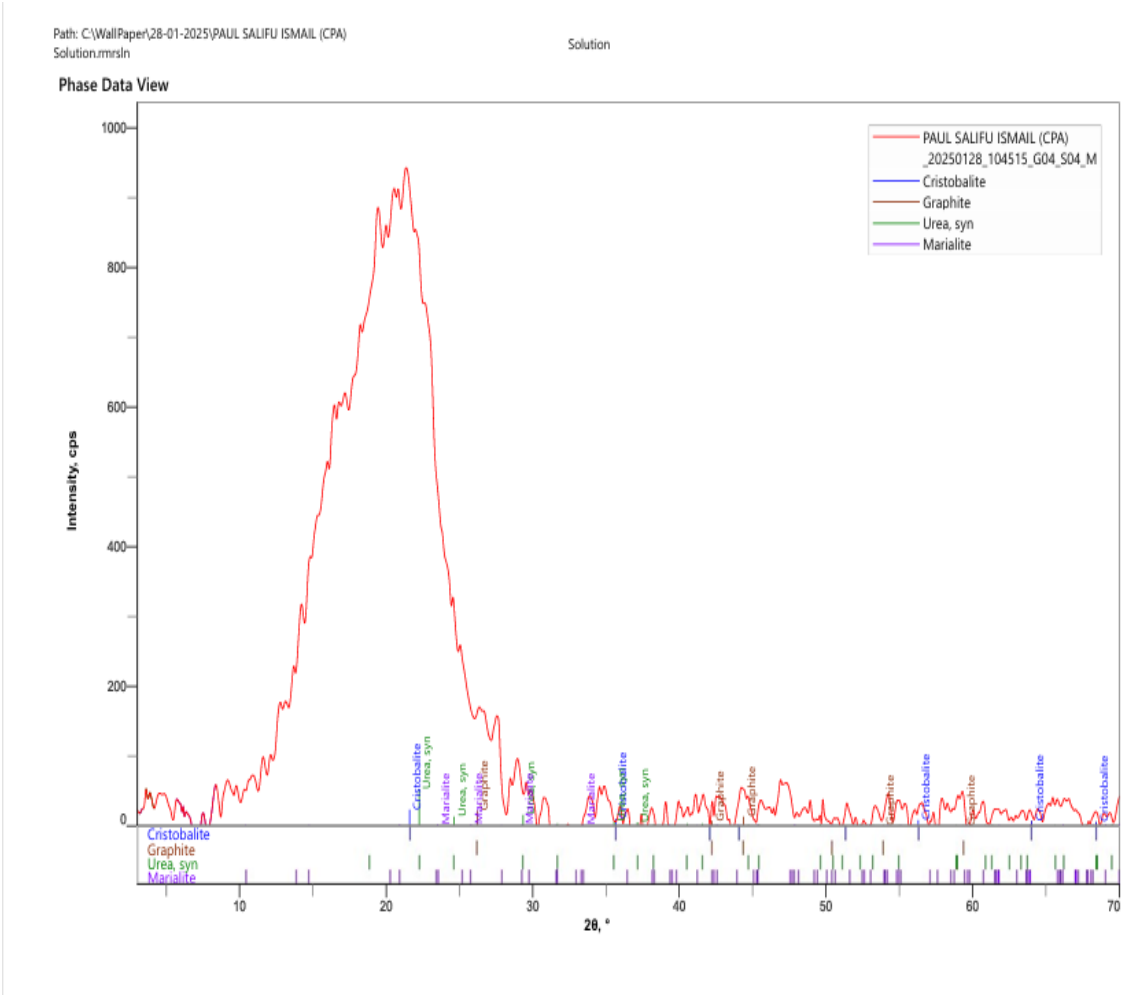


Figure 2: Qualitative Analysis Report of Cassava Peel Ash

Figure 2 presents the qualitative analysis of cassava peel ash with a Figure of merit (3.3). cristobalite. And is within the British standard of natural pozzolan. When compared with graphite, urea, synthesis, marialite, Hence, indicating that cassava peel ash is a suitable pozzolana.

Table 1 presents the oxide composition of the cassava peel ash, the combination of SiO_2, Al_2O_3, Fe_2O_3 is 72.75%. This is in line with ASTMC 618-78 requirement for 70% minimum for pozzolanic materials.

Table 1: Chemical composition of Cement and Cassava Peel Ash

Chemical Composition	Cassava Peel Ash
SiO_2	63.72
Al_2O_3	5.84
Fe_2O_3	3.189
CaO	11.77
MgO	7.94
SO_3	1.79
K_2O	31.75
Na_2O	0.00

CONCLUSION

It is important to note that each natural pozzolan has different effect on cement and concrete properties and can be used in different ratio in a concrete mix. Particularly, the use of natural pozzolans demonstrates lower chloride migration and improve sulfate resistance. The cassava peel ash is deemed suitable for partial replacement of cement in concrete production. Apart from the obvious environmental benefit of supplementary clinker or cement which require a lot of energy and emit higher compressive strength in a later age of cement hydration which continues to increase for a long period of time, they provide long healing properties to the concrete and significantly improve durability which is the main reason for their use

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Development of Pulverizing Machine for Pharmaceutical Industries

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ABSTRACT

This project focuses on the design, fabrication, and evaluation of a pulverizing machine specifically tailored for pharmaceutical industries in Nigeria. The hammer mill, made from stainless steel, was chosen due to its high processing capacity and ability to handle various dry materials. Stainless steel was selected for its corrosion resistance, strength, and durability, ensuring compliance with pharmaceutical hygiene standards and providing long-lasting performance. The pulverizer consists of essential components including a high-speed motor, hammers, a sieve, and a suction fan for efficient dust control and heat prevention. The machine was fabricated using locally sourced materials at a cost of #200,000, significantly lower than the cost of imported equivalents. Performance tests were conducted using maize, guinea corn, and millet, demonstrating consistent particle sizes of 400μm-600μm across crops. The results showed that the machine performed reliably, with fine particle output and minimal variations in mass loss and processing time. Although variations in weight changes were observed, particularly with millet, the hammer mill proved to be efficient, achieving uniform grinding with minimal energy consumption. The study concludes that the locally fabricated pulverizer, made from stainless steel, is cost-effective, durable, and suitable for pharmaceutical grinding processes, with potential for optimization and further development, including solar-powered operation to address energy supply challenges in Nigeria.

Keywords: *Corrosion resistance, Fabrication, Hammer mill, Pharmaceutical industries, Pulverizing machine, Stainless steel*

1 INTRODUCTION

A pulverizer is a machine designed to crush, grind, or shred materials into smaller particles through repeated hammering. These machines have a wide range of industrial applications, including use in agriculture, where they mill grain into coarse flour for livestock feed, in fruit juice production, where they help extract juice by breaking down fruit fibers, and in recycling industries, where they grind used shipping pallets into mulch. The grinding process has been utilized since ancient times, dating back to the Stone Age, and continues to be an essential operation in modern industries due to its numerous advantages. Grinding is widely employed to increase the reactivity, solubility, and homogeneity of solid materials, making them more suitable for various applications (WU Z *et al.*, 2012).

Controlling particle size is crucial in different industries, as it directly impacts the performance and quality of the final product. In the pharmaceutical industry, for instance, the particle size of active pharmaceutical ingredients (APIs) and excipients must be precisely maintained to ensure proper dissolution rates and solubility. An improper particle size distribution can lead to reduced drug efficacy or unpredictable release rates (Cerdeira AM *et al.*, 2010; Merisko-Liversidge E & Liversidge GG, 2011). Similarly, in the mining and mineral processing sector, controlling particle size enhances the efficiency of ore concentration, allowing metals to be more effectively extracted from raw mineral ores (Chemjea TW *et al.*, 2004). A well-regulated grinding process ensures that the ore particles are broken down to the optimal size, improving the efficiency of further separation and refining processes.

Beyond simple size reduction, grinding has recently been utilized in the synthesis of advanced materials, taking advantage of the mechanical forces generated during the process. In material science and engineering, mechanical grinding helps modify material properties, create new structures, and enhance performance characteristics for specialized applications. This approach is being explored for improving catalysts,

enhancing fuel cell efficiency, and even developing high-performance composite materials.

The size reduction process depends on several material properties, including hardness, toughness, moisture content, abrasiveness, and thermal sensitivity. Grinding and cutting are common methods for reducing the size of solid materials, while emulsification and atomization are used for liquids. There are various types of size-reduction machines designed for specific applications, and their efficiency is influenced by factors such as feed size, final particle size, energy consumption, and material handling properties. Ensuring an optimal grinding process requires a deep understanding of these factors to achieve desired particle size distribution while maintaining efficiency.

Despite advancements in grinding technology, the understanding of grinding phenomena remains challenging due to the complex interactions of particles, mechanical forces, and fluid movements within the system. In recent years, researchers have attempted to analyze grinding processes using numerical simulation techniques, which help model the motion of particles and the forces acting on them. However, one of the major challenges in numerical simulation is accurately predicting particle breakage mechanisms. Although many studies have focused on single-particle breakage, there is still a lack of comprehensive models that can simulate overall grinding behavior in an industrial setting.

To overcome these limitations, ongoing research is focused on developing novel simulation methods that can integrate both single-particle breakage and bulk grinding phenomena. Such advancements will enhance the efficiency, precision, and predictability of grinding processes across various industries, ensuring better control over particle size distribution and improving material processing. Understanding and optimizing these processes will have significant implications in fields ranging from pharmaceuticals and materials science to mining and manufacturing.

2 METHODOLOGY

This section outlines the procedures and methods used in the research, including the design, fabrication, and performance evaluation of the pulverizer. The methodology includes machine description, materials selection, design analysis, fabrication process, testing procedures, and data analysis.

2.1 RESEARCH DESIGN

The study follows an experimental research approach, involving the design, fabrication, and performance evaluation of a pulverizer. The research process consists of four key phases:

i. Conceptual Design and Analysis – Reviewing existing pulverizer designs, identifying limitations, and developing an improved design.
ii. Material Selection and Fabrication – Choosing appropriate materials based on strength, durability, and corrosion resistance, followed by the machine's fabrication.
iii. Performance Testing – Conducting tests to evaluate the efficiency, throughput, and operational reliability of the pulverizer.
iv. Data Collection and Analysis – Measuring key performance parameters, including particle size distribution, energy consumption, and throughput rate.

2.2 DESIGN AND FABRICATION PROCESS

The pulverizer was designed to operate based on the principle of impact and attrition. The hammer mill mechanism was selected for its high efficiency in pulverizing different dry materials. The design process included:

- Structural Design: CAD software (SolidWorks) was used to design and simulate the components to ensure structural integrity.
- Material Selection: Materials were chosen based on strength, durability, heat resistance, and corrosion resistance. The materials used for various components are listed in Table 3.1.
- Fabrication Steps:
  i. Cutting and shaping of stainless-steel sheets for the pulverization unit.
  ii. Welding and assembly of frame components using medium-carbon steel.
  iii. Installation of hammers, rotors, and bearings.
  iv. Mounting the electric motor, belt system, and fan assembly.
  v. Assembly of the cyclone system for dust control and improved efficiency.

2.3 PERFORMANCE EVALUATION

The fabricated pulverizer was tested for efficiency using the following parameters:

i. Rate (kg/hr): Measured by Throughput determining the weight of processed material over time.
ii. Particle Size Distribution: A sieve analysis was conducted to evaluate the uniformity of the output.
iii. Energy Consumption: The power input of the 3.69 kW electric motor was recorded during operation.

iv. Operational Efficiency: The effectiveness of the suction fan in preventing clogging and heat buildup was observed.

2.4 SAFETY AND MAINTAINABILITY CONSIDERATION

i. Safety measures such as protective enclosures for the cutting blades and insulated heating coils were incorporated to prevent hazards.
ii. The machine was designed for easy maintenance, with bolts and nuts facilitating the replacement of parts like the heating coil, motor, and rotor.

2.5 DATA COLLECTION AND ANALYSIS

i. Experimental data were recorded, tabulated, and analyzed statistically.
ii. Results were presented using graphs, tables, and charts to evaluate machine performance.

2.6 DESIGN ANALYSIS FOR SMALL HAMMER MILL

2.6.1 Determination of shank diameter of bolts connecting the Coupler to disc-1

This is given by

$$\sigma_b = \frac{F}{A} \quad (1)$$

Where σ_b is bearing stress
F is force acting on shank
A is bearing area on disc-1
But

$$A = dt \quad (2)$$

Where d is diameter of shank
t is the thicknes of disc-1, Therefore,

$$\sigma_b = \frac{F}{dt}$$

$$d = \frac{F}{\sigma_b t} \quad (3)$$

But $F = 125\ N, t = 2\ mm, \sigma_b = 20\ N/mm^2$, then

$$d = \frac{125}{20 \times 2}$$

$$\boldsymbol{d = 3.13\ mm}$$

Based on the above result, the M4 bolt size of root diameter of 3.16mm is selected

2.6.2 DETERMINATION OF TORQUE ON SHAFT

Torque on the motor shaft is given by the relation

$$T = 2Fr \quad (4)$$

Where F is force on each coupler bolt
r is coupler bolt distance form shaft center
but $F = 123\ N, r = 0.02\ m$, therefore,

$$T = 2 \times 123 \times 0.02$$

$$\boldsymbol{T = 4.92\ Nm}$$

2.6.3 POWER TO DRIVESHAFT

The power to drive shaft is determined from the given relation

$$P = T\omega \quad (5)$$

$$\omega = \frac{2\pi N}{60} \quad (6)$$

$$P = \frac{2\pi NT}{60} \quad (7)$$

Where N is speed of electric motor in rpm.
Having N as 1400 rpm, then

$$P = 2\pi \times 1440 \times 4.92/60$$

$$\boldsymbol{P = 742.0\ W}$$

Based on the above result, a 1HP (746 W) Electric motor is selected

2.6.4 DETERMINATION OF THICKNESS OF STRIKER

Let the force acting per unit length of hammer be q.

$$q = \frac{F_s}{l} \quad (8)$$

Taking the length of the striker to be 55 mm and resultant force on hammer as 61.83 N, then

$$q = \frac{61.83}{55}$$

$$q = 1.124\ N/mm$$

Considering the striker as a cantilever, the following expression holds

$$S = \frac{M_{max}}{\sigma_{all}}, \text{ Gere, J, 2006} \quad (9)$$

Where S is sectional modulus
M_{max} is maximum bending moment
σ_{all} is allowable stress

If b is the breadth of the striker and h is its thickness, then

$$S = \frac{bh^2}{6} \quad (10)$$

Equating 9 and 10 gives

$$\frac{M_{max}}{\sigma_{all}} = \frac{bh^2}{6} \quad (11)$$

But for a cantilever,

$$M_{max} = \frac{qL^2}{8} \quad (12)$$

$$\frac{qL^2}{\sigma_{all}} = \frac{4bh^2}{3}$$

$$h = \sqrt{\frac{3qL^2}{4b\sigma_{all}}} \quad (13)$$

When L = 55mm, b = 10 mm and $\sigma_{all} = 30\ Nmm^2$, then

$$h = \sqrt{\frac{3 \times 1.124 \times 55^2}{4 \times 10 \times 30}}$$

$$h = 2.9\ mm$$

2.6.5 SHANK DIAMETER OF BOLT CONNECTING THE STRIKER TO DISC-1 AND DISC-2

Recalling equation 3 where F is now centrifugal force, F_c

$$d = \frac{F_c}{\sigma_b t} \quad (14)$$

$$F_c = m\omega^2 r \quad (15)$$

$$d = \frac{m\omega^2 r}{\sigma_b t} \quad (16)$$

but

$$\omega = \frac{2\pi N}{60} \quad (17)$$

Where m is mass of striker
ω is angular velocity
r is distance from origin

Taking $m = 0.03\ kg,\ r = 0.06\ m, t = 0.002\ m, \sigma_b = 20\ MPa$

$$\omega = \frac{2 \times 3.142 \times 1440}{60}$$

$$\omega = 150.816\ rad/s$$

$$d = \frac{0.03 \times 150.816^2 \times 0.06}{20 \times 10^6 \times 0.02}$$

$$d = 0.002\ m$$

2.6.6 DETERMINATION OF CENTRIFUGAL FAN PARAMETERS

As the striker hammers on materials in the chamber it also functions as a centrifugal fan. Hence the need to analyze it as one of such.
Generally, the tangential velocity for centrifugal fan is:

$$u = \omega r$$

Therefore, tangential blade velocities at inlet and outlet respectively are given by:

$$u_1 = \omega r_1\ ;\ u_2 = \omega r_2 \quad (18)$$

Where r_1 = radius of inlet cylinder surface

r_2 = radius of outlet cylinder surface

ω =Angular Velocity

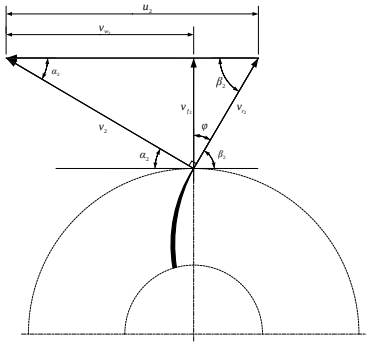


Figure 1: Free body diagram for the impeller blade

Applying continuity equation to the inlet and outlet for the mass flow rate$\dot{m}$ gives

$$\dot{m} = 2\pi r_1 \rho_1 b_1 v_{f1} = 2\pi r_2 \rho_2 b_2 v_{f2}$$ J. M. Gasiorek, 2000

Where:b_1 = Impeller width at inlet

b_2 = Impeller width at outlet

ρ_1= density of air at inlet

ρ_2= Density of air at outlet

v_{f1}= Velocity of flow at inlet

v_{f2}=Velocity of flow at outlet

For incompressible flow

$$m = r_1 b_1 v_{f1} = r_2 b_2 v_{f2} \quad 19$$

Assumptions;

1. For inlet, absolute velocity, V is radial. Therefore
$$V = v_{f1}, v_w = 0, \alpha_1 = 90^0$$
Where v_{w1} is velocity of whirl at inlet,
α_1 is angle that absolute inlet velocity make with tangent.
2. Blade angle at inlet,β is such that the blade meets the relative velocity tangentially.
3. Fluid leaves impeller with a relative velocity tangential to the blade at outlet.

Theoretical head is given by Euler's equation

$$H_{th} = \frac{u_2 v_{W2} - u_1 v_{W1}}{g} \quad 20$$

Where H_{th} istheoretical head

$V_{w1}$is Tangential component of absolute fluid velocity an inlet. Also, known as velocity of whirl. But vω1 = 0, Therefore,

$$H_{th} = \left(\frac{U_2 V_{\omega 2}}{g}\right) \quad 21$$

Volume of flow Q is given as

$$Q = v_{f2} A_2$$

$$A_2 = 2\pi r_2 b_2$$

$$Q = 2 v_{f2} \pi r_2 b_2 \quad 22$$

Where $A_2$is area of outlet cylinder surface

Torque on shaft is given as

$$T = \frac{Q \rho v_{\omega 2} r_2}{g} \quad 23$$

Where ρ is density of air and $g$is acceleration due to gravity

Therefore, power required to drive fan is given as

$$P = T\omega \quad 24$$

But from figure 1

$$\alpha_2 = 180 - 90 - \beta_2 \quad 25$$

$$\varphi = 180 - 90 - \beta_2 \quad 26$$

$$\frac{v_{r2}}{Sin\alpha_2} = \frac{u_2}{Sin90}; v_{r2} = \frac{u_2 Sin\alpha_2}{Sin90} \quad 27$$

$$\frac{v_{f2}}{Sin\beta_2} = \frac{v_{r2}}{Sin90}; v_{f2} = \frac{v_{r2} Sin\beta_2}{Sin90} \quad 28$$

$$\frac{v_{\omega 2}}{Sin(90-\varphi)} = \frac{v_{f2}}{Sin\alpha_2}; v_{\omega 2} = \frac{v_{f2} Sin(90-\varphi)}{Sin\alpha_2} \quad 29$$

Considering equations 17 to29 when

r1 = 0.03 m, r2 = 0.05 m, $b_1 = b_2 = 0.02\ m$, β_2 = 60,$\omega = 150.816\ rad/s$

$$u_1 = \omega r_1$$
$$= 150.816 \times 0.03$$
$$u_1 = 4.5245\ m/s$$
$$u_2 = \omega r_2$$
$$= 150.816 \times 0.05$$
$$u_2 = 7.5408\ m/s$$
$$\alpha_2 = 180 - 90 - \beta_2$$
$$= 180 - 90 - 60$$
$$\alpha_2 = 30°$$
$$\varphi = 30°$$
$$v_{r2} = \frac{u_2 Sin\alpha_2}{Sin90} = \frac{7.5408 \times Sin30}{Sin90}$$
$$v_{r2} = 3.7704\ m/s$$
$$v_{f2} = \frac{v_{r2} Sin\beta_2}{Sin90} = \frac{3.7704 \times Sin60}{Sin90}$$
$$v_{f2} = 3.2653\ m/s$$

$$v_{\omega 2} = \frac{v_{f2} Sin(90 - \varphi)}{Sin\alpha_2} = \frac{3.2653 \times Sin(90 - 30)}{Sin30}$$

$$v_{\omega 2} = 5.6556\, m/s$$

Considering equation 5, the theoretical head is given by

$$H_{th} = \frac{u_2 v_{W2}}{g}$$

$$\frac{7.5408 \times 5.6556}{9.81}$$

$$H_{th} = 4.3474\, m$$

The volume of flow is given by equation 22

$$Q = v_{f2} 2\pi r_2 b_2$$

$$= 2 \times 3.142 \times 0.05 \times 0.02$$

$$Q = 0.0205\, m^3/s$$

Using equations 23 and 24, the Torque and power respectively for blowing out air by the fan are given.

$$T = \frac{Q\rho v_{\omega 2} r_2}{g} = \frac{0.0205 \times 1.23 \times 5.6556 \times 0.05}{9.81}$$

$$T = 0.0007\, Nm$$

$$P = T\omega = 0.0007 \times 150.816$$

$$P = 0.1097\, W$$

3 RESULTS AND DISCUSSION

The designed hammer mill was successfully fabricated using locally sourced materials at a cost of 200,000 Naira. The cost of acquiring a hammer mill of equivalent capacity from foreign sources such as China and Europe range between 900,000 and 3,500,000 Naira. Significant design parameters as calculated are shown in Table 1. The fabricated hammer mill was tested by using it to pulverize various quantities of dried Maize, Guinea Corn and Millet. The performance evaluation of the machine is across maize, Guinea Corn and millet are shown in Table 2, 3, 4 below which was carried out based on three key operational output which include:

i. Particle size of pulverized material
ii. Mass of the material (kg)
iii. Duration of pulverization (min)

TABLE 1: RESULT OF CALCULATED PARAMETERS

Parameters	Symbol	Value	Unit
Centrifugal force exerted by the hammer	C.F	3473	N
Shaft Speed	N_2	2880	rpm
Diameter of main shaft	d	40	Mm
Length of Belt	L	1235	mm
Belt Contact Angle	B	3.48	°c
Angle of wrap between belt and pulley	A	199.2	°c
Tension in the slack side of belt	T2	194	N
Tension in the tight side of belt	T1	464	N
Power transmitted to the shaft	P	7460	W
Weight of hammer	W_{hammer}	1.25	N
Diameter of hammer shaft	D	15	mm
Weight of hammer shaft	Ws	0.243	N
Bending force of blade	Fb	101.7	N
Maximum bending moment of blade	Mb (max)	2034	Nm m
Total surface area of material of cyclone	Ats	1.2	M2
Volume of cyclone	Vc	0.064	M3

3.1 DATA REPRESENTATION OF HAMMER MILL CROPS

3.1.1 PULVERIZED MAIZE

TABLE 2. HAMMER MILL TEST RESULTS USING MAIZE

Trials	Mass of Maize before grinding (kg)	Mass of Maize after grinding (kg)	Time Taken (min)	Particle Size Remark
1	7	6.5	16	Fine (400µm-600400µm)
2	7	6.9	14	Fine (400µm-600400µm)
3	7	6.8	15	Fine (400µm-600400µm)
4	7	6.6	13	Fine (400µm-600400µm)
Average	7	6.7	14.5	Fine (400µm-600400µm)

The table above shows the results obtained from the operation carried out by the pulverizer. The results show that the hammer mill effectively grinds maize to a consistent particle size of 400µm to 600µm, with minimal variation in mass loss and grinding time across trials. The system demonstrates reliable and consistent performance, making it suitable for applications requiring fine grinding of maize. The slight variations in mass and time are within acceptable ranges, underscoring the mill's efficiency and effectiveness in processing maize.

3.1.2 PULVERIZED GUINEA CORN

TABLE 3: HAMMER MILL TEST RESULT USING GUINEA CORN

Trials	Mass of Guinea Corn before grinding (kg)	Mass of Guinea Corn after grinding (kg)	Time taken (min)	Particle Size Remark
1	5	4.8	15	Fine (400µm-600400µm)
2	5	4.7	14	Fine (400µm-600400µm)
3	5	4.9	16	Fine (400µm-600400µm)
4	5	4.5	15	Fine (400µm-600400µm)
Average	5	4.725	15	Fine (400µm-600400µm)

The hammer mill demonstrated consistent performance in grinding 5 kg of Guinea Corn per trial, with an average mass loss of 5.5% due to fine particle generation and dust. The grinding time ranged from 14 to 16 minutes, averaging 15 minutes, indicating stable operation. The particle size of the ground material remained within the 400µm to 600µm range, suitable for applications like animal feed production. Overall, the system exhibited reliability, efficiency, and uniform performance across all trials.

3.1.3 PULVERIZED MILLET

TABLE 4: HAMMER MILL TEST RESULT USING MILLET

Trials	Mass of Maize before grinding (kg)	Mass of maize after grinding (kg)	Time Taken(min)	Particle Size Remark
1	5	5.2	14	Fine (400µm-600400µm)
2	5	5.6	16	Fine (400µm-600400µm)
3	5	5.8	15	Fine (400µm-600400µm)
4	5	5.7	17	Fine (400µm-600400µm)
Average	5	5.575	15.5	Fine (400µm-600400µm)

The hammer mill trials for millet grinding showed consistent performance in particle size (400–600µm) and grinding time (14–17 minutes, averaging 15.5 minutes). However, an unusual increase in mass after grinding (5.2–5.8 kg from an initial 5 kg) suggests potential measurement errors or anomalies in the setup. Possible causes include moisture absorption, weighing scale calibration issues, or residual accumulation. While the grinding process was efficient, further investigation or repeated trials with careful measurement are recommended to verify the results.

3.1.4 AVERAGE PULVERIZED CROPS

S/N	Crops	Mass before grinding (kg)	Mass After grinding (kg)	Time Taken (min)	Particle Size Remark
1	Maize	7	6.7	14.5	Fine (400µm-600400µm)
2	Guinea Corn	5	4.725	15	Fine (400µm-600400µm)
3	Millet	5	5.575	15.5	Fine (400µm-600400µm)

The results indicate that all crops achieved a fine particle size between 400µm and 600µm, demonstrating the hammer mill's capability to produce a uniform grind across different materials. The milling time remained consistent, ranging from 14.5 to 15.5 minutes, suggesting similar efficiency for maize, guinea corn, and millet. Weight changes varied among the crops—while maize and guinea corn exhibited weight losses, millet showed a notable weight gain, pointing to potential differences in moisture content and physical properties post-milling. These variations highlight the need for further investigation into crop-specific milling conditions. Overall, the hammer mill effectively grinds diverse crops to fine particle sizes suitable for various applications, though factors such as moisture content and hardness influence milling outcomes.

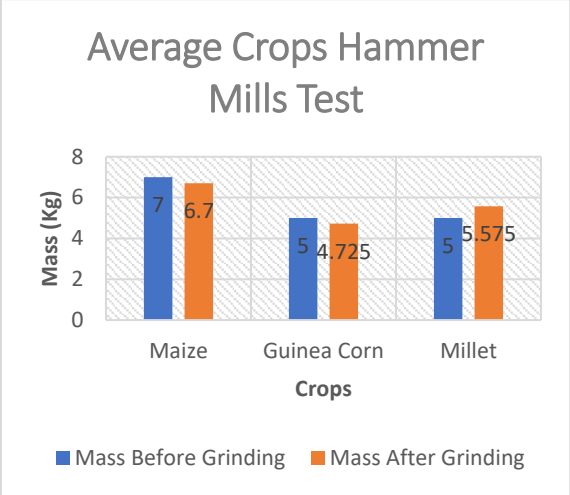


Figure 2: Graphical Representation of Hammer Mills Test Mass (Kg) against Crops.

3.2 SUMMARY OF DISCUSSION OF RSULT

The particle size distribution analysis of the hammer mill output confirms that the machine produces only fine particles for both tested grains. This affirms the effectiveness of the integrated mechanical separator, which ensures that only particles meeting the desired specifications are retained in the final output. Additionally, incorporating a feedback mechanism allows uncrushed and coarse materials to be recirculated into the crushing chamber for further fracturing. This feature enhances the machine's efficiency by ensuring the production of high-quality, fine-grained products suitable for processing solid minerals and agricultural materials.

Furthermore, the fabricated hammer mill is designed to be compact, making it suitable for production environments with limited workspace. The elimination of the sieve screen and separation chamber contributes to its reduced size, distinguishing it from previous models such as the hammer mill developed by Nasir (2005), which included a sieve screen, and the one designed by Ebunilo *et al*. (2010), which featured a separation chamber. These modifications not only optimize space utilization but also improve the overall performance and usability of the machine.

4 CONCLUSION

The study highlights the significant impact of moisture content on the grinding efficiency, throughput capacity, and particle size distribution of corncobs and corn. Higher moisture levels resulted in coarser particle sizes and improved throughput but also led to increased energy consumption. In contrast, lower moisture levels produced finer particles at the cost of reduced throughput. Additionally, the frictional heat generated during grinding caused moisture loss, which must be accounted for in mass balance calculations.

The grinding process using a hammer mill is inherently complex due to the random movement of materials within

the milling chamber. While sieve dimensions strongly influence particle size distribution, feeding flow plays a lesser role. Optimizing this process remains a challenge, necessitating further research to enhance efficiency, minimize energy consumption, and achieve consistent grinding performance.

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EVALUATION OF MEDICAL WASTE GENERATION AND COMPOSITION IN SOME FACILITIES IN LAFIA,

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ABSTRACT:
Adequate management of medical waste is a prerequisite for efficient delivery of healthcare services, human health and environmental protection; and the availability of adequate data with regard to medical waste generation and composition is generally considered to be fundamental in the development of efficient medical waste management. However, in Lafia, the state capital of Nasarawa State, Nigeria and a rapidly developing town, there is inadequate information on the medical waste generation and composition. This study thus sets to evaluate the medical waste composition and generation in Lafia by direct observation during both rainy and dry seasons. It is anticipated that the outcome of this research will avail resourceful data that will be needed for effective hospital waste management and other planning and design works. The study involved the survey of a cross section of four (4) tertiary health institution. The study showed that there is significant variation in healthcare waste management practices and sustainability factors (Reduce, Reuse and Recycle) (3Rs). The test showed that the prominent method of healthcare waste management at the studied institution was practice of incineration, pit burning and burying and frequency of waste disposal, leaving out other new and improved technologies for proper waste managements. The present system of medical waste management in lafiya is environmentally ineffective, in efficient and hazardous to health. No proper segregation has been practiced in the medical facilities. It was observed that all medical waste in the studied facilities is non-hazardous and may be treated as general waste.
Keywords: Environmental Hazard, Healthcare Waste Management practices, Physical planning and Sustainability.

I. Introduction

Medical care also termed healthcare is essential to life and wellbeing [1, 2, 3], however medical waste includes expired, unused, split and contaminated pharmaceutical products, drugs, vaccines and sera that need to be disposed appropriately. It also includes discarded items contaminated from use in the handling of pharmaceuticals, such as bottles or boxes with residues, masks, connecting tubes, syringe, bodies and drugvials and by-products that could threaten life and wellbeing [4, 5].Currently, there are several terms used to describe the waste generated from medical care activities such as; healthcare waste, hospital waste; medical waste, health facility waste, biomedical waste and clinical waste [6, 7, 8]. Some of the terms are sometimes used interchangeably and the choice of term is usually based on factors, such as geographic location, individual discretion, organization preference etc.; for instance, "healthcare waste (HCW)" is the preferred term by the world health organization (WHO).

This study uses the term "medical waste" given it is one of the widely used term in Nigeria, the location of this study, as noted in the following studies [9, 10, 11, 12, 13, 14, 15, 16]. Interestingly, the term medical waste has been variedly defined, indicative, articles like [10, 17, 18, 19, 20, 21, 22, 23]referred to the term medical waste as the total waste stream generated in the course of healthcare activities:; whereas studies like [27, 28, 29, 30] referred to the term as pathogenic or potentially pathogenic materials generated as a result of diagnosis, treatment or immunization of human beings or animals which is a subset of waste generated in the course of healthcare activities. In this study, the term

medical waste is used to represent the total waste stream generated in the course of healthcare activities.

According to [31] the various types of medical wastes generated from medical care activities are broadly grouped into general wastes/non-hazardous waste which constitutes about 75 % to 90 %; and hazardous wastes which constitutes about 10 % to 25 % (the percentage composition is a rough estimate which is subject to variation across hospitals and regions). Although only a small fraction of medical waste is hazardous (10 % to 25 %), mismanagement of medical waste poses significant environmental and health hazards that could even pose greater threat and hazards than the original diseases [11, 26, 32, 33]. Therefore, health policy makers and professionals have come to a consensus that efficient management of medical waste is an integral part of quality healthcare service delivery [34].

Various researchers have asserted that the availability of enough information about the amount and composition of the generated medical waste is fundamental for the implementation of sustainable and efficient medical waste management systems. Interestingly the generation rate and composition of medical waste varies among the type of healthcare facility and across geographic locations [41].Therefore, the generation rate and composition should be estimated separately, considering environmental and economic status [40].

This study therefore investigates the medical waste generation rate and composition in Lafia, Nasarawa State, Nigeria, a fast-developing town; given it is currently lacking this information requisite for efficient planning of medical waste systems and sustainable management.

I Aims

These study aimed to evaluate the medical waste generation and composition in Lafia, Nasarawa State, Nigeria across public and private hospitals, using a case study of four selected groups of hospitals and clinics responsible to different authorities.

In Nigeria, tertiary medical-care facilities also called teaching hospitals are usually affiliated to a university [16]. They are categorized based on the fact that they have modern equipment and a large number of specialists trained in handling a variety of health problems [12]. They are made up of large numbers of departments and wards. They normally carry out advanced surgery. Secondary medical-care facilities are large hospitals and clinics with capacity to handle simple to fairly complicated health problems [12].They do not practice routine teaching. Primary medical-care facilities are usually small in scope of service delivery [12]. Nurses (rather than doctors) are normally in charge of them [16]. They attend routinely to out-patients with simple ailments. Private medical-care facilities are owned by individuals to render essential healthcare services. If well-funded they may have some facilities similar to those of secondary or tertiary institutions [16].

II Statement of the research problem

In recent times, medical waste management is one of the trust areas drawing global attention given its environmental and health hazards. Several studies have reported some of its health and environmental risks; notable among such is the WHO report indicating that unsafe disposal of unsterilized syringes cause between 8 to 16 million cases of hepatitis B, 2.3 to 4.7 million cases of hepatitis C, and 80,000 to 160,000 cases of HIV annually; reports of [36] attributing the outbreak of severe acute respiratory syndrome (SARS) in 2003 to mismanagement of medical wastes; reports by [42] avowing medical waste as the fourth largest emitter of mercury to the environment; and [43] showing that mismanagement of hazardous medical waste can interrupt ecological balance.

Consequently, adequate management of medical waste has become an imperative environmental and public health issue; and the availability of adequate data regarding medical waste generation and composition is generally considered to be fundamental in the development of efficient medical waste management. However, in Lafia, the State capital of Nasarawa State, Nigeria and a rapidly developing town, there is inadequate information on the medical waste generation and composition. Therefore, these research aimed to fill the existing information by assessing the existing medical waste generation rate and composition in Lafia Nasarawa State.

III. The Study Area

Lafia is the capital of Nasarawa state, Nigeria, with a population of 317,985 as of 2006 [117]. It falls

within latitudes 9°11' N to 9°20' N and longitudes 12°23' E to 12°33' E, at an altitude of about 185.9 m[118]. The area is characterized by broadly flat topography with gentle undulations and hill ranges [118]. The major occupations of the people are farming, trading, and civil servants [117]. They also engage in local crafts such as blacksmithing, calabash decoration, cap making and clothes design [117]. A map of the study area is presented in Figure 3.1.

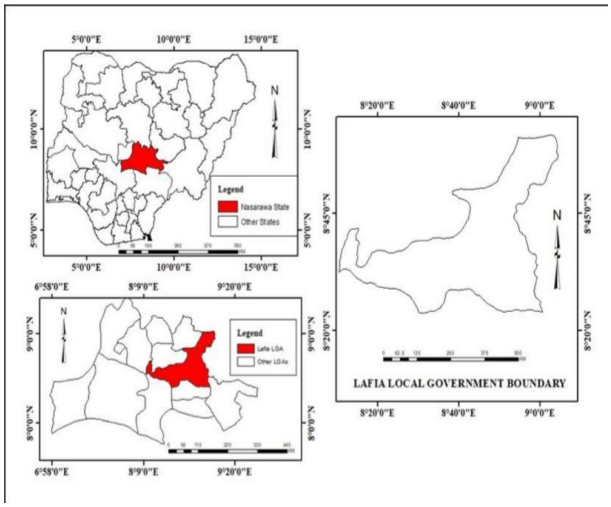


Figure 3. 1: Map of study area

IV Justification; -

Medical waste requires increased attention and diligence to avoid the extensive hazards associated with poor management practices. However, in many developing countries like Nigeria, medical waste management has received less attention and low priority.

On the premise that, adequate information and data on the prevailing medical waste generation and composition in an environment is requisite for planning and development of efficient and sustainable management schemes peculiar to the environment; it becomes imperative to access the current medical waste generation and composition in Lafia.

The outcome of these study will therefore provide useful information on the prevailing Healthcare Waste Management (HWM) practices in Lafia, Nasarawa State Capital, and its conformity to standard practice. The information generated from these study is envisaged to enable policy makers, program designers and health workers to improve healthcare waste management systems and hence improve infection prevention and control at healthcare facilities in Lafia.

V. Methodology

This chapter was designed to describe the procedures adopted in this research. The procedures involve the following: research design, population of the study, sample and sampling techniques, instrumentation, validation of the instrument, administration of the instrument and data analysis techniques. This research covered the study of Generation and Composition of Medical Waste In Lafia, This study was conducted in five (5) medical facilities under three selected groups responsible to different authorities in Lafia, Nasarawa state. Details are presented in Table 3.1.

The focus of the survey aspect of the research includes all residents residing within these areas. Primary data was collected through questionnaires using random sampling for the residential questionnaire. The field survey was inclusive of all areas within research scope. The research boundaries of the study include the system elements of the integrated solid waste management system. We also search for other relevant gray publications such as national and international agencies 'publications, international conferences, convention guidelines, policy briefs and project documents of agencies. We also included relevant documents identified from the reference list of the selected materials.

Table 3. 1: Details of selected medical facilities

Facility category	Name of selected facility
Tertiary facility	Dalhatu Araf specialist hospital
Primary healthcare centers	Comprehensive Primary Healthcare Centre, Kwandare. Primary Healthcare Centre, Lafia East.
Private hospitals	Agu hospital Kowa hospital

These facilities were classified based on their sizes, functions and type of services rendered.

A Sampling

Five (5) medical facilities in three categories namely, tertiary facility, primary healthcare centers and private hospitals are purposive sampling method. The choice of the proposed facilities is aimed at studying facilities that adequately represents the medical facilities in the town. The

names of the selected hospitals in the three categories are presented in Table 3.1.

Primary data were collected through questionnaires using random sampling for the health facilities questionnaire. The field survey was inclusive of all areas within research scope. The research boundaries of the study include the system elements of the integrated Medical Waste Management System.

The targeted area planned for this survey were the stockrooms (for equipment / medications and vaccines etc.), injection providers, supervisors of the staff responsible for administering injections, waste handlers, waste sorting, healthcare recipient (Patients who will receive injection in the study facilities.

B Data collection

Upon sampling, data collectors were trained and briefed on data collection procedures. The data collection was conducted in both the dry and wet season for a period of five consecutive days during weekly hours of operation by direct observation. Well-structured and designed color-coded waste containers were used to collect waste under standardized conditions. The Color Codes were; Black for General Wastes, Yellow for Infectious Wastes, red for pathological wastes and brown for pharmaceutical healthcare wastes. Also, collection was ordered in such a way to take cognizance of the individual generation points in the hospital.

Quantity of waste were estimated by weighing medical waste from all departments of the study hospitals using a calibrated sensitive weight scale.

Reports from WHO [59] revealed that high-income countries generate on average up to 0.5 Kg/bed/day of hazardous waste; whereas low-income countries generate on average 0.2 Kg/bed/day; whereas [37] reported that total generation rate of medical waste from developed countries indicated a range from 1-5 Kg/bed/day, with substantial inter country and inter specialty differences while rural hospitals of Africa were estimated to be between 0.3-1.5 Kg/bed/day (5-20% Hazardous waste).

C Research Design

This study adopts survey research design to study the Generation and composition of Medical waste management in Lafia. According to Nworgu (2006), survey research design insurance that a group of people or items is studied by collecting analyzed data from only a few people or items considered to be representative of the entire group. Questionnaire were used to determine the opinions, preferences, attitudes and perceptions of people about issues that concern them. As in this study this parameter were used.

D Sampling and Sampling Size

In sampling, quantitative sampling techniques is adopted under which a simple random techniques were considered suitable for the study. The Yaro Yamane formula below were used to determine the sample size at 0.05 confidence level (level of significance).

The sample size was obtained using formula below:

$$n = \frac{N}{1 + N(e)^2}$$

Where:

n = expected questionnaire
N = Target population
1 = constant
e = level of significance.

Now, having; n =? 1 = constant, N = 150, and e = 0.05

We have:

$$N = \frac{150}{1 + 150(0.05)^2},$$

Therefore, n = 109.09

Approximately 109 questionnaires are admitted to the 5 health facilities at random order. In other to have equal distribution the researcher used the calculation to get the expected questionnaire per facility. In order to avoid insufficiency in quantity or questionnaire 16 more questionnaires were added to the calculated 109 questionnaires making it a total of 125 questionnaire distributed.

Expected number of questionnaire = $\frac{\text{calculated number of questionnaire}}{\text{Number of areas}}$

Expected number of questionnaire= $\frac{125}{5} = 25$

Having the above result, the expected number of questionnaires distributed is 25 each questionnaire to five facilities.

E. Results and Discussion

The data are presented in tables and the analysis is done using t-Test. The PC method was used in the validation of the hypothesis, where in it's based on the aims and objective of the project. The data imputed from 74 respondents who submitted the

question after careful response to the question, the respondents per variable which is the questions are noted by frequency or percentage over 100%. Out of 100 questionnaires given out, 8 is confirmed invalid, among which 12 was not returned and 6 was not properly filled. Hence 74 is used for the analysis, interpretations, and conclusion. Note that the actual intended number of questionnaires to be distributed was 125, a total of 100 was finally used for the study, giving a percentage validity of 80% which is above significant level for the research work.

The study showed little or no evidence of training and re-training of the waste handlers, it also revealed that most facilities agreed that waste are coded using different colors but dump in the same location. The level of waste minimization at tertiary health facilities in Lafia is extremely poor and does not exist. Even though the HCFs adopt minimal recycling, reuse, or reduction, this is not done on a regular basis.

It was observed that all medical waste in the studied facilities is non-hazardous and may be treated as general waste. Due to lack of proper segregation, this large portion of non-hazardous waste is unnecessarily polluted by hazardous waste besides, there is no separate collection bin for medical waste and all kinds of waste from medicals including clinical and sharp waste; is dumped in the municipal waste collection bins. None of the sampled facilities studied has architectural design provision for holding of medical waste neither does any have a single electrical/ medical incinerator.

Poorly managed healthcare waste adversely affect public health and environmental quality in specific areas of patient's health, safety of the healthcare workers and injury to illegal scavenger/ waste collectors.

F. Findings

i. The findings in respect of the hypothesis revealed that the level of awareness of waste generation and composition is neither low nor high,
ii. Due to lack of proper segregation, this large portion of non-hazardous waste is unnecessarily polluted by hazardous waste besides, there is no separate collection bin for medical waste and all kinds of waste from medicals including clinical and sharp waste; is dumped in the municipal waste collection bins.
iii. Another finding from this research is that, they don't allow their waste to accumulate within their facility for over 24 hours before evacuation
iv. Many researchers have established that; adequate understanding of waste composition is very important in the provision of efficient management
v. Remarkably, substantial efforts have been devoted to research on medical waste in the country. The synopsis of these studies is an indication of poor practices and non/partial compliance with the standardized globally acceptable MWM practices in different parts of Nigeria. At present, research on MWM in varying forms is still ongoing in different parts of the country, however at the time of this research no study has been conducted to evaluate the medical waste generation and composition of Lafia, a fast developing town.

CONCLUSION

The survey result reveal that while several medical personnel in Lafia health facilities locally understand the need to have a clean environment as well as the challenges that might occur if the opposite were the case, the storage, collection and final disposal of waste is overwhelming the authorities of Nassarawa State.

Steady increase in waste variety and quantity coupled with highly in efficient and in effective solid waste management system in Lafia evidenced by waste dumps in drains and public spaces has established the need for improvement.

Despite environmental agencies, the deterioration of the urban environments remains a challenge to the communities especially the Local Government that are constitutionally responsible for managing the waste. the system is based on temporary storage within health facilities / household and /or communal dump site' collection and transportation to final disposal site for open burning and open dumping.

Majority of this medical facilities have a walled built incinerator. After this waste are being burnt, they are later taken to the facility backyard for burial. The medical infectious and biomedical waste

are separated from non-infectious ones before burning.

friendly than incineration. They include low heat thermal processes and mechanical processes.

Lack of Funding and advanced technology, facility for separation at source, strength of solid waste management policy and lack of effective composition of medical care wastes generated in medical facilities in Lafia are the factors responsible for waste generation.

RECOMMENDATION

The following recommendation are hereby made:

There is need for the public / private hospital to have a Waste Management Department saddled with the responsibility of strict monitoring of the amount and type/ nature of medical waste resulting from daily operations. This is to adequately plan for the waste management either by on-site disposal facility or establishing collaboration with private hospital for the purpose of disposal

Waste sorting at source coupled with pre-treatment before disposal should be enforced by the management of public hospitals so as to prevent health risks to the waste handlers and the public at large.

There is need to embark on the use of newer method for medical waste treatment before final disposal which are safer and environmentally friendly.

A medical waste management policy should be formulated separately from a hospital waste management policy. This can be done by a multidisciplinary team including Environmental Health experts and waste management experts.

All staff and personnel handling medical waste in each hospital should be trained and re-trained on methods and new techniques of medical waste management.

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Investigation of Influence of Geotechnical and Environmental Factors on Road Pavement Failure in North-Central Nigeria: A Review

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ABSTRACT
Pavement failure is a critical issue affecting road infrastructure in Nigeria, particularly in the North-Central region of the country. This review explores the impact of geotechnical and environmental factors on pavement deterioration, emphasizing the challenges posed by poor design, substandard materials, environmental stresses, and inadequate maintenance practices. By integrating insights from existing studies, this paper highlights the need for a comprehensive pavement deterioration model, tailored to the unique conditions of North-Central Nigeria. It also underscores the importance of institutional reforms, advanced analytical techniques, and sustainable maintenance strategies to enhance road performance and longevity in this part of the country.

Keywords: *Climate; Environmental factors; Geotechnical factor; Pavement deterioration; Traffic*

1.0 INTRODUCTION

Road infrastructure is essential for facilitating economic growth and connectivity, yet Nigerian roads face significant challenges due to rapid deterioration. Pavement structures are composed of superimposed layers, designed to work cohesively; however, in Nigeria, defects such as potholes, rutting, corrugation, raveling, flushing, and cracking are prevalent. Contributing factors include poor construction practices, heavy traffic loads, and inadequate maintenance regimes (Okigbo, 2012; Osuolale *et al*., 2012 Mubaraki, 2015; Owoseni, 2019; Abed, 2020). These issues necessitate a systematic approach to road maintenance and the development of predictive models for pavement performance.

Pavement management systems have emerged as a valuable tool for optimizing maintenance and rehabilitation strategies. Accurate prediction of pavement condition and the timing of interventions is crucial for effective resource allocation and informed decision-making. Several studies have explored the development of regression models and machine learning techniques for predicting pavement condition indices and structural capacity (Karballaeezadeh *et al*., 2020; Abed, 2020).

2.0 REVIEWED LITERATURE

Roads remain the most widely used mode of transportation globally due to their convenience in providing door-to-door service and efficiency in short-distance travel. (Alo and Oni, 2018). The ability of road transport to provide access to remote and urban areas alike, makes it indispensable for economic activities, trade, and social interactions. In Nigeria, road transport is the predominant means of mobility, due to the high costs and underdevelopment of alternative transport systems, such as rail and water transport (FMW,1997). However, the increasing number of heavy vehicles and their axle loads contribute significantly to pavement deterioration, thereby escalating maintenance challenges and cost (FMW,1997). Road construction is a capital-intensive investment that requires meticulous planning, design, and execution to ensure long-term functionality. The durability of a pavement depends largely on the quality and integrity of its design, construction standards, and maintenance practices (Alhasan and Mustapha, 2020). Poorly designed pavements are susceptible to early failure, which manifests through various distress indicators, including cracks, potholes, and depressions that compromise ride quality and road safety (Onuoha and Onwuka, 2014). Pavement distress indicators, such as cracks, patches, and rutting, serve as essential markers for evaluating maintenance needs and predicting pavement life cycles (Luo and Prozzi, 2005). The integrity of a pavement depends on its ability to withstand repeated traffic loads, while maintaining essential properties such as skid resistance, surface smoothness and durability ((Khanna and Justo,1997). Inadequate design, overloading, poor construction materials, and environmental factors often lead to defects such as corrugations, rutting, and alligator cracking, which significantly compromise pavement integrity (Hassan, 2006). Pavements are categorized into two main types: flexible and rigid. Flexible pavements distribute loads through aggregate interlock and particle-to-particle contact within the aggregate layers, allowing stress dissipation with depth (Khanna and Justo, 1997). Effective pavement design is crucial to ensuring road longevity and optimal functionality. It involves strategic load distribution, stress management, and material

selection, all of which contribute to a durable and sustainable road network (Okigbo, 2012; Gupta, 2004).

2.1 Pavement Deterioration and Structure

Pavement deterioration results from various distresses, including fatigue cracking caused by repeated loading, weathering effects, moisture infiltration, and material disintegration. These factors significantly impact ride quality, road safety, and overall pavement performance (Gary, Smith, & Johnson, 2009) Pavement failures often result from inadequate design specifications, excessive traffic loads beyond design capacity, use of substandard materials, and exposure to extreme environmental conditions. These failures manifest as surface defects, including waves, corrugations, depressions, and rutting, all of which undermine structural integrity and user comfort (Hassan, 2006). Timely intervention through routine maintenance and rehabilitation is necessary to restore pavement serviceability and prevent extensive deterioration.

2.1.1 Pavement Deterioration in Nigeria

Nigerian roads often fail prematurely, with many deteriorating immediately after construction due to environmental stresses, poor drainage, and insufficient oversight. The North-Central region's climatic conditions, characterized by high rainfall (1077-1787 mm annually) and temperatures ranging from 16 to 35°C, exacerbate these challenges. Combined with heavy traffic, particularly on major routes like Ilorin-Jebba and Mokwa-Bida, these factors significantly contribute to pavement failures (Highway Manual, 2013).

2.2 Geotechnical and Environmental Factors

2.2.1 Geotechnical Factors

Geotechnical properties including soil strength, compaction characteristics, and subgrade stability, play fundamental role in pavement performance. Weak subgrades, characterized by low California Bearing Ratio (CBR) values and high natural moisture content, contribute to pavement instability and accelerated deterioration (Emmanuel *et al*., 2021). Table 1 presents recommended ranges of geotechnical properties for some components of road pavement.

Furthermore, existing pavement deterioration models used in Nigeria are often adapted from standardized global models that do not adequately reflect the region's unique geotechnical and environmental conditions. These models fail to incorporate key variables such as soil properties, temperature variations, and localized traffic loading patterns, resulting in unreliable predictions of pavement lifespan and maintenance needs (Carvalho *et* al., 2019). The absence of an integrated analytical approach that accounts for these localized conditions has hindered effective road maintenance planning and decision-making.

Pavement condition assessment is crucial for determining appropriate maintenance strategies and ensuring the longevity of road infrastructure (Melyar *et al.*, 2021). In North-Central Nigeria, understanding the specific geotechnical and environmental factors that lead to pavement failure can inform the development of more effective rehabilitation and maintenance programs. Previous studies have emphasized the need to consider both technical and economic factors when evaluating pavement performance, as well as the necessity for standardized performance criteria and deterioration models (Li *et al*., 2013). Various pavement evaluation methods, including the Surface Distress Index (SDI) and Pavement Condition Index (PCI), provide useful insights into road conditions and can guide policy decisions for infrastructure maintenance (Abed, 2020; Melyar *et al*., 2021).

Table 1: Material Properties for Subgrade and Sub base.

Property	Subgrade	Sub base
% passing sieve, No 200 (75µm) (%)	≥35	≥35
Liquid Limit (%)	≤50	≤35
Plastic Index (%)	≤30	≤12
OMC (%)	-7	6-7
MDD (Mg/m^3)	≥1.8	≥1.6
Soaked CBR (%)	≥15	≥30
Unsoaked CBR (%)	≥15	≥80

Source; FMW (2011)

2.2.2 Environmental Factor

Environmental factors such as rainfall intensity, temperature fluctuations, and inadequate drainage systems exacerbate pavement degradation. The North-Central region of Nigeria, which experiences significant variations in climatic conditions, is particularly vulnerable to these influences. Heavy rainfall leads to water infiltration into pavement layers, compromising the structural integrity of the road, while high temperatures contribute to material fatigue and cracking (Olowosulu *et al*., 2020).

Umar *et al*. (2020) stated that environmental conditions, particularly poor drainage and water infiltration, exacerbate pavement deterioration and highlighted that inadequate drainage systems lead to water accumulation, which weakens the subgrade and base layers, resulting in pavement failures. Their study emphasized the importance of proper drainage design and maintenance to mitigate water-related damages. Studies by Akudo *et al*. (2023) have also revealed that seasonal variations, such as heavy rainfall during the wet season, contribute to the weakening of pavement structures. The infiltration of water into pavement layers causes a reduction in shear strength and an increase in pore water pressure, leading to structural failures.

2.3 Pavement Deterioration Models

Predictive models for pavement deterioration are critical for effective maintenance planning. Existing models in Nigeria, are limited in scope, often failing to incorporate critical factors like geotechnical characteristics and environmental influences. This review emphasizes the need for a comprehensive model integrating parameters such as California Bearing Ratio (CBR), natural moisture content, rainfall intensity, and temperature trends. Advanced analytical techniques and mechanistic-empirical approaches offer promising avenues for improving prediction accuracy (Highway Manual, 2013).

2.3.1 Justification for a Comprehensive Model

The unique geotechnical and environmental conditions of North-Central Nigeria demand a tailored pavement deterioration model. Subgrade strength, material properties, and climatic factors significantly influence road performance but are often overlooked in existing models. By addressing these gaps, a comprehensive model can enhance decision-making in road maintenance, reduce costs, and improve infrastructure sustainability.

2.3 Conclusion.

The study identifies weak subgrade soils, poor construction practices, excessive axle loads, and adverse climatic conditions as key causes of pavement failure in North-Central Nigeria. It highlights the inadequacy of existing global pavement deterioration models, which do not account for regional-specific factors like soil properties, climate variations, and traffic patterns. The paper emphasizes the need for a customized model, while reinforcing the importance of geotechnical and environmental factors in pavement performance, it calls for further research on field data, mitigation strategies, and assessment methodologies. A regionally adapted deterioration model is essential for improving road maintenance, reducing costs, and enhancing infrastructure sustainability.

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Utilization of Bamboo as Reinforcement in Mitigation of In-situ Lateral Earth Pressure in Tropical Residual Soils: Review

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ABSTRACT

The misapplication of concepts developed for transported soils in evaluating in-situ lateral earth pressure in tropical residual soils, coupled with limited data and inaccuracies in traditional measurement techniques, has impeded accurate assessments. These challenges have contributed to failures associated with landslides and slope instability resulting from lateral earth pressure. Bamboo, known for its favorable mechanical properties and sustainability, has gained attention as a cost-effective reinforcement material in geotechnical applications. This review identifies key research gaps in lateral earth pressure evaluation and proposes future directions for optimizing bamboo reinforcement as an innovative technique to mitigate in-situ lateral earth pressure in this understudied soils.

Keywords: *Lateral Erath pressure; Residual soils; Bamboo; Soil reinforcement; In-situ; Residual soils; Transported soils; Pull out capacity*

1 INTRODUCTION

Soil reinforcement is a widely used ground improvement technique that enhances soil stability by incorporating tensile-resistant materials such as metal strips, geosynthetics, and natural fibers (Jaiswal and Chauhan, 2021). Among these materials, bamboo has emerged as a sustainable alternative due to its high strength-to-weight ratio, durability, and environmental benefits.

Research indicates that bamboo reinforcement enhances soil shear strength through frictional interaction, effectively reducing lateral earth pressures (Ahirwar and Mandal, 2018; Samal *et al*., 2023). While synthetic reinforcements are commonly used to counteract lateral earth pressure, their high cost and environmental impact have driven interest in natural alternatives such as bamboo (Fay *et al*., 2012; Pinto, 2003).

Studies on transported soils of temperate regions is extensive, yet a significant knowledge gap persists regarding soils of the tropic. This gap often leads to misapplication of soil mechanics principles, complicating the understanding of their geotechnical behavior (Pitts and Kannan, 1986). In countries like Nigeria, residual soils are prevalent and are formed through intense weathering, resulting in complex heterogeneities that influence their engineering properties (Huat *et al*., 2004; Wesley, 2013).

Geotechnical principles developed for transported soils are seldom been misapplied to these understudied tropical residual soils (Wesley, 2013). Additionally, inaccuracies in traditional measurement methods (Sabouni and Naggar, 2016) and discrepancies between predicted and measured field lateral earth pressure values highlight the need for improved in-situ measurement techniques when dealing with these soils (Alam *et al*., 2021; Hu *et al*., 2022).

To mitigate the risk associated with soil instability resulting from lateral earth pressure, and given bamboo's potential as a reinforcement material (Bang *et al*., 2015), further studies are necessary to evaluate field lateral earth pressure and the utilization of bamboo as reinforcement, across different soils, environments, and excavation conditions to mitigate in-situ lateral earth pressure in the tropical region of the world.

The integration of bamboo as reinforcement in geotechnical applications aligns with sustainable development goals by offering a cost-effective, environmentally friendly solution to mitigate lateral earth pressure in tropical residual soils (Mustapha and Alhassan, 2017; Rochim *et al*., 2020). This study explores bamboo's potential as a reinforcement material, and consequently addressing research gaps in lateral earth pressure measurement, contributing to advancing an innovative reinforcement technique using locally available fibre.

2 LITERATURE REVIEW

2.1 GEOTECHNICAL CHARACTERISTICS AND ENGINEERING BEHAVIOR OF TROPICAL RESIDUAL SOILS

Tropical residual soils form in-situ through prolonged chemical weathering of parent rock under high temperatures and heavy rainfall (Wesley, 2010). Their formation occurs through physical, chemical, and biological mechanisms. In tropical climates, intense weathering produces deep soil profiles with significant mineralogical changes (Gupta, 2011). Biological processes, including root activity and acid production,

further contribute to soil formation (Banfield *et al.*, 1999).

Geotechnically, tropical residual soils exhibit variable permeability, compressibility, and shear strength, largely controlled by mineral composition, moisture content, and compaction (Gidigasu, 1976). The upper lateritic hardpan layers offer high shear strength, whereas deeper layers are more compressible. Water content significantly affects soil stability—saturation reduces shear strength and increases landslide risks, while drying induces shrinkage and cracking (Zhang *et al*., 2017).

Their physical properties, including grain size distribution, bulk density (1.4–1.8 g/cm³), and specific gravity (2.6–2.8), vary with weathering, while moisture content ranges from 16 to 49% (Nixon *et al*., 1957; Blight, 1997; Huat, 2004).

Studies on decomposed granite soils in Kaduna and residual soils from Nigeria's basement complex regions highlight significant variations in geotechnical behavior with depth, these soils exhibit moderate shear strength, low plasticity, and moderate permeability (Sueoke *et al*., 1984), whereas residual soils in Ore and Abuja demonstrate different strength characteristics affecting their construction suitability (Idehai *et al*., 2014). Similarly, southwestern Nigerian residual soils, shaped by alternating wet and dry seasons, display high moisture content, variable plasticity, and specific gravity values between 2.64 and 2.77.

However, further research is needed to assess their long-term performance under varying environmental conditions. The profile and the categories of material type are shown in Figure 1 and the details are presented in Table 1

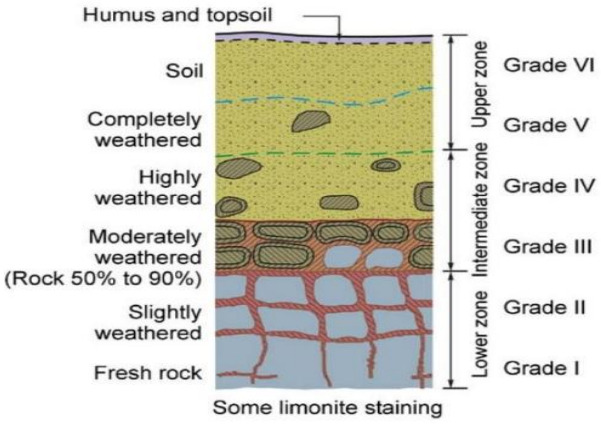


Figure 1: Schematic diagram of typical residual soil profile (Little, 1969).

Anon (1977) proposed a generalized description for a scale to categorize the weathering grades of rock masses, as outlined in Table 1.

Table 1: Weathering Grades of Rock Mass (Anon, 1977)

Term	Description	Grade
Fresh	No visible sign of rock material weathering.	IA
Faintly Weathered	Discoloration on major discontinuity surfaces.	IB
Slightly Weathered	Discoloration indicates weathering of rock material and discontinuity surfaces. All the rock material may be discolored by weathering.	II
Moderately Weathered	Less than half of the rock material is decomposed or disintegrated to a soil. Fresh or discolored rock is present either as a continuous framework or as core stones.	III
Highly Weathered	More than half of the rock material is decomposed or disintegrated to a soil. Fresh or discolored rock is presented either as a discontinuous framework or as core stones.	IV
Completely Weathered	All rock material is decomposed and or disintegrated to soil. The original mass structure is still largely intact.	V
Residual Soil	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported.	VI

2.2 THEORIES, COEFFICIENTS, AND FUNDAMENTALS OF LATERAL EARTH PRESSURE:

Lateral earth pressure is a fundamental aspect of geotechnical engineering, representing the horizontal force exerted by soil on retaining structures like walls, basements, and foundations. (Das, 2010). Since late 17th century, numerous theories on earth pressure have been proposed by various researchers. Among these; Rankine's theory (which assumes no wall friction) and Coulomb's theory (which incorporates wall friction) are the most widely utilized for calculating active and passive earth pressures. These are collectively referred to as the classical lateral earth pressure theories. Both theories require that the soil mass, or at least a portion of it, be in a state of plastic equilibrium, meaning it is on the verge of failure. In this context, failure is defined as a stress condition that satisfies the Mohr-Coulomb failure criterion.

Lateral earth pressure is classified into three types—*active*, *passive*, *and at-res*t (Figure 2), where each is associated with varying soil movement and structural constraints. These classifications underpin the analysis and design of retaining systems, ensuring their resilience against soil forces.

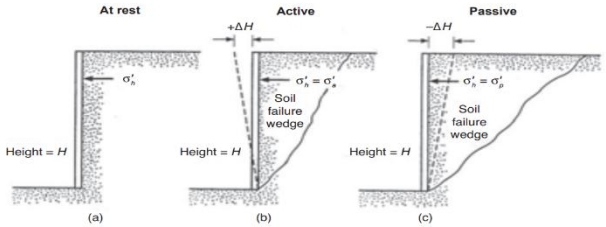


Figure 2: Nature of lateral earth pressure on retaining wall (Das, 2010)

The coefficient of lateral earth pressure (K) represents the ratio of horizontal to vertical stress in soils and is essential in geotechnical engineering. Its value depends on factors such as soil type, density, moisture content, and stress history. The three main states of lateral earth pressure are at-rest (Ko), active (Ka), and passive (Kp), depending on direction of movement of the wall (Figure 3), and with each influenced by different loading conditions.

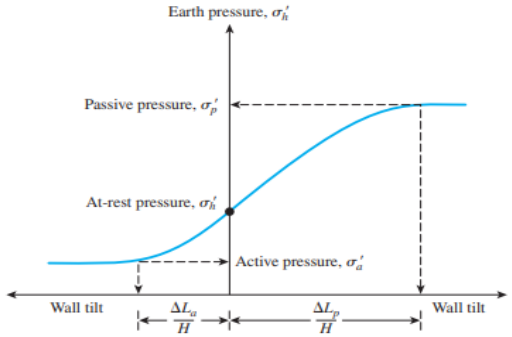


Figure 3: Variation of the magnitude of lateral earth pressure with wall tilt

The following section outlines the equations for different types of lateral earth pressures based on this theory.

The at rest pressure at a depth z is then:

$$po = \text{Ko}\gamma z \quad (1)$$

The total at rest earth pressure (thrust) acting on a wall of height H is:

$$Po = \frac{1}{2}\text{Ko}\gamma H^2 \quad (2)$$

The active earth pressure at a depth z is then:

$$Pa = \text{Ka}\gamma z - 2c\sqrt{ka} \quad (3)$$

$$\text{Ka} = \frac{1-sin\phi}{1+sin\phi} \text{ or } tan^2(45 - \phi/2) \quad (4)$$

is the active earth pressure coefficient.

For Passive Pressure:

$$\sigma p = kp\sigma v + 2c\sqrt{kp} \quad (5)$$

The active earth pressure at a depth z is then:

$$Pp = \text{Kp}\gamma z + 2c\,kp \quad (6)$$

$$\text{Kp} = \frac{1+sin\phi}{1-sin\phi} \text{ or } tan^2(45 + \phi/2) \quad (7)$$

is the active earth pressure coefficient.

The total active earth pressure (thrust) acting on a wall of height H is:

$$Pp = \frac{1}{2}\text{Kp}\gamma H^2 + 2c\,kp\text{H} \quad (8)$$

2.3 In-Situ and Laboratory Techniques for Measuring Lateral Earth Pressure: Implications for Tropical Residual Soil

The primary measurement techniques for the evaluation of lateral earth pressure are categorized into in-situ and laboratory testing methods**,** each providing distinct advantages, depending on soil properties and site conditions (Terzaghi *et al*., 1996).

2.3.1 IN-SITU TESTING METHODS

In-situ methods allow for direct or inferred measurement of lateral earth pressure under real field conditions. One common technique is the use of earth pressure cells**,** which are flat, disc-shaped sensors embedded in soil or structures to measure and transmit pressure data. Strain gauge-based sensors detect deformations in soil or structural elements, providing an estimate of lateral pressure. Optical fiber sensors, such as those utilizing fiber Bragg gratings, offer high-resolution spatial measurements for monitoring geotechnical structures.

2.3.2 LABORATORY TESTING METHODS

Laboratory tests provide controlled conditions to simulate soil behavior and determine lateral earth pressure. The direct shear test evaluates soil shear strength by applying horizontal force to a sample under normal load, helping to estimate lateral resistance. The triaxial compression test assesses soil response under different stress conditions, yielding critical parameters such as cohesion and friction angle.

By selecting appropriate testing methods based on soil conditions and project requirements, engineers can obtain accurate lateral pressure data for designing safe and efficient geotechnical structures. The combination of in-situ and laboratory techniques enhances the understanding of lateral earth pressure distribution and its implications for geotechnical engineering.

While significant progress has been made in studying lateral earth pressure in various soil types, research on tropical residual soils remains limited. Alam *et al.* (2021) examined soil pressure on a temporary trench shoring system in sensitive clay soils, emphasizing discrepancies between measured pressures and theoretical predictions, particularly under surcharge conditions. Their findings suggested that existing analytical models, such as those by Terzaghi and Peck, may underestimate actual pressures, necessitating revisions for improved accuracy. Similarly, Hu *et al.* (2022) investigated lateral earth pressure in finite soils using optical fiber measurements, revealing that Rankine's active earth pressure model overestimates pressure and inaccurately predicts soil failure.

Their study provided an improved theoretical framework for finite soil conditions, enhancing geotechnical design precision.

Massarsch (1975) introduced an innovative pressure cell technique for measuring lateral earth pressure in cohesive soils, demonstrating that measured values were significantly higher than elasticity theory predictions. The study emphasized the influence of pore pressure changes on lateral stress distribution, reinforcing the importance of accurate measurement techniques in soil pressure analysis.

Alkhafaji *et al.* (2022) developed a modified oedometer test for clayey soils, enhancing accuracy in assessing lateral pressure under varying loads. Their findings support the need for improved laboratory

techniques to capture the complexities of soil behavior. In the context of tropical residual soils, studies have highlighted the impact of anisotropic soil structures, seasonal moisture variations, and cementation on lateral earth pressure (Wesley, 2010; Blight, 2013; Ali *et al*., 2019).

Generally, while studies have provided critical insights into lateral earth pressure behavior, significant gaps remain, particularly concerning tropical residual soils. There is the need for long-term monitoring and integration of field data with numerical models to enhance predictive accuracy. Addressing these gaps will improve geotechnical design reliability, particularly in regions like Nigeria, where research on in-situ lateral earth pressure variation remains scarce.

2.4 BAMBOO FOR SOIL REINFORCEMENT

Bamboo has emerged as a promising sustainable reinforcement material due to its advantageous physical, mechanical, and durability properties. Rolt (2008) reported that bamboo exhibits tensile strengths ranging from 75–350 MPa, with a typical modulus of elasticity of approximately 18,000 MPa.

Further studies by Nindyawati and Baiq (2016) examined bamboo's role in lightweight concrete, revealing tensile strengths between 133.5–144.2 MPa and pull-out strengths of 0.33–0.48 MPa. Mustapha (2008) demonstrated that embedding circular bamboo specimens in soil increased the applied stress from 226 kN/m² (unreinforced) to 621 kN/m² when three layers of bamboo were used. Similarly, Marto and Uthman (2011) analyzed embankments on soft clay, showing that a Bamboo-Geotextile Composite (BGC) outperformed High Strength Geotextile (HSG) and unreinforced embankments. Their study indicated that the BGC significantly reduced settlement (588 mm compared to 744 mm for the unreinforced case) and minimized lateral movement at depth.

Further research by Aazokhi (2014) on peat soils found that reinforcing with bamboo increased the bearing capacity by 140% with one layer, 224% with two layers, and 279% with three layers. Mustapha and Alhassan (2017) tested Nigerian bamboo in kaolinite clay and observed that using two layers of bamboo reinforcement increased the ultimate bearing capacity from 435 kN/m² to 600 kN/m². These findings highlight bamboo's potential as an eco-friendly and cost-effective reinforcement material for geotechnical applications. Long-term field studies on bamboo's behavior under varying environmental conditions are limited, underscoring the need for further research to optimize its application in geotechnical engineering.

2.5 STUDIES ON THE PULLOUT CAPACITY OF FIBERS

Bamboo reinforcement has emerged as a sustainable approach to improving soil stability and mitigating lateral earth pressure due to its high tensile strength and rough surface texture (Zhang *et al*., 2021). Research has demonstrated that bamboo grids enhance bearing capacity and shear strength by increasing soil cohesion and frictional resistance (Hegde and Sitharam, 2018). Therefore, optimizing design parameters is essential to maximize the benefits of bamboo reinforcement in soil stabilization.

Tardío *et al.* (2018) examined the effectiveness of bamboo-based crib walls in soil bioengineering for erosion control and slope stabilization in Nepal. The research assessed various bamboo species for their mechanical properties, root reinforcement potential, and adaptability to different environmental conditions. Case studies and experimental applications were reviewed to evaluate bamboo's role in slope stabilization. Findings demonstrated that bamboo-based bioengineering techniques significantly enhance slope stability and erosion control.

Bamboo exhibits favorable mechanical properties, with compressive strength ranging from 35–70 N/mm², tensile strength averaging 160 N/mm², shear strength of 6–12 N/mm², and bending strength between 50–150 N/mm². However, its natural durability is limited, lasting only 1–2 years in open-ground conditions due to high starch content, which makes it vulnerable to decay and insect attack. The research recommends further research to optimize bamboo-based design methodologies, enhance structural performance, and assess its long-term effectiveness under diverse climatic and geotechnical conditions. The findings of Tardío *et al.* (2018) reinforce the potential of bamboo as a cost-effective and sustainable material for mitigating in-situ lateral earth pressure.

The study by Cheng *et al*. (2020) examines the bearing characteristics of a Moso bamboo micropile-composite soil nailing (BMCSN) system in soft soil areas in China. The research aims to assess the feasibility of using bamboo micropiles as a sustainable alternative to conventional soil reinforcement techniques, focusing on their load-bearing capacity and deformation behavior. By integrating bamboo micropiles with traditional soil nails. The methodology involves field experiments, laboratory tests, and numerical simulations to analyze the mechanical performance of the BMCSN system. Findings reveals axial force distribution follows an oval pattern, with maximum values **of** 88.5 kN, 105.2 kN, and 127.7 kN from top to bottom, increasing with excavation depth. Pile bending resembles **a** cantilever beam**,** with significant deformation near the foundation pit's bottom, and settlement accelerates when loading reaches a critical level. Earth pressure decreases above the pit bottom during excavation but increases proportionally to loading, with a sudden spike near failure**.**

Numerical simulations align with laboratory results, demonstrating the system's effectiveness in improving bearing capacity. Research reveals BMCSN system

significantly improves soil reinforcement by increasing load-bearing capacity and reducing deformation compared to conventional soil nailing alone. The study highlights bamboo's potential as a cost-effective and environmentally friendly reinforcement material but also acknowledges durability concerns. Further research is recommended to refine design parameters, enhance bamboo's resistance to biodegradation, and evaluate long-term performance under varying environmental and loading conditions.

Bang *et al*. (2015) explored the feasibility of using bamboo as an alternative to conventional steel soil nails for excavation and earth-retaining structures in China. It aims to evaluate the mechanical behavior, stability, and overall effectiveness of bamboo soil nailing systems. The research highlights the potential advantages of bamboo, particularly its sustainability, cost-effectiveness, and suitability for soil stabilization applications.

By investigating its performance in retaining structures, the study contributes to the growing interest in eco-friendly reinforcement materials for geotechnical engineering. The findings suggest that bamboo soil nailing systems are a viable and sustainable reinforcement option, offering comparable mechanical performance to steel in certain conditions. The study emphasizes bamboo's economic and environmental benefits, making it a promising alternative for soil stabilization. However, further research is recommended to refine design parameters, optimize bamboo-soil interaction, and evaluate long-term performance under varying soil and environmental conditions to enhance its practical application in geotechnical engineering.

3 CONCLUSION

The utilization of bamboo as a reinforcement material presents a sustainable and cost-effective solution for mitigating in-situ lateral earth pressure in tropical residual soils. Its high tensile strength, frictional resistance, and ability to enhance soil cohesion, shear strength, and bearing capacity make it a viable alternative to synthetic reinforcements, effectively reducing lateral deformations in geotechnical applications. However, existing theoretical models often fail to accurately predict lateral earth pressures, highlighting the need soils modifications that incorporate the unique interaction mechanisms of bamboo-reinforced soils as well as a cost effective method to evaluate in-situ lateral earth pressure in tropical residual.

The integration of both in-situ and laboratory testing methods is crucial for a comprehensive understanding of lateral earth pressure variations over a long period of time. While real-time measurement techniques, such as earth pressure cells and optical fiber sensors, provide valuable insights, cost-effective alternatives must be explored to enhance accessibility in practical engineering applications. Laboratory tests, including triaxial compression and oedometer tests, remain essential for controlled evaluations, complementing field data to refine predictive models.

Future research should focus on optimizing bamboo reinforcement performance under varying soil conditions, moisture levels, and long-term loading scenarios. Additionally, the development of cost-effective evaluation techniques and practical design guidelines based on field and laboratory data will enhance the implementation of bamboo reinforcement in geotechnical engineering. Establishing standardized methodologies for assessing lateral earth pressure in bamboo-reinforced soils will further contribute to the advancement of sustainable reinforcement strategies in tropical regions.

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Assessment of Index and Compaction Characteristics of Residual Lateritic Soils in Kontagora and Environ for use as Flexible Road Pavement Materials

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ABSTRACT
This study assesses the index and compaction characteristics of residual lateritic soils in Kontagora and its surrounding areas for flexible pavement road applications. A total of 20 soil samples were collected, and various tests, including Natural Moisture Content (NMC), specific gravity (Gs), Atterberg limits, and compaction (Maximum Dry Density - MDD and Optimum Moisture Content - OMC), were conducted. The results show significant variation in moisture content (7.87 to 15.4%) and compaction characteristics, with MDD values ranging from 1.83 to 2.13 g/cm³ and OMC between 9.0 and 17.0%. The Atterberg limits indicated Liquid Limits (LL) ranging from 32 to 62%, and Plasticity Index (PI) values between 15.41 and 35.90%, demonstrating a range of plasticity typical for soils from this region. Correlation analysis revealed strong negative correlations between MDD and OMC, and positive correlations between OMC and plasticity indices. The American Association for State Highway and Transportation Officials (AASHTO) classification indicated that most of the soils fall under A-6 and A-7-6 sub-groups, which may not be suitable for use as flexible road pavement materials without modification. The study highlights the need for careful moisture control and possible stabilization methods to enhance the soils' performance in road construction. The findings provide essential insights into the geotechnical properties of residual lateritic soils in the region, informing better decisions in the planning and design of flexible pavements for road infrastructure.

Keywords: *Compaction characteristics; Flexible Pavement; Index Properties;Residual Lateritic Soil.*

1 INTRODUCTION

Assessment of residual lateritic soils is fundamental to road pavement applications, particularly in regions like Kontagora and its environs, where these soils are prevalent. Lateritic soils, commonly found in tropical and subtropical regions, develop through intense weathering of parent rock, resulting in deposits rich in iron and aluminum oxides. Their engineering suitability for flexible pavement construction depends largely on geotechnical properties, which can vary significantly due to differences in formation processes, environmental conditions, and mineralogical composition (Wang and Li, 2015).

For flexible pavement construction, the performance and longevity of the pavement structure are influenced by the quality of materials used in the subgrade and sub-base layers. Properly assessed and utilized, lateritic soils can provide the necessary strength and stability to support traffic loads and mitigate pavement distress (Laldintluanga, 2024). However, their variable index and compaction characteristics necessitate thorough geotechnical evaluation to determine their suitability for road construction. Key parameters such as particle size distribution, Atterberg limits and compaction behavior must be analyzed to ensure compliance with engineering standards. Where deficiencies exist, stabilization techniques may be required to enhance their performance under varying traffic and environmental conditions (Mansur, 2021).

Kontagora, located in Niger State, Nigeria, has substantial lateritic soil deposits that have been widely used in road construction. However, their properties exhibit spatial variability, making a comprehensive assessment essential for effective application in pavement design and construction (Umaru, 2014). Understanding these variations is crucial for optimizing their application and ensuring structural stability. As noted by Winch (2009).The success of civil engineering projects depends on a thorough understanding of material properties and their behavior under field conditions.

This study aims to assess the index and compaction characteristics of residual lateritic soils in Kontagora and its environs, in order to determine their suitability for flexible pavement construction. By evaluating their geotechnical properties, this research provides insights into their engineering behavior and guide best practices for their use in road pavement applications. The findings will contribute to improved material selection and design approaches, ensuring sustainable and durable road infrastructure in the region.

2 MATERIALS AND METHODS

2.1 SOIL SAMPLES COLLECTION

Twenty (20) soil samples used in this study were collected from ten (10) different locations in Kontagora, at a depth ranging from 1.2 to 1.5m below the ground surface The samples were transported to the Civil Engineering laboratory, Federal University of Technology Minna for tests and analysis.

2.2 TESTING METHODOLOGY

To assess the index and compaction characteristics of the residual lateritic soils deposit for pavement application, comprehensive laboratory investigations of the collected soils was conducted. Tests carried out include: Natural Moisture Content, Sieve analysis, Atterberg limits, and Compaction Test. All laboratory tests were in conformity with the guideline as outlined in BS 1377 (1990). Determination of the compaction characteristics was done under the British Standard Heavy (BSH) compactive effort.

3 RESULTS AND DISCUSSION

3.1 NATURAL MOISTURE CONTENT (NMC)

The NMC of residual lateritic soils plays a significant role in their suitability for road pavement applications, as it affects compaction behavior, shear strength, and load-bearing capacity (Ajayi *et al.*, 2024). The NMC values of the soil ranges from 7.87% (K16) to 15.4% (K11), indicating notable variability (Table 2). This variation can be attributed to differences in soil composition, drainage conditions, and environmental factors (Oluyinka and Olubunmi, 2018). Higher moisture content in samples, like K11 (15.4%) and K12 (14.63%) suggests increased clay content or poor drainage, which may reduce soil strength and increase susceptibility to shrink-swell behavior. In contrast, lower moisture content in samples such as K16 (7.87%) and K15 (8.87%) indicates better drainage or coarser soil fractions, which may require moisture conditioning during compaction.

Most samples fall within the 9.0–11.5% range, which is typical for lateritic soils in tropical regions (Oluyinka and Olubunmi, 2018). This range suggests moderate moisture retention, which can support effective compaction and strength development. However, variations in NMC necessitate site-specific compaction efforts to achieve optimal dry density and reduce potential pavement failures. Improperly managed moisture content can lead to excessive settlement, poor load distribution, and premature pavement deterioration, emphasizing the need for precise moisture control in construction practices (Ogaga *et al.*, 2024).

To enhance the performance of these lateritic soils in flexible pavement applications, stabilization techniques such as lime or cement treatment may be required, especially for soils with excessive moisture retention (Jain, 2024). Proper geotechnical assessment and tailored compaction strategies are crucial to optimizing their use as subgrade or sub-base materials. The findings highlight the importance of understanding moisture content variability to ensure durable and stable pavement structures in the region.

3.2 SPECIFIC GRAVITY (GS)

The specific gravity (Gs) values of the soils, as shown on Table 2, range from 2.43 (K10, K14, K15, K17) to 2.67 (K4, K9, K19), indicating moderate variability. Specific gravity is a key index property that reflects the mineralogical composition of soils, with higher values typically associated with iron-rich lateritic soils and lower values indicating the presence of lighter minerals such as quartz or organic matter (Alhaji *et al.*, 2021). Majority of the samples fall within the 2.50–2.63 range, which is typical for lateritic soils and suggests a balance between clay and iron-oxide content (Alhaji *et al.*, 2021). The relatively higher values observed in samples K4, K9, and K19 (2.67) suggest a higher concentration of heavy minerals, which could enhance soil strength, while lower values around 2.43 (K10, K14, K15, K17) may indicate the presence of more weathered or silty materials with lower compaction potential.

The variation in specific gravity has direct implications for soil compaction and stability in road pavement applications. Higher Gs values typically correlate with increased density and load-bearing capacity, making the soil more suitable for subgrade and sub-base layers (Ibrahim *et al.*, 2018). Conversely, soils with lower specific gravity may require stabilization or blending with stronger materials to improve performance under traffic loads (Audu and Okoyido, 2019). Given the observed range, it is essential to consider site-specific assessments and possible treatment methods to optimize the use of these residual lateritic soils in flexible pavement construction.

3.3 PARTICLE SIZE DISTRIBUTION ANALYSIS

Particle size distribution of the residual lateritic soil samples was evaluated against the Nigerian General Specification for Roads and Bridge Works (2016), which stipulates that materials used in road pavement construction should generally have ≤35% fines (Passing No. 200 sieve) for sub-base and subgrade applications to ensure adequate drainage and strength. From the resultson Table 1, several samples, including K1, K2, K6, K7, K8, K13, K14, K19, and K20, have fines content exceeding this threshold, indicating potential susceptibility to poor drainage and reduced shear

strength. However, samples such as K3 (22.87%), K9 (35.93%), K10 (32.03%), K11 (11.5%), and K16 (29.27%) fall within the acceptable range, making them more suitable for use in road pavement layers (FMWH, 2016). The variability in fines content suggests that, while some of the soils can be directly utilized, others may require stabilization or blending with coarser materials to meet the standard requirements. Therefore, site-specific assessments and possible modifications are necessary to enhance their performance in road construction.

3.4 CONSISTENCY LIMITS RESULTS

TheAtterberg limits, which include LL, PL, PI, are essential for evaluating the workability and shrink-swell potential of lateritic soils in road pavement applications. According to the Nigerian General Specification for Roads and Bridge Works (1997), lateritic soils used for subgrade and sub-base layers should ideally have LL ≤ 50% and PI between 10 and 30% to ensure adequate strength and minimal deformation under loading. From Table 1, most samples meet the LL requirementexcept for K13 (62.00%), K11 (55.00%), and K14 (55.00%), which suggest a higher clay fraction, leading to increased moisture retention and potential swelling. Similarly, the PI values range from 15.41% (K4) to 35.90% (K13), with K13 exceeding the recommended limit, indicating excessive plasticity, which may result in undesirable deformation under traffic loads (Adewumi *et al.*, 2023).

Most samples exhibit moderate plasticity, making them generally suitable for pavement applications, though variations exist. Samples like K4 (15.41%), K5 (16.96%), and K17 (15.91%) have relatively low plasticity indices, suggesting lower clay content and better stability. Conversely, K13 (35.90%) and K2 (28.07%) have higher PI values, indicating higher cohesion and potential shrinkage issues, which may necessitate stabilization before use. The observed variation in plasticity highlights the need for careful selection and possible improvement measures, such as lime or cement stabilization, to enhance performance in road construction (Audu and Okoyido, 2019). Proper assessment of these soil properties is crucial to ensuring long-term pavement stability and minimizing failures due to excessive moisture sensitivity.

3.5 SOIL SAMPLES CLASSIFICATION

The AASHTO soil classification system categorizes soils based on their suitability for highway subgrade applications, with A-1 to A-3 representing granular materials of high quality and A-4 to A-7 indicating fine-grained soils with increasing plasticity and moisture susceptibility. Majority of the tested samples fall under A-6 and A-7-6 (Table 1), indicating silty or clayey soils with poor drainage and moderate to high compressibility, which may require stabilization for effective use in road construction. Samples K3, K11, and K16 (A-2-7) and K10 (A-2-6) are better suited for pavement applications due to their improved drainage and reduced plasticity, making them preferable for subgrade layers. However, the predominance of A-7-6 soils (e.g., K2, K5, K6, K7, K12, K13, K14, K15, K20) suggests high clay content, requiring stabilization to enhance strength and reduce shrink-swell behavior. Given these classifications, site-specific treatment, including lime or cement stabilization, is essential to improve performance and meet Nigerian pavement construction standards.

3.6 COMPACTION CHARACTERISTICS

MDD and OMC obtained under British Standard Heavy (BSH) compaction energy provide insights into the compaction characteristics and load-bearing capacity of the residual lateritic soils (Table 2). The MDD values range from 1.83 to 2.13 g/cm³, with the highest recorded in K12 (2.13 g/cm³) and K9 (2.10 g/cm³), indicating a well-compacted soil structure with high strength potential. Conversely, K11 (1.83 g/cm³) and K13 (1.83 g/cm³) exhibited the lowest densities, suggesting higher void ratios and potentially lower strength under loading. The variations in MDD are primarily influenced by soil composition, particularly the presence of fines, with higher clay content generally leading to reduced dry density due to increased water retention and lower particle interlock.

The OMC values range from 9.00 to 17.00%, with K13 (17.00%) and K11 (16.70%) requiring the highest moisture for compaction, suggesting high plasticity and fine content. In contrast, K10 (9.00%) and K16 (9.00%) require the least moisture, indicating a coarser soil matrix that achieves maximum density at lower moisture levels. Lateritic soils with higher OMC tend to be more moisture-sensitive, requiring careful moisture control during construction to prevent excessive shrinkage or expansion (Ajayi *et al.*, 2024). The observed range of OMC suggests that some samples, particularly those with OMC above 14%, may require stabilization to optimize their compaction performance and long-term stability in pavement applications.

According to the Nigerian General Specification for Roads and Bridges (1997), lateritic soils intended for use as subgrade materials should have an MDD of at least 1.80 g/cm³, while materials for sub-base and base courses should typically exceed 2.00 g/cm³ (FMWH, 2016). Majority of the soil samples met the subgrade requirement, as all values exceed 1.80 g/cm³. However, only samples such as K5, K8, K9, K10, K12, and K16 surpass 2.00 g/cm³, making them more suitable for sub-base applications. Additionally, the specification recommends an OMC range of 8–18%, meaning all tested soils fall within the acceptable limit. However, the higher OMC values exceeding 14% indicate the presence of fine-grained materials, which may require modification to reduce moisture susceptibility. Overall, while most soils meet the basic subgrade requirements, stabilization may be necessary for improved performance in road pavement layers, particularly for those with lower MDD and higher OMC values.

3.7 COMPACTION CHARACTERISTICS AND INDEX PROPERTIES RELATIONSHIP

The correlation matrix reveals several key relationships between the compaction characteristics and index properties of the residual lateritic soils (Table 3). A strong negative correlation exists between MDD and OMC (-0.7910), which indicates that as the moisture content increases, the compaction density of the soil decreases. This is a common observation in lateritic soils, where higher moisture levels lead to a reduction in particle interlock and overall compaction (Afolayan *et al.*, 2022). Additionally, MDD is negatively correlated with LL (-0.4947) and PI (-0.4797), suggesting that soils with higher plasticity are less compacted. This behavior is due to the ability of finer-grained, high-plasticity soils to retain more water, making them more difficult to compact effectively. On the other hand, the correlation between MDD and NMC is weak (-0.0659), indicating that the natural moisture content does not have a significant influence on the soil's ability to achieve maximum compaction density in this study.

In terms of other index properties, OMC shows a strong positive correlation with both Liquid Limit (0.5984) and Plasticity Index (0.5147), further supporting the idea that soils with higher plasticity require more moisture to achieve optimal compaction. There is also a negative correlation between Sand Content and Liquid Limit (-0.4484) and Plasticity Index (-0.4143), suggesting that soils with higher sand content tend to have lower plasticity and, therefore, require less moisture for compaction. The weak correlation between fine grain content and OMC (0.1187) and MDD (-0.1079) shows that fine-grained content has a more modest effect on compaction behavior. Finally, the strong correlation between PL and PI(0.8209) highlights that these two properties are closely related in defining the plasticity characteristics of the soil. Overall, these correlations emphasize the significant role of fine content and plasticity in determining the compaction characteristics of lateritic soils, with implications for their use in road pavement construction.

TABLE 1: CLASSIFICATION PROPERTIES OF THE SOIL SAMPLES

DESCRIPTION	PASSING NO.10 (%)	PASSING NO.40 (%)	PASSING NO. 200 (%)	LL (%)	PL (%)	PI (%)	AASHTO	COLOUR
K1	87.73	70.57	40.57	33.00	11.51	21.49	A-6	REDDISH
K2	88.43	58.23	41.00	45.00	16.93	28.07	A-7-6	REDDISH
K3	80.63	38.27	22.87	47.00	27.25	19.75	A-2-7	REDDISH
K4	78.93	61.40	38.93	32.00	16.59	15.41	A-6	REDDISH
K5	68.77	50.83	36.97	41.00	24.04	16.96	A-7-6	REDDISH
K6	93.53	75.53	52.97	41.00	19.38	21.62	A-7-6	REDDISH
K7	95.77	76.97	52.63	47.00	21.27	25.73	A-7-6	REDDISH
K8	81.2	51.8	41.73	37.00	14.75	22.25	A-6	REDDISH
K9	74.23	54.07	35.93	36.50	13.07	23.43	A-6	REDDISH
K10	69.97	49.07	32.03	33.00	14.4	18.60	A-2-6	REDDISH
K11	57.73	38.13	11.5	55.00	27.19	27.81	A-2-7	GRAY
K12	61.03	46.9	36.93	47.00	25.96	21.04	A-7-6	GRAY
K13	69.73	57.67	48.4	62.00	26.1	35.90	A-7-6	GRAY
K14	62.1	53.87	43.23	55.00	27.5	27.50	A-7-6	GRAY
K15	61.4	51	39.07	46.00	24.17	21.83	A-7-6	GRAY
K16	63.4	39.7	29.27	46.00	23.74	22.26	A-2-7	GRAY
K17	96.13	67.7	36.23	38.00	22.09	15.91	A-6	GRAY
K18	92.03	65.73	36.1	36.00	16.94	19.06	A-6	GRAY
K19	88.87	73.67	48.6	36.00	13.83	22.17	A-6	GRAY
K20	95.67	74.23	41.4	40.50	20.56	19.94	A-7-6	GRAY

TABLE 2: NATURAL MOISTURE CONTENT, SPECIFIC GRAVITY AND COMPACTION CHARARISTICS OF SOIL SAMPLES

DESCRIPTION	NMC (%)	GS	MDD (G/CC)	OMC (%)
K1	10.40	2.60	2.03	11.00
K2	14.3	2.48	1.92	12.50
K3	9.71	2.57	1.95	12.00
K4	10.7	2.67	1.88	14.50
K5	13.7	2.53	2.02	10.70
K6	9.78	2.5	1.95	15.00
K7	11.18	2.61	1.91	12.50
K8	10.43	2.57	2.00	9.70
K9	10.93	2.67	2.10	10.30
K10	9.71	2.43	2.09	9.00
K11	15.4	2.58	1.83	16.70
K12	14.63	2.57	2.13	13.00
K13	9.79	2.6	1.83	17.00
K14	10.24	2.43	1.89	14.50
K15	8.87	2.43	1.97	13.00
K16	7.87	2.61	2.06	9.00
K17	9.71	2.43	1.99	11.00
K18	10.43	2.63	1.99	12.00
K19	10.25	2.67	1.93	13.00
K20	9.96	2.63	1.91	14.00

TABLE 3: CORRELATION MATRIX FOR MDD, OMC AND INDEX PROPERTIES

	MDD (G/CC)	OMC (%)	NMC (%)	GS	SAND (%)	FINE GRAIN (%)	LL (%)	PL (%)	PI (%)
MDD (G/CC)	1								
OMC (%)	-0.7910	1							
NMC (%)	-0.0659	0.2611	1						
G_S	-0.0712	0.0908	0.0283	1					
SAND (%)	-0.0600	-0.1956	-0.0156	0.1989	1				
FINE GRAIN (%)	-0.1079	0.1187	-0.2838	0.0247	-0.2627	1			
LL (%)	-0.4947	0.5984	0.2019	-0.1830	-0.4484	-0.1020	1		
PL (%)	-0.3208	0.4479	0.1622	-0.2984	-0.3094	-0.3045	0.8209	1	
PI (%)	-0.4797	0.5147	0.1616	0.0193	-0.4143	0.1618	0.7807	0.2841	1

4 CONCLUSION

The assessment of the index and compaction characteristics of the residual lateritic soils in Kontagora and its environs reveals important insights into their suitability for use in flexible pavement road construction. The soils exhibited a range of natural moisture contents, with values between 7.87 and 15.4%, suggesting variability in moisture conditions across the region. This variability, alongside the moderate to strong negative correlation between MD) and OMC, underscores the need for careful moisture control during compaction to achieve optimal pavement performance. The soils' plasticity, indicated by LL and PI, varied considerably, with higher plasticity soils showing reduced compaction densities and suggesting potential challenges in meeting compaction requirements for pavement stability.

Further, the results from the Specific Gravity (Gs), Atterberg limits, and AASHTO classification suggest that the soils primarily fall under A-6 and A-7-6 categories, indicating that they are generally unsuitable for pavement subgrade without modification or stabilization. The correlation analysis further confirmed that moisture content, fine-grained content, and plasticity significantly influence the compaction behavior, with higher plasticity soils requiring stabilization to improve their compaction characteristics. Additionally, the MDD and OMC values of some soil samples did not fully meet the Nigerian General Specification for road and bridges, indicating the necessity for soil stabilization techniques or blending with other materials to enhance their engineering properties for road construction. Therefore, a comprehensive understanding of these geotechnical properties is crucial for designing durable and stable flexible pavements in the region, highlighting the importance of proper soil evaluation and the potential benefits of stabilization methods in enhancing the performance of these soils in road construction.

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ASSESSMENT OF WATER TARIFFING FOR MUNICIPAL WATER SUPPLY. A CASE STUDY OF FCT WATER BOARD, ABUJA.

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Abstract: Water tariffing is a crucial aspect of sustainable municipal, Bwari and Gwagwalada water supply, ensuring cost recovery, accessibility, and efficiency in water distribution. This study investigates the effectiveness of the current water tariffing system in the Federal Capital Territory (FCT) Water Board, focusing on revenue generation, affordability, and accessibility. A structured questionnaire was administered to households across selected areas in Abuja, and data were analysed using the Statistical Package for Social Sciences (SPSS) with descriptive statistics and analysis variance (ANOVA). Findings indicate that while the tariff system is considered fair and transparent, concerns persist regarding revenue sufficiency and the affordability of potable water for lower-income households. The study also highlights the need for policy adjustments, increased stakeholder engagement, and alternative water sources to improve service delivery. Recommendations include tariff restructuring, targeted subsidies for vulnerable populations, and enhanced public awareness on water conservation. Implementing these measures will contribute to a more sustainable and equitable water supply system in the FCT.
Key words: Improve service delivery, Tariff restructuring, Targeted subsidies and Water Conservation.

I. INTRODUCTION

Water is one of the most valuable natural resources vital to the existence of any form of life. An adequate supply of safe, clean water is the most important precondition for sustaining human life, for maintaining ecosystems that support all life and for achieving sustainable development [1]. According to [2], about 844 million people globally lack access to clean water supply while 2.5 billion people have no access to adequate sanitation. It was also estimated that 319 million people are without access to improved water supply in sub-Saharan Africa. The consequence of this is that a large proportion of human beings have resorted to the use of potentially harmful sources of water. In this regard, millions of people are locked up in a cycle of poverty and disease. For example, [3] recorded that more than 14,000 people die each day, 11,000 of them being children are under five years of age. [4] inserted that there are more people in the world hospitals today, suffering from water-borne diseases than any other ailment. Some two million children every year – about 6,000 a day – die from such infections. Out of this figure, 1.6 million are from the developing countries [5]. The Water Project [6] concludes that poor water and sanitation conditions cause about 80% of all diseases and more than one-third of all deaths in developing countries. [7] confirmed that with adequate supplies of safe drinking water, the incidence of some illnesses and death could drop by as much as 75%. Emphasizing the importance of water, [8] asserted that safe drinking water is not just a luxury because it's a necessity: it usually creates a distinction between life and death.

Nigeria has 36 State Water Agency (SWAs) and 12 River Basin Development Authorities (RBDAs). Several of these water agencies and authorities still depend on obsolete water equipment. This has been primarily due to reduced management by Government and private sector organization in the water sector compared with other sectors such as oil and gas, energy, housing among others [9]. Despite this, government in recent times has made efforts to ensure provision of water supply in Nigeria, yet only 47 percent of the population had access to an improved water source in 2008. In 2010, 54% had access to safe water in

urban households while less than 50% of rural households had access to good portable water in Nigeria as against the National target of 65% [10]. Public water supply is regarded as a measure of access to safe water. However, access to public water supply among Nigerians has decreased extensively from 14% in 1990 to 6% in 2008 [11]. People still depend very much on other sources such as hand-dug wells, ponds, streams, river and shallow wells for their water needs. During the dry season, some of these sources dry up, and households have to invest a substantial amount of their resources to get water of doubtful quality.

In the past most cities and utilities in the world have provided water to their customers almost free of charge because water is considered a necessity, and because water was a relatively cheap and abundant resource. But now with much larger communities requiring service, the only way to ensure that everyone has access to this basic need is to ration it in some way. And perhaps the best way to utilize water to the best and most-valued uses is to put a price on water, and construct appropriate tariff structures to meet different social, political and economic goals in different situations [12].

Drastic changes in water pricing policies are likely to occur in the coming years in particular in the fast-growing urban areas all over the world. Urban populations are growing as never before. While today, 45% of the world population live in urban areas and this population is likely to increase to 61% by 2025 [13].

The Federal Capital Territory Water Board (FCTWB) is the only agency that has the Mandate to supply potable water to the populace of the FCT, it is also responsible for collecting/remitting revenue for water consumed by customer on behalf of the Government.

I Aims

The aim of this research is to evaluate effectiveness and Method of water supply and tariffing for municipal, Gwagwalada, and Bwari water by management in FCT Abuja

II Statement of the Problem

The problem faced by the water sector is that prices and tariffs are almost universally below the full-cost of supply indicating that there are large inefficiencies in the water sector and that water prices need to be raised. The monthly tariff for water from household connections is low and with few connectors and low tariffs, little revenue is generated beyond subsidies provided by the government. Water authorities cannot afford to maintain such systems up to a level that is reliable and so the consumers are forced to supplement the pipe water from traditional sources [14].

In a developing country like Nigeria, tariffs are controversial for many reasons. For policy makers, one objective can be more important than another, which can lead to the adoption of different tariff structures. The impact of such structures on consumers is ambiguous. Despite recent advances, policy makers are not sufficiently informed of the effects on consumer behavior. A lack of competition in the water market implies that policy makers do not have a market test of whether a tariff structure is functioning effectively, with consumers unable to reject a tariff structure that is negatively impacting them [15]. Based on the foregoing, the need to have an effective water tariff structure that will take into consideration consumers' perception is imperative. This study considers effective water tariffing in municipal water supply in FCT Abuja.

IV Justification; -

A water tariff is an important management tool that can be used to assist with the reform of the municipal water and sanitation sector. The

pricing of water services is however controversial. There is disagreement over the objectives of water pricing and tariff design. Water pricing decision affect several different objectives or goals of policy makers in conflicting ways. This means that a pricing policy may impact differently on each water tariff objective, thus leading to different conclusions about the attractiveness of the policy. There is also a disagreement on what would happen if different water tariffs were implemented. Inadequate empirical data on how changes in water prices would affect consumers in terms of water use and decision to connect or stay connected is often lacking. There are insufficient numbers of providers of piped water services for consumers to reject inappropriate water tariffs thus giving room for bad ideas to thrive in the water market and policy discussion.

Despite this controversial nature of municipal water pricing and the poor performance of municipal water supply in virtually all Nigeria cities including the Federal Capital Territory Abuja, pricing policy reforms are possible that will benefit almost everyone. The outcome of this study will yield empirical data that will be useful for policy makers and water managers in designing an effective tariff system in the study area.

V. Methodology

This chapter was designed to describe the procedures adopted in this research. The procedures involve the following: research design, population of the study, sample and sampling techniques, instrumentation, validation of the instrument, administration of the instrument and data analysis techniques. This research covered the study that impacts on parameters for effective municipal water tariffing includes interviews, observations, sampling, and data collection of all available information on issues associated with municipal water tariffs in the FCT Water Board.

VI. Study Area

Abuja is located in the central part of Nigeria and it lies at latitude 9.07°N and longitude 7.48°E with an elevation of 840m (2760 ft) above sea level [67]. It has a land area of about 8000km^2, making it almost two and a half times the size of Lagos State. The city is defined by two distinguished rock formations – the Zuma and Aso rock. FCT Abuja has an estimated population of over 3 million people [68]. Its rapid urbanization rate has made it to be the fastest-growing city in Africa [69].

The Abuja area has 2 distinct seasons: the rainy and dry season. Six local area councils were created within the FCT Abuja, namely Abuja municipal, Abaji, Bwari, Kuje, Gwagwalada, and Kwali as depicted in Figure 4. These area councils are further subdivided into districts. It has a total land area of 713 km2 with a tropical climate and predominantly tropical savannah. A total annual rainfall that averages 1100mm per annum has also been recorded for Abuja [70]. Abuja city is located within the Abuja Municipal area and the city is directly administered by the Federal Capital Territory Administration (FCTA). The FCTA has several departments and agencies, supervised by directors, including the Federal Capital Territory Water Board.

The Water supply mains have its sub-station at Bwari Area Council where the treatment plant is located before it is distributed through the pipe network shown in Fig. 3.1 distribution across the Municipal area councils.

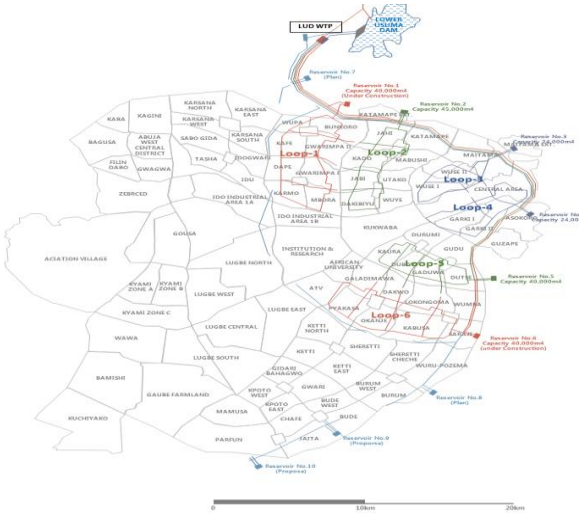


Fig. 3.1 Map Showing Water Distribution network in the study area.

The primary source of water collection comes from the River Usman and being augmented by Gurara River in Kaduna where the Usman Dam is fed to enable optimum production at the peak period. The treatment occurs at the Usman Dam and is distributed to various Tank Locations such as Tank 1 – to Tank 6. The distribution across each tank flow chart is shown in fig 3.2

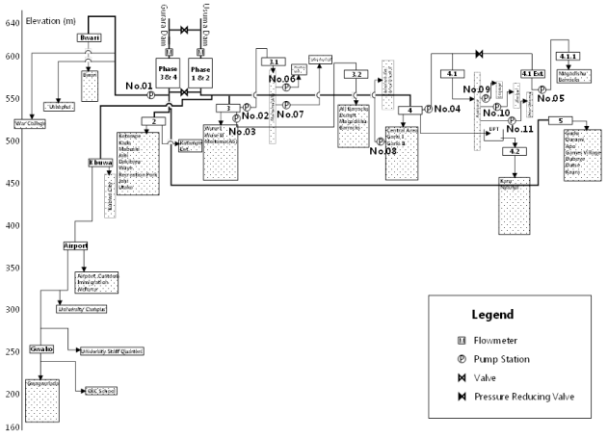


Fig. 3.2 The Tank Flow and Hydraulic Network distribution

VII Data Collection and Sampling Technique

Data were collected with the aid of a structured questionnaire containing open-ended questions. The questionnaire was structured to collect data on:

1. Household Characteristics
2. Economic Characteristics
3. Source Characteristics

Three Hundred (300) questionnaire survey was carried out of which only One Hundred and Fifty (150) respondents who were Household in the selected area for the study responded for proper assessment on the Impact of Parameters for Effective Municipal Water Tariffing, there was an interview of the various heads of Departments of the FCT Water Board administration to obtain accurate information on the management of the Effective Municipal Water Tariffing.

Primary data were collected through questionnaires using random sampling for the health facilities questionnaire. The field survey was inclusive of all areas within research scope.

A Data collection

The following data were required for performing this analysis:

i. FCT Water Board total asset value
ii. Average monthly cost of production
iii. Average monthly Personnel cost
iv. Average monthly Operations and maintenance cost
v. Average Daily Production
vi. Total number of active domestic and commercial customers
vii. Current domestic and commercial tariffs
viii. Questionnaire for consumers' perception of water supply and Tariffing

B. Method of Data Analysis

A simple descriptive test was used to describe the result as obtained from secondary data from the FCT Water board and the fieldwork, with the aid of questionnaires,

This analysis is made based on the following assumptions:

i. The government has 30 years to recoup its investment (minimum design life of must engineering infrastructures)

ii. All customers are metered

iii. All customers are billed

iv. The government is not expecting any profit from its investments

v. Wastages are highly minimized (Non-Revenue Water is Zero

This is shown in tabular format and further interpreted using analytical software known as Statistical Package for Social Sciences SPSS) version 22.

ANOVA Model for Water Tariffing System in FCT Water Board

To analyze the differences in respondents' perceptions regarding the water tariffing system managed by the FCT Water Board, a one-way Analysis of Variance (ANOVA) model was applied. This model evaluates whether significant differences exist in perceptions across key variables such as affordability, transparency, sustainability, and service adequacy.

4.3.1 The ANOVA model

$Y_{ij} = \mu + \alpha_i + \varepsilon_{ij}$

where:

- Y_{ij} represents the perception score of respondents concerning a specific aspect of the water tariffing system.
- μ is the overall mean perception score.
- α_i denotes the effect of independent variables such as affordability, revenue generation, and fairness.
- ε_{ij} is the error term, accounting for individual variations in responses.

4.3.2 The hypothesis for the analysis

- **Null Hypothesis (H_0):** There is no significant difference in respondents' perceptions across the various aspects of the water tariffing system in the FCT Water Board.
- **Alternative Hypothesis (H_1):** There is a significant difference in respondents' perceptions across different aspects of the water tariffing system.

The test statistic is calculated using:

$$F = \frac{MS_{between}}{MS_{within}}$$

where:

- $MS_{between}$ represents the mean square variance between groups, capturing differences in perception across key tariffing factors.
- MS_{within} represents the mean square variance within groups, reflecting variability among individual responses.

If the computed F-value is greater than the critical value at a chosen significance level (e.g., 0.05), the null hypothesis is rejected, indicating significant differences in perceptions regarding the FCT Water Board's tariffing system.

Applying this ANOVA model to the study provides insights into how tariffing policies affect different socioeconomic groups. The results will help policymakers understand public concerns regarding affordability, fairness, and sustainability, allowing for informed decision-making to improve water service delivery in Abuja.

Table 4.2.1.4 Analysis of variance (ANOVA)

		Sum of Squares	df	Mean Square	F	Sig
Between People		6.722	9	.747		
Within People	Between Items	73.674	2	36.837	99.636	.000
	Residual	6.655	18	.370		
	Total	80.329	20	4.016		
Total		87.051	29	3.002		

From the table 4.2.1.4 the highly significant **p-value (0.000)** suggests strong differences in how respondents rated the various aspects of water tariffing. The **high F-value (99.636)** indicates that variations between the tested objective questions are much greater than variations within responses, meaning respondents perceived meaningful distinctions among the survey questions. Since the residual variance is relatively low (6.655), the responses are fairly consistent.

Table 4.2.1.5 One-Sample Test

One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
To evaluate the impact of water tariffing on the affordability and accessibility	14.023	9	.000	3.21500	2.6964	3.7336
To identify potential areas for improvement in current water tariffing system	29.583	9	.000	3.51900	3.2499	3.7881

Result from the table 4.2.1.5 the One-Sample t-test results indicate that respondents strongly believe water tariffing impacts affordability and accessibility (**t = 14.023, p = 0.000, mean = 3.215**) and that the current system needs improvement (**t = 29.583, p = 0.000, mean = 3.519**). Both findings are statistically significant, with confidence intervals excluding zero, confirming that these concerns are widely shared. This suggests that many households struggle with water costs and perceive the tariff system as needing reform. These insights highlight the need for the **FCT Water Board** to review its pricing structure to enhance affordability and service delivery.

C. Results and Discussion

The analysis of the water tariffing system in the FCT Water Board, Abuja, reveals varying perceptions among respondents regarding its effectiveness, affordability, transparency, and impact on households. The demographic breakdown of respondents indicates that the study is male-dominated (57.3%) with a significant proportion of participants aged 50 years and above (47.3%). Most respondents are well-educated, with 31.3% holding MSc degrees and 30.7% being graduates. The income distribution shows that a majority fall within the middle-to-high-income brackets, with 37.3% earning between N150,000 and N250,000 monthly, while only 6.7% earn below N20,000. These factors likely influence perceptions of the water tariffing system.

The effectiveness of the water tariffing system in generating revenue for the FCT Water Board received mixed responses, with a mean score of 2.49 indicating general skepticism. Similarly, the perception of revenue increase over the past year was low, with a mean score of 2.53. However, fairness and reasonableness of the tariff system were rated relatively higher, with a mean of 3.71, suggesting that a significant proportion of respondents believe the charges are justified. In terms of service provision, 33.3% agreed and 29.3% strongly agreed that the FCT Water Board provides adequate services for the current tariff, resulting in a moderate mean score of 3.63.

Transparency and accountability in the tariffing system were perceived positively,

with a mean score of 3.73, indicating relative approval. Likewise, communication effectiveness received a mean score of 3.71, suggesting that respondents are generally aware of tariff policies. Flexibility in addressing socioeconomic conditions was rated slightly higher at 3.77, indicating that respondents perceive some level of adaptability in the system. However, concerns were raised about the sufficiency of revenue from tariffing to cover operational costs, as reflected in a low mean score of 2.25, showing a lack of confidence in financial sustainability.

The study also examined the affordability and accessibility of potable water. While the affordability of tariffs was perceived positively (mean = 3.73), many respondents (mean = 2.25) indicated that the current system affects their ability to access potable water. Additionally, the impact of tariffing on household well-being was rated low (mean = 2.13), suggesting that the high cost of water has financial and health implications. Support for low-income households in accessing water was moderately rated (mean = 3.71), and sensitivity to different socioeconomic groups received a similar rating (mean = 3.71), indicating mixed perceptions. Notably, respondents strongly supported alternative water sources for residents who cannot afford the tariff (mean = 3.73) and subsidies for vulnerable populations (mean = 3.01).

Further, the study explored areas for improvement in the water tariffing system. The results showed a strong preference for reviewing and adjusting the system (mean = 3.75) to enhance equity and sustainability. Although transparency and accountability received a moderate score (mean = 3.57), concerns remain regarding the system's responsiveness to different socioeconomic conditions (mean = 3.19). Support for stakeholder engagement in tariff reform was mixed, with a relatively low mean score of 2.58, suggesting a need for increased awareness and participation in policy discussions. However, respondents strongly supported incentives for water conservation (mean = 3.61) and alternative water sources (mean = 3.84), highlighting the demand for sustainable solutions.

Reliability analysis using Cronbach's Alpha (0.705) indicates an acceptable level of internal consistency in the responses, suggesting that the questionnaire was well-structured. The ANOVA test ($F = 99.636$, $p = 0.000$) confirms significant differences in how respondents rated various aspects of water tariffing, indicating strong and meaningful distinctions among perceptions. Additionally, the One-Sample t-test results reinforce that respondents widely believe the tariffing system affects affordability and accessibility ($t = 14.023$, $p = 0.000$, mean = 3.215) and needs improvement ($t = 29.583$, $p = 0.000$, mean = 3.519).

D. Findings

Overall, the study findings highlight critical concerns regarding affordability, accessibility, revenue sufficiency, and equity in the FCT Water Board's tariffing system. While there is moderate satisfaction with fairness, communication, and transparency, the need for a review and adjustment of tariffs, increased stakeholder engagement, and support for vulnerable populations remains evident. These insights provide a strong basis for policy recommendations to ensure a more sustainable and inclusive water tariffing framework in Abuja.

Conclusion

The study underscores the challenges in the water tariffing system in the FCT, particularly in revenue generation, affordability, and accessibility. While respondents acknowledged the fairness and transparency of the current system, concerns about financial sustainability and equitable distribution of water services

remain. The findings suggest that adjusting the tariffing structure, engaging stakeholders, and providing support for low-income households are crucial steps toward establishing a more effective and equitable system.

Recommendation

The following recommendation are hereby made:

1. The FCT Water Board should introduce a fairer tariff system that takes household income into account, making water more affordable for low-income earners while ensuring that higher-income households pay rates that match their consumption.
2. To improve revenue collection and financial stability, the board should adopt smart meters, automated billing, and digital payment options, making the process more efficient and reducing financial leakages.
3. It is important to involve the public in decision-making by organizing customer forum, public discussions, and providing easy digital access to tariff policies, ensuring transparency and building trust.
4. Sustainable water management should be encouraged by offering incentives for water-saving technology, and expanding borehole networks to guarantee a reliable water supply for the future.

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AN OVERVIEW: INVESTIGATING THE EFFECT OF COCONUT FIBRE ASH ON THE FLEXURAL STRENGTH OF RE-VIBRATED CONCRETE BEAM

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ABSTRACT
Previous studies have reported findings about the possibilities of using coconut fibre ash (CFA) to partially replace cement in the production of concrete. Based on the outcome of previous findings, there is a need for further research to determine the degree of the suitability of using the CFA in re-vibrated concrete beam. This becomes inevitable because some studies reported positive contribution to the compressive strength of concrete with less emphasis on the flexural strength of re-vibrated concrete beam. This study highlights the chemical and physical properties of CFA as reported by previous studies and compared these properties to those of cement. The properties of fresh and hardened concrete that were produced using CFA as partial replacement for cement, as reported in previous works are presented and discussed in this study. Based on the outcome of this study, it has been found that, CFA is a good pozzolona due to its high percentage of silicon oxide, it is readily available and there is a need for large volume consumption of the agricultural waste material. Re-vibrating concrete reduces voids, increases density and strength of the concrete which tends to improves both the compressive and flexural strength of re-vibrated concrete beam.

Keywords: *Concrete properties; Coconut fibre ash; Pozzolana; Re-vibrated concrete; Flexural strength*

1 INTRODUCTION

The most used engineering material for construction in the world today is concrete. Conventional concrete manufacture substantially makes a significant to CO_2 emissions because of the high energy needed to generate Portland cement, the main binder of concrete (Kahan *et al*. 2023; Althoey *et al*. 2023). Recent searches have stated that roughly 0.9 tonnes of CO_2 are released while manufacturing 1 ton of Portland cement, which accounts for approximately 5% of the human-induced CO_2 emissions globally (Althoey *et al*. 2023; Nassar *et al*. 2022). Therefore, in recent years, a vast majority of researchers have searched for sustainable resources for environmentally friendly cement and concrete, to decrease CO_2 emissions. Due to a substantial surge in the demand for sustainable concrete, which is one of the most extensively utilized construction materials globally (Althoey *et al*. 2023).

The over-reliance on the usage of concrete produced from cement (as a binder) for buildings have kept their cost high and this has prevented low-income earners in developing nations of the world from building houses for their local dwellers that make up the greater percentage of their population and most often are agriculturally dependent (Aguwa *et al*.,2016). As a result of the high cost of acquiring the required materials to construct functional and stable houses, a greater proportion of the country's population cannot afford the cost (Aguwa,2009). An easy way out of this, points at suitable means of replacing a proportion of cement with cheap and easily obtainable pozzolanic materials. In (ASTM C618,2012) defined pozzolana as "siliceous or siliceous and aluminous material which in themselves have little or no cementitious properties but in finely divided form and the presence of moisture, react with calcium hydroxide which is liberated during the hydration of Portland cement at ordinary temperatures to form compounds possessing cementitious properties". The global increase in human population has triggered an increase in the demand for scarce and expensive engineering materials for building and engineering infrastructure construction.

Concrete according to (Anzar,2015), is that pourable composite mix of cement, fine aggregates, coarse aggregates and water in the right proportion that hardens into a super-strong material for building. When concrete is re-vibrated, it momentarily liquefies again. The primary chemical process that occurs in the first 120 minutes after the concrete is placed, is the formation of calcium hydroxide, which typically makes up 15 to 25 percent of ordinary Portland cement concrete. The other major product of hydration is calcium silicate hydrate, which usually constitutes about 50% of OPC concrete which gives the concrete its hardness and durability. Initial vibration of concrete may not eliminate defects such as honeycomb and voids causing a reduction in strength and performance. But re-vibration can eliminate such defects (honeycomb and voids) and thereby increasing bond, improving concrete quality, better impermeability, reduction in shrinkage and creep, increasing the compressive strength of the concrete,

reduction in surface and other voids as well as cracks in fresh concrete and so on (Krishna et al.,2008). According to (Auta *et al*., 2015) RHA is not recommended to be used as partial replacement for cement in concrete when re-vibration is not envisaged as it results in concrete having very low compressive strength at all ages of curing. An average duration of 90 minutes is recommended for re-vibration of concrete with 20 % RHA as cement replacement for optimal or higher compressive strength. An investigation was conducted on the usage of wood waste ash as a partial replacement for cement in the production of mortar and structural grade concrete, assessment of the fresh concrete properties of self-compacting concrete containing SDA, and it was evident that ash from timber waste was a material capable of replacing cement (Elinwa *et al*.,2008).

Much work has not been reported on the behavior of re-vibrated concrete beam produced from coconut fibre ash (CFA) as a partial replacement for cement. As such, this study aims to examine the effect of CFA on flexural strength of re-vibrated concrete beam made from 0%, 5, 10, 15, and 20% replacements of OPC.

2 PHYSICAL PROPERTIES OF COCONUT FIBRES

Coconut fibre, also known as coir, is derived from the fibrous husk of the coconut plant and is used in the production of coir. Coconut fibres are mostly brown in color with varying lengths and diameters. More-over, other properties such as tensile strength and modulus of elasticity vary depending on the source and usage. A different researcher reported different physical properties of coconut fibre. The details of the physical properties of fibres as per past researchers (Naveen *et al*., 2013: Tensile strength is 175Mpa, water absorption 130 to 180 %, elongation 30 %; Amadi *et al*., 2013: Length 25mm, diameter 0.25mm, aspect ratio 100, tensile strength 405Mpa; Bai *et al*., 2019: Length 18mm, diameter 0.1 to 0.5mm, density 0.67 to 10g/cm^3; Ramakrishna *et al.*, 2005: Length 8 to 10mm, diameter 0.5 to 1.0mm, tensile strength 15 to 327Mpa; Ahmad *et al*., 2021: Length 20 to 30mm, diameter 0.32mm, tensile strength 176MPa, modulus 22.4GPa.

3 FRESH PROPERTIES

Concrete workability is a term that relates to how easily mixed concrete can be placed, compacted, and finished while retaining it homogeneity to the greatest extent possible. Unworkable concrete is one that cannot be easily worked. In unworkable, the cement paste is not sufficiently lubricated and it does not adhere to the aggregates correctly, resulting in significant aggregate segregation. Maintaining the homogeneity of an unworkable concrete mix is very difficult, and compaction of concrete requires a significant amount of work, which has a negative impact on the mechanical and durability performance of concrete.

According to one study, the value of slump flow decreased when the dose of coconut fibres was raised. The increased surface area of coconut fibres requires more water to cover, resulting in less free water for flowability. Moreover, CFA increased internal friction among concrete elements, necessitating more cement paste (Ahmad *et al*., 2020). Adding 0.25 percent coir fibre (by weight of aggregate) reduced slump to 50mm. The slumps of the following variants indicate decreasing values with increasing coir fibre content. This propensity is due to the coir fibres surface shape and physical qualities (Rumbayan *et al*.,2019). According to one study, coir fibres have hydrophilic surfaces and hence repel water (Ahmad *et al*.,2021). In similar manner, several studies have shown that the slump value decreases when coconut fibre is included (Ali *et al*., 2012; Pierad *et al*., 2013; Zhang *et al*., 2019).

According to one study, fresh density rose as the proportion of coconut fibre increased upto 2.0 percent, after which it decreased when compared to reference concrete. Coconut fibre at a dose of 2.0 percent exhibits the highest fresh density when compared to reference concrete (0 percent addition of coconut fibres). However, the fresh density was lowered with the addition of coconut fibres, with a minimum fresh density of 3.0 percent when compared to other coconut fibres reinforced concrete. The increase in fresh density of concrete reinforced with coconut fibre is related to crack prevention since CFA reinforced concrete has fewer plastic shrinkage voids and produces denser concrete (Althoey,2021). However, with the 4 percent addition of CFA, compaction becomes problematic, resulting in porous concrete and lower fresh density. A study claims that adding 1.5 percent CFA by volume to concrete increases density by 15% as compared to the reference concrete (Tadepalli et al., 2013). In contrast, when the fibre content of a specimens increased, the density of the specimens dropped (Ahmad et al., 2020). Due to the fact that fibres are light, their addition to concrete causes cavities in the matrix, which reduces the density of the concrete. As a consequence of the inclusion of low-density coconut fibres, a phenomenon is known as the “filled void effect” occurs, which decreases the density of the concrete when compared to palin concrete (Syed et al., 2020).

Density is an important factor that influences the flowability of concrete. A lack of workability leads to void in occupied space and reduced density (Ramli *et al*.,2023).

4 TREATMENT OF COCONUT FIBRES

To investigate the durability of coconut fibre, several treatments were carried out on the material. For the first minute, each fibre was soaked in an adherent solution (deionized water or natural latex) to ensure that it adhered to the other fibres. During this process, the adherent solution surrounds the coconut fibre, forming bonding layers between the two materials. A coating agent was then applied, which consisted of pozzolanic materials (silica fume or metakaolin). Pozzolans are attracted to the coconut fibre by the adhering solution in which they are dissolved. The production of "chicken fingers" is comparable to the process used in the development of this novel medicine (da Silva *et al*., 2022).

Using a latex polymer film and a pozzolan layer, the coconut fibre treatment was created to increase the flexural strength and durability of cement-based composites. The performance of the sample treated with silica fume and natural latex was 42.2 percent better than the performance of the sample without any treatment. When fibre samples were subjected to degradation tests, the mass conservation rate increased as a consequence of this treatment (silica fume and natural latex). This treatment resulted in an enhancement in the retention of fibre against the degradation process, according to the microstructural examination of the treated fibres isolated from CF. This treatment (silica fume and natural latex) has the potential to be a viable alternative to the use of CF in the creation of novel cementitious composite materials that have appropriate performance and long-term durability. The compressive and flexural strengths of the structures increased by up to 13 percent and 9 percent, respectively, according to the testing data. However, in terms of durability, the chloride penetration, intrinsic permeability, and carbonation depth increased with CF. The authors propose that the CF could be treated before being used in concrete to ensure that is protected against deterioration (Ramli *et al.,2022).* Coconut fibres were immersed in NaOH solutions with concentration ranging from 2 to 10% for four weeks. The authors discovered that the tensile strength reduced as the concentration of NaOH increased, which they attributed to the fibres becoming more fragile (Wang *et al*., 2021).

5 MECHANICAL PROPERTIES

5.1 Compressive Strength: is a material's or structure's capacity to bear loads without cracking or deflection. Compression shrinks a material's size. Concrete compressive strength gives an indication of the concrete properties. This single test determines whether or not concrete was correctly performed. In commercial or industrial construction, concrete's compressive strength ranges from 15N/mm2 to 30N/mm2. Compressive strength is tested on a cube or a cylinder. The American Society of Testing Materials established ASTM C39/C39 for compressive strength testing of cylindrical concrete specimen.

Research also found that fibres increased concrete's compressive strength up to a certain point before decreasing owing to a lack of workability (Ahmad et al., 2020). Even at a larger dosage, the compressive strength of concrete is lower to that of reference concrete. The fibre reinforcement's confinement on the specimen has a favorable impact on compressive strength. Compressive results in lateral expansion, which is limited by the coconut fibres (CF), resulting in increased compressive strength. Because of their strength, the fibres can sustain strain and shear (Ahmad et al., 2020). Compaction becomes problematic at larger dose (more than 2.0%) owing to a lack of workability, resulting in decreased strength. A study reported that in compression to reference concrete, 1.5 percent of the fibres enhanced compressive strength by over 15% (Tadapalli et al.,2013). At 1.0% by volume, fibres significantly improve the mechanical performance of concrete at both the initial and later ages. The greatest 28-day strength increase was found to be 29.15% (Usman et al.,2020). As a result, coconut fibre has an ideal limit. The experiments indicate that the best dosage of coconut fibre for strength is 2.0% by weight of cement (Ahmad *et al*.,2021).

A study indicates that the optimal quantity of coir fibre in concrete is 0.25%, which results in a 19% increase in 28-day compressive strength (Rumbayan *et al*., 2019). However, the optimum dose of fibres varies depending on the type of fibre, the physical aspect such as length and diameter, as well as the concrete mix design and the water-to-binder ratio. A study reported that in CF of 50 mm to 75 mm long, the compressive

strength decreases with the increase in fibre content. The decrease in compressive strength could be attributed to the decreased workability of fresh concrete caused by the increased content and length of fibres, as well as the lack of proper compaction during specimen casting, resulting in the formation of air voids. It might be possible due to the dilution of the cement matrix/hardened cement paste caused by the addition of fibres (Ahmad *et al*.,2020).

5.2 Flexural Strength: Flexural strength is the capability of an unreinforced concrete beam or reinforced concrete beam to withstand bending failure. According to ASTM standards, it is by loading 150mm by 150mm concrete beam with a span length that is at least three times the depth (ASTM,2010).

Research found that, when the percentage of coconut fibre is raised by the weight of cement up to 2.0%, the flexure strength improves, but subsequently drops when the percentage of CF is further increased as compared to a reference or standard concrete (Kikuchi et al.,2020).

The inclusion of CF at a rate of 2.0% resulted in the greatest possible flexure strength. After the addition of CF at a rate beyond 2.0%, the flexure strength gradually reduced. The flexural strength of all coconut fibre reinforced concrete is much higher than that of ordinary concrete. Coconut fibre increase flexural capacity by inhibiting the development of fracture. Because of the interfacial between the concrete components and the coconut fibres, the load is quickly transmitted to the coconut fibres. The breaking of cracks is prevented by coconut fibres, which allow the crack to flow around the fibres and transfer the stress. The coconut fibres and concrete matrix resist the load as a whole, resulting in increased flexural strength for the structure (Usman *et al.*,2020). The compaction process becomes more complicated as the quantity of fibre in the mixture increases. Using higher dosage, such as 3.0%, the workability of the concrete worsened, causing porous concrete and drop in flexural strength. According to other findings, the best quantity of CF IS 0.25%, which results in 19 % increase in 28-day flexural capacity (Ali *et al.*,2019). Table 1 shows a summary of the flexural strength of concrete with different doses of CF.

Table 1. Summary of mechanical performance of concrete with coconut fibres.

Author	Percentage of Replacement	Compressive Strength (MPa)	Flexural Strength (MPa)
Abbas *et al.*, (2021)	0 0.1 0.2 0.3 0.4 0.5 0.6	36 38 38 36.5 35 33.5 30	4.8 5.2 5.4 4.98 4.85 4.75 4.50
Srinivas *et al*., (2021)	0 0.5 1 1.5	8.0 8.66 9.93 4.75	6.33 3.23 3.82 2.80
Kumar *et al.*, (2020)	0 CF: 5% CF ASH: 15%	22.3 19.53 34.87	6.73 5.27 5.33
Khan *et al*., (2020)	Silica Fume: CF 0:2 5:2 10:2 15:2 20:2	 27.2 27.5 28.8 32.4 26.6	 6.2 6.6 7.8 8.3 4.7
Raj *et al.*, (2020)	0 0.3 0.4 0.5	9.5 11.5 8.0 7.5	1.4 1.7 1.2 1.1
Wongsa *et al*., (2020)	0 0.5 0.75 1	31 33 28 25	3.2 5.3 6.2 6.7
Krishna *et al*., (2018)	0 0.5 1 1.5 2	37.5 35 47.5 51 41.75	 -

6 DURABILITY

6.1 Water Absorption

The water absorption test analyses the rate of water absorption of the outer and inner concrete surface. The test includes measuring the increase in mass of concrete samples caused by water absorption as a function of the time when the specimen is exposed to water. Higher water absorption results in less durability since water contains various hazardous compounds that seeps into the concrete, causing concrete breakdown and resulting in reduced durability.

Research revealed that with the addition of CF, the amount of water absorbed increased (Abdullah *et al*., 2011). The effects of fibre volume fraction on heat conductivity and water absorption were not significant (Wongsa *et al*., 2020). A study concluded that the water absorption decreases as the percentage of coconut increase up to 2.0% addition of CF, and

decrease occurs gradually, with maximum water absorption observed at 0 % substitution and minimum water absorption observed at 2.0% addition of CF (Ahmad *et al*.,2021). It has also been reported that the inclusion of CF would result in an increase in the tensile strain characteristics of concrete, which would limit the creation and development of early fractures in the concrete (Huang *et al*.,2011). In other words, increasing concrete density reduces water absorption. Due to lack of workability, greater dosage (above 2.0%) resulted in less dense concrete. Because of the increased porosity of the coconut coir fracture mortar compared to the control mortar, according to one research, more water absorption was noticed in CF reinforced concrete than the control mortar. The porous structure of the cement blocks, as well as the presence of an interfacial zone surrounding the particles, are the most important elements influencing water absorption. The findings reveal that as compared to the control mortar; the coconut coir mortar noticed water absorption considerably in the greater amount (Sathiparan *et al*.,2017).

6.2. Permeability

The water absorption by immersion provides an estimate of the total pore volume of the concrete, but it provides no information on the permeability of the concrete, which is more essential in terms of long-term performance.

It is discovered that the permeability of concrete increased with the addition of CF. The continuous pore structure of the specimen has a significant influence on the permeability of the specimen (Hearn et al.,1994). Generally speaking, the wider the width of continuous pores, the more permeable the concrete would be considered to be. It is possible to produce continuous holes under a variety of situations, some of which include the capillary network formed by hydration, the interfacial transition zone between paste and aggregate, the production of micro-cracks, and others (Hearn *et al*.,2021). Not only the interfacial zones between the aggregate and the paste but there will also be a gap between the fibre and the matrix (Savastano and Agopyan, 1999). However, the authors hypothesized that there is another mechanism at work that is also responsible for the disparity. This gap may be linked to the strong water absorption characteristics of the coconut fibre, which is responsible for its existence. During the mixing process, a water film is formed around the fibre's immediate surroundings. The absorption capabilities of the film, as well as the osmosis pressure, will keep the film in place and cause the fibre to inflate. As the hydration process advances, the formation of the permanent shell structure starts to take place. As water is consumed by cement hydration and evaporation, the water film gradually vanishes, finally creating a gap between the fibre/matrix interfacial zone of the composite. When the fibre shrinks back to its former shape after inflating as a result of the drying process, the gap widens even further, creating a larger opening. According to the findings of a study, nitrogen gas travels through the natural fibre during the permeability test because the natural fibre has a porous cellular structure, increasing the likelihood of pore network connection during the test (Persson, 2000).

7 CONCLUSIONS

This paper presents a summary of research progress on coconut fibres. Coconut fibres are an inexpensive, recyclable, low-density, and environmentally acceptable building material. These fibres have excellent tensile qualities, and they may be utilized instead of traditional fibres such as glass and carbon steel fibres as partial replacement of cement in concreting. Based on a detailed review, the following conclusions have been made:

- The flowability of concrete decreased with addition of coconut fibre due to the larger surface of the fibre, which enhanced the internal friction among concrete ingredients, leading to less workability. Furthermore, an increase in fresh density is observed up to 2% addition of coconut fibres.
- Increased durability properties were also observed with addition of coconut fibres. However, less information is available in this regard.
- Mechanical characteristics such as compressive, split tensile, and flexural strength were improved up to a certain dose of coconut fibre, which depends on the physical properties

of fibres such as length, diameter, and aspect ratio. Furthermore, it can also be observed that coconut fibres improved flexure capacity (47%) more efficiently than compressive capacity (12%).

- The optimum dose of coconut fibres is the most important parameter for better performance of concrete, as a higher dosage results in more voids in hardened concrete due to lack of workability, leading to lower mechanical and durability performance of concrete.
- Re-vibration improves both compressive and flexural strength of fibres reinforced concrete beam.

It can be concluded that coconut fibres enhanced flexure capacity more efficiently than compressive capacity. Therefore, further research was recommended to add some pozzolanic materials such as silica fume and fly ash to improved compressive capacity of fibre reinforced concrete for high strength concrete. It is necessary to re-vibrate concrete when its still in it plastic form. It is also necessary to investigate a novel strategy that makes use of the water retention capacity of coconut fibres in order to generate high-performance cement composites using internal curing technology.

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Effect of Calcium Carbide Residue on the Compaction Characteristics of Tropical Black Clay Soil

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ABSTRACT
This study examines the effect of Calcium Carbide Residue (CCR) on the compaction characteristics of tropical black clay (TBC). The soil (TBC) was stabilized with 0, 2, 4, 6, 8 and 10% of CCR by weight of the dry soil. Laboratory compaction tests were conducted using British Standard Heavy (BSH), West African Standard (WAS), and British Standard Light (BSL) compactive efforts, to evaluate influence of the CCR on the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of the soil. The results show that MDD soil increases with increases in percentage of CCR, up to an optimum range of 6 – 8%, particularly under moderate compaction effort (WAS), before decreasing with further increase of CCR. Similarly, the OMC initially decreases at moderate CCR content, indicating improved particle packing, but increases beyond the optimal level due to the hydration demand of cementitious compounds. These findings highlight the potential of CCR as a cost-effective stabilizer for improving the compaction characteristics of tropical black clay, making it a viable alternative for soil improvement in geotechnical applications.

Keywords: *Calcium Carbide Residue, Compaction Characteristics, Tropical Black Clay Soil*

1 INTRODUCTION

Soil compaction is a critical factor influencing the strength and stability of geotechnical structures, as it directly affects load-bearing capacity, settlement behavior, and permeability of the bearing soil. However, certain soils, such as tropical black clay, exhibit poor compaction characteristics due to their high plasticity, low shear strength, and excessive shrink-swell potential (Osinubi *et al.*, 2011). These properties make them unsuitable for direct use in construction, necessitating stabilization to improve their engineering performance. Effective stabilization techniques, particularly chemical stabilization, have been explored to enhance the compaction behavior and overall suitability of such soils for construction applications.

Tropical black clay is an expansive soil commonly found in semi-arid regions where evaporation exceeds precipitation, including the Chad Basin and Upper Benue Trough in Nigeria (Amu *et al.*, 2011). The soil is rich in montmorillonite, a clay mineral responsible for its high-water absorption and volume change characteristics (Alhassan and Mustapha, 2015). These properties result in significant challenges in construction, as the soil experiences substantial swelling during wet seasons and shrinkage with cracking during dry seasons. The poor compaction characteristics of tropical black clay contribute to instability in structures and roads, leading to excessive maintenance costs and frequent failures.

To improve the compaction properties of tropical black clay, various soil stabilization methods have been employed, including mechanical and chemical stabilization. Mechanical methods such as densification and compaction can reduce void ratios and increase load-bearing capacity, but these methods are often insufficient for highly plastic soils (Osinubi, 2000). Chemical stabilization, on the other hand, involves the addition of materials such as cement, lime, fly ash, and industrial by-products to alter the soil's properties and improve its compaction characteristics (Arash *et al.*, 2012). However, the high cost and environmental concerns associated with conventional stabilizers have led to the exploration of alternative, cost-effective stabilizers derived from industrial waste.

Calcium Carbide Residue (CCR), a by-product of acetylene gas production, has emerged as a promising stabilizer for problematic soils. CCR contains high percentage of calcium hydroxide, which reacts with clay minerals to improve soil stability by reducing plasticity and enhancing compaction characteristics (Onyelowe

and Okafor, 2012). Utilizing CCR not only offers a sustainable approach to soil stabilization but also helps in waste management by repurposing industrial by-products for engineering applications. Several studies have shown that CCR has the potential to enhance the strength, density, and moisture retention properties of expansive soils, making it a viable alternative to conventional stabilizers (Osinubi *et al.*, 2010).

This study investigates the effect of Calcium Carbide Residue on the compaction characteristics of tropical black clay soil. The research evaluated the influence of CCR on compaction parameters, such as MDD and OMC, which are essential in achieving desired soil strength and stability. By analyzing the effectiveness of CCR as a stabilizer, this study contributes to the advancement of sustainable and cost-efficient soil stabilization techniques for geotechnical engineering applications.

2 MATERIALS AND METHODS

2.1 MATERIALS

The materials used for this study are Tropical Black Clay (TBC) and Calcium Carbide Residue (CCR).

2.1.1 TROPICAL BLACK CLAY (TBC)

The tropical black clay was collected by method of disturbed sampling at depth of 1.5m at Gwako village, latitude of 8°58'22.8" N and longitude of 7°7'8.4" E along Gwagwalada express way, FCT Abuja, Nigeria. The sample was preserved in polythene bags and transported to the Geotechnical laboratory of Federal University of Technology, Minna.

2.1.2 CALCIUM CARBIDE RESIDUE (CCR)

The calcium carbide residue was obtained from panel beaters at Ketaren Gwarri Mechanic Village in Minna. It was dried, grind and sieved through sieve No. 200 (75μm) before usage.

2.2 METHODOLOGY

Laboratory experiments were conducted to assess the effect of the calcium carbide residue on the compaction characteristics of the tropical black clay. The tests conducted include: Natural moisture content, specific gravity, sieve analysis, Atterberg limit and compaction test. The test procedures were in conformity with BS 1377 (1990). British Standard Heavy (BSH), British Standard Light (BSL) and West African Standard (WAS) energy levels were deployed in the compaction characteristics assessment.

3 RESULTS AND DISCUSSION

3.1 CHEMICAL COMPOSITION OF CALCIUM CARBIDE RESIDUE

Table 1 shows the chemical composition of the Calcium Carbide Residue (CCR) used in the study. The result indicates that calcium oxide (CaO) is the dominant constituent, accounting for 65.04% of the material. This high CaO content makes CCR highly alkaline and suggests its strong cementitious potential. The significant loss on ignition (LOI) of 26.67% further implies the presence of bound water or volatile components, likely due to the formation of calcium hydroxide ($Ca(OH)_2$) upon exposure to moisture. Such characteristics enhance the potential for CCR to be used in soil stabilization. This trend of oxide composition is similar to that reported by (Utser and Taku, 2012; Manasseh and Ejelikwu, 2013).

TABLE 1: SOIL CHEMICAL COMPOSITION OF CALCIUM CARBIDE RESIDUE (CCR)

Oxide	% composition
SiO_2	2.45
Al_2O_3	1.83
Fe_2O_3	0.12
CaO	65.04
K_2O	0.08
Na_2O	0.13
MgO	1.81
SO_3	0.57
MnO	.
P_2O_5	0.71
TiO_2	.
LOI	26.67

LOI = Loss on ignition

3.2 PROPERTIES OF THE TROPICAL BLACK CLAY

The index properties and compaction characteristics of TBC is presented on Table 2. The result indicates that the soil is highly plastic, fine-grained with significant swelling and shrinkage tendencies. The particle size distribution from Table 2 and Figure 1 shows that 75.66% of the soil passes the No. 200 sieve (0.075 mm), confirming its fine-grained nature, which aligns with its

classification as a high plasticity clay (CH) under the Unified Soil Classification System (USCS) and an A-7-5 soil, under the AASHTO classification system. These classifications suggest that the soil has poor drainage, low bearing capacity, and high susceptibility to volume changes due to moisture fluctuations. The liquid limit of 66% and plastic limit of 21.53% indicate a soil with a high-water retention capacity, while the Plasticity Index (PI) of 44.47% confirms its expansive nature. This high PI signifies a strong tendency to undergo significant swelling when wet and shrinkage when dry, making it problematic for engineering applications, particularly for roads and foundations. The linear shrinkage of 12.97% further underscores its volume instability, which could result in surface cracks and structural damage when used as a subgrade material. The specific gravity of 2.61 suggests predominance of clay minerals such as montmorillonite, which are known for their high swelling potential.

The compaction characteristics of the TBC vary under different compaction efforts. The MDD decreases as compaction effort reduces, while the OMC increases. Under British Standard Heavy (BSH) compaction, the soil achieves an MDD of 1.83 g/cm^3 at an OMC of 15.3%, indicating that higher compactive effort results in better densification of the soil particles. Under West African Standard (WAS) compaction, the MDD drops to 1.63 g/cm^3, and the OMC increases to 17.6%, suggesting that the soil requires more water to achieve maximum compaction with lower compactive effort. Similarly, with British Standard Light (BSL) compaction, the MDD further reduces to 1.62 g/cm^3, while the OMC increases to 18%, indicating that with minimal compactive effort, the soil retains more moisture and remains less dense. This trend highlights the influence of compaction effort on the soil's structure, as higher energy compaction leads to a denser, stronger soil matrix, which is crucial for improving its engineering performance.

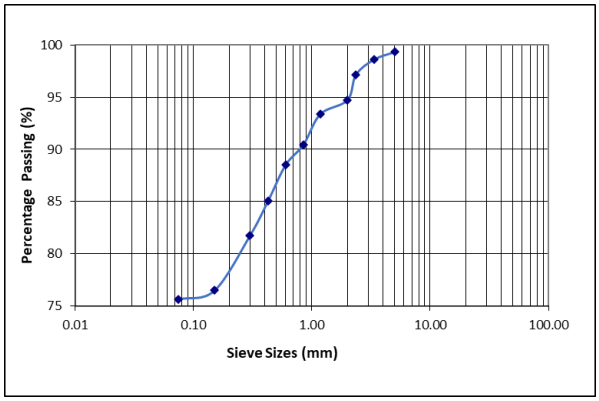


Figure 1: Particle size distribution curve for the tropical black clay

TABLE 2: BASIC PROPERTIES OF THE TROPICAL BLACK CLAY (TBC)

Basic characteristics	TBC		
% larger No.200 sieve (>0.075 mm)	24.34		
% passing No.200 sieve (<0.075 mm) (%)	75.66		
Liquid limit (%)	66		
Plastic limit (%)	21.53		
Plasticity index (%)	44.47		
Linear shrinkage (%)	12.97		
Specific gravity	2.61		
USCS	CH		
AASHTO	A-7-5		
Colour	Greyish black		
	BSH	WAS	BSL
MDD (g/cc)	1.83	1.63	1.62
OMC (%)	15.3	17.6	18

3.3 EFFECT OF CALCIUM CARBIDE RESIDUE (CCR) ON CONSISTENCY LIMIT

Consistency limits of the TBC stabilized with CCR, illustrated on Figure 2, exhibit a progressive reduction in the Liquid Limit (LL) and Plasticity Index (PI) with increasing CCR content, while the Plastic Limit (PL) increases. This trend is indicative of the modification in the clay's plasticity due to the pozzolanic reaction between the calcium-rich CCR and the clay minerals,

leading to particle aggregation and improved soil workability.

The LL of the untreated TBC is 66%, signifying high water retention capacity and substantial volume change potential. With the addition of 2% CCR, the LL decreases to 61%, further reducing to 57% at 10% CCR. This reduction aligns with the findings of Gurugubelli *et al.* (2017) and Joel and Edeh (2016), who reported that the introduction of calcium-based stabilizers reduces the clay's affinity for water due to cation exchange and flocculation. Similarly, the PI, which initially measures 44.47%, decreases consistently with CCR addition, reaching 27.33% at 10% CCR. A lower PI indicates reduced swelling and shrinkage tendencies, making the soil more stable under moisture fluctuations. This behavior corroborates the observations of Osinubi *et al.* (2010), who noted that lime and similar stabilizers significantly lower the PI of expansive clays by binding free water within cementitious compounds.

Conversely, the PL increases from 21.53% in the untreated TBC to 29.67% at 10% CCR, implying a reduction in the clay's plasticity and an enhancement in its strength at lower moisture contents. The increase in PL is consistent with previous studies by Isah and Sharmila (2015) and Joel and Edeh (2016), who found that soil stabilization with calcium-based additives enhances soil cohesion and reduces deformability. Overall, the observed changes in the consistency limits confirm the effectiveness of CCR in improving the engineering properties of tropical black clay, making it a viable stabilizer for geotechnical applications.

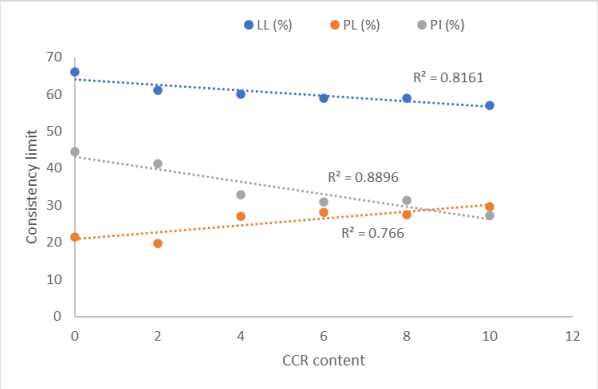


Figure 2: Effect of CCR on the consistency limit

3.4 Effect of Calcium Carbide Residue (CCR) on the Compaction Characteristics

3.4.1 Maximum Dry Density

Maximum Dry Density (MDD) of the tropical black clay stabilized with CCR varies across different compaction efforts, showing a noticeable trend in response to increasing CCR content (Figure 3). Under British Standard Heavy (BSH) compaction, the MDD remains relatively stable between 1.83 and 1.84 g/cm^3 for CCR contents up to 6%, indicating that moderate CCR addition does not significantly affect the soil's compactability under high-energy compaction. However, at 10% CCR, the MDD decreases to 1.79 g/cm^3, suggesting a reduction in particle packing efficiency due to the replacement of soil fines with lighter CCR particles.

Under West African Standard (WAS) compaction, the MDD shows a gradual increase from 1.63 g/cm^3 at 0% CCR to 1.67 g/cm^3 at 8% CCR, before slightly reducing to 1.65 g/cm^3 at 10% CCR. This trend indicates that the inclusion of CCR improves the densification of the soil up to an optimal point, beyond which further CCR addition reduces the soil's compactability. The improved MDD at moderate CCR levels could be attributed to the flocculation and aggregation of clay particles, which enhances particle rearrangement and densification (Akinmade, 2008; Oyediran and Fadamoro, 2015). However, excessive CCR may lead to increase in voids, reducing the overall dry density. A similar trend is observed under British Standard Light (BSL) compaction, where the MDD initially increases slightly from 1.62 to 1.63 g/cm^3 at 4 and 6% CCR, but then decreases progressively to 1.57 g/cm^3 at 10% CCR. The reduction at higher CCR contents suggests that the lower energy compaction does not effectively overcome the increasing particle voids, leading to reduced densification.

Generally, the results indicate that inclusion of CCR up to an optimum level (around 6 – 8%) enhances the compactability of tropical black clay, particularly under medium compaction effort (WAS). However, excessive CCR content beyond 8% reduces MDD across all compaction levels, likely due to the replacement of heavier clay particles with lower-density CCR and an increase in voids.

3.4.2 OPTIMUM MOISTURE CONTENT

The optimum moisture content (OMC) of tropical black clay stabilized with CCR exhibits variations across different compaction efforts (Figure 4), indicating the influence of CCR on the soil's water requirement for maximum compaction. Under British Standard Heavy (BSH) compaction, the OMC remains relatively stable, ranging between 15.3 and 15.5% for most CCR contents, except at 6% CCR, where it drops to 12%. This reduction suggests that at this CCR level, the soil achieves maximum densification with less water, likely due to the improved particle arrangement and binding effect of CCR. However, beyond 6% CCR, the OMC increases again, indicating that higher CCR levels require more moisture for proper hydration and compaction.

Under West African Standard (WAS) compaction, the OMC increases from 17.6% at 0% CCR to 20.2% at 4% CCR, demonstrating that the addition of CCR enhances the soil's water demand at lower compaction effort. This increase could be attributed to the reaction of CCR with the clay minerals, leading to the formation of cementitious compounds that require additional water. At 6% CCR, the OMC drops to 18%, suggesting an optimal point where the soil structure is modified sufficiently to reduce water demand. However, beyond this, the OMC starts to increase again, reaching 19.1% at 10% CCR, further confirming that excessive CCR addition increases the soil's moisture requirement.

Under British Standard Light (BSL) compaction, the OMC follows a similar trend, increasing from 18% at 0% CCR to 21.8% at 10% CCR. This consistent rise suggests that under lower compactive effort, the presence of CCR significantly alters the soil's water retention properties, leading to a higher moisture requirement. The increase in OMC at higher CCR levels can be attributed to the finer particle size of CCR, which creates a greater surface area for water absorption and the need for hydration reactions.

Generally, the results indicate that introduction of CCR affects the water demand of tropical black clay, with an optimal range observed around 6% CCR, where the OMC is lowest across all compaction methods. Beyond this point, increasing CCR content results in a higher moisture requirement, likely due to the increased chemical reactions and the presence of finer particles. This observed trend of OMC variation is also similar to that reported by Isah and Sharmila (2015).

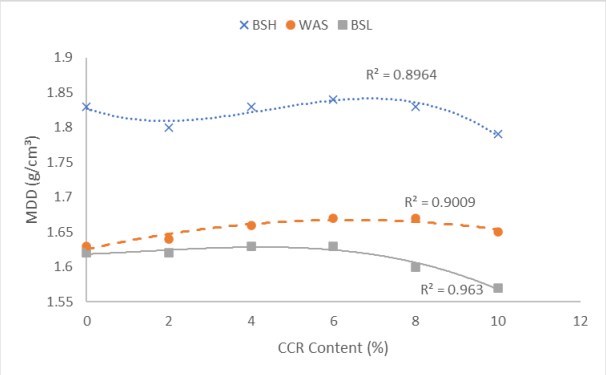


Figure 3: Variation of maximum dry density with CCR content

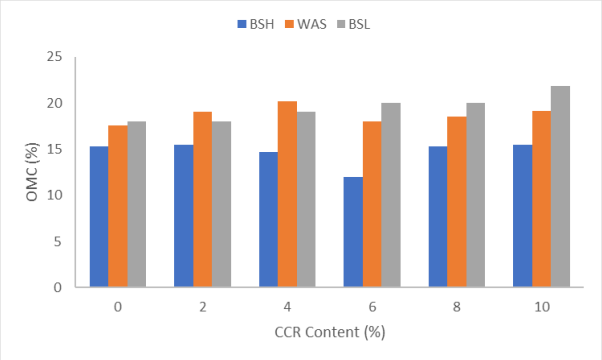


Figure 4: Variation of optimum moisture content with CCR content

4 CONCLUSION

The study has demonstrated that addition of CCR to clay soil, significantly influences its compaction characteristics. The high calcium oxide (CaO) content in CCR enhances its cementitious potential, promoting particle flocculation and aggregation, which affects soil densification. The natural soil exhibits high plasticity, poor drainage, and significant swelling-shrinkage tendencies, making it unsuitable for direct engineering applications. Compaction results show that the MDD increases with CCR addition up to an optimal range of 6–8%, particularly under moderate compaction effort (WAS), before declining at higher CCR contents. This reduction in MDD beyond 8% is attributed to the replacement of heavier clay particles with lighter CCR and an increase in void spaces.

Similarly, the OMC trends indicate that moderate CCR addition initially reduces the soil's water demand due to improved particle arrangement. However, beyond the optimal CCR content, the OMC increases due to the hydration requirements of the cementitious compounds formed. The variation in compaction characteristics across different compactive efforts highlights the role of

CCR in modifying soil structure, with higher compaction energy achieving better densification. These findings suggest that CCR is an effective stabilizer for tropical black clay soil when used within optimal limits, offering a sustainable and cost-effective approach to soil improvement in geotechnical applications.

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CIRCULAR ECONOMY FRAMEWORKS FOR MANUFACTURING INDUSTRY-A REVIEW

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ABSTRACT
Manufacturing industries have been played a significant role in terms of production in attempt to improve economy worldwide. However, in a traditional linear economy setting, it becomes unrealistic prove to achieve sustainable production and consumption patterns. The concept of circular economy has been proved to be the only way out in the present environmental issues and unavailability resources, it aims at eventually severing this link, through keeping resources in the loop. Through a systematic literature review, this paper attempts to revisit the concept of circular economy in the manufacturing industries in order to determine whether the body of research has improved beyond framework development and into verified implementation in manufacturing industry.

The review shows that the research field has indeed advanced from purely conceptual framework into empirical studies and research into implementation tools. However, in empirical studies and framework development the sustainability impact of CE practices is completely addressed only through the environmental issues, neglecting the social dimension, economic dimension and even the percentage of virgin material usage for production is neglected. Further, a key finding is that the generality of narrow approaches to sustainability in manufacturing results to a risk that circular economy implementation efforts will become difficult if percentage of virgin materials usage by industries are not evaluated. Holistic approaches are needed to avoid the implementation of solutions that may be framed as circular, but neglect the sustainability component.

Keywords: *Business and supply loop, circular economy, framework, indicators, Manufacturing.*

1.1 INTRODUCTION

To make it clear, circular economy (CE) is a new introduction concept which is achieving growing interest as a way to explain the practices of market agents to protect natural resources and reduce their impacts on natural resources. The main idea of this concept is to review the production and consumption patterns of the current socioeconomic system through the promotion of a series of serious interventions in the contemporary linear production process (i.e., take-make-dispose). These interventions promote a CE model whereby the consumption of raw materials and natural resources can be substantially reduced (Charalampides, Arvanitidis et al. 2014)

The CE is an economic system considered to transform the traditional linear economy and it has been accepted as a potential enabler of sustainable development (Urbinati, Chiaroni et al. 2017) . In a linear economic system, raw materials are sourced, manufactured, used and then discarded; such an end-of-life process leads to environmental degradation due to the continued exploitation of limited resources (Millar, McLaughlin et al. 2019).

CE can now be defined as "an industrial system that is restorative or regenerative by intention and design"(MacArthur 2013, MacArthur 2013) . It the replaces traditional linear economy concept with restoration, taking products and material use from 'cradle to grave' to 'cradle to cradle' (MacArthur 2013), (McDonough 2002). That is, CE considers discarded products or components as materials and resources for the input of new manufacturing processes. For manufacturing industries facing challenges of resource scarcity and environmental impact, it is important to reduce, reuse and recover resources in production and consumption processes and keep products and materials at their highest utility and value (Kirchherr, Reike et al. 2017), (Lieder and Rashid 2016).

Over the decade now serious attention had been paid worldwide to the new concept and development of framework model for Circular Economy, CE, especially in the manufacturing industries with the aim to provide a better alternative to the dominant economic development model, so called “take, make and dispose will be minimised. (Mendoza, Sharmina et al. 2017), (Reike, Vermeulen et al. 2018) and (Blomsma, Kjaer et al. 2018) pointed out that such circular strategies frameworks can identify or emphasize different (groups of) circular strategies, which can be linked to addressing different types of structural waste. (Blomsma, Kjaer et al. 2018) established the fact that little work has been carried out with regard to ensuring that frameworks are seen as relevant and useful by intending manufacturing industries. For these reasons, there is scope to further develop these frameworks to support visioning in Circular Oriented Innovation (COI). The plastic manufacturing industry in particular is important to global economic development because it provides raw materials for a variety of sectors. However, the industry's linear nature in some countries, as demonstrated by the production-consumption-disposal cycle, has resulted in extensive environmental deterioration and resource depletion. Plastic garbage, in particular, is a major hazard to ecosystems, human health, and the economy. In today's world, plastic waste is one of the environmental contaminants. According to (Karstensen, Engelsen et al. 2020), proved that manufacturing industries waste creates more environmental hazards through greenhouse gas emissions, climate change, and causing global warming. It implies that the traditional linear economy which causes environmental nuisance should be looked into and develop a framework which allows sustainable economy. The Manufacturing Industries in Nigeria is at a critical crossroads, striving with the far-reaching environmental condition of its linear production-consumption-disposal cycle. With serious concerns about plastic pollution, resource depletion, and climate change, the industry immediately needs radical action. To accomplish the circular economy in the plastic manufacturing sector, implementing this new paradigm shift also calls for new frameworks and behavioural changes. Recently research on circular economy has gained significantly attention to researchers, there is a well-established need to consider the circular economy for industrial wastes such as metals, papers, plastics when addressing the challenges of pollution. Most research on plastics focus within the context of achieving a circular economy addresses a specific technology, plastic product, material or intervention that applies to a segment of a supply chain.

1.2 CIRCULAR ECONOMY AND MANUFACTURING INDUSTRY

(Blomsma, Pieroni et al. 2019) presented a framework that introduces a taxonomy of circular strategies, developed for use by manufacturing companies engaging in circular economy (CE) oriented innovation. (De Mattos and De Albuquerque 2018) proposed a framework that analysed how organisation can develop a circular business model, identifying the feasibility factors and respective strategies. (Lanaras-Mamounis, Kipritsis et al. 2022) used a framework for evaluating the progress of firms towards the implementation of circular economy (CE) strategies by utilizing an evaluation matrix which is based on the three-level context of CE, the key “Rs” principles/strategies of CE, and material loops, an empirical analysis was carried out in a sample of plastic industries. (Di Maio and Rem 2015) presented a micro-level indicator,

evaluated the recaptured economic value of products through recycling strategies. (Park and Chertow 2014) established the reuse potential indicator (a micro-level CE strategy-oriented indicator) which estimated the reuse capability of waste materials by taking into account alternative waste management technologies. (Felicio, Amaral et al. 2016) proved a single indicator which assesses the achieved level of industrial symbiosis and the resulting presence of by-product and waste synergies in EIPs. (Saidani, Yannou et al. 2019) provided 10 criteria for classification of circular economy CE indicators linked to implementation level (i.e., micro-, meso-, macro-level) and the application level of indicators (i.e., general indicators or indicators for a specific sector). (Bocken, De Pauw et al. 2016) established three types of circular business models, namely, the first type is the closed loop which operates on minimising the use of virgin materials at the manufacturing stage and on the valorisation of materials within their useful lifetime. Another type of business model is the narrow loop which defines CE actions and core strategies that are not closed the loop but to reduce the use of virgin material and their losses. The third business model is the slow loop which intends at increasing the useful lifetime of materials and products in order to reduce the demands for new production and consequently the use of virgin materials. (Elia, Gnoni et al. 2017), (Chun-Rong and Jun 2011), (Saidani, Yannou et al. 2019) developed suitable methods, techniques, and frameworks and evaluated the progress towards CE facilitating governments, firms, and various stakeholders to set, achieve, and monitor realistic CE targets. Such measurement frameworks have been proposed for each level of CE implementation developing various types of indicators. (Felicio, Amaral et al. 2016) established a single indicator and used it to assess the achievement level of industrial symbiosis and the resulting presence of by-product and waste synergies in eco-industrial parks EIPs. (Wang, Lee et al. 2018) developed a framework on a circular composite index used group of indicators and assessed the level of circularity in a sample of 40 Chinese cities. (Pauliuk 2018) presented a framework and recorded inputs, outputs, and material stocks of selected sample firms through LCA thinking. It is based on a single-level indicator which provided interesting insights for many of the CE strategies allowing direct comparisons between them. (Genovese, Acquaye et al. 2017)applied a framework that were involved a combination of emission indicators and compared the environmental impact of linear and circular supply chains, in which the by-products from one sector are considered input for another one.

RESEARCH TRENDS IN DEVELOPMENT OF CE FRAMEWORK

In many research attempts to develop a suitable methods, techniques, and frameworks to measure the achievement towards CE, facilitating governments, firms, and various stakeholders to set, achieve, and monitor realistic CE targets. Such measurement frameworks have been developed for each level of CE implementation though the majority of these studies provide useful classifications for CE indicators. The incorporation of CE strategies into the business models (i.e., material loops) has also addressed in the literature. The shift in the orientation in measuring the frameworks with respect to the CE strategies, widely known as “Rs” models/frameworks has been investigated. With this background, a review of some of the trending works would further widen the research gap in the quest to improve circular economy framework that could be

recommended for implementation in manufacturing industries in Nigeria.

FUTURE TREND IN DEVELOPMENT OF CE FRAMEWORK

It has been affirmed that many research works have been done in efforts on developing CE transition methodology and framework from traditional linear economy that is frequently characterised by the presence of structural waste and environmental nuisance as reviewed and overviewed by many researchers. It is of worth research that CE indicators and measurement frameworks should be carefully studied in order to underline the crucial aspects, for holistic framework which will be able to define the integration of CE progress of organisation at all levels. From a waste management standpoint and managerial point of view, as well as percentage of raw material usage, such a framework could be a practical tool for managers and investors to identify the crucial points of CE performance and CE investments, providing information about investment risks and the progress of already funded CE projects. Therefore, some further analysis of plastic manufacturing industries CE indicators is necessary.

2. METHODOLOGY

This paper considered the research method of systematic literature review. An exhaustive search of the literature was performed, before combining narrative and tabular methods for synthesizing literature. The literature on the field of CE is, by now, abundant. It was therefore crucial to limit the scope of the research to only literature relevant to the research questions. A systematic approach was key. The literature review was therefore performed stepwise. This stage included stating the main goal of the study and associated research questions. A search strategy and key criteria for inclusion and exclusion of papers was developed. Thereafter, the data collection step, at which database selection and the identification of appropriate keywords were central elements. This was followed by sorting and exclusion.

Table 1: Developments in Circular Economy Frameworks for Manufacturing Industry

S/N	Conceptual Framework	Factor(s) and Enabler(s)	Production Product	Findings	Research Gap	Reference
1	Assessing the corporate CE practices in relation to all levels of CE implementation (i.e., micro-, meso-, and macro-level),	Examine the effectiveness of the proposed framework and identify key elements which can be further improved.	plastic	Firms show a better performance at the macro-level than the other levels	The frameworks were tested for plastic industry and underscored other manufacturing industries	(Lanaras-Mamounis, Kipritsis et al. 2022)
2	Developing a circular strategies framework for manufacturing companies to support circular economy-oriented innovation	Inappropriate mapping strategies currently applied. Lack of Finding solution for improving circularity across a range of business processes.	Manufacturing companies	It provided guidance in identifying what business areas eco-innovation for CE is possible or necessary.	A tool for inspiring, motivating and aligning people should be further study.	(Blomsma, Pieroni et al. 2019)
3	Performance indicators for a circular economy	Environmental challenges	Post-industrial plastic waste	The results show that the indicator can be a very useful approach to guide waste streams towards their optimal valorization.	Thermosets material or other material types were not addressed	(Huysman, De Schaepmeester et al. 2017)
4	Companies innovate business models and supply chains for a circular economy.	Product/Process/Service innovation.	Manufacturing industries	The findings strengthen the understanding of interlink between the two major types of innovation.	Setting for circular innovation strategy was not addressed.	(Kaipainen, Urbinati et al. 2022)
6	Evaluation of Factors Affecting the Transition to a Circular Economy.	Climate change and reduction carbon emissions.	Both business model and manufacturing processes.	The results of empirical research showed that the factors attention to the environment and attitude towards intention.	Framework model limited to planned behavior but not manufacturing process industries.	(Trần, Phan et al. 2022)
7	Facilitating Circular Economy Strategies Using Digital Construction Tools: Framework Development	Resource constraints, human health and climatic change.	Construction sector.	Framework offers practical insights for construction industry practitioners and helps to investigate several critical barriers.	Framework was not considering other stakeholders in the construction process.	(Jemal, Kabzhassarova et al. 2023)
8	Moving from Linear to Circular Economy: Life-Cycle Assessment on Plastic Waste Management	Environmental issues	Plastic materials	Study revealed that the combined mechanical recycling and pyrolysis with incineration of residuals scenario has the lowest environmental impact.	The model did not provide solution to transitioning to circular economy.	(Almadhi, Abdelhadi et al. 2023)
9	Value-addition to plastic waste towards achieving a circular economy.	Unsustainable waste management practices and environmental issues	Plastics	The new technologies need to employ to close the waste generation loop.	Further research need to be looking into how to expand reuse models, new business models.	(Kumar, Bhujbal et al. 2024)
10	Circular economy for the built environment: a research framework	Sustainability of the built environment	Manufacturing industries	The result shown that the greatest challenges ahead lie not in further technological innovation but rather in the role of people, both as individuals and as a society.	The research undermine the circular economy at macro level.	(Pomponi and Moncaster 2017)
11	Assessment of plastic waste generation and management	Environmental issue and unsustainable waste disposal practices	Plastic	The result shown that the facility to segregate, recycling, and up cycling of plastic waste were not provided	The research only focused plastic materials, however, undermined other materials.	(Oladipupo, Ayanshola et al. 2024)

12	Plastic circular economy framework using hybrid machine	Environmental issues	Plastics	The results shown the maximum recycling rate for the case study.	The research framework focused on plastics waste while other industrial wastes were unexplored.	(Chin, Varbanov et al. 2022)
13	Plastic Pollution, Waste Management Issues, and Circular Economy Opportunities	Plastics management	plastic pollution effects on rural communities and Waste Management Issues	The results revealed that rural communities need to be enlightening the economy opportunities on circular economy through generation of plastics wastes.	The study underexplored other industrial wastes.	(Mihai, Gündoğdu et al. 2021)
14	Understanding circular economy awareness and practices in manufacturing firms	Manufacturing industries	Environmental issues	The research findings shown that with the growing emphasis on CE across the globe by governing bodies, firms are becoming more aware of CE practices.	The study provides manufacturing firms with a thorough understanding of the state of CE practices.	(Liakos, Kumar et al. 2019)
15	Implementation of circular economy approaches in the electrical and electronic equipment (EEE) sector	Electrical Manufacturing industries	Due to large untapped potential in the Electrical Manufacturing industries.	The findings indicate that no single instrument alone from a specific policy domain can address the variety of existing barriers and gaps.	The study covered only Electrical Manufacturing industries understudied other manufacturing industries.	(Rizos and Bryhn 2022)

CONCLUSION

The aim of this research paper was to provide a review of the empirical literature on CE framework in manufacturing industry and to identify the research findings and research gaps taking place between industrial actors and academics to promote further studies. It was found that most published literature from before 2015 was conceptual; this review study finds that literature based on case studies has grown. All case studies reviewed are from after 2015, showing that there is progress towards more empirical research on manufacturing companies relating to CE framework implementation.

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STABILIZATION OF CLAY- RAP COMPOSITE WITH CALCIUM CARBIDE RESIDUE AND ZEOLITE FOR ROAD CONSTRUCTION - A REVIEW

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ABSTRACT
This paper review the previous studies on the stabilization of clay – RAP composite using calcium carbide residue (CCR) and zeolite as additive. Various studies have categorized clay soils as deficient soils for use as road construction material. The reclaimed asphalt pavement (RAP) have also been studied extensively as material that contained aggregate which can effectively be reutilized to improve deficient soil materials for road construction. However, the mixture of RAP with deficient clay soil was observed to perform satisfactorily without the intrusion of water from external sources. Where water get to the compacted clay-RAP mixture, the compacted specimen loose its strength immediately which makes the mixture to possess low durability. Addition of chemicals like calcium carbide residue (CCR) and Zeolite have been found to improve the engineering properties of individually and as a mixture. The CCR contributes calcium ion while the zeolite contribute both the silica and aluminate which together form a cementitious calcium silicate hydrate (CSH) and calcium silicate aluminate (CSA). The mixture of these two chemicals will serve to increase the durability of the deficient clay soil. Application of response surface methodology will bring out the relationship between all the variables used in the study and which can be used to derive a model equation that later can be applied for response prediction and the determination of optimal conditions.
Keywords: *Clay-Rap Composite; Calcium Carbide Residue; Zeolite; Response Surface Methodology; Stabilization; Unconfined Compressive Strength;*

1.0 INTRODUCTION

The stability and serviceability of most engineering projects or structure depends largely on their foundation and the bearing capacity of soil that supports them (Chesworth, 2008). A road pavement may serve its purpose if the foundation or sub grade meets the minimum required standard in the highway codes. Globally today there is an incessant increase in collapse of buildings and roads due to the foundation failure which result in the loss of lives and properties.

Clay composed of soil particles that are extremely fine (0.002mm in diameter). The particles are composed predominantly of mineral group of kaolinite, illite and montmorillonite (Craig, 1992; Das, 1998). Expansive soils of clay out-crop in large areas have caused persistent difficulties in road construction which is associated with volumetric change when subjected to water content (Houmadi *et al.,* 2009). These soils require stabilization to improve the requisite engineering properties of clay.

Clays are generally composed of micro-crystalline particles of a group of minerals. Since clay science has been the interest of people from different backgrounds, a specific definition of this material is not available (Sirivitmaitrie, C., *et al.*, 2008). Generally, clays are naturally occurring material primarily composed of fine-grained minerals, show plasticity when mixed with appropriate amount of moisture and become hard when dried (Sirivitmaitrie, C., *et al.*, 2011; Das, B., *et al.*, 2015). Das, 2015 indicated the characteristics of clay, which included: (a) Small particle size (usually smaller than 0.002 mm) (b) Net negative charge (c) Show plasticity when mixed with moisture

Clay Mineralogy Clay minerals are crystalline sheet like structure, which consist of hydrous alumino-silicates and metallic ions. There are two fundamental crystal units of clay minerals, i.e. tetrahedral and octahedral. A tetrahedral unit belongs to four oxygen enclosing silicon, where as an octahedral unit composes of six oxygen or hydroxyls at corners surrounding aluminum, magnesium, iron or other ions. The schematic of basic tetrahedral and octahedral unit are presented in Figures 1 and 2, respectively.

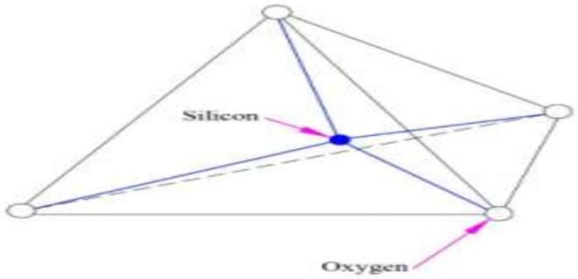


Figure 1.0: Single unit of tetrahedral mineral (Source: Mitchell, J., *et al.*, 2005)

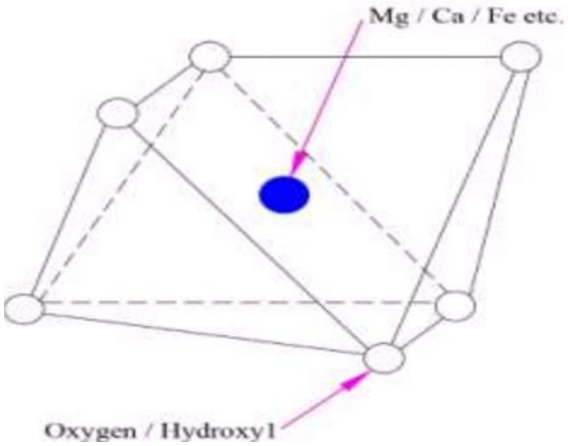


Figure 1.1: Single unit of octahedral mineral (Source: Mitchell, J., *et al.*, 2005)

Based on the arrangement of stacks, bonding, isomorphous substitution, and presence of metallic ions, different clay minerals can be constituted. Some of the common clay minerals are kaolinite, montmorillonite, illite, nontronite, muscovite, (Peng, X., *et al.,* 2006). However, for engineering purpose kaolinite, montmorillonite and illite have particular importance in geotechnical engineering (Hwang, C., *et al.,* 2006).

Kaolinite Kaolinite is known as 1:1 mineral because the inherent crystal structure consists of one tetrahedral and one octahedral sheet. Successive basic layers are bonded together by hydrogen bond between hydroxyls of the octahedral sheet and oxygen of the tetrahedral sheet. Due to this hydrogen bond, a large crystal of kaolinite is developed. The thickness of the basic crystal layer is 0.72 nm. A schematic of the crystal structure of kaolinite is presented in Figure 3.

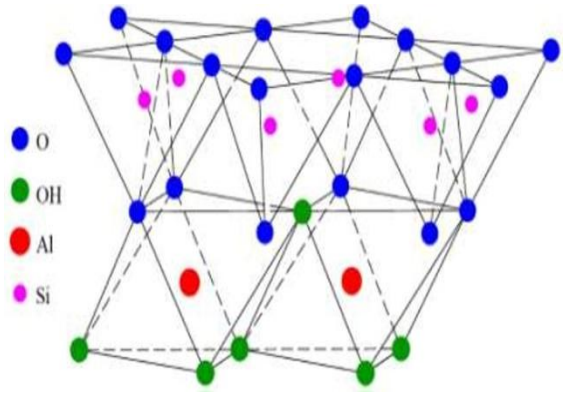


Figure 1.2: Structure of kaolinite crystal (Source: Mitchell, J., *et al.*, 2005)

Montmorillonite The basic unit of montmorillonite consisted of two silica sheets and one alumina sheet. This mineral is known as 2:1 mineral where the distance between the unit cells is approximately 0.96 nm. The top of the silica sheets are bonded by van der Waals force, and there is a net negative charge deficiency in octahedral sheet. Therefore, water and exchangeable ions can center and break the layer. The structural unit of montmorillonite is presented in Figure 4. Because of the layer separation and hydration, montmorillonite mineral is characterized by swelling behavior. In addition, montmorillonite minerals show extensive isomorphous substitution for $Si^{4+}$and Al^{3+} by available cations. According to the literature, Al^{3+} can replace as much as 15% of Si^{4+} in the tetrahedral sheet (Peng, X., *et al.*, 2006). The overall charge deficiency resulting from the ion substitution ranges from 0.5 to 1.2 per unit cell. The typical ranges of cation exchange capacity of montmorillonite are between 80 and 150 meq/100 g. The surface morphology of montmorillonite mineral is characterized by equidimensional flakes, and may appear as thin films. Furthermore, directional strain may cause by large amount of substitution of Fe^{3+} and/or Mg^{2+} for Al^{3+} which may result needle shaped fabric structure in montmorillonite. Due to the inherent configuration and high surface activity, the specific surface area (exclusive of interlayer zone) of montmorillonite can vary from 50 to 120 g /m .

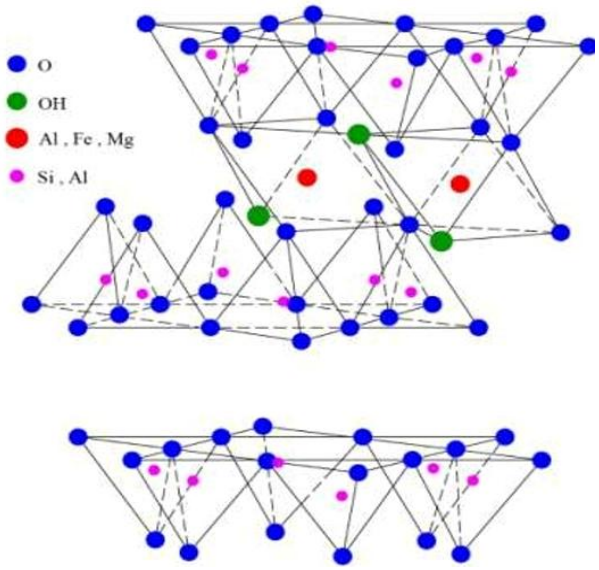


Figure 1.3: Structure of montmorillonite crystal (Source: Mitchell, J., *et al.*, 2005)

Illite Illite mineral is composed of two silica sheets and one alumina sheet, and known as 2:1 mineral. The basic unit configuration is similar to montmorillonite; however, the basic layers are bonded by potassium. The diameters of hexagonal aperture in silica sheet are exactly similar to the ionic radius of potassium (K^+). Therefore, the presence of potassium (K^+) makes the bond between the layers very strong. The schematic of the structure of illite is presented in Figure 5. The overall charge deficiently is mostly in the silica sheets, and ranged between 1.3 to 1.5 units per cell. The additional charge is balanced by non-exchangeable potassium (K^-) ions. The typical cation exchange capacity of montmorillonite ranges from 10 to 40 meq/100 g.

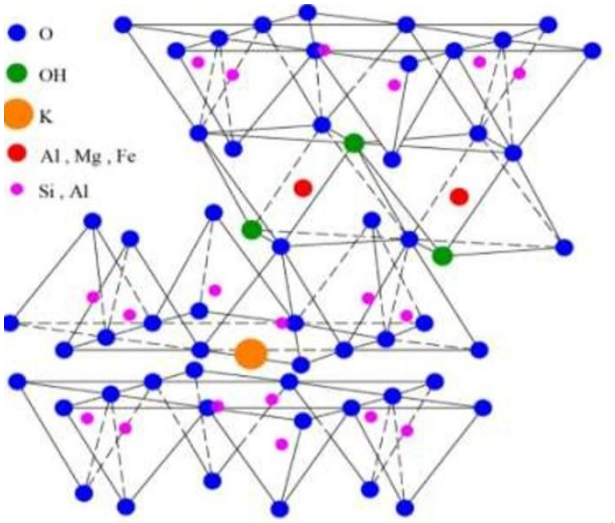


Figure 1.4: Structure of illite crystal [19]

Soil stabilization is the use of stabilizing agents (binder materials) in weak soils to improve its geotechnical properties such as compressibility, strength, permeability and durability to withstand the engineering structural loads (Sherwood, 1993). Improvement in the various geotechnical properties of soil can be achieved by stabilization with suitable materials. Reclaimed Asphalt Pavement (RAP) is the term given to reprocessed and or removed pavement materials which, has been pulverized usually by milling and is used like an aggregate in recycled asphalt pavement (Jeff & Miles, 2006). Therefore, the recycling of pavement materials has become a viable alternative material for consideration in road maintenance and rehabilitation with conservation of resources and environment (Taha *et al.*, 2002).

Calcium carbide residue (CCR) is another form of industrial waste being used by researchers to improve properties of expansive soils (Krammart *et al.*, 2004). It is a by-product obtained from the acetylene gas (C_2H_2) production process. Mixture of CCR with pozzolana which has high silica (SiO_2) or alumina (Al_2O_3) can yield pozzolanic reactions and formation of excess cementitious material. The results have been found to be similar to those obtained from the cement hydration process (Wang *et al.*, 2013).Welding activities in Nigeria has led to the generation of calcium carbide residue deposits.

Zeolites as a pozzolana are aqueous aluminum silicates containing alkali and alkaline earth elements. Their structure is made up of a framework of SiO_4 and AlO_4 tetrahedrons linked to each other's corners by sharing oxygen atoms. Zeolites have been recognized over the decades, but only during the middle of the twentieth century they have attracted the attention of researchers who demonstrated their technological importance in several fields (Cincotti *et al.*, 2006).

Response Surface Methodology (RSM) is a mathematical and statistical technique useful for modeling and analysis of a problem in which a response of interest influenced by several variables with the aim of optimizing the process parameters (Meyers *et al.*, 2002). The design of experiments, the RSM expels systematic errors and reduces the number of experiments required to obtain the optimum values. There are several classes of response surface design that are useful in practice, such as the Central composite design (CCD), Box-Boekhen design, Hybrid design, and Three-design (Khuri and Connell 1996, Mason *et al.*, 2003). The central composite design (CCD) approach was used to design and build model for experimental variables to evaluate and determine their responses of interest. This optimization approach tool can be used in any process or product design and is more helpful for researchers whose area is concerned with the optimization. The major advantages of RSM can be stated as follows (1). No. of experimental run can be reduced (2). Response can be predicted prior to the experimentation phase. (3). It can able to detect the parameter interaction effect on response. CCD and Box-Behnken are two effective designs used in RSM. The central composite design (CCD) is a well-known design for setting a quadratic model. Based on the number of levels and parameters CCD can be classified into CCC, CCI and CCF as described earlier. Box-Behnken method is used for solving the multi objective optimization problem (Meyers *et al.*, 2002).

2.0 PROBLEM STATEMENT

Many researchers have used waste recycled reclaimed asphalt pavement (RAP) to stabilize weak soil materials for road construction purposes (Alhaji and Alhassan, 2018; Jeff and Miles, 2006). Weak soils have been stabilized in Nigeria by many researchers using different chemicals and methods to achieve different results. However, optimization of RAP-clay composite using CCR and Zeolite for stabilization has not been given much attention in literature.

The study by (Rehman *et al.*, 2017; Moghal *et al.*, 2016 and Abdullah *et al.*, 2021) indicated that, an enormous amount of energy, time and numbers of experimental trial are required to determining the optimal or best possible solutions using the optimization models, and optimization technique in chemical stabilization to reduce the number of samples required to be tested to achieve optimal chemical mixtures for maximum strength and stability. Over the years, cementitious materials like cement, lime and fly ash has been used for soil stabilization in Nigeria but some researchers like (Alhaji *et al.*, 2014; Ismail *et al.*, 2014; Osinubi and Alhaji, 2008; Prasad *et al.*, 2017; Basha *et al.*, 2005 and Ibrahim *et al.*, 2020) all worked on stabilization of soil using the combination of other materials, methods and the studies recorded higher strength compared to the use of cement alone.

A limited numbers of geotechnical studies have been reported in the literature on the use of RSM technique of optimization, from which we can cite the work of some researchers like (Badri *et a*l 2020; Lu *et al.,* 2015; Myers *et al*., 2016; Shirazi *et al*, 2020, Zhang *et al*., 2020) used and recommended the response surface methodology for the design of experiments (DOE) in civil engineering experimental studies.

3.0 LITERATURE REVIEW

3.1 Response Surface Method Application in Engineering

Response surface methodology (RSM) was introduced by Box and Wilson in the early 1950s; it was a collection of statistical and mathematical techniques useful for the development and optimization of processes (Dwornicka & Pietraszek, 2018). The Concepts and techniques of response surface methodology (RSM) have been applied successfully and extensively in different scientific and research areas (Zangeneh *et al*., 2002). The philosophy behind a response surface method is to sequentially run relatively simple experiments or models in order to optimize a response variable of interest. In other words, we run a small number of experiments sequentially that can provide a large amount of information upon augmentation. Some researchers like (Badri *et al*., 2020; Lu *et al*., 2015; Myers *et al*., 2016; Shirazi *et al*., 2020; Zhang *et al*., 2020) used and recommended the response surface methodology for the design of experiments (DOE) in civil engineering experimental studies.

In general, the response surface can be visualized graphically. The graph is helpful to see the shape of a response surface; hills, valleys, and ridge lines. Hence, the function f (x_1, x_2) can be plotted versus the levels of x_1 and x_2 as shown in Fig. 2.4 (Montgomery, 2005). The RSM optimization involves three primary steps:

i. Statistically calculated trials.
ii. Estimating the coefficients.
iii. Predicting the response and validating the model adequacy with the experimental arrangement (Mahalik *et al.,* 2010).

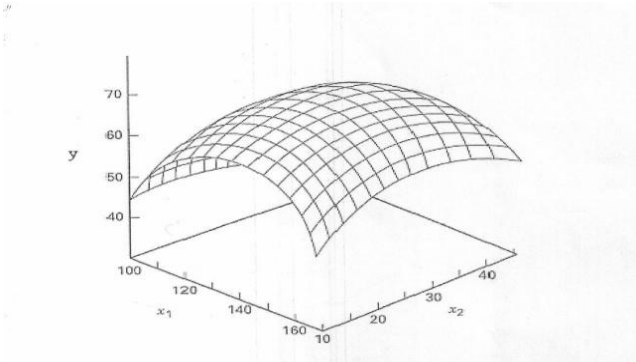


Figure 3.1: Response surface plot (Source: Montogomery, 2005)

In order to understand the surface of a response, graphs are helpful tools. But, when there are more than two independent variables, graphs are difficult or almost impossible to use to illustrate the response surface, since it is beyond 3-dimension. For this reason, response surface models are essential for analyzing the unknown function *f*(x). In such circumstances response surface methodology is recommended to establish an approximate explicit functional relationship between input variables say (x_1, x_2, x_3 ...xn) and output response (y) through regression analysis for the range of expected variation in the input parameters in Equation (3.1).

$$Y = f(x_1, x_2, x_3 ...) + e \quad \text{.....3.1}$$

Where error "e" represents the noise or error observed in the response y. If we denote the expected response by E(y) = f(x1, x2) = n, then the surface represented by n = f(x_1, x_2) is called a response surface.

The above relationship can be simple linear or factorial model, or more complex quadratic or cubic model. "e" represents other sources of uncertainty not accounted for in "f", such as measurement error on the output response, other sources of variation inherent in the process or the system, effect of other variables and so on. In brief, 2^a factorial design is often used to fit linear and non-linear (second order) response surface models for n number of input variables. These set of input variables are also termed as natural variables as they are given in their respective units. If the response is well modeled by a linear function of the independent variables, then the approximating function is the first order model given by Equation (2.2)

$$y = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + E \quad \text{.....(3.2)}$$

If there is curvature in the system, then a polynomial of higher degree must be used, such as the Second-order model given by Equation (3.3)

$$y = \beta_o + \sum_{i=1}^{k} \beta_i x_i \sum_{i=1}^{k} \beta_{ii} x^2_i + \sum\sum_{I<i\,j} x_j + E \ldots\ldots \quad (3.3)$$

The second order or quadratic regression model includes the square terms in addition to the terms above. For a 3-component variable, it may be expressed in Equation $Y = \beta_0 + \beta_{1x1} + \beta_{2x2} + \beta_{3x3} + \beta_{11x1}{}^2 + \beta_{22x2}{}^2 + \beta_{33x3}{}^2 + \beta_{12x1x2} + \beta_{13x1x3} + \beta_{23x2x3} + E$ .....(3.4)

In the above equations x, is the input variables, βo is the regression coefficient this empirical model is called response surface model.

The contour plots can show contour lines of x_1 and x_2 pairs that have the same response value y as shown in in Figure (2.1). There are several classes of response surface design that are useful in practice, such as Central composite design (CCD), Box-Behnken design, Hybrid design, and Three-design (Khuri & Comell 1996, Mason *et al*., 2003).

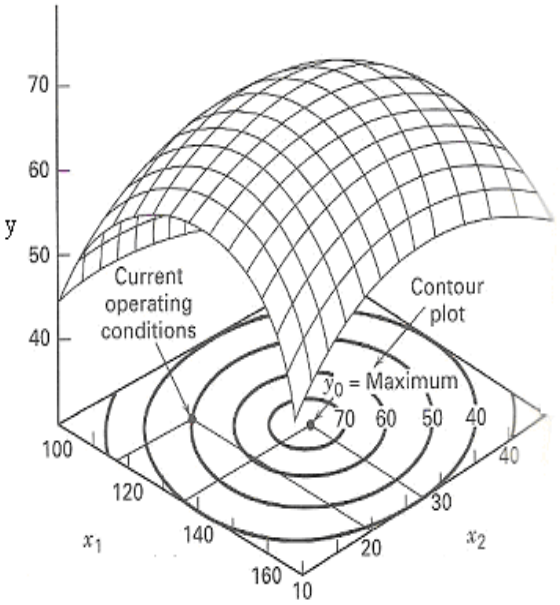


Figure 3.2: Response surface contour plot (Source: Montgomery, 2005).

In a recent study by Zhang et al (2020) that worked on micaceous problematic soil. In the study, RSM modeling was used to model UCS of micaceous soils as a function of the dosage of various additives. The additives included two combinations: (i) slag and fiber, and (ii) slag and polymer. In the end, the performances of micaceous soils were improved by applying a combination of granulated blast furnace slag, fiber and polymer additive. Most of the combinations were found to increase the material strength and ductility. To refine the dosage, response surface method was used to conduct experimental design and develop predictive models for material strength. The developed models formulate the material strength as a nonlinear function of dosages, which was used to optimize additive contents in terms of target requirements.

The model was verified through trials and was used to determine dosages to upscale micaceous soils to field conditions. The combinations of fibers and pozzolanic additives are able to enhance both the strength and ductility.

Lin of al. (2005) performed a study on the effect of Sewage Sludge Ash (SSA) on the strength of silty clay, and found that the Unconfined Compressive Strength (UCS) performance of soil is enhanced two or three times with the decrease of swelling properties. Also, the increment in the amount of Sewage Sludge Ash (SSA) results in increase in the cohesion and decrease in the angle of internal friction. Lin et al (2007a) employed SSA and hydrated lime for improvement of the engineering properties of soft soil. It is found that the addition of SSA+ lime increases the UCS of soft cohesive soil as much as three to seven times and reduces the swelling properties. They concluded that SSA-lime mixture could be introduced to soft cohesive soil in order to improve its geotechnical properties such as compressive strength, California bearing ratio and swelling in the soil stabilization applications modeled using the RSM.

Lin *et al*. (2007b) performed an investigation on the use of Sewage Sludge Ash (SSA) as a soil stabilizer for improvement of the strength characteristics of soft cohesive soil such as compressive strength, bearing capacity and shear strength. They found that the UCS performance of soil treated with Sewage Sludge Ash SSA is 14-2 times better than that of untreated soil. Chen & Lin (2009) used Sewage Sludge Ash (SSA) mixing with cement in order to improve the strength properties of soft soil. While the UCS value increases roughly three-seven times of native soil, the swelling potential decreases up to 60%. They concluded that SSA could be used together with cement for the stabilization purposes.

Lia *et al* (2013) proposed a response surface optimization design method for the foundation pit soil nailing, and Algin (2016) used RSM in the multi objective optimization analysis to present the optimized design solution of a jet grouted raft.

Khoshnevisan *et al*. (2017) used response surface-based robust geotechnical design of supported excavation by means of a spreadsheet-based solution. Lafifi *et al*. (2019) on the other hand, used a combination of Taguchi's design of experiment (DOE), RSM to optimize geotechnical parameters of a synthetic soil for pressure-meter test.

Du *et al*., (2011), used Calcium Carbide Residue (CCR) and lime as binders to treat over-wetted clays being used us as embankment filling material. It was concluded from their tests that CCR treated soils have better performance than that of lime treated soils and can be adopted as an alternative binder to treat over-wetted soils being used for highway embankment. Bandyopadhyay *et al*., (2016) worked on stabilization of soil using ground granulated blast furnace (GGBS) and CCR. It was concluded that with increase of CBR values, the optimum moisture content (OMC) increased and maximum dry density (MDD) decreased which was due to the water absorbing nature of CCR.

4.0 APPLICATION OF DESIGN OF EXPERIMENTS (DOE)

The choice of the design of experiments can have a large influence on the accuracy of the approximation and the cost of constructing the response surface. An important aspect of RSM is the design of experiments (Box and Draper, 1987), usually abbreviated as DOE. These strategies were originally developed for the model fitting of physical experiments but can also be applied to numerical experiments. The objective of DOE is the selection of the points where the response should be evaluated. Most of the criteria for optimal design of experiments are associated with the mathematical model of the process. Generally, these mathematical models are

polynomials with an unknown structure, so the corresponding experiments are designed only for every particular problem. In a traditional DOE, screening experiments are performed in the early stages of the process, when it is likely that many of the design variables initially considered have little or no effect on the response. The purpose is to identify the design variables that have large effects for further investigation. A detailed description of the design of experiments theory can be found in Box & Draper (1987), Myers & Montgomery (1995), among many others. A particular combination of runs defines an experimental design. The possible settings of each independent variable in the N dimensional space are called levels.

The Box-Whilson Central Composite Design, commonly called a Central Composite Design (CCD), is the most popular of all second-order designs. This design consists of the following parts:

i. A complete or a fractional of 2k factorial design whose factors' settings are coded as (Low-1, High = 1), this is called the factorial portion.
ii. An additional design, star points, which provides justification for selecting the distance of the star points from the center; the CCD always contains twice as many star points as there are factors in the design (2*k*)
iii. Thus, the total number of design points in a CCD is $n = 2^k + 2k + 1$.

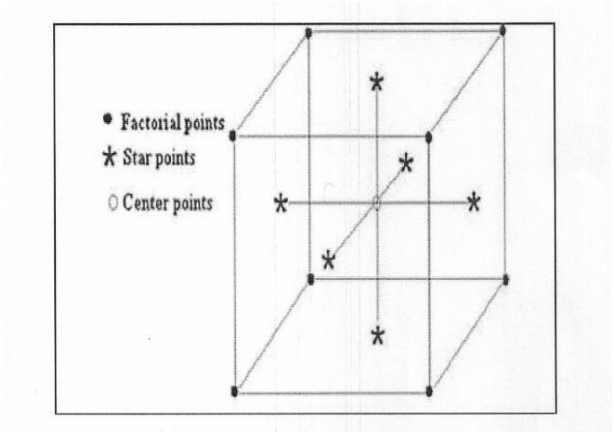


Figure 4.1 Structure of composite Design (Source: Pradeep ***et al*., 2020)**

A CCD is obtained by augmenting the first-order design of a 2k factorial with additional experimental runs, the 2k axial points, and the center-point replications. This design is consistent with the sequential nature of a response surface investigation. The analysis starts with a first-order design and a fitted first-degree model, followed by the addition of design points to fit a higher second-degree model. The first-order design in the preliminary phase gives initial information about the response system and assesses the importance of the factors in a given experiment. The additional experimental runs are performed for the purpose of obtaining more information. This information helps to determine the optimum operating conditions of the independent variables by using the second-degree model. In the CCD, the values of α and 1, are chosen for their desirable properties, where α is the axial point and 1 the number of center point replicates. (Khuri *et al*., 2017; Khuri & Cornell; 1996).

The number of tests required for CCD is given by:
$2^k + 2k + 1$…….(3.5)
Where,
N = total number of runs or experiments
k = number of independent variables or factors.
nc = number of center points if the distance from the center of the design space to a factorial point is ±1 unit for each factor, the distance from the center of the design space to a star point is $|a| > 1$. The precise value of α depends on certain properties desired for the design and on the number of factors involved.

5.0 CONCLUSION

The use of CCR and Zeolite additives in the literature was found to enhance the pozzolanic reaction, improve the microstructure, and increase the resistance to degradation of the soil foundation. The use of central composite design (CCD) or Box-Behnken method using the analysis of variance (ANOVA) to evaluate the degree of accuracy held by the derived model based on several responses, to determine the best experimental design in order to identify the relationship between variables. The results from the papers showed significant improvements in the mechanical properties of the stabilized clay, indicating it potential as sustainable and cost – effective materials for road construction, reducing the risk of incessant road failures, and minimizing environmental impacts by providing valuable insights into the use of industrial by-products and natural minerals as additives for soil stabilization.

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ANALYZING GEOTECHNICAL FACTORS CONTRIBUTING TO PAVEMENT FAILURE: A CASE STUDY OF THE MINNA-PAIKO ROAD IN NIGER STATE

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ABSTRACT
Pavement failure poses a significant challenge to transportation infrastructure worldwide, impacting economic development and societal well-being. This paper investigates the geotechnical factors contributing to pavement failure along the Minna-Paiko road in Niger State, Nigeria. The study employed a combination of field investigations, including visual inspection, soil sampling, and laboratory testing, to characterize the subgrade soil properties. The results revealed that the subgrade soil along the Minna-Paiko road is characterized by low bearing capacity, poor drainage, and susceptibility to volume changes. These geotechnical deficiencies, coupled with inadequate pavement design and construction practices, have significantly contributed to the observed pavement distresses, including cracking, rutting, potholes, and edge failures. The paper concludes with recommendations for improved geotechnical investigation, pavement design, construction, and maintenance practices to mitigate future pavement failures along this critical roadway.

Keywords*: Pavement failure, Geotechnical factors, Subgrade soil, Minna-Paiko Road, Niger State, Nigeria, Case Study.*

1 INTRODUCTION

Road infrastructure plays a vital role in connecting communities, facilitating trade, and driving economic growth. However, the effectiveness of roads is often compromised by premature pavement failures. Pavement failure is defined as the deterioration of the pavement structure to a point where it no longer provides a safe, comfortable, and functional riding surface. These failures can manifest as cracking, rutting, potholes, edge failures, and other forms of distress (Aliyu & Eberemu, 2018).

The Minna-Paiko road in Niger State, Nigeria, is a critical transportation artery connecting the state capital, Minna, to other significant towns and agricultural areas. However, this road has been experiencing significant pavement failures within a relatively short period after construction and/or rehabilitation. These failures disrupt traffic flow, increase travel time and costs, and pose safety hazards to road users.

While traffic loading and environmental factors contribute to pavement deterioration, geotechnical factors relating to the subgrade soil properties are often the primary culprits. Understanding these geotechnical factors is crucial for developing effective pavement design and construction strategies to ensure long-term pavement performance (Ahmed, 2014).

This study aims to investigate the specific geotechnical factors contributing to pavement failure along the Minna-Paiko Road corridor. By identifying the underlying causes of the failures, this research will contribute to improved pavement design and maintenance practices, ultimately enhancing the durability and service life of this crucial transportation infrastructure.

1.1 Description of the Study Area

Paiko-Minna Road originates from Diko junction to Kaduna-Abuja dual carriageway way. It passes through towns and villages such as Maje, Izom, Lambata, Kwakuti, Farin Doki, Gwam, Wabe, Paiko, Pogo, and terminates in Minna. The study area is located between latitude 9°16'N, longitude 6°33'E (Minna). The entire length of the road is about 12.1km. The existing highway is of standard 7.3m wide single carriageway with asphaltic concrete surfacing and base course of naturally occurring lateritic soil. It exhibits various conditions ranging from the newly repaired portion to the fair, and to completely failed sections. Figure 1. shows the Minna-Paiko road in Minna, Nigeria.

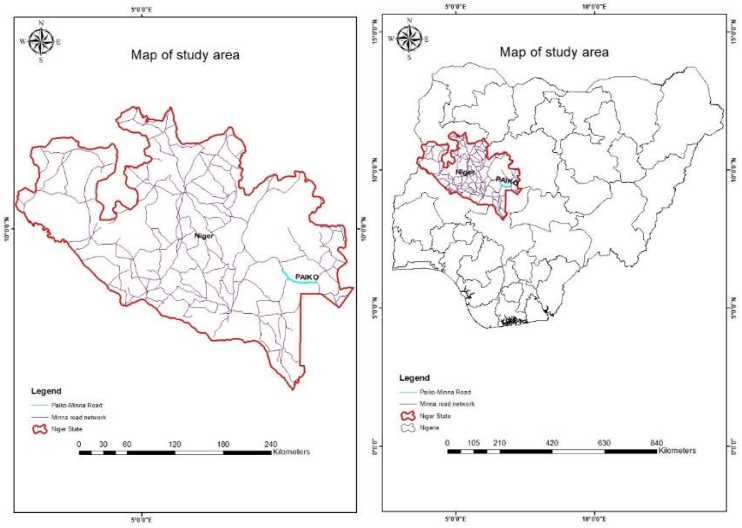


Figure 1: Map of Study Area

2 LITERATURE REVIEW

Previous research highlights the significant influence of geotechnical factors on pavement performance. Several studies emphasize the importance of understanding the subgrade soil properties, including:

i. Bearing Capacity: Low bearing capacity of subgrade soils can lead to excessive pavement deformation under traffic loads, resulting in rutting and cracking (Ahmed, 2014).

ii. Drainage: Poor drainage can saturate the subgrade soil, reducing its strength and leading to accelerated pavement deterioration. This is particularly critical in areas with high rainfall (Jones & Smith, 2010).

iii. Volume Change: Expansive soils, which swell and shrink with changes in moisture content, can exert significant stresses on the pavement structure, causing cracking and unevenness (Nelson & Miller, 1992).

iv. Soil Type and Gradation: The type and gradation of subgrade soil influence its permeability, stability, and resistance to erosion. Well-graded soils generally provide better support for pavements compared to poorly graded soils (Das, 2010).

v. Compaction: Adequate compaction of the subgrade and pavement layers is crucial for achieving the desired strength and stability. Poor compaction can lead to premature pavement failure (Huang, 2004).

Studies specific to Nigeria have also highlighted the challenges posed by expansive clays and inadequate drainage in many regions (Ezeokonkwo & Olofsson, 2015; Aliyu & Eberemu, 2018). These findings emphasize the need for site-specific geotechnical investigations to characterize the subgrade conditions adequately and tailor pavement design accordingly.

3 METHODOLOGY

The methodology employed in this study comprised the following steps:

a) Site reconnaissance and visual inspection: A preliminary site reconnaissance was conducted along the Minna-Paiko road to identify areas exhibiting significant pavement failures. The type and extent of distresses (cracking, rutting, potholes, edge failures) were documented and photographed.

b) Soil Sampling: Disturbed soil samples were collected from the subgrade at representative locations along the road alignment, focusing on areas where pavement failures were observed. Samples were taken at depths representative of the subgrade layer, typically within 1 meter of the pavement surface.

c) Laboratory Testing: The collected soil samples were subjected to a series of laboratory tests to characterize their geotechnical properties. These tests included:

   i. Particle Size Analysis (Sieve Analysis and Hydrometer Test): To determine the soil gradation and classification.

   ii. Atterberg Limits (Liquid Limit, Plastic Limit, and Plasticity Index): To assess the soil plasticity and potential for volume change.

   iii. Moisture Content Determination: To determine the in-situ moisture content of the soil.

iv. Compaction Test (Standard Proctor Test): To determine the optimum moisture content and maximum dry density for compaction.
v. California Bearing Ratio (CBR) Test: To assess the bearing capacity of the subgrade soil under saturated conditions.
vi. Permeability Test: To evaluate the drainage characteristics of the soil.

- Data Analysis and Interpretation: The laboratory test results were analyzed and interpreted to assess the suitability of the subgrade soil for pavement construction. The data was compared with established geotechnical criteria and guidelines for pavement design.
- Correlation and Conclusions: The results of the laboratory tests were correlated with the observed pavement distresses to identify the specific geotechnical factors contributing to the failures. Conclusions were drawn regarding the causes of pavement failure and recommendations were made for improved pavement design and construction practices.

Ultimately, the study involved two aspects; Field investigations and laboratory tests.

Field investigation

The field investigation was in three folds;

i. Condition survey of the road,
ii. Dynamic cone penetration test, and
iii. Sample collection along the road.

Condition Assessment

As part of the condition evaluation process, a five-point rating system was used for the principal categories of distress along the route, along with their intensities and extents. The World Bank/Organization for Economic Cooperation and Development (OECD) five-point rating system, which is shown below, was used to assess the state of the road:

1=Excellent (No pavement distress exists)
2=Good
3=Fair
4=Critical
5=Poor (Complete pavement deterioration)

The average rating for each major category of distress in a segment of road pavement is the condition rating of that section. The average of each section's rating represents the overall state of the pavement.

Dynamic cone penetration

The dynamic cone penetration test is a test carried out to find the resistance value of the cone against the soil that helps us to determine different mechanical properties of soil such as strength, bearing capacity, and so on. The CBR values are calculated from penetration resistance readings, obtained from the DCP test on site. The California Bearing Ratio (CBR) values were then used to judge the stability of the required pavement structures.

A sub-grade sounding test was also carried out along the road as shown in Plates I at specific intervals (at failed and unfailed sections) using a Dynamic Cone Penetrometer (DCP). This was done at somewhat smaller horizontal intervals in order to assess the subgrade strength (in-situ CBR). The Dynamic Cone Penetration (DCP) test was performed using a 60-degree cone head dynamic penetrometer and a lightweight 10 kg rammer. The number of blows for every 10 cm penetration was noted during the penetration test, which was carried out to a maximum depth of 1.20 meters. However, the average measurements for a stratum thickness of 20 cm were used for analysis and presentation. Using the correlation depicted in Equation 1, the strength (CBR) of the pavement structures (subgrade) was determined by averaging the number of strikes.

$$Log\ (CBR) = 2.48 - 1.057Log(PI) \quad (1)$$

Where PI = Penetration Index or Penetration Rate



Plate I: DCPT test in progress

The test measures the materials' insitu resistance to penetration and was carried out in compliance with TRL (2008) of the UK. A metal cone was driven into the ground during the test by continuously hitting it with an 8 kg weight rammer that was dropped from a height of

575 mm. To obtain a continuous measure of the penetration resistance up to 5 1.5 meters below the ground surface, the cone's penetration was measured and recorded following each strike.

Collection of samples

The pavement investigation was done by digging trial pits of 1.0 m x 1.0 m and soil samples were collected at some selected critical and stable locations along shoulders and median of the highway and dynamic cone penetration test was carried out. The depth at which samples were collected ranged from 0.8 m to 1.7m based on the terrain of each location. Samples were preserved in polythene bags to avoid contamination and moisture loss and were transported to the laboratory for further investigation.

Samples were collected from subgrade, subbase and base layers of the road. The collected samples were taken from different locations along the road, at both unfailed (Plate III) and failed (Plate II) sections from trial pits at dug collection points.



Plate II: Collection of Samples



Plate III: Collection of Samples

The natural moisture content of the samples was determined within 48 hours in the laboratory. This was followed by air drying of the samples, by spreading them out on trays at enclosed area at room temperature for four days. Large soil particles (clods) in the samples were broken with a wooden mallet.

Laboratory Test

All the collected soil samples were tested based on procedures outlined in BS. 1377 (1990). The tests included index properties, compaction characteristics and strength properties test.

Natural moisture content determination

The ratio of the mass of water to the mass of solids in a specific mass of soil is known as the natural water content, or natural moisture content. The moisture content was calculated using Equation 2.

$$NMC = \frac{M_2 - M_3}{M_3 - M_1} * 100 \qquad (2)$$

Where;
NMC= natural moisture content
M_1= mass of empty cans
M_2= mass of empty cans plus wet samples
M_3= mass of empty cans plus dry samples.
The procedure was repeated for all the remaining soil samples.

Index properties test

Particle Size Distribution

300g of air-dried soil sample was weighed as total mass in (g) and soaked with water for 24hrs, the soaked sample was washed through BS sieve 0.075mm. The material retained on BS sieve 0.075mm was then transferred into tray and dried in oven at 105^0C to 110^0C. After allowing it to cool, it was weighed as mass of soil after washing. The dried sample was placed on the top of set of sieves and mechanical sieve shaker was operated for 10min and the amount of soil retained on each sieve was weighed and recorded, while the percentage of soil passing each sieve was calculated and the grading curve plotted on a semi-log graph.

Atterberg limits

a) Liquid Limit

The test was carried out in accordance with BS 1377 (1990); part 2. 300g of air dried sample passing through BS sieve 0.425mm was weighed and placed on glass plate and distilled water was added to the sample and mixed for at least 10min. Using two palates knifes, the mixed soil sample was placed into cup with palate knife up to the brim. The excess sample was striked off to give a smooth level.

b) Plastic Limit and Plasticity Index

Plastic limit and plasticity index were carried out in accordance with BS 1377 (1990); part 2. 40g of clay sample passing through BS sieve 0.425mm was placed on a glass plate and then mixed thoroughly with water. The mixed sample was rolled between the palms and flat glass plate to form a thread of 3mm diameter. The process continued until the thread crumbled when the diameter is 3 mm. The sample of the thread was collected for moisture content determination and plasticity index was calculated using Equation 3.

$$P = LL - PL \quad (3)$$

(c) Specific Gravity Test

Specific gravity of clay soil was carried out in accordance with BS 1377 (1990); part 2. The specific gravity will then be calculated using Equation (4).

$$GS = \left(\frac{W2 - W1}{(W4 - W1) - (W3 - W2)}\right) \quad (4)$$

Where: G_s is the Specific Gravity.

W_1 is the mass of density bottle (g)

W_2 is the mass of bottle +dry soil (g)

W_3 is the mass of bottle + dry soil + water (g)

W_4 is the mass of bottle + water (g)

Strength properties

a. Compaction test

The compaction test was carried out in accordance with the procedure outlined in BS 1377 (1990). The empty mould and moisture content cans were weighed and recorded. The height and diameter of the mould was recorded. 3000g of the air-dried soil sample was measured and poured into the mixing tray. Using a wooden hammer, lumps of the sample were pulverized. Relatively little quantity of water was added to the soil, mixed properly, and divide into 5 portions. The collar of the mould was placed back on the mould and secured. Each portion was placed as a layer into the assembled mould and compacted using 4.5kg rammer. 25 blows were applied to each layer. The collar was removed, excess soil trimmed, and the surface of sample at the top was scraped to level with the top of the mould's rim. If there are voids, the remaining materials was used to fill these voids. And scraped again to level. The mould and sample were weighed without the collar, and recorded. Using the knife, samples were taken from the top and bottom of the mould and placed in two different labelled moisture content cans, and placed in oven for 24 hours to dry, for moisture content. The masses of the cans and wet samples were recorded. The samples were then extracted from the mould, unto the mixing tray. The wooden hammer was used to pulverize the sample and it was remixed with additional quantity of water, and the whole procedure was repeated until the system failed. This is when the mass of sample and mould drops. The bulk and dry densities for each trial were calculated using Equations 4 and 5.

$$\rho_b = \frac{Mass\ of\ wet\ soil}{volume\ of\ mould} \quad (4)$$

$$\rho_d = \frac{\rho_b}{1 + w} \quad (5)$$

where

ρ_b = bulk density (Mg/m3)

ρ_d = dry density (Mg/m3)

W = moisture content

Compaction test was also carried out on samples collected from the stone base.

b. California bearing ratio (CBR)

The California Bearing Ratio (CBR) test is a penetration test carried out to evaluate the mechanical strength of sub-grade, sub-base or base course materials. It measures

the shearing resistance, controlled density and moisture content. In order to characterise the soil for use as base or sub-base materials, CBR is applied both soaked and unsoaked.

A 6000g of the air-dried soil was weighed and mixed with the percentage of water base on the predetermined OMC of each energy level will be added and mixed thoroughly. The mould base place and collar will be fixed and put on flat surface, concrete floor. For modified energy level the moist sample is divided in five portions, each portion will be compacted into CBR mould by using 4.5kg rammer giving each layer 62 blows. The collar will then be removed, the excess sample is trimmed and the sample is placed in polyethene leather for 7, 28 and 60days before testing. After curing of day of each sample, the samples will be tested using CBR machine by recording force reading of 0.25mm intense penetration for both top and bottom.

CBR was calculated from Equation 3.8 and 3.9

$$\text{CBR at 2.5mm} = \left(\frac{Px41.6}{1000}\ divided\ by\ 13.24\right)x100 \quad (3.8)$$

where

P = proving ring reading at 2.5mm, using

41.6 = proving ring constant

$$\text{CBR at 5.0mm} = \left(\frac{Px41.6}{1000}\ divided\ by\ 19.96\right)x100 \quad (3.9)$$

Average of the two values was taken as CBR of the material.

CBR test was also carried out on samples collected from the stone base.

4 RESULTS AND DISCUSSION

Condition Survey Result

The road is generally rated fair (4) to poor (5), the shoulders are generally in fair to poor condition along the investigated road segment, and drainage is generally insufficient over the whole stretch of the road, according to the Table 1 below. As a result, the road's overall condition might be considered fair to poor.

Table 1: Result of condition assessment of the road

Pavement Section			Distress Condition Rating [5 Point Scale]			Carriageway Condition Rating [Pavement]	Shoulder Rating	Drainage Adequacy	Remarks
From	To	Length (m)	Cracks Rating	Pot Hole Rating	Rut/Depression Rating				
0	500	500	5	5	5	5	5	5	Poor condition
500	800	300	4	3	4	3	4	5	Fair Condition
800	900	100	5	5	5	5	5	5	Poor condition
900	1000	100	4	4	4	3	4	5	Fair Condition
1000	1100	100	5	5	5	5	5	5	Poor condition
1100	1400	300	3	3	3	3	4	5	Fair Condition
1400	1700	300	5	5	5	5	5	5	Poor condition
1700	1800	100	3	3	3	3	4	5	Fair Condition
1800	2000	200	5	5	5	5	5	5	Poor condition
2000	2300	300	3	3	3	3	4	5	Fair Condition
2300	3000	700	5	5	5	5	5	5	Poor condition
3000	3700	700	3	3	3	3	4	5	Fair Condition
3700	3900	200	5	5	5	5	5	5	Poor condition
3900	5000	1100	4	3	4	3	4	5	Fair Condition
5000	5200	200	5	5	5	5	5	5	Poor condition
5200	5300	100	4	3	4	3	5	5	Fair Condition
5300	5600	300	5	5	5	5	5	5	Poor condition
5600	6100	500	3	4	4	3	5	5	Fair Condition

It can be observed from Table 1 that:

1. The road is generally rated to be in fair (4) to poor (5) condition.
2. The shoulders of the studied road are generally in poor condition.
3. There is no drainage along the entire stretch of the road.

Therefore, the condition of the road can be categorized as fair to poor.

Dynamic Cone Penetrometer Test (DCPT) Result

The DCPT result of the samples taken from the study area is summarized and presented in Table 2. The results indicated that the California Bearing ratio (CBR) values

from the DCPT result on both failed and unfailed sections of the subgrade material on the road were mostly above the minimum (10%) specified by the Specification for Road and Bridge Work (2016). Four tested sections of the subgrade at chainages 1+00 (6.7%), 1+100 (6.7%), 3+000 (8%), and 5+000 (9%) presented CBR values below 10% respectively. This is indicative of a weak subgrade material with low strength and bearing capacity (Al-Refeai & Al-Suhaibani, 1997).

On the other hand, the sub-base material showed that a few sections of the road had CBR values above the minimum (30%) as recommended by the NGS (2016). All other results of the CBR for the sub-grade showed values less than 30%. In the context of sub-base materials for road construction, a California Bearing Ratio (CBR) value below 30% obtained through a Dynamic Cone Penetrometer (DCP) test indicates that the material has relatively low bearing capacity and strength, making it less suitable for use as a sub-base without treatment or additional reinforcement (Feitosa Monteiro *et al.*, 2016).

Table 2: Summary of DCPT on tested road section

					CBR from DCPT (%)		
	From	To	Length (m)	Condition of Section	Subgrade	Sub base	Base
0+500	0	500	500	Failed	22.5	28	32
0+800	500	800	300	Failed	19.3	30	37
0+900	800	900	100	Failed	17.3	27	31.5
1+00	900	1000	100	Failed	6.7	18	19
1+100	1000	1100	100	Failed	6.7	9	22
1+400	1100	1400	300	Failed	15.3	28	36
1+700	1400	1700	300	Failed	26	30.5	36
1+800	1700	1800	100	Failed	21	34.5	38
2+000	1800	2000	200	Failed	22	36	38
2+300	2000	2300	300	Failed	18	19	22.3
3+000	2300	3000	700	Failed	21	26	40
3+700	3000	3700	700	Failed	8	27	38.5
3+900	3700	3900	200	Failed	19.5	29	37.5
5+000	3900	5000	1100	Failed	9	12.5	30.3
5+200	5000	5200	200	Failed	29	31.5	35
5+300	5200	5300	100	Failed	10	15.25	29.7
5+600	5300	5600	300	Failed	7.25	12	18
6+100	5600	6100	500	Failed	26	36.5	39

Furthermore, the CBR results of the base materials showed no section (both failed and unfailed) reached the minimum standard of 80% recommended for CBR value for road base material by the NGS (2016). However, the failed sections of the road presented lower CBR values in comparison to the unfailed sections.

These trends are generally attributed to the softening of the pavement structure by the infiltrating water resulting from the failure of the protective wearing course and the general absence of roadside drainage facilities along the entire stretch of the road. Additionally, the base layer serves as the primary structural layer in a pavement system, distributing traffic loads to the sub-base and subgrade. A CBR below 80% suggests the material lacks the strength needed to perform this function effectively, which could lead to premature pavement failure. Such material might deform under heavy traffic loads, leading to rutting or settlement (AASHTO, 1993).

Summary of Geotechnical Test on Sub-grade Materials

A summary of the geotechnical tests comprising the specific gravity (Gs), sieve analysis, moisture content, Atterberg limit, compaction, soil classification, and CBR for sub-grade materials is presented in Table 3.

Table 3: Summary of properties of sub-grade materials

Sample	Gs	Percentage Passing Sieve 200	Moisture Content	Atterberg Limits		Compaction Characteristics		Soil Classification	Soaked CBR (%)
				LL (%)	PI (%)	MDD (Mg/m^3)	OMC (%)	AASHTO	
0+500	2.67	35.7	2.2	34	13.2	1.69	13.1	A-7-6	8.30
0+800	2.64	35.9	2.1	34.6	12.6	1.69	13.1	A-7-6	7.10
0+900	2.65	36.7	3	40.6	14.4	1.68	14.8	A-7-6	7.30
1+00	2.55	38.1	2.9	40.6	15.3	1.67	14.8	A-7-6	6.00
1+100	2.62	36.9	2.8	34	13.2	1.7	13.8	A-7-6	7.20
1+400	2.65	36.2	2.7	28.2	3.9	1.72	13.8	A-4	5.20
1+700	2.64	39.1	3.7	27.2	8.3	1.7	13.8	A-4	6.10
1+800	2.60	35.5	3.8	22.5	11.5	1.71	11.8	A-6	10.20
2+000	2.59	34.5	3.4	22.1	15.8	1.71	11.8	A-6	7.25
2+300	2.57	34	3.2	23.1	15.2	1.63	16.3	A-6	8.10
3+000	2.55	37.9	2.8	38.3	23.6	1.63	16.3	A-7-6	5.10
3+700	2.57	36.5	3.2	23.6	14.1	1.74	9.8	A-6	11.40
3+900	2.65	36.6	3.6	23.6	14.1	1.74	9.8	A-6	7.20
5+000	2.64	35.1	2.7	27.7	18.8	1.66	12.1	A-6	6.50
5+200	2.60	34.7	3.5	36.8	11.9	1.65	12.1	A-7-6	7.00
5+300	2.60	36	3.2	30.9	16.4	1.65	12.1	A-7-6	8.10
5+600	2.67	33.7	3.1	27.7	18.8	1.62	12.1	A-6	6.80
6+100	2.56	36.2	3	30.4	18	1.71	13.8	A-7-6	6.70

*Gs= Specific Gravity

Table 3 indicated that the specific gravity of the sub-grade material ranged from 2.55-2.67. Specific gravity between 2.55 and 2.67 implies that the subgrade material likely consists of typical mineral soils with good compaction characteristics and moderate bearing capacity. While generally suitable for road subgrades, further evaluation of gradation, compaction, and moisture sensitivity is crucial to confirm its adequacy for the intended application (Braja, 2010).

The sieve analysis result presented in Table 3 showed that the percentage passing 75μm sieve ranges from 33.7% - 39.1%. This indicates a subgrade material with a moderate to high fine content, primarily composed of silts and clays. This may imply moisture sensitivity that makes the material prone to water retention, swelling, and shrinkage. Furthermore, it translates to reduced load-bearing capacity, especially under saturated conditions which may necessitate stabilization. This sub-grade material might be suitable for low-traffic roads if compacted and well-drained. However, for heavy-traffic roads, additional treatment or stabilization is required (ASTM, 2007).

Furthermore, the liquid limit result presented in Table 3 showed a range between 22.1% and 40.6%. This indicates moderate lower LL (22.1–30%) plasticity soils that include silts and clay which implies better strength and stability to higher LL (30.1–40.6%) which indicates greater moisture sensitivity and deformation risk. Its suitable for low-traffic roads if compacted and drained. For high-traffic roads while soils with LL > 30% may need stabilization (AASHTO, 1993; Braja, 2010).

The plasticity index for the sub-grade material ranged between 3.9% and 23.6%. Low PI (3.9–10%) demonstrates low-plasticity soils like silty sands, with good stability and lower water sensitivity while moderate to high PI (10.1–23.6%) signifies clayey soils with higher cohesion but more prone to swelling, shrinkage, and strength loss when wet. PI < 12% is more suitable for subgrade without additional treatment while PI > 12% may require stabilization for better performance, especially for high-traffic roads (Bowles, 1996; Koti, 2018).

The maximum dry density (MDD) test results for the sub-grade materials ranged from $1.62 Mg/m^3$ to $1.74 Mg/m^3$. This represents typical fine-grained soils for subgrade construction. Soils with higher MDD values ($1.74 Mg/m^3$) are better suited for road foundations, while those with lower values ($1.62 Mg/m^3$) may require additional treatment to meet load-bearing requirements.

The optimum moisture content (OMC) test results for the sub-grade materials ranged from 9.8% to 14.8%. This may suggest that the subgrade material consists of silts

and clays, with moderate moisture requirements for compaction. Proper moisture control during compaction is crucial to ensure the subgrade's load-bearing capacity and durability in road construction (Braja, 2010; Bowles, 1996).

The subgrade samples were classified mostly as A-4 (fine-grained, silty soil), A-6 (fine-grained, clayey soil), and A-7-6 (fine-grained, high plastic clay) on AASHTO soil classification (AASHTO, 1993). The soaked CBR values for the sub-grade material ranged from 5.1% to 10.20%. These values are lower than the minimum 10% CBR specified by Nigeria General Specification for Road and Bridge Works - NGS (2016). This and the observed absence of side drains along the entire stretch of the road explain the larger percentage of causes of pavement collapse and eventual road failure.

Summary of Geotechnical Test on Sub-base Materials

A summary of the geotechnical tests comprising the specific gravity (Gs), sieve analysis, moisture content, Atterberg limit, compaction, soil classification, and CBR for the sub-base materials is presented in Table 4.4.

Table 4: Summary of properties of sub-base materials

Sample	Gs	Percentage Passing Sieve 200	Moisture Content	Atterberg Limits		Compaction Characteristics		Soil Classification	Soaked CBR (%)
				LL (%)	PI (%)	MDD (Mg/m^3)	OMC (%)	AASHTO	
0+500	2.52	46. 19	4.5	28.82	7.9	2.18	4.9	A-6	30.9
0+800	2.54	48. 43	4.9	31.44	7.5	2.17	5.4	A-7-5	32.6
0+900	2.60	46. 59	4.3	27.52	7.2	2.14	4.5	A-6	32.4
1+00	2.58	45. 87	5.4	26.42	8.3	2.09	3.8	A-6	35.6
1+100	2.60	46. 9	4.8	34.32	7.1	2.21	3.4	A-7-5	39.4
1+400	2.62	46. 76	10.2	29.11	7.9	2.25	7.2	A-6	35.3
1+700	2.48	46. 32	7.5	27.64	8.3	2.19	6.5	A-6	36.7
1+800	2.50	48. 12	4.2	26.31	7.7	2.13	4.4	A-6	38.4
2+000	2.55	45. 37	6.5	25.61	7.1	2.16	5.2	A-6	34.2
2+300	2.48	45. 63	5.5	29.02	8.6	2.08	3.1	A-6	34.5
3+000	2.51	48. 21	6.4	32.41	6.2	2.24	7.1	A-7-5	33.7
3+700	2.53	45. 39	5.0	33.09	7.4	2.34	6.5	A-7-5	31.3
3+900	2.58	45. 36	5.5	31.13	6.3	2.12	4.5	A-7-5	31.2
5+000	2.50	47. 33	6.8	28.23	7.3	2.16	5.5	A-6	30.5
5+200	2.50	47. 85	7.2	25.80	9.1	2.22	5.5	A-6	29.8
5+300	2.55	48. 32	5.2	26.55	6.9	2.17	4.8	A-6	33.4
5+600	2.45	44. 27	8.5	29.43	6.6	2.26	7.2	A-6	32.6
6+100	2.47	46. 19	7.3	36.8	11.9	2.35	9.8	A-7-6	31.4

Table 4 indicated that the specific gravity of the sub-base material ranged from 2.45-2.62. This implies that the subgrade material likely consists of typical mineral soils with good compaction characteristics and moderate bearing capacity. While generally suitable for road subgrades, further evaluation of gradation, compaction, and moisture sensitivity is crucial to confirm its adequacy for the intended application (Braja, 2010).

The sieve analysis results for sub-base material presented in Table 4 also showed that the percentage passing 75µm sieve ranges from 44.27% - 48.43%. This indicates sub-base material with high fine content, which is generally unsuitable for sub-base use without stabilization. Proper treatment or material replacement is necessary for reliable performance in road construction (ASTM, 2007). The liquid limit result for the sub-base ranged between 25.80% and 36.8%. This indicates moderate lower LL (25.80–30%) plasticity soils that include silts and clay which implies better strength and stability to higher LL (30.1–36.8%) which indicates greater moisture sensitivity and deformation risk. Its suitable for low-traffic roads if compacted and drained. For high-traffic

roads while soils with LL+ > 30% may need stabilization (AASHTO, 1993; Braja, 2010).

The plasticity index of the sub-base material ranged between 6.2% and 11.9%. This suggests a sub-base material with low to moderate plasticity, suitable for many road construction projects. Proper compaction and drainage are critical to ensuring its performance, and stabilization may be necessary for soils with higher PI values in this range, particularly under heavy traffic or in wet conditions (Bowles, 1996; Koti, 2018).

The maximum dry density (MDD) test results for the sub-base materials shown in Table 4 ranged from 2.08Mg/m^3 to 2.35Mg/m^3. A maximum dry density (MDD) between 2.08 Mg/m³ (2080 kg/m³) and 2.35 Mg/m³ (2350 kg/m³) for sub-base material in road construction indicates the material's compaction potential and its suitability as a load-bearing layer.

The optimum moisture content (OMC) test results for the sub-base materials ranged from 3.1% to 9.8%. This reflects the water content required to achieve maximum dry density (MDD) during compaction.

Low OMC (3.1–5%) indicates coarse-grained materials such as sands and gravels, which require less water for compaction due to their lower surface area and minimal fine content while moderate OMC (5.1–9.8%) suggests the presence of silts or minor clay content, increasing the water demand due to greater surface area and cohesion. (Braja, 2010; Bowles, 1996).

The sub-base samples were classified mostly as A-6 (fine-grained, clayey soil), A-7-5 (silty soil), and A-7-6 (fine-grained, high plastic clay) on AASHTO soil classification (AASHTO, 1993). The soaked CBR values for the sub-base material ranged from 29.8% to 39.4%. These values are higher than the minimum 10% CBR specified by Nigeria General Specification for Road and Bridge Works - NGS (2016). This indicates the evidence of relative quality control measures taken during the construction/rehabilitation stages of the road.

Results of Base Course Materials Testing

A large portion of the road has crushed granite as base course material. These materials were tested for particle size distribution, compaction characteristics and CBR. The results are presented below.

Properties of the stone base materials

Particle size distribution of crushed stone base materials

Results of particle size distribution of the crushed stone base course materials collected along the road are presented in Figures 2 to 19.

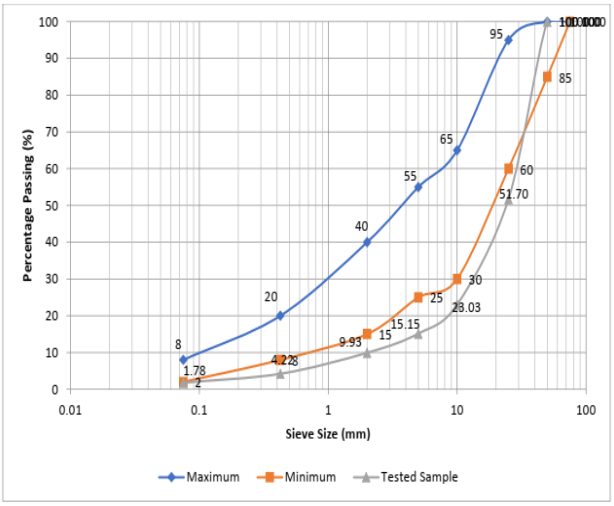


Figure 2: Grading envelope (gradation A) for base course sample taken from CH 0+500

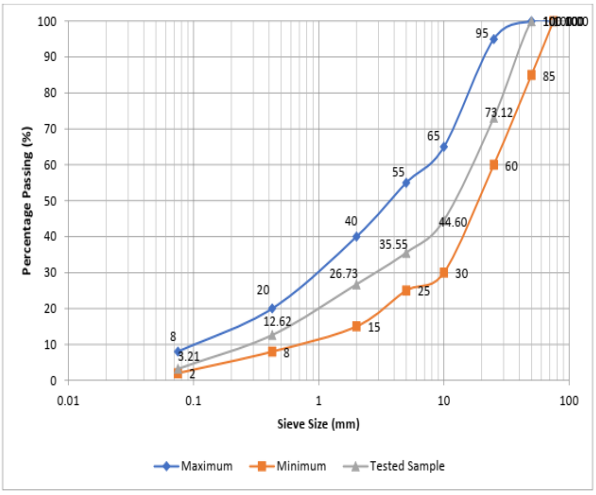


Figure 3: Grading envelope (gradation A) for base course taken from CH 0+800

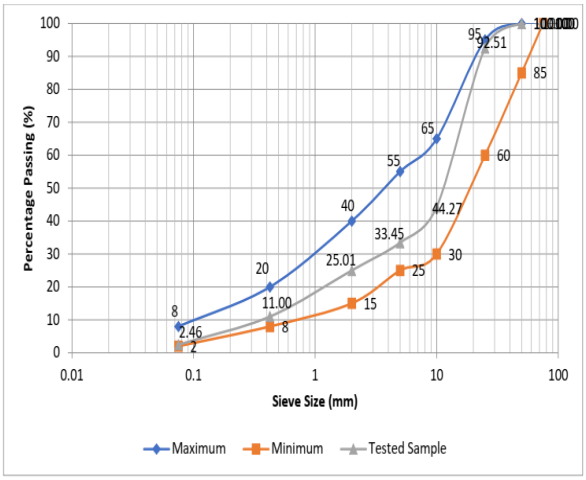


Figure 4: Grading envelope (gradation A) for base course sample taken from CH 0+900

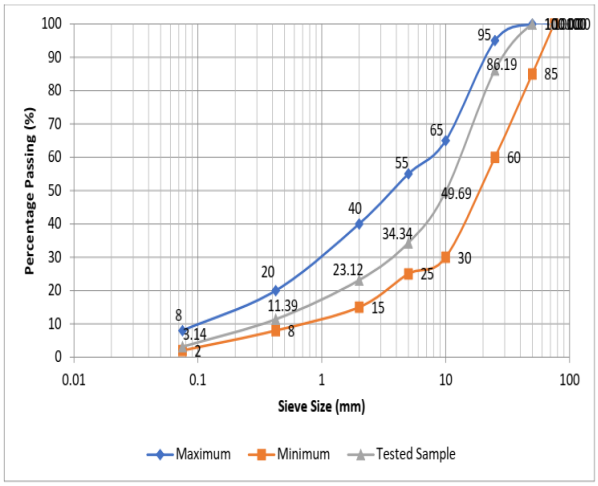


Figure 5: Grading envelope (gradation A) for base course sample taken from CH 1+00

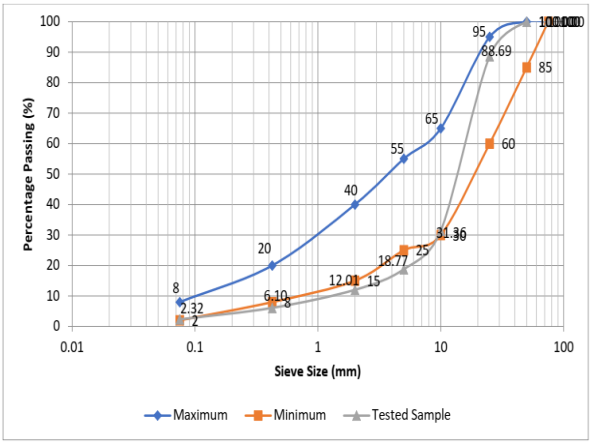


Figure 6: Grading envelope (gradation A) for base course sample taken from CH 1+100

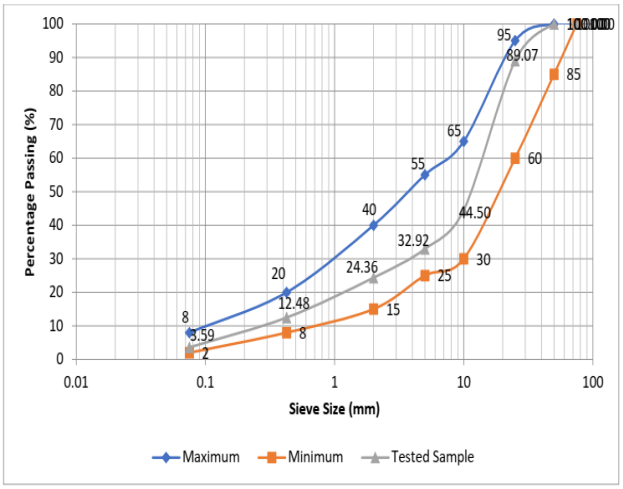


Figure 7: Grading envelope (gradation A) for base course sample taken from CH 1+400

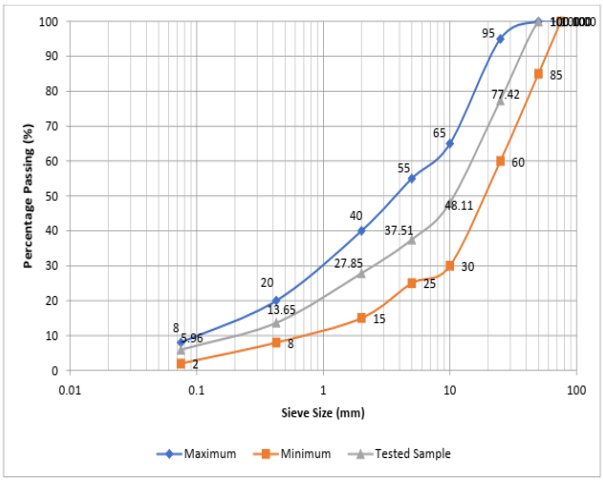


Figure 8: Grading envelope (gradation A) for base course sample taken from CH 1+700

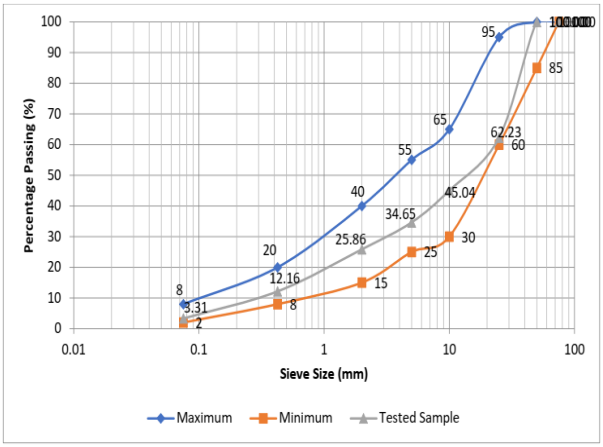


Figure 9: Grading envelope (gradation A) for base course sample taken from CH 1+800

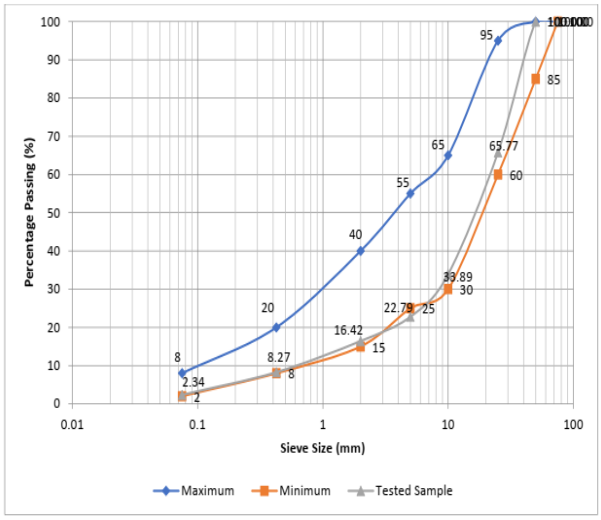


Figure 10: Grading envelope (gradation A) for base course sample taken from CH 2+000

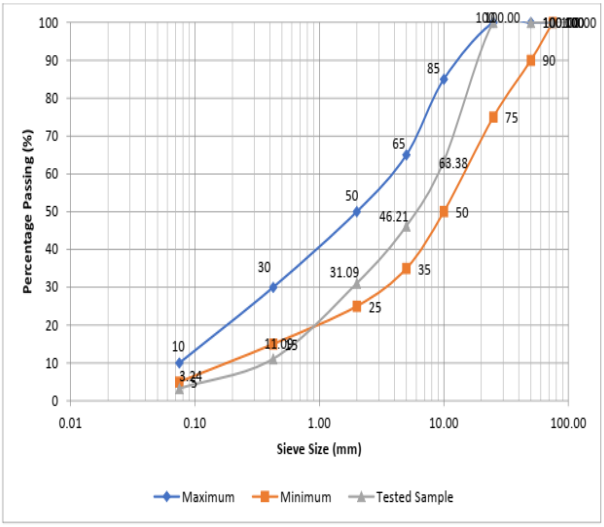


Figure 11: Grading envelope (gradation C) for base course sample taken from CH 2+300

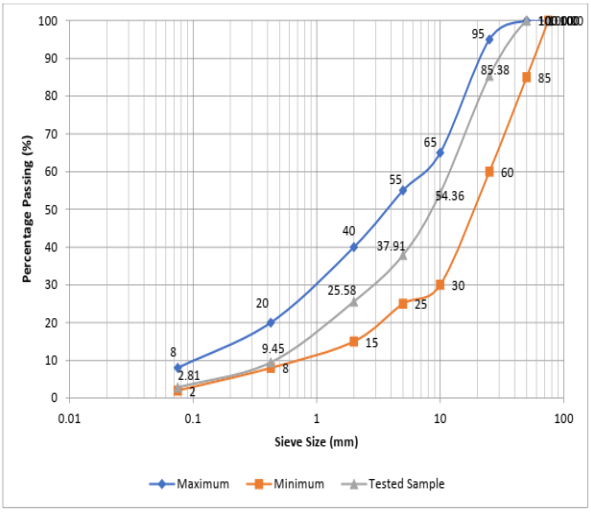


Figure 12: Grading envelope (gradation A) for base course sample taken from CH 3+000

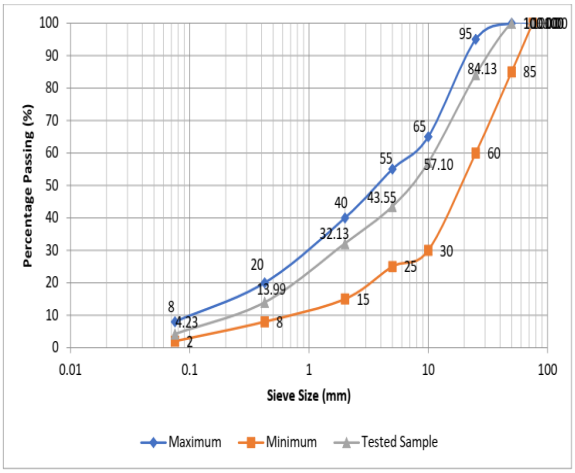


Figure 13: Grading envelope (gradation A) for base course sample taken from CH 3+700

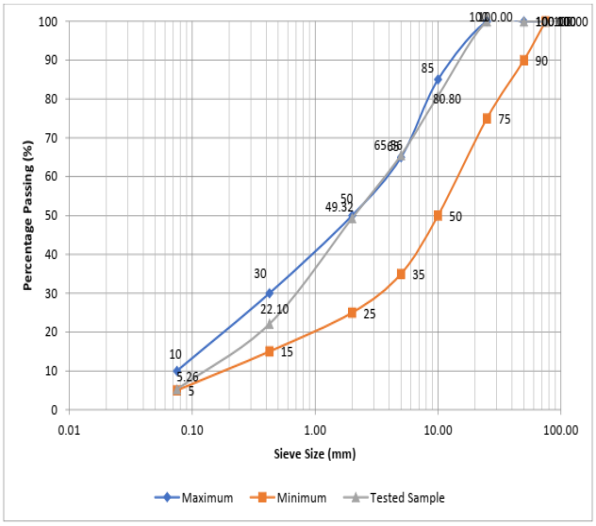


Figure 14: Grading envelope (gradation C) for base course sample taken from CH 3+900

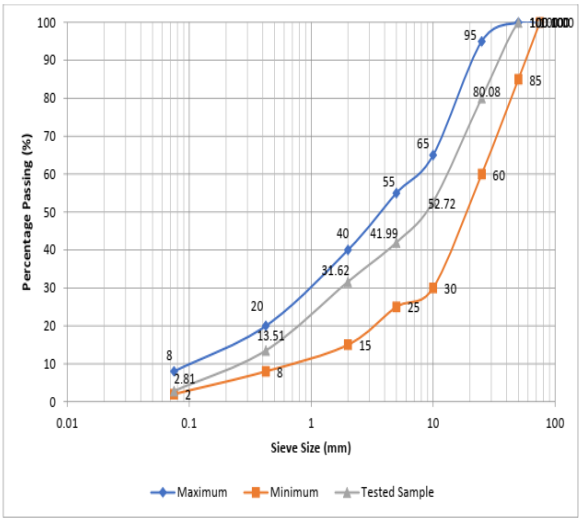


Figure 15: Grading envelope (gradation A) for base course sample taken from CH 5+000

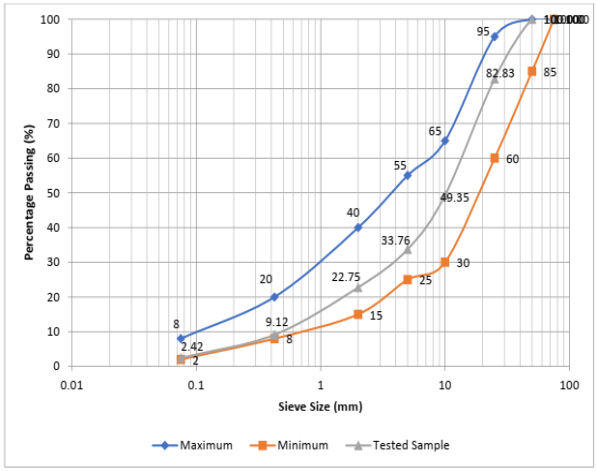


Figure 16: Grading envelope (gradation A) for base course sample taken from CH 5+200

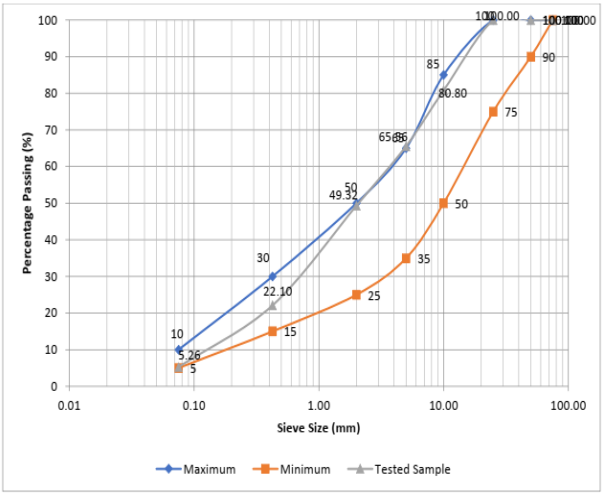


Figure 17: Grading envelope (gradation C) for base course sample taken from CH 5+300

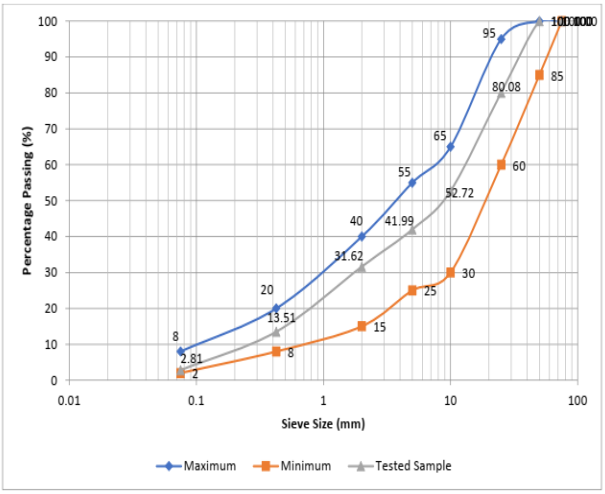


Figure 18: Grading envelope (gradation A) for base course sample taken from CH 5+600

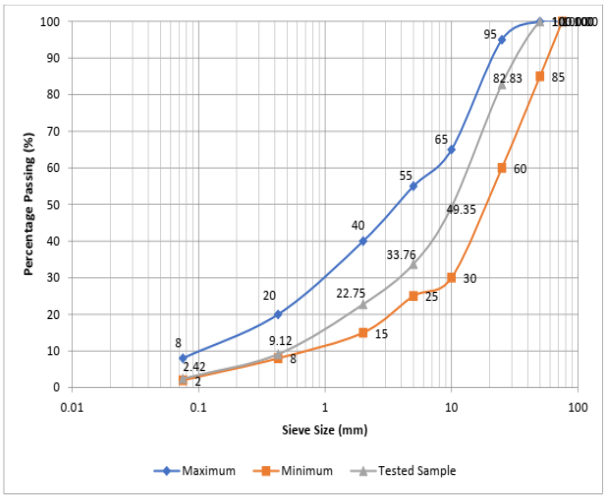


Figure 19: Grading envelope (gradation A) for base course sample taken from CH 6+100

It can be observed that all the base course material (stone base) tested fit into gradation as recommended by the Nigeria General Specification for Road and Bridge Works- NGS (2016). However, samples from CH 0+500 (see Figure1) generally fell below the lower limit of the zone. Samples from CH 2+300 and CH 3+900 (see Figures 11, 14, and 16) fit into gradation C, with samples from CH 2+300 having lower fine content below the minimum specified by the Nigeria General Specification for Road and Bridge Works (2016). The observed trend also indicated evidence of relative quality control measures during the construction/rehabilitation stages of the road base.

Results of Strength Properties of the Base

The results of compaction characteristics (MDD and OMC) of the stone base materials are presented on Table 4.5.

Table 5: Summary of Strength properties of the stone base materials

Sample	Compaction Characteristics	
	MDD (Mg/m^3)	OMC (%)
0+500	2.18	4.5
0+800	2.19	5.5
0+900	2.16	7.6
1+00	2.19	10.4
1+100	2.17	12.7
1+400	2.16	12.4
1+700	2.18	9.6
1+800	2.17	8.3
2+000	2.15	7.1
2+300	2.19	4.8
3+000	2.15	3.2
3+700	2.16	4.2

3+900	2.19	5.5
5+000	2.19	6.8
5+200	2.17	7.4
5+300	2.16	6.5
5+600	2.16	5
6+100	2.18	4.5

The result presented in Table 5 showed that the MDD of the stone base material along for the study area ranges from 2.15 to 2.19 Mg/m^3 while the OMC ranges between 3.2% to 12.7%. This indicates the moisture level at which the material achieves its maximum dry density during compaction. A lower OMC reflects coarse-grained materials such as crushed stone, while a higher OMC suggests finer particles or clay content. These values are within those typical for stone base materials of the stated gradation zones.

Results of CBR of the stone base materials

The results of CBR of the stone base materials are also presented on Table 5. From the table, it is observed that CBR values of the tested stone base materials ranges between 18% to 40%, which are typical values for crushed stone base materials as reported in literature (Braja, 2010; Koti, 2018).

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

It can be concluded from the current study that the result from the condition assessment of the road indicated that it can be generally referred to as being in fair to poor condition.

The sieve analysis on the subgrade material indicated that the tested area might be suitable for low-traffic roads if compacted and well-drained. The liquid limit demonstrated that the road has greater moisture sensitivity and deformation risk signifying its suitability for low-traffic roads if compacted and drained. Additionally, the plasticity index results demonstrated low-plasticity soils with good stability and lower water sensitivity to moderate clayey soils with higher cohesion but more prone to swelling, shrinkage, and strength loss when wet.

Furthermore, the subgrade samples were classified mostly as A-4 (fine-grained, silty soil), A-6 (fine-grained, clayey soil), and A-7-6 (fine-grained, high plastic clay) on AASHTO soil classification (AASHTO, 1993).

The soaked CBR values for the sub-grade material ranged from 5.1% to 10.20%. These values are lower than the minimum 10% CBR specified by Nigeria General Specification for Road and Bridge Works - NGS (2016). This and the observed absence of side drains along the entire stretch of the road explain the larger percentage of causes of pavement collapse and eventual road failure.

On the other hand, the sieve analysis result from the sub-base samples indicated material with high fine content, which is generally unsuitable for sub-base use without stabilization.

The sub-base samples were classified mostly as A-6 (fine-grained, clayey soil), A-7-5 (silty soil), and A-7-6 (fine-grained, high plastic clay) on AASHTO soil classification (AASHTO, 1993).

However, the soaked CBR values for the sub-base material ranged from 29.8% to 39.4% which were higher than the minimum 10% CBR in comparison to the sub-grade material samples. Therefore, it can be concluded that there is evidence of relative quality control measures taken during the construction/rehabilitation stages of the road.

5.2 Recommendations

From the study, the following are recommended:

1. Proper investigation should be carried out to ascertain the depth of the subgrade material to be removed before placement of other pavement structures, during reconstruction/rehabilitation of the road.
2. Side drains should be provided to reduce ponding and infiltraion of surface runoff into the pavement structure, during reconstruction/rehabilitation of the road.

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Department of Civil Engineering
Federal University of Technology, Minna, Nigeria

ESTIMATION OF STREAMFLOW IN SHIRORO DAM USING SOIL AND WATER ASSESSMENT TOOL (SWAT) MODEL

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ABSTRACT
The focus of hydrological studies has been on climate change, while much attention has not been focused on the effect of Best Management Practices on streamflow. Streamflow was likely to be estimated using the Sequential-Uncertainty-Fitting method of the Soil and Water Assessment Tool (SWAT-SUFI2). The streamflow was divided into datasets: calibration (2011-2018) and validation (2019-2021). Nash-Sutcliffe Efficiency (NSE) method was used to evaluate the performance of the models. The results showed that Nash–Sutcliffe efficiency (NSE) and coefficient of determination (R^2), PBIAS, P- factor, and R-factor for monthly streamflow in conservation practice were 0.52, 0.53, -4.5, 0.13, and 0.1 in the calibration. The validated models were 0.58, 0.63, 20.5, 0.28, and 0.47 at the Shiroro sub-basin 5. Similar results were found for streamflow in contouring during calibration, but the PBIAS was -2.8. The corresponding values are 0.64, 0.65, -8.1, 0.31, and 0.48 for validation. In the Shiroro sub-basin, strip cropping was confirmed by NSE and R^2 (0.58 and 0.58) during calibration. Also, the PBIAS, P, and R-factors have values of -2.7, 0.13, and 0.19, respectively. The equivalent values were 0.65, 0.65, 1.3, 0.28 and 0.39 during validation. During calibration, the values of the Nash–Sutcliffe efficiency (NSE) and coefficient of determination (R^2), PBIAS, P-factor, and R-factor were 0.58, 0.58, -3.2, 0.09, and 0.07 for the terrace. The corresponding values for validation include 0.58, 0.65, 23.3, 0.11, and 0.05. The SWAT models are satisfactory. Water policymakers need to discourage farmers from the use of non-conservation practices around Shiroro Dam.

Keywords: *Streamflow, SWAT model, Shiroro Dam and Best Management Practices.*

1. INTRODUCTION

Streamflow is a critical component of the water cycle and refers to the volume of water that flows through a river or stream over a given time (Fan, 2023). Fresh liquid water suitable for humans can be found in rivers and reservoirs as surface water or in aquifers as groundwater. Although the total amount of fresh water accessible has stayed constant over time, water demands are growing by the day due to population increase, economic development, urbanisation, and other factors. Rainfall patterns will likely be affected by climate change, resulting in increasing volatility and issues in stream flow and water supply management. Runoff prediction plays an important scientific and practical role in engineering projects and water resource management (Kushwaha et al., 2013), such as the design and management of reservoirs. The most valuable and commonly used tool for the prediction of runoff is the hydrological model (Hinmanshu et al., 2019). One of the best models is the SWAT model, which represents the hydrologic process and the interaction between them (Jain et al., 2017). This model requires hydroclimatic parameters such as observed streamflow, rainfall, and minimum and maximum temperature and represents the physical properties of the catchment. The model can be calibrated using sequential fitting algorithm 2 (Abaspour et al., 2017).

The SWAT model is used to simulate long-term streamflow, sediment, and phosphorus (Pandey *et al*., 2016); it was developed by the USDA Agricultural Research Service (ARS) to forecast the effect of activities related to land management on the transport of hydrology, pollutants and sediment in complex, large watersheds (Bera and Mati 2021). Several researchers have applied the SWAT model for discharge/runoff prediction (Pandey *et al.*, 2016) and sediment load (Kuti and Ewemoje, 2021; Krause et al., 2005; Song et al., 2015; Himanshu et al., 2017). The model performance of these studies was satisfactory. Daramola *et al.* (2019) estimated sediment yield in Shiroro Dam using the SWAT model—however, there is no available information about the simulated discharge in the catchment. In addition, Adeogun et al. (2022) predict the effect of BMPs on sediment yield; however, there is no available information on the effect of BMPs (terracing, contouring and strip cropping) on simulated streamflow. The main objective of the study is to estimate stream flow behaviour under different Best Management Practices (BMPs) in the Shiroro watershed and find out the most sensitive parameters which are critically responsible for the hydrologic response with pre-defined conditions.
The outcome of this study would be used by policymakers, land managers, and researchers to inform decision-making processes. The application of BMPs,

such as terracing, contouring, and strip cropping, resulted in varying effects on streamflow. Specifically, terracing increased streamflow by approximately 4%, while contouring and strip cropping increased it by about 7% and 9%, respectively. Conversely, non-conservation practices led to a significant increase in streamflow by 19%. The implementation of contouring and strip cropping BMPs is expected to reduce flooding downstream by approximately 2 times, highlighting the potential benefits of these practices in mitigating flood risks.

2.0 METHODOLOGY

2.1 Description of the study area

The study area, Shiroro Dam, which is about 66 km, is situated at the former Shiroro village in North-Central Nigeria. It can be found between Latitude 9.35°N, Longitude 6.45°E and Latitude 11.28°N Longitude 8.55°E, with an appraised land area of 32,125 km^2. The watershed has a mean elevation of 683 m above sea level (Figure 3.1). The Shiroro dam derives its water sources from the Kaduna watershed (32,125 km^2), which consists of four sub-watersheds. These four sub-watersheds are named after some commonly known rivers - Dinya, Gutalu, Sarkinpawa and Kaduna. The Dinya (365 km^2) consists of a basin; Gutala (2,672 km^2) and Sarkinpawa (3,413 km^2) on the other consists of seven basins, whilst the largest of them, the Kaduna sub-watershed (25,675 km^2) contains 69 basins. The northern part of the watershed is a little drier than the south. The sedimentary geology nature of the study area, alongside the predominately sandy soil with Guinea and Sudan savannah vegetation cover, makes the study area susceptible to soil erosion, which is a major sediment yield driver.

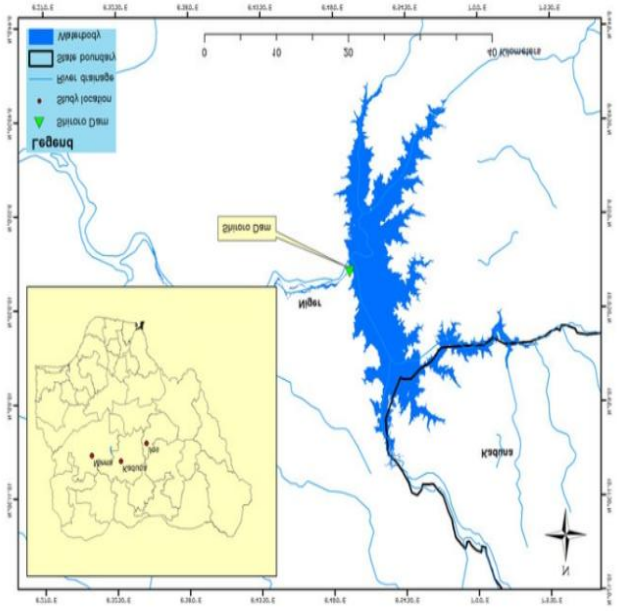


Figure 1: Location map of Shiroro

2.2 Climate of the study area

The Shiroro Lake watershed receives in excess of 100 mm with a peak value of about 280 mm –300 mm in July. Rainfall amount is in excess of 300 mm in the western half of the area. The highest rainfall receipt of over 400 mm is to be expected in September during a normal rainy year but can drop sharply to a maximum of 130 mm – 150 mm during a low rainfall year. The onset of the seasonal rainfall is between 20 – 30th April, and the length of the rainy season is between 161- 200 days.

The maximum temperature (< 35 ^{0}C) is recorded between March and June, while the minimum is usually between December and January (Niger State, 2012). The climate of the area is tropical and belongs to the tropical wet and dry (AW) of Koppen's climatic classification (Eze, 2004). However, the creation of Shiroro Lake has led to a change in climatic conditions in and around the lake area (Ezugwu, 2013).

2.3 Land use

The watershed and hydrological response unit of Shiroro was divided into 18 sub-basins with a total of 35 hydrological response units. Fig. 2 indicates that agricultural land (51.24%) has the highest percentage of land use, and next to it is water (45.14%), followed by forest (3.54%) and office building (0.07%). Ferric luvisols and lithosol cover the Shiroro sub-basins. Ferric luvisol covers 80.3% of the land, while the remaining 19.7% contains lithosol.

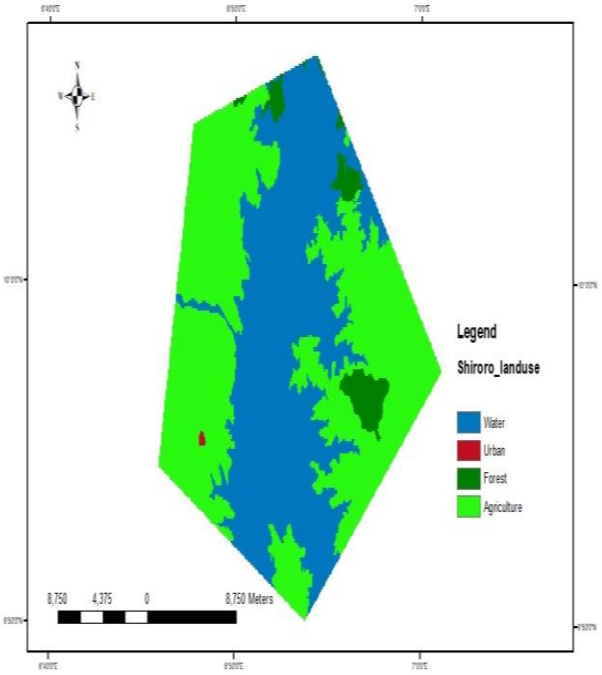


Figure 2 Landuse of the study area

3.1 Estimation of streamflow using the SWAT model

SWAT is a model that predicts streamflow (Abbaspour *et al*., 2015) and eroded sediment and nutrients (Kuti and Ewemoje, 2021). In line with landuse and land slope,

SWAT also splits a basin into sub-basins and separates them into hydrological response units (HRU). The water balance equation estimates streamflow through the hydrological cycle employing SUFI2 (Abbaspour *et al*., 2015).

3.2 Data collection

The 90-meter DEM was downloaded from the website of the Shuttle Radar Topography Mission (http://srtm.csi.cgiar.org). A land-use map was taken from the United States Geological Survey website with a resolution of 2 km (https://www.usgs.gov). A soil map was downloaded from the website of the Food and Agriculture Organization's database (2009) with a resolution of 1 km (http://www.fao.org).
The data, including rainfall, temperature, wind speed, relative humidity, and solar radiation, were obtained from the Upper NigerRiver Basin Authority (Shiroro Dam, 2023). The climatic data covers 11 years (2011 - 2021).

3.3 Watershed delineated and hydrological response units

The boundaries of Shiroro Dam were delineated using a polygon tool from Google Earth. The model was built using the ArcSWAT 2012 interface (Kuti and Ewemoje, 2021). The flow direction and accumulation of the streams (area of 5904.37 ha) were extracted from the DEM. The outlets in each location were selected and defined before the model sub-basin parameters were calculated. These further divided the entire watershed into 18 subbasins, which were also subdivided into 35 hydrological response units (HRUs) based on soil, land use, and slope in Shiroro Dam. One HRU is assumed to be a standardised unit for calculating water balance. The meteorological data were prepared between 2011 and 2021. The model writes input data and runs the Soil and Water Assessment tool (SWAT). The simulation runs for eleven years (2011-2021). The watershed delineation in Shiroro Dam is shown in Figure 3.

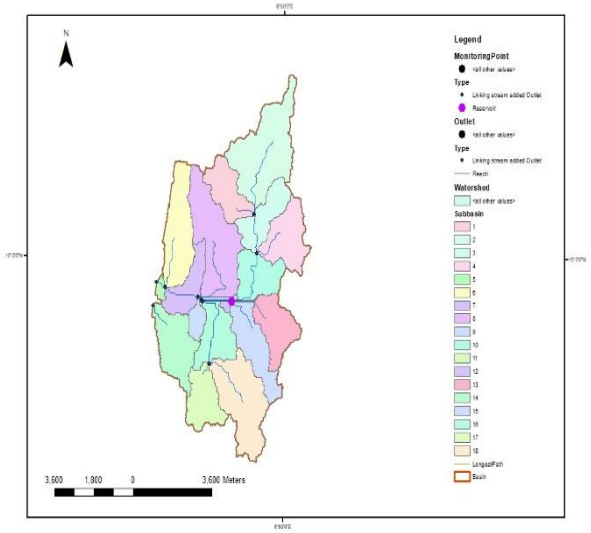


Figure 3. Shiroro watershed delineation

3.4 Calibration And Validation of Streamflow using SUFI2

Tables 1 and 2 show the modification of SWAT input parameters and input variables for SWAT. Streamflow prediction was executed by employing the SWAT procedure (Kuti and Ewemoje, 2021; Abbaspour *et al.*, 2015). The Latin hypercube method was used to calibrate, validate, and estimate uncertainty. The streamflow records were divided into two sets: the first dataset was used for calibration (2011-2018), and the second dataset was used for validation (2019-2021). This calibration and validation were conducted under different Best Management Practices: terracing, contouring, strip cropping and non-conservation practice (ridge along the slope) by changing the values of SCS runoff curve number for moisture condition and USLE equation support practice factor in ARCSWAT. It was also used to identify the input variables that change inflow.

Table 1: Modification of SWAT Input Parameters in ArcSWAT

S/N	BMPs	Original Value	Modified value
1	Terrace	91	71
		1	0.10
2	Contour	91	75
		1	0.5
3	Strip cropping	91	75
		1	0.38

Table 2: SWAT Input Parameters in ArcSWAT

SWAT Parameters	Minimum value	Maximum value	Fitted value
r__CN2.mgt	-0.2	0.2	-0.40
v__ALPHA_BF.gw	0	1	-0.33
v__GW_DELAY.gw	30	450	74.01
v__GWQMN.gw	0	2	1.15
r__GW_REVAP.gw	0	10	4.08
v__ESCO.hru	0	1	-0.09
r__CH_N2.rte	0	3	2.39
r__CH_K2.rte	5	130	71.81
r__SOL_K().sol	-0.8	0.8	-0.19
r__SOL_BD().sol	-0.5	0.6	0.20
r__SOL_AWC().sol	-0.2	4	0.82

3.5 Model performance

As reported by Abbaspour *et al*. (2015), the objective function of the model was Nash-Sutcliffe Efficiency (NSE). The coefficient of determination (R^2) and percent bias (PBIAS) decide the strength of the models. The model performance was evaluated as follows using equations 1 – 3.

$$(\text{NSE}) = 1 - \frac{\sum_{=i}^{n}(O_i - P_i)^2}{\sum_{=i}^{n}(O_i - O_{avr})^2} \quad \ldots 1$$

$$(R^2) = \left[\frac{\sum_{=i}^{n}(O_i - O_{avr})(P_i - P_{avr})}{\sum_{=i}^{n}(O_i - O_{avr})^2 \sum_{=i}^{n}(P_i - P_{avr})^2}\right]^2 \quad \ldots 2$$

$$(PBIAS) = \left[\frac{\sum_{=i}^{n}(O_i - P_i)\times 100}{\sum_{=i}^{n}(O_i)}\right] \quad \ldots 3$$

Where,
$O_i = i^{th} observed\ value,$
$O_{avr} = average\ observed\ value\ of\ the\ entire\ study\ period,$
$P_i = i^{th} simulated\ value,$
$P_{avr} = average\ of\ simulated\ value.$

Table 3: Classification of statistic indices

NSE	PBIAS	R^2	Classification
0.75 -1.00	PBIAS ≤ ±10	>0.75 -0.75 - 1.00	Very Good
0.60 - 0.75	±10 - ±15	0.6 – 0.75	Good
0.36 - 0.60	± 15 - ±25	0.50 - 0.60	Satisfactory
0.00 - 0.36	±25 - ±50	0.25 - 0.50	Bad
NSE ≤ 0.00	PBIAS< ± 50	R^2 ≤ 0.25	Inappropriate

Source: Almeida *et al.* (2018)

4.0 RESULTS AND DISCUSSIONS

4.1 Estimation of streamflow using SWAT-SUFI2 under ridging along the slope

Table 4 presents the calibration and validation of streamflow under BMPs. Figures 4 and 5 display the streamflow under ridge along the slope. The values of PBIAS were -4.5 and 20.5 for streamflow along the slope ridge during calibration and validation. The SWAT model also showed a better simulation with R-factors of 0.53 and 0.63. During calibration and validation, NSE values of 0.52 and 0.58 for streamflow along the slope ridges.

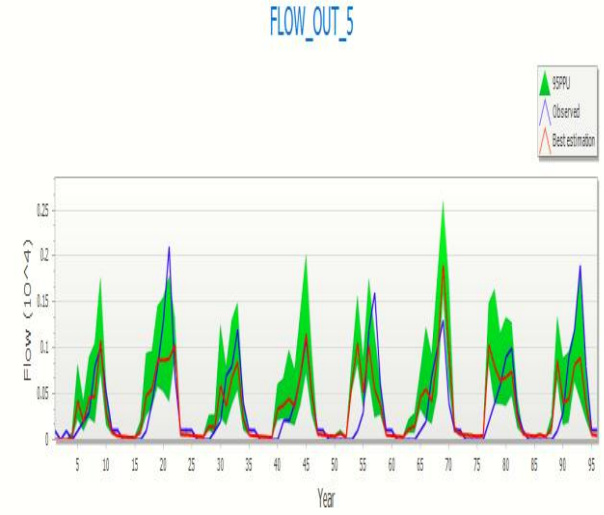


Figure 4: A monthly observed vs SWAT simulated streamflow for calibration (Jan. 2011 – Dec. 2018) in the Shiroro sub-basins under Ridge along the slope

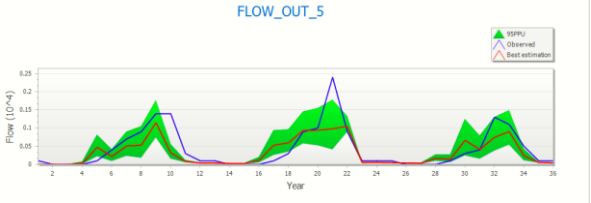


Figure 5: A monthly observed vs SWAT simulated streamflow for validation (Jan. 2019 – Dec. 2021) in the Shiroro sub-basins under Ridge along the slope

4.3 Estimation of streamflow using SWAT-SUFI2 under contouring

Figures 6 and 7 display the calibration and validation of streamflow under contouring. The values of PBIAS were -2.8 and -8.1 for streamflow under contouring during calibration and validation, which shows that the observed values are underestimated (Table 4). The SWAT model shows their variance in the observed data with R^2 of 0.58 and 0.65 during calibration and validation, but NSE values indicated a strong relationship between the simulated data and the observed data with 0.58 and 0.64 for streamflow under contouring.

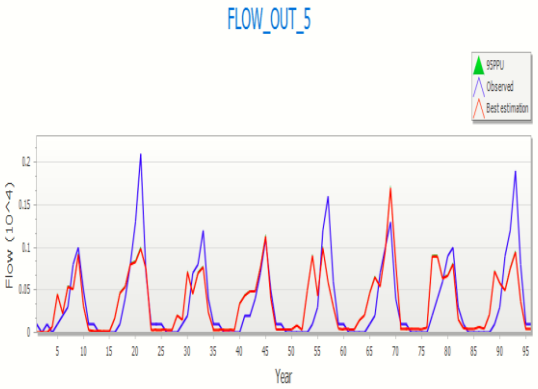


Figure 6: A monthly observed vs SWAT simulated streamflow for calibration (Jan. 2011 – Dec. 2018) in the Shiroro sub-basins under contouring

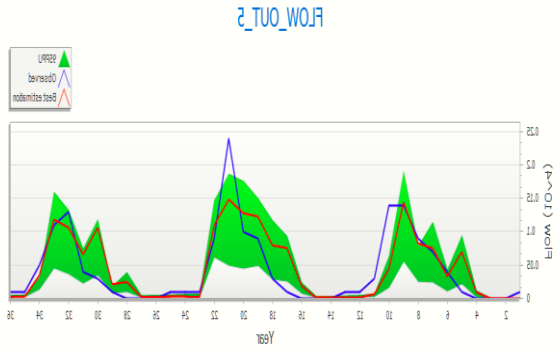
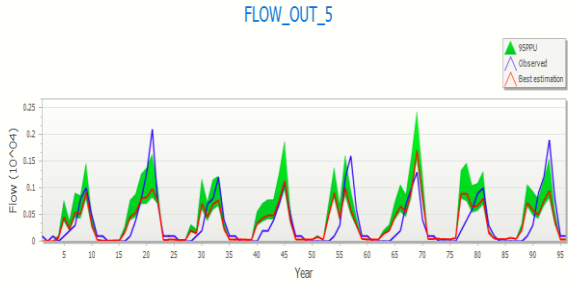


Figure 7: A monthly observed vs SWAT simulated streamflow for validation (Jan. 2019 – Dec. 2021) in the Shiroro sub-basins under contouring

4.4 Estimation of streamflow using SWAT-SUFI2 under strip cropping

Figures 8 and 9 display the calibration and validation of streamflow under strip cropping. The values of PBIAS were -2.7 and 1.3 during calibration and validation, which represents a good estimation of the observed data for streamflow under strip cropping (Table 4). The SWAT mod



el also showed a good simulation with R^2 values of 0.58 and 0.65 during calibration and validation. NSE values of 0.58 and 0.65 for calibration and validation indicated strong proximity of the simulated data to the observed data for streamflow under strip cropping.

Figure 8: A monthly observed vs SWAT simulated streamflow for calibration (Jan. 2011 – Dec. 2018) in the Shiroro sub-basins under strip cropping

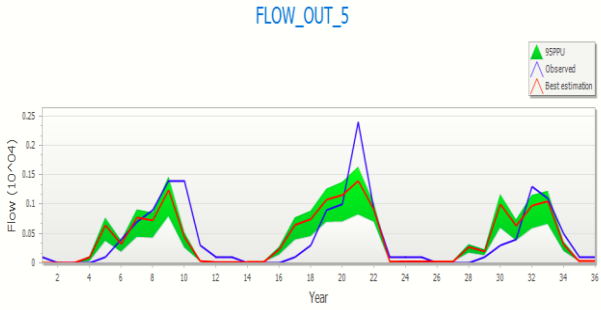


Figure 9: A monthly observed vs SWAT simulated streamflow for validation (Jan. 2019 – Dec. 2021) in the Shiroro sub-basins under strip cropping.

4.5 Estimation of streamflow using SWAT-SUFI2 under terracing

The calibration and validation of streamflow under terracing are shown in Figures 10 and 11. The values of PBIAS were -3.2 and 23.3 during calibration and validation (Table 4). The validation shows an underestimation of the observed data for streamflow under terracing. The SWAT model also showed a good simulation with R^2 values of 0.58 and 0.65 during calibration and validation. NSE values of 0.58 and 0.58 for streamflow terracing indicate a level of closeness between the simulated and the observed data.

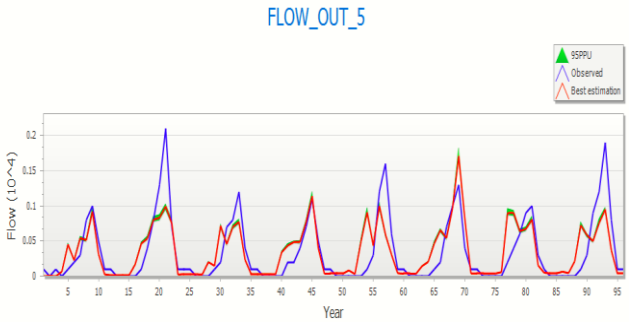


Figure 11: A monthly observed vs SWAT simulated streamflow for calibration (Jan. 2011 – Dec. 2018) in the Shiroro sub-basins under terracing

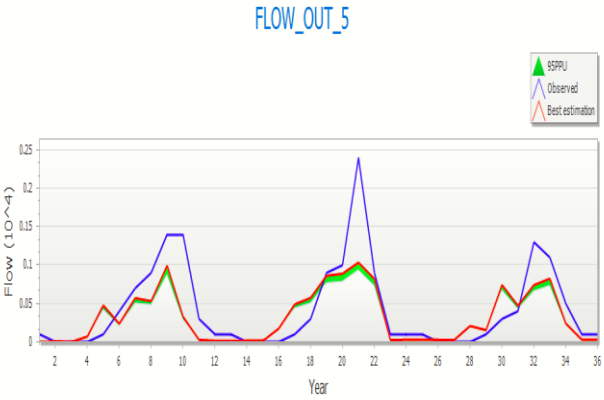


Figure 12: A monthly observed vs SWAT simulated streamflow for validation (Jan. 2019 – Dec. 2021) in the Shiroro sub-basins under terracing.

Table 4: Calibration and validation of streamflow

BMPs	Calibration and Validation of flow	NSE	P_{BIAS}	R^2	P-factor	r-factor
RALS	Calibration	0.52	-4.5	0.53	0.13	0.1
	Validation	0.58	20.5	0.63	0.28	0.47
CON	Calibration	0.58	-2.8	0.58	0.07	0.02
	Validation	0.64	-8.1	0.65	0.31	0.48
STR	Calibration	0.58	-2.7	0.58	0.13	0.19
	Validation	0.65	1.3	0.65	0.28	0.39
TER	Calibration	0.58	-3.2	0.58	0.09	0.07
	Validation	0.58	23.3	0.65	0.11	0.05

CONCLUSION

The SWAT model effectively simulated observed streamflow, demonstrating its reliability using SUFI2.

Notably, conservation practices such as terracing, contouring, and strip cropping resulted in modest increases in simulated streamflow. In contrast, non-conservation practices increase streamflow by 19%, and it is concluded that non-conservation practices around water bodies like the Shiroro Dam significantly increase streamflow and contribute to annual flooding. The implementation of contouring and strip cropping BMPs is expected to reduce flooding downstream by approximately 2 times, implying their potential benefits in mitigating flood risks by controlling runoff and preventing excessive water accumulation. There is a need for farmers to discourage non-conservation practices around water bodies like the Shiroro Dam, as they significantly increase streamflow and contribute to annual flooding.

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PRODUCTION AND CHARACTERISATION OF COCOA POD HUSK AND BANANA PEEL ACTIVATED CARBON USING CHEMICAL IMPREGNATION (ZINC CHLORIDE) FOR REMOVAL OF HEAVY METALS FROM SURFACE WATER

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ABSTRACT

The agricultural wastes cause environmental pollution. In view of this, the study produced and characterised cocoa pod husk and banana peel activated carbon (CPH and BPAC) differently using zinc chloride to remove heavy metals in surface water. The samples were characterised using Brunauer-Emmett-Teller (BET) and Barrett-Joyner-Halenda (BJH) methods. A mixture and optimal design were used to optimise the mixture of CPH and BPAC. Nine (9) surface water samples were collected from the Garatu, Kataeregi, and Gadayeregi, where mining activities were conducted along river banks. The surface water samples were analysed using standard methods. The results indicated that the surface areas for impregnated CPH and BPAC, as determined by BET, were 762.775$m^2g^{-1}$and 678.415m^2g^{-1}, respectively, while their Dubinin-Radushkevich micropore volumes were 0.272$ccg^{-1}$and 0.273 ccg^{-1}, respectively, implying that CPH and BPAC exhibited a higher adsorptive capacity. The results included the concentrations of Lead, Chromium, and Cadmium, ranging from 0.24 - 0.55,0.24 - 0.55, and 1.55 to 3.12, were very high in the water samples when compared to WHO standard, implying that Lead, Chromium, and Cadmium pose significant health risks. Therefore, the CPH and BPAC (50, 50) removed Nickel and Zinc, implying that these heavy metals were within acceptable levels of WHO limits. The study concluded that the CPHAC (50%) and BPAC (50%) is the best for removing nickel and zinc in surface water. Future studies should use the composition ratio of BPAC (60%) and CPHAC (40%) to remove lead, chromium, and cadmium in surface water.

Keywords: *cocoa husk pod, banana peel, chemical impregnation-zinc chloride, activated carbon, heavy metal and surface water.*

1. INTRODUCTION

Mining activities also interfere with either surface or groundwater sources. These waters have been diverted from either river or stream into mining wells, which has affected the river regime (Dukiya, 2013). Additionally, the digging and washing of mined minerals find their way into surface water, causing increased accumulation of heavy metals. Heavy metal contamination in surface water is a significant environmental concern arising from various sources, including industrial, agricultural, and urban activities (Zhang et al., 2023; Aziz et al., 2023). This pollution is a global issue due to the widespread presence of toxic heavy metals in water bodies. This pollution is a global issue due to the widespread presence of toxic heavy metals in water bodies (Zhang et al., 2023). According to Zhang et al. (2023), common heavy metal pollutants include arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), Nickel (Ni), and zinc (Zn). These metals are found in the earth's crust and are non-biodegradable. Some heavy metals, such as copper, iron, manganese, molybdenum, selenium, and zinc, are essential in small quantities but can be toxic at higher concentrations. Other heavy metals, like lead, cadmium, and mercury, are toxic even at low concentrations. These contaminants pose severe health risks, including neurological disorders, organ damage (such as liver and kidney damage), skin lesions, and cancer (Zhang et al., 2023).

Despite the availability of various water treatment methods, many conventional techniques, such as Ion exchange and membrane filtration techniques (reverse osmosis and nanofiltration) and advanced oxidation processes (Lubal, 2024), are often expensive and energy-intensive. These methods can generate secondary waste or prove inefficient in removing low concentrations of heavy metals. Therefore, there is a pressing need for affordable, sustainable alternatives for heavy metal removal from contaminated mine water sources using adsorption (activated carbon and biochar).

Cocoa and banana production have been a significant source of economic development in South-West Nigeria

and other parts of Nigeria, contributing to the country's economy (Biney, 2017). However, the increase in productivity can lead to higher rates of pollution due to the waste generated by these activities (Velázquez-Araque, 2023; Vásquez et al., 2019). A variety of wastes, such as cocoa pod husk and banana peels, are abundantly generated in large quantities and often abandoned in field sites, littered in the surroundings, constituting foul odours, breeding grounds for pathogenic micro-organisms and environmental pollutants.

Activated carbon (AC) is a product derived from charcoal or mineral with physicochemical properties that make it a suitable filter medium in different industrial, medicinal, environmental remediation, food, and commercial applications (Velázquez-Araque, 2023). Because of its high cellulosic and hemicellulosic content, there are two types of activation techniques for AC: chemical activation and physical activation (Prauchner and Rodríguez-Reinoso, 2012; Macia-Agullo et al., 2004). While physical activation employs steam, air, CO2, or a mixture of those as an activation agent, chemical activation uses chemicals such as ZnCl2, H3PO4, and KOH (Cruz et al., 2012). Chemical activation, on the other hand, has a few advantages over physical activation: it yields much higher activated carbons, uses temperatures lower than pyrolysis, usually only needs one step, and produces activated carbons with extremely high surface areas and well-developed microporosities. Additionally, the activated carbons produced significantly reduce the mineral matter content.

Few studies used AC (adsorption) to remove heavy metals from groundwater, while others did not apply it as a filter medium. Cruz et al. (2012) employed cocoa pod husks from activated carbon to remove arsenic (As) in groundwater pollution and discovered that AC from cocoa pod husks can absorb up to 80% of arsenic in less than an hour. However, the research did not vary the percentage of cocoa pod husk and banana prior to ZnCl2 impregnation to establish the optimal biomass for the removal of arsenic in groundwater. In addition, Velázquez-Araque et al. (2023) produced activated carbon (AC) from cocoa pod husks and banana peels prior to phosphoric acid (H_3PO_4) and sulfuric acid (H2SO4) impregnation. This study found that cocoa husk pod and 50 % concentration of sulfuric acid solution as an activating agent, making it highly suitable to be used as a filter medium. However, this research did not vary the percentage of cocoa pod husk and banana peels prior to phosphoric acid (H3PO4) and sulfuric acid (H2SO4) impregnation to determine optimal biomass that will be suitable for the removal of heavy metals in mine water. In this research, the percentage of cocoa pod husk and banana peels was varied prior to ZnCl2 impregnation to determine its effect on the quality of the activated carbon produced, aiming to find an optimal biomass for effective AC production from cocoa pod husks and banana peels, which will remove heavy metals in mine water.

Varying the percentage of cocoa pod husk and banana peels helps determine the best proportion of activated carbon. Different proportions of cocoa pod husk and banana peel can significantly influence the chemical composition and physical characteristics of the biomass, which in turn affects the efficiency of the ZnCl2 activation process. Moreover, varying the biomass composition can help tailor the final product for specific applications, such as improving its adsorption capabilities or combustion properties. The research aims to establish the optimal biomass from cocoa pod husks and banana peels for effective AC production. The variation in percentages of cocoa pod husk and banana peel prior to ZnCl2 impregnation would give not only the optimal biomass but also a strategic approach to enhancing the quality and performance of activated carbon derived from agricultural waste.

2.0 METHODOLOGY

2.1 Description of the study area

Location	Latitude	Longitude
Garatu	9.483202	6.439378
Kataeregi	9.365477	6.165388
Gadayeregi	9.387992	6.34921

2.2 Materials

The materials used for this study include cocoa pod husk, banana peel, water sample, distilled water, $Zncl_2$ and Liquid nitrogen. The equipment used for this study includes a Muffle furnace (model number: HSX-2-6-13 and serial number: 20220412), Electronic weighing balance (Metlab electronic compact scale, SF-400C), Ultraviolet spectrophotometer (Jenway, Model 6300); Cutlass; Porosimeter (ASAP 2020 model from micrometric); Oven dryer (model number: PBS118SF and serial number: 94L234); Buhr mill (model number: XM0240X90 and year: June 2022); Crucible; Oven (hot air oven, drier box AX-OV73); Atomic Absorption Spectrometry (Jenway, Model PFP7); Nova 4200e (model number:1413052102)

2.3 Preparation of Activated Carbon

Cocoa pod husks (CPH) and banana peels (BP) were sun-dried, reduced to smaller sizes (Plate I), and washed with distilled water to remove external waste particles. The washed cocoa pod husk and banana peel pieces were dried in an oven (model number: PBS118SF and serial number: 94L234) at 105^0C for 24 hours to remove moisture content (fig1).



Figure 1A and B Pieces of cocoa pod husk and banana peel during sun-dried and oven-dried

CPH and BPAC were subjected to a carbonisation process at 350^0C in the muffle furnace, as shown in Figure 2 (Velázquez-Araque *et al*., 2023; Rangari and Priyanka, 2017).



Figure 2: Carbonisation of cocoa pod husk and banana at the Muffle furnace

The sample was later crushed to sizes of 0.25mm and 0.5mm (Figure 3 A and B) with a buhr mill (model number: XM0240X90 and serial number: 80220452).



Figure 3 A and B: Crushed cocoa pod husk and banana peel before impregnation

The crushed samples were divided into two portions and accurately weighed 50 grams each. The first sample was non-impregnated, and the second sample was impregnated with sulfuric acid of 10% concentration level for 24 hours until the mixed sample turned into a paste to the level of activation carbon properties as shown in Figure 4 A and B (Kuti *et al.*, 2018*;* Rangari and Priyanka, 2017). The percentage of cocoa pod husk and banana peels varied after ZnCl2 impregnation to determine its effect on the quality of the activated carbon, which has not been conducted before in the literature. One molar of zinc chloride was used for the impregnation.



Figure 4. A and B: Impregnation of cocoa pod husk and banana peel with Zinc Chloride ($ZnCl_2$)

2.4 Characterisations of Activated Carbon

The Brunauer- Emmet- Teller theory (BET) was used to determine the surface area of the activated carbon produced from cocoa pod husk and banana peel according to Chen *et al.* (2018) and Rouquero *et al.* (2013), respectively. The samples were degassed at 523^0C for 3 hours for moisture and removal. The degassed samples were then analysed for physisorption of the adsorbate (nitrogen) by the adsorbent in a liquid nitrogen environment on the surface (Kariim et al., 2015).

2.5 Data analysis

The surface area of impregnated CPH and BPAC were determined using the BET method with Nova 4200e (Kariim et al., 2015). The equipment analysed and generated results in descriptive statistics such as mean values and correlation coefficients.. The removal efficiency was determined as followed:

$$Removal\ Efficiency\ (\%) = \frac{(C_i - C_f)}{C_i} \times 100$$

where C_i and C_f represent the initial and final concentration of heavy metals.

3.0 RESULT AND DISCUSSIONS

3.1 Characterisation of Activated Carbon from Cocoa Pod Husk and Banana Peels

Cocoa pod husk (CPH) and Banana peel (BPAC) with Zinc Chloride acid were characterised by Nitrogen gas analysis at 250^0C. Appendices I and II showed multi-point BET plots for CPH and BPAC with Zinc Chloride acid. Also, the results showed linear and nonlinear, indicating correct and incorrect BET plots for both CPH and BPAC with Zinc Chloride acid. The CPH and BPAC impregnated with (ZnCL2) have a correlation coefficient and slope values of 0.999297 and 2.936, then 0.995275 and 3.933, respectively. Furthermore, Appendices I and II have positive constant C for CPH (2.801) and BPAC (4.277). The Multi-BET surface area for the CPH and BPAC with Zinc Chloride acid had a mean of 762.775 m^2g, 678.415m2/g, implying a significant difference in Multi BET area obtained in different relative pressure ranges (Table 1). Its Langmuir surface area also had a mean of 14635.233 m^2g(CPH) and 2547.965m^2/g(BPAC) (Table 1), implying that the CPH and BPAC with Zinc Chloride acid had a large surface area under the BET and Langmuir method. The curves sharply increase at low relative pressure, showing a high adsorptive capacity for CPH and BPAC impregnated with Zinc Chloride acid. This finding aligns with related studies (Kuti *et al*., 2018a).

The Dubinn-Radushkevic Method **(**DR) micropore pore volume and average pore width for CPH and BPAC impregnated with Zinc Chloride acid ($ZnCl_2$) were 0.272cc/g, 6.503nm and 0.273cc/g and 6.006nm, respectively. In comparison, the values for CPH and BPAC with Zinc Chloride are shown in Table 1. This finding is evidenced by a remarkable increase of 36.25% in the Langmuir surface area, as shown in Table 1. These results are consistent with related studies (Kuti et al., 2018a). However, Kuti et al. (2018) utilised bamboo as a precursor with different chemical activation methods, and their findings indicated that Zinc Chloride acid treatment resulted in a higher surface area (Langmuir). Similarly, agricultural waste (bamboo) had a higher surface area than carbons activated with zinc chloride (Ademiluyi et al., 2012). The correlation between the two samples is positive and very high. The Barrett-Joyner-Halenda surface area, pore volume, and pore diameter were like the Multi-BET surface area (Table 1). However, the micropore analysis using the Dubinin-Astakhov (DA) method had the highest pore volume, followed by the BJH pore volume (Table 1). The study revealed that the micropore Analysis (Dubinin-Astakhov (DA) method is preferred over other methods in terms of pore volume (Sdanghi et al., 2020). A study conducted by Velázquez-Araque*et al*. (2023) revealed that the CPH and BPAC had the highest surface area of 762.775 m^2g, with a 50% Zinc Chloride acid solution and aligns with the finding of this study, although with 10% Zinc Chloride acid. Cruz *et al*. (2012) also discovered that the highest surface area

obtained for Zinc Chloride that removed heavy metals from the water was 762.775 m^2g; similarly, the adsorption efficiency of cocoa pod husk biochar for heavy metals ranged from 99.97% to 99.99% (Abbey et al., 2023), implying that CPH had a higher affinity for heavy metals removal. The activated carbon from cocoa pod husk and banana peel removed heavy metals.

Table 1: Textural porous characteristics of cocoa pod husk (CPH) and banana peel (BP) activated carbon using ($ZnCl_2$)

Characteristics	Impregnated Cocoa pod husk with Zinc Chloride ($ZnCl_2$)	Impregnated Banana Peel With Zinc Chloride ($ZnCl_2$)
Multi-point BET surface area (m^2/g)	762.775	678.415
DA micropore volume (cc/g)	0.678	0.618
DA pore diameter (nm)	3.000 e^{+00}	2.860 e+00
BJH surface area (m^2/g)	789.483	806.347
BJH pore volume (cc/g)	0.389	0.391
BJH pore diameter (nm)	2.105	2.115
Langmuir surface area (m^2/g)	14635.233	2547.965
DR micropore volume (cc/g)	0.272	0.273
DR micropore surface area (m^2/g)	765.718	767.118
DFT pore volume (cc/g)	0.196	0.210
DFT surface area (m^2/g)	161.766	176.707
DR Absorption energy (KJ/mol)	3.998	4.329
DR average pore width (nm)	6.503	6.006

Note: Brunauer-Emmett-Teller (BET), Barrett-Joyner-Halenda (BJH), Dubinn-Radushkevic Method (DR), Dubinin-Astakhov (DA), Density Functional Theory (DFT).

3.2 Removal of Heavy Metals from Surface Water using Cocoa Pod Husk and Banana Peel Activated Carbonin Selected Study Area

Table 2 presents the removal rate of heavy metals in surface water under different compositions of cocoa pod husk and banana activated carbon in selected study areas. The results showed the removal rates of heavy metals across different locations and compositions of CPH and BP. The highest removal rates were observed for Nickel (Ni) at Garatu, where a composition of 50:50 CPH and BP achieved an impressive 97% removal rate. Similarly, Zinc (Zn) removal was maximised at Kataeregi with the same 50:50 composition, reaching a removal rate of 94%. In Garatu, the cocoa pod husk and banana-activated carbon consistently demonstrated higher removal rates for Ni and Zn compared to Kataeregi and Gadaeregi.

In contrast, the cocoa pod husk and banana-activated carbon removed Zn and Lead (Pb), while Gadayeregi showed a notable efficiency in removing Cadmium (Cd). The results also showed that CPH and BP-activated carbon (50,50 composition) had a minimum removal rate of 45% for zinc. A similar trend was observed for CPH and BP-activated carbon (80,20 and 65,35), where their minimum removal rates were 14% (Zinc) and 15% (Chromium). The effect of composition on removal efficiency was another critical factor. Generally, as the proportion of CPH increased relative to BP, the removal efficiency decreased. However, there were exceptions to this trend. For instance, at Kataeregi, the removal of Zn remained effective even with varying compositions, indicating that specific metal removals can be less sensitive to changes in CPH and BP ratios under certain conditions.

Table 2: Removal rate of heavy metals in surface water in selected study area

Sample Locations	CPH and BP	Pb (%)	Cr (%)	Cd (%)	Cu (%)	Zn (%)	Ni (%)
A	50,50	86	80	81	79	88	97
A	65,35	61	45	38	68	75	59
A	80,20	56	24	52	53	62	53
B	50,50	80	69	83	70	94	80
B	65,35	70	62	60	59	87	47
B	80,20	62	57	43	33	89	39
C	50,50	65	76	96	68	45	81
C	65,35	29	15	65	53	17	54
C	80,20	41	32	58	56	14	27

3.3 Determination of the optimal biomass for effective Activated Carbon production from cocoa pod husks and banana peels

The mean concentrations of heavy metals varied across different composition ratios. For Lead (Pb), the lowest concentration was observed at a 50:50 composition ratio (0.08 ppm), while the highest concentrations were found at the 80:20 and 65:25 ratios (0.19 ppm and 0.18 ppm, respectively). Chromium (Cr) showed its highest concentration at the 80:20 ratio (1.31 ppm) and its lowest at the 50:50 ratio (0.54 ppm). Cadmium (Cd) concentrations were consistent at 0.06 ppm for both the 80:20 and 65:25 ratios but significantly lower at 0.02 ppm for the 50:50 ratio. Copper (Cu) had its highest concentration at the 80:20 ratio (0.13 ppm) and its lowest at the 50:50 ratio (0.07 ppm). Zinc (Zn) concentrations were highest at the 80:20 ratio (0.58 ppm), decreasing to 0.36 ppm at the 50:50 ratio. Lastly, Nickel (Ni) concentrations decreased from 0.10 ppm at the 80:20

ratio to 0.03 ppm at the 50:50 ratio. This study discovered that the 50:50 composition ratio resulted in the lowest concentrations of all heavy metals tested.

Table 3: Mean concentration of heavy metals using cocoa pod husk and banana peel activated carbon under different compositions in the selected study area

Ratio	Pb (ppm)	Cr (ppm)	Cd (ppm)	Cu (ppm)	Zn (ppm)	Ni (ppm)
80,20	0.19	1.31	0.06	0.13	0.58	0.10
65,25	0.18	1.20	0.06	0.11	0.55	0.08
50,50	0.08	0.54	0.02	0.07	0.36	0.03

Table 4 presents the treatment of heavy metal in surface water using cocoa pod husk and banana peel-activated carbon. Comparing the results with the WHO standard, as shown in Table 1, the study observed that nickel was below the limits (0.07), followed by zinc (3). The remaining heavy metals were above the WHO standard.

Table 4: Treatment of heavy metals in surface water using cocoa pod husk activated (50%) and banana peel activated carbon (50%)

Sites	Pb (ppm)	Cr (ppm)	Cd (ppm)	Cu (ppm)	Zn (ppm)	Ni (ppm)
SL1	0.05	0.39	0.03	0.04	0.04	0
SL2	0.11	0.97	0.02	0.07	0.19	0.04
SL3	0.09	0.37	0.01	0.11	0.78	0.04

Note: SL1: Garatu; SL2: Kataeregi; SL3: Gadayeregi

These findings align with an existing study, which reported that Chromium levels were higher than the safe limit of 0.141 mg/l in the water hand pump samples at Gupta Gate, Shivnagar **(**Tripathi and Chaurasia, 2020). The contamination level of cadmium in the surface water was high in the selected area, ranging from 1.55 to 3.12. This outcome aligns with a previous study (Panwar and Ahmed, 2018), which reported that a sample of groundwater had a level up to 0.28 mg/l, which was above the safe level standard. These findings imply that lead, chromium, and cadmium pose significant health risks, including kidney damage, bone disorders, and increased cancer risk (Bouida et al., 2022; Sholehhudin et al., 2021). The concentrations of the heavy metals are linked to mining activities.

The Cocoa pod husk activated with Zinc Chloride ($ZnCl_2$) had a surface area of 762.775 m^2/g, while the surface area for the banana peel was 678.415 m^2/g. This finding aligns with an existing study (Velázquez-Araque et al., 2023), which reported that activating cocoa pod husk and banana peel with sulphuric acid had a mean of 600 and above (m^2/g) is appropriate.

The study revealed that the removal of Zn remained effective even with varying compositions of cocoa pod husk and banana peel activated carbon for different compositions: 80,20, 50,50, and 65, 35. There is little or no information about the suitable composition of cocoa pods and banana peel activated for the removal of nickel and zinc. Therefore, the cocoa pod husk and banana peel activated carbon (50,50) removed Nickel and Zinc.

4.0 CONCLUSION

The study characterised cocoa pod husk and banana peel and activated them with zinc chloride for the removal of heavy metals in surface water near mining activities in the selected study area. The results discovered that the surface water samples contain high concentrations of lead, chromium, and cadmium, posing serious health risks to consumers. The BET surface area also showed that cocoa pod husk activated with zinc chloride has a higher surface area compared to banana peel, which could potentially enhance its adsorption capabilities. Findings from this study showed that the removal of zinc remained effective across varying compositions, indicating its robustness in different conditions. The optimal biomass composition for the removal of heavy metals was 50 percent cocoa pod husk and banana peel, and the level of its removal rate was high. In addition, the correlation coefficient revealed a positive and strong relationship between the percentage of cocoa pod husk and heavy metal concentrations after treatment, while a negative correlation was observed with banana peel. These findings suggest that banana peel may be more effective in reducing heavy metal levels.

Furthermore, the study found that nickel and zinc levels were within acceptable limits after treatment and concluded that the removals of nickel and zinc were superb. A composition ratio of cocoa pod husk (50%) and banana peel (50%) is recommended to remove nickel and zinc from gold mining wastewater. It is also recommended that future studies should use the composition ratio of banana (60%) and cocoa pod husk (40%) to optimally remove lead, chromium, and cadmium in gold mining surface wastewater.

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Development of Pulverizing Machine for Pharmaceutical Industries

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ABSTRACT

This project focuses on the design, fabrication, and evaluation of a pulverizing machine specifically tailored for pharmaceutical industries in Nigeria. The hammer mill, made from stainless steel, was chosen due to its high processing capacity and ability to handle various dry materials. Stainless steel was selected for its corrosion resistance, strength, and durability, ensuring compliance with pharmaceutical hygiene standards and providing long-lasting performance. The pulverizer consists of essential components including a high-speed motor, hammers, a sieve, and a suction fan for efficient dust control and heat prevention. The machine was fabricated using locally sourced materials at a cost of #200,000, significantly lower than the cost of imported equivalents. Performance tests were conducted using maize, guinea corn, and millet, demonstrating consistent particle sizes of 400µm-600µm across crops. The results showed that the machine performed reliably, with fine particle output and minimal variations in mass loss and processing time. Although variations in weight changes were observed, particularly with millet, the hammer mill proved to be efficient, achieving uniform grinding with minimal energy consumption. The study concludes that the locally fabricated pulverizer, made from stainless steel, is cost-effective, durable, and suitable for pharmaceutical grinding processes, with potential for optimization and further development, including solar-powered operation to address energy supply challenges in Nigeria.

Keywords: *Corrosion resistance, Fabrication, Hammer mill, Pharmaceutical industries, Pulverizing machine, Stainless steel*

1 INTRODUCTION

A pulverizer is a machine designed to crush, grind, or shred materials into smaller particles through repeated hammering. These machines have a wide range of industrial applications, including use in agriculture, where they mill grain into coarse flour for livestock feed, in fruit juice production, where they help extract juice by breaking down fruit fibers, and in recycling industries, where they grind used shipping pallets into mulch. The grinding process has been utilized since ancient times, dating back to the Stone Age, and continues to be an essential operation in modern industries due to its numerous advantages. Grinding is widely employed to increase the reactivity, solubility, and homogeneity of solid materials, making them more suitable for various applications (WU Z *et al.*, 2012).

Controlling particle size is crucial in different industries, as it directly impacts the performance and quality of the final product. In the pharmaceutical industry, for instance, the particle size of active pharmaceutical ingredients (APIs) and excipients must be precisely maintained to ensure proper dissolution rates and solubility. An improper particle size distribution can lead to reduced drug efficacy or unpredictable release rates (Cerdeira AM *et al.*, 2010; Merisko-Liversidge E & Liversidge GG, 2011). Similarly, in the mining and mineral processing sector, controlling particle size enhances the efficiency of ore concentration, allowing metals to be more effectively extracted from raw mineral ores (Chemjea TW *et al.*, 2004). A well-regulated grinding process ensures that the ore particles are broken down to the optimal size, improving the efficiency of further separation and refining processes.

Beyond simple size reduction, grinding has recently been utilized in the synthesis of advanced materials, taking advantage of the mechanical forces generated during the process. In material science and engineering, mechanical grinding helps modify material properties, create new structures, and enhance performance characteristics for specialized applications. This approach is being explored for improving catalysts, enhancing fuel cell efficiency, and even developing high-performance composite materials.

The size reduction process depends on several material properties, including hardness, toughness, moisture content, abrasiveness, and thermal sensitivity. Grinding and cutting are common methods for reducing the size of solid materials, while emulsification and atomization are used for liquids. There are various types of size-reduction machines designed for specific applications, and their efficiency is influenced by factors such as feed size, final particle size, energy consumption, and material handling properties. Ensuring an optimal grinding process requires a deep understanding of these factors to achieve desired particle size distribution while maintaining efficiency.

Despite advancements in grinding technology, the understanding of grinding phenomena remains challenging due to the complex interactions of particles, mechanical forces, and fluid movements within the system. In recent years, researchers have attempted to analyze grinding processes using numerical simulation techniques, which help model the motion of particles and the forces acting on them. However, one of the major challenges in numerical simulation is accurately predicting particle breakage mechanisms. Although many studies have focused on single-particle breakage, there is still a lack of comprehensive models that can simulate overall grinding behavior in an industrial setting.

To overcome these limitations, ongoing research is focused on developing novel simulation methods that can integrate both single-particle breakage and bulk grinding phenomena. Such advancements will enhance the efficiency, precision, and predictability of grinding processes across various industries, ensuring better control over particle size distribution and improving material processing. Understanding and optimizing these processes will have significant implications in fields ranging from pharmaceuticals and materials science to mining and manufacturing.

2 METHODOLOGY

This section outlines the procedures and methods used in the research, including the design, fabrication, and performance evaluation of the pulverizer. The methodology includes machine description, materials selection, design analysis, fabrication process, testing procedures, and data analysis.

2.1 RESEARCH DESIGN

The study follows an experimental research approach, involving the design, fabrication, and performance evaluation of a pulverizer. The research process consists of four key phases:

i. Conceptual Design and Analysis – Reviewing existing pulverizer designs, identifying limitations, and developing an improved design.
ii. Material Selection and Fabrication – Choosing appropriate materials based on strength, durability, and corrosion resistance, followed by the machine's fabrication.
iii. Performance Testing – Conducting tests to evaluate the efficiency, throughput, and operational reliability of the pulverizer.
iv. Data Collection and Analysis – Measuring key performance parameters, including particle size distribution, energy consumption, and throughput rate.

2.2 DESIGN AND FABRICATION PROCESS

The pulverizer was designed to operate based on the principle of impact and attrition. The hammer mill mechanism was selected for its high efficiency in pulverizing different dry materials. The design process included:

- Structural Design: CAD software (SolidWorks) was used to design and simulate the components to ensure structural integrity.
- Material Selection: Materials were chosen based on strength, durability, heat resistance, and corrosion resistance. The materials used for various components are listed in Table 3.1.
- Fabrication Steps:
  i. Cutting and shaping of stainless-steel sheets for the pulverization unit.
  ii. Welding and assembly of frame components using medium-carbon steel.
  iii. Installation of hammers, rotors, and bearings.
  iv. Mounting the electric motor, belt system, and fan assembly.
  v. Assembly of the cyclone system for dust control and improved efficiency.

2.3 PERFORMANCE EVALUATION

The fabricated pulverizer was tested for efficiency using the following parameters:

i. Rate (kg/hr): Measured by Throughput determining the weight of processed material over time.
ii. Particle Size Distribution: A sieve analysis was conducted to evaluate the uniformity of the output.
iii. Energy Consumption: The power input of the 3.69 kW electric motor was recorded during operation.
iv. Operational Efficiency: The effectiveness of the suction fan in preventing clogging and heat buildup was observed.

2.4 SAFETY AND MAINTAINABILITY CONSIDERATION

i. Safety measures such as protective enclosures for the cutting blades and insulated heating coils were incorporated to prevent hazards.
ii. The machine was designed for easy maintenance, with bolts and nuts facilitating the replacement of parts like the heating coil, motor, and rotor.

2.5 DATA COLLECTION AND ANALYSIS

i. Experimental data were recorded, tabulated, and analyzed statistically.
ii. Results were presented using graphs, tables, and charts to evaluate machine performance.

2.6 DESIGN ANALYSIS FOR SMALL HAMMER MILL

2.6.1 Determination of shank diameter of bolts connecting the Coupler to disc-1

This is given by

$$\sigma_b = \frac{F}{A} \quad (1)$$

Where σ_b is bearing stress
F is force acting on shank
A is bearing area on disc-1

But

$$A = dt \quad (2)$$

Where d is diameter of shank
t is the thicknes of disc-1, Therefore,

$$\sigma_b = \frac{F}{dt}$$

$$d = \frac{F}{\sigma_b t} \quad (3)$$

But $F = 125\ N, t = 2\ mm, \sigma_b = 20\ N/mm^2$, then

$$d = \frac{125}{20 \times 2}$$

$$\boldsymbol{d = 3.13\ mm}$$

Based on the above result, the M4 bolt size of root diameter of 3.16mm is selected

2.6.2 DETERMINATION OF TORQUE ON SHAFT

Torque on the motor shaft is given by the relation

$$T = 2Fr \quad (4)$$

Where F is force on each coupler bolt
r is coupler bolt distance form shaft center
but $F = 123\ N, r = 0.02\ m$, therefore,

$$T = 2 \times 123 \times 0.02$$

$$\boldsymbol{T = 4.92\ Nm}$$

2.6.3 POWER TO DRIVESHAFT

The power to drive shaft is determined from the given relation

$$P = T\omega \quad (5)$$

$$\omega = \frac{2\pi N}{60} \quad (6)$$

$$P = \frac{2\pi NT}{60} \quad (7)$$

Where N is speed of electric motor in rpm.
Having N as 1400 rpm, then

$$P = 2\pi \times 1440 \times 4.92/60$$

$$\boldsymbol{P = 742.0\ W}$$

Based on the above result, a 1HP (746 W) Electric motor is selected

2.6.4 DETERMINATION OF THICKNESS OF STRIKER

Let the force acting per unit length of hammer be q.

$$q = \frac{F_s}{l} \quad (8)$$

Taking the length of the striker to be 55 mm and resultant force on hammer as 61.83 N, then

$$q = \frac{61.83}{55}$$

$$q = 1.124\ N/mm$$

Considering the striker as a cantilever, the following expression holds

$$S = \frac{M_{max}}{\sigma_{all}}, \text{ Gere, J, 2006} \quad (9)$$

Where S is sectional modulus
M_{max} is maximum bending moment
σ_{all} is allowable stress
If b is the breadth of the striker and h is its thickness, then

$$S = \frac{bh^2}{6} \quad (10)$$

Equating 9 and 10 gives

$$\frac{M_{max}}{\sigma_{all}} = \frac{bh^2}{6} \quad (11)$$

But for a cantilever,

$$M_{max} = \frac{qL^2}{8} \quad (12)$$

$$\frac{qL^2}{\sigma_{all}} = \frac{4bh^2}{3}$$

$$h = \sqrt{\frac{3qL^2}{4b\sigma_{all}}} \quad 13$$

When L = 55mm, b = 10 mm and $\sigma_{all} = 30\ Nmm^2$, then

$$h = \sqrt{\frac{3 \times 1.124 \times 55^2}{4 \times 10 \times 30}}$$

$$h = 2.9\ mm$$

2.6.5 SHANK DIAMETER OF BOLT CONNECTING THE STRIKER TO DISC-1 AND DISC-2

Recalling equation 3 where F is now centrifugal force, F_c

$$d = \frac{F_c}{\sigma_b t} \quad 14$$

$$F_c = m\omega^2 r \quad 15$$

$$d = \frac{m\omega^2 r}{\sigma_b t} \quad 16$$

but

$$\omega = \frac{2\pi N}{60} \quad 17$$

Where m is mass of striker
ω is angular velocity
r is distance from origin

Taking $m = 0.03\ kg,\ r = 0.06\ m, t = 0.002\ m, \sigma_b = 20\ MPa$

$$\omega = \frac{2 \times 3.142 \times 1440}{60}$$

$$\omega = 150.816\ rad/s$$

$$d = \frac{0.03 \times 150.816^2 \times 0.06}{20 \times 10^6 \times 0.02}$$

$$d = 0.002\ m$$

2.6.6 DETERMINATION OF CENTRIFUGAL FAN PARAMETERS

As the striker hammers on materials in the chamber it also functions as a centrifugal fan. Hence the need to analyze it as one of such.
Generally, the tangential velocity for centrifugal fan is:

$$u = \omega r$$

Therefore, tangential blade velocities at inlet and outlet respectively are given by:

$$u_1 = \omega r_1\ ;\ u_2 = \omega r_2 \quad 18$$

Where r_1 = radius of inlet cylinder surface

r_2 = radius of outlet cylinder surface

ω =Angular Velocity

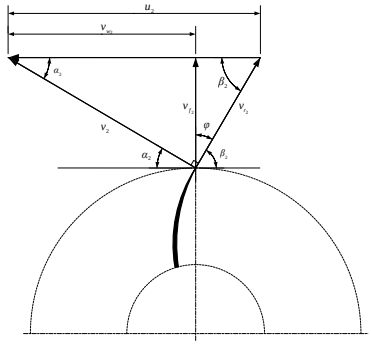


Figure 1: Free body diagram for the impeller blade

Applying continuity equation to the inlet and outlet for the mass flow rate$\dot{m}$ gives

$$\dot{m} = 2\pi r_1 \rho_1 b_1 v_{f1} = 2\pi r_2 \rho_2 b_2 v_{f2}$$

J. M. Gasiorek, 2000

Where:b_1 = Impeller width at inlet

b_2 = Impeller width at outlet

ρ_1= density of air at inlet

ρ_2= Density of air at outlet

v_{f1}= Velocity of flow at inlet

v_{f2}=Velocity of flow at outlet

For incompressible flow

$$m = r_1 b_1 v_{f1} = r_2 b_2 v_{f2} \quad 19$$

Assumptions;

1. For inlet, absolute velocity, V is radial. Therefore
$$V = v_{f1}, v_w = 0, \alpha_1 = 90^0$$

Where v_{w1} is velocity of whirl at inlet,

α_1 is angle that absolute inlet velocity make with tangent.

2. Blade angle at inlet,β is such that the blade meets the relative velocity tangentially.
3. Fluid leaves impeller with a relative velocity tangential to the blade at outlet.

Theoretical head is given by Euler's equation

$$H_{th} = \frac{u_2 v_{W2} - u_1 v_{W1}}{g} \quad 20$$

Where H_{th} istheoretical head

$V_{w1}$is Tangential component of absolute fluid velocity an inlet. Also, known as velocity of whirl. But vω1 = 0, Therefore,

$$H_{th} = \left(\frac{U_2 V_{\omega 2}}{g}\right) \quad 21$$

Volume of flow Q is given as

$$Q = v_{f2} A_2$$

$$A_2 = 2\pi r_2 b_2$$

$$Q = 2 v_{f2} \pi r_2 b_2 \quad 22$$

Where $A_2$is area of outlet cylinder surface

Torque on shaft is given as

$$T = \frac{Q \rho v_{\omega 2} r_2}{g} \quad 23$$

Where ρ is density of air and $g$is acceleration due to gravity

Therefore, power required to drive fan is given as

$$P = T\omega \quad 24$$

But from figure 1

$$\alpha_2 = 180 - 90 - \beta_2 \quad 25$$

$$\varphi = 180 - 90 - \beta_2 \quad 26$$

$$\frac{v_{r2}}{Sin\alpha_2} = \frac{u_2}{Sin90}; v_{r2} = \frac{u_2 Sin\alpha_2}{Sin90} \quad 27$$

$$\frac{v_{f2}}{Sin\beta_2} = \frac{v_{r2}}{Sin90}; v_{f2} = \frac{v_{r2} Sin\beta_2}{Sin90} \quad 28$$

$$\frac{v_{\omega 2}}{Sin(90-\varphi)} = \frac{v_{f2}}{Sin\alpha_2}; v_{\omega 2} = \frac{v_{f2} Sin(90-\varphi)}{Sin\alpha_2} \quad 29$$

Considering equations 17 to29 when

r1 = 0.03 m, r2 = 0.05 m, $b_1 = b_2 = 0.02\ m$, β_2 = 60,$\omega = 150.816\ rad/s$

$$u_1 = \omega r_1$$

$$= 150.816 \times 0.03$$

$$u_1 = 4.5245\ m/s$$

$$u_2 = \omega r_2$$

$$= 150.816 \times 0.05$$

$$u_2 = 7.5408\ m/s$$

$$\alpha_2 = 180 - 90 - \beta_2$$

$$= 180 - 90 - 60$$

$$\alpha_2 = 30°$$

$$\varphi = 30°$$

$$v_{r2} = \frac{u_2 Sin\alpha_2}{Sin90} = \frac{7.5408 \times Sin30}{Sin90}$$

$$v_{r2} = 3.7704\ m/s$$

$$v_{f2} = \frac{v_{r2} Sin\beta_2}{Sin90} = \frac{3.7704 \times Sin60}{Sin90}$$

$$v_{f2} = 3.2653\ m/s$$

$$v_{\omega 2} = \frac{v_{f2} Sin(90-\varphi)}{Sin\alpha_2} = \frac{3.2653 \times Sin(90-30)}{Sin30}$$

$$v_{\omega 2} = 5.6556\ m/s$$

Considering equation 5, the theoretical head is given by

$$H_{th} = \frac{u_2 v_{W2}}{g}$$

$$\frac{7.5408 \times 5.6556}{9.81}$$

$$H_{th} = 4.3474\ m$$

The volume of flow is given by equation 22

$$Q = v_{f2} 2\pi r_2 b_2$$

$$= 2 \times 3.142 \times 0.05 \times 0.02$$

$$Q = 0.0205\ m^3/s$$

Using equations 23 and 24, the Torque and power respectively for blowing out air by the fan are given.

$$T = \frac{Q\rho v_{\omega 2} r_2}{g} = \frac{0.0205 \times 1.23 \times 5.6556 \times 0.05}{9.81}$$

$$T = 0.0007\ Nm$$

$$P = T\omega = 0.0007 \times 150.816$$

$$P = 0.1097\ W$$

3 RESULTS AND DISCUSSION

The designed hammer mill was successfully fabricated using locally sourced materials at a cost of 200,000 Naira. The cost of acquiring a hammer mill of equivalent capacity from foreign sources such as China and Europe range between 900,000 and 3,500,000 Naira. Significant design parameters as calculated are shown in Table 1. The fabricated hammer mill was tested by using it to pulverize various quantities of dried Maize, Guinea Corn and Millet. The performance evaluation of the machine is across maize, Guinea Corn and millet are shown in Table 2, 3, 4 below which was carried out based on three key operational output which include:

i. Particle size of pulverized material
ii. Mass of the material (kg)
iii. Duration of pulverization (min)

TABLE 1: RESULT OF CALCULATED PARAMETERS

Parameters	Symbol	Value	Unit
Centrifugal force exerted by the hammer	C.F	3473	N
Shaft Speed	N_2	2880	rpm
Diameter of main shaft	d	40	Mm
Length of Belt	L	1235	mm
Belt Contact Angle	B	3.48	^{o}c
Angle of wrap between belt and pulley	A	199.2	^{o}c
Tension in the slack side of belt	T2	194	N
Tension in the tight side of belt	T1	464	N
Power transmitted to the shaft	P	7460	W
Weight of hammer	W_{hammer}	1.25	N
Diameter of hammer shaft	D	15	mm
Weight of hammer shaft	Ws	0.243	N
Bending force of blade	Fb	101.7	N
Maximum bending moment of blade	Mb (max)	2034	Nmm
Total surface area of material of cyclone	Ats	1.2	M2
Volume of cyclone	Vc	0.064	M3

3.1 DATA REPRESENTATION OF HAMMER MILL CROPS

3.1.1 PULVERIZED MAIZE

TABLE 2. HAMMER MILL TEST RESULTS USING MAIZE

Trials	Mass of Maize before grinding (kg)	Mass of Maize after grinding (kg)	Time Taken (min)	Particle Size Remark
1	7	6.5	16	Fine (400µm-600400µm)
2	7	6.9	14	Fine (400µm-600400µm)
3	7	6.8	15	Fine (400µm-600400µm)
4	7	6.6	13	Fine (400µm-600400µm)
Average	7	6.7	14.5	Fine (400µm-600400µm)

The table above shows the results obtained from the operation carried out by the pulverizer. The results show that the hammer mill effectively grinds maize to a consistent particle size of 400µm to 600µm, with minimal variation in mass loss and grinding time across trials. The system demonstrates reliable and consistent performance, making it suitable for applications requiring fine grinding of maize. The slight variations in mass and time are within acceptable ranges, underscoring the mill's efficiency and effectiveness in processing maize.

3.1.2 PULVERIZED GUINEA CORN

TABLE 3: HAMMER MILL TEST RESULT USING GUINEA CORN

Trials	Mass of Guinea Corn before grinding (kg)	Mass of Guinea Corn after grinding (kg)	Time taken (min)	Particle Size Remark
1	5	4.8	15	Fine (400µm-600400µm)
2	5	4.7	14	Fine (400µm-600400µm)
3	5	4.9	16	Fine (400µm-600400µm)
4	5	4.5	15	Fine (400µm-600400µm)
Average	5	4.725	15	Fine (400µm-600400µm)

The hammer mill demonstrated consistent performance in grinding 5 kg of Guinea Corn per trial, with an average mass loss of 5.5% due to fine particle generation and dust. The grinding time ranged from 14 to 16 minutes, averaging 15 minutes, indicating stable operation. The particle size of the ground material remained within the 400µm to 600µm range, suitable for applications like animal feed production. Overall, the system exhibited reliability, efficiency, and uniform performance across all trials.

3.1.3 PULVERIZED MILLET

TABLE 4: HAMMER MILL TEST RESULT USING MILLET

Trials	Mass of Maize before grinding (kg)	Mass of maize after grinding (kg)	Time Taken(min)	Particle Size Remark
1	5	5.2	14	Fine (400µm-600400µm)
2	5	5.6	16	Fine (400µm-600400µm)
3	5	5.8	15	Fine (400µm-600400µm)
4	5	5.7	17	Fine (400µm-600400µm)
Average	5	5.575	15.5	Fine (400µm-600400µm)

The hammer mill trials for millet grinding showed consistent performance in particle size (400–600µm) and grinding time (14–17 minutes, averaging 15.5 minutes). However, an unusual increase in mass after grinding (5.2–5.8 kg from an initial 5 kg) suggests potential measurement errors or anomalies in the setup. Possible causes include moisture absorption, weighing scale calibration issues, or residual accumulation. While the grinding process was efficient, further investigation or repeated trials with careful measurement are recommended to verify the results.

3.1.4 AVERAGE PULVERIZED CROPS

The results indicate that all crops achieved a fine particle size between 400µm and 600µm, demonstrating the hammer mill's capability to produce a uniform grind across different materials. The milling time remained consistent, ranging from 14.5 to 15.5 minutes, suggesting similar efficiency for maize, guinea corn, and millet. Weight changes varied among the crops—while maize and guinea corn exhibited weight losses, millet showed a notable weight gain, pointing to potential differences in moisture content and physical properties post-milling. These variations highlight the need for further investigation into crop-specific milling conditions. Overall, the hammer mill effectively grinds diverse crops to fine particle sizes suitable for various applications, though factors such as moisture content and hardness influence milling outcomes.

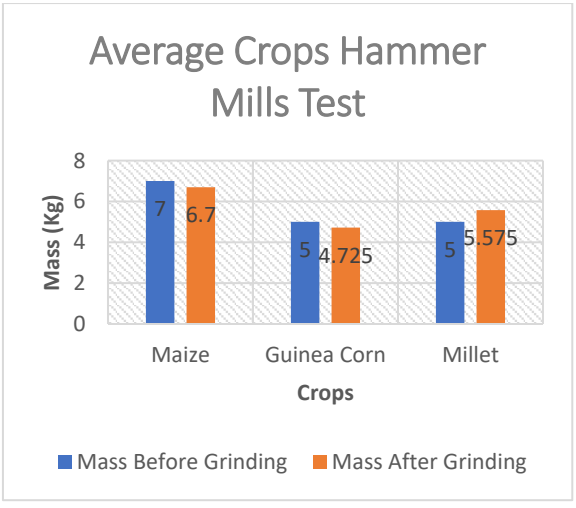


Figure 2: Graphical Representation of Hammer Mills Test Mass (Kg) against Crops.

3.2 SUMMARY OF DISCUSSION OF RSULT

The particle size distribution analysis of the hammer mill output confirms that the machine produces only fine particles for both tested grains. This affirms the effectiveness of the integrated mechanical separator, which ensures that only particles meeting the desired

specifications are retained in the final output. Additionally, incorporating a feedback mechanism allows uncrushed and coarse materials to be recirculated into the crushing chamber for further fracturing. This feature enhances the machine's efficiency by ensuring the production of high-quality, fine-grained products suitable for processing solid minerals and agricultural materials.

Furthermore, the fabricated hammer mill is designed to be compact, making it suitable for production environments with limited workspace. The elimination of the sieve screen and separation chamber contributes to its reduced size, distinguishing it from previous models such as the hammer mill developed by Nasir (2005), which included a sieve screen, and the one designed by Ebunilo *et al*. (2010), which featured a separation chamber. These modifications not only optimize space utilization but also improve the overall performance and usability of the machine.

4 CONCLUSION

The study highlights the significant impact of moisture content on the grinding efficiency, throughput capacity, and particle size distribution of corncobs and corn. Higher moisture levels resulted in coarser particle sizes and improved throughput but also led to increased energy consumption. In contrast, lower moisture levels produced finer particles at the cost of reduced throughput. Additionally, the frictional heat generated during grinding caused moisture loss, which must be accounted for in mass balance calculations.

The grinding process using a hammer mill is inherently complex due to the random movement of materials within the milling chamber. While sieve dimensions strongly influence particle size distribution, feeding flow plays a lesser role. Optimizing this process remains a challenge, necessitating further research to enhance efficiency, minimize energy consumption, and achieve consistent grinding performance.

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Optimization of Microbial-Induced Calcite Precipitate - Zeolite Stabilisation of Silt-Sand Soil for Geotechnical Application Using Response Surface Methodology

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ABSTRACT
Microbially-Induced Calcite Precipitation (MICP) is an innovative soil improvement technique in geotechnical engineering, that deals with microbiological activity to enhance soil properties. Studies conducted using the techniques have shown its potentials in geotechnical engineering applications. However, the ammonia generated as by-product during the MICP process limits its broader application. This study aims to optimize the MICP input parameters to minimize the ammonia generation, by incorporating zeolite, using Response Surface Methodology (RSM) for design of experiment. Urease positive bacteria (Lysinibacillus fusiformis) was isolated, characterized and identified to specie level using biochemical and molecular DNA test, which was then used for the MICP treatment. Series of laboratory experiments were conducted, varying pH, zeolite content, bacterial suspension density, cementation reagent concentration, and compactive effort. These input variables were optimized to improve shear strength, reduce permeability, and lower the ammonia production. The results demonstrated the effectiveness of using Lysinibacillus fusiformis as a urease producing bacteria for MICP and the potential of incorporating zeolite into the process, which significantly improves soil strength, decrease permeability, and reduce the production of excess ammonia. Thus, the optimized MICP process with zeolite presents an effective sustainable solution for reducing ammonia, while enhancing the geotechnical properties of silt-sand soil.

Keywords: *Ammonia Reduction,* Lysinibacillus fusiformis, RSM, Silt-Sand, Zeolite

1 INTRODUCTION

Microbial induced carbonate precipitation has been attracting researchers in many fields due to its sustainable and environmentally friendly nature (De Muynck *et al.*, 2010; Dejong *et al.*, 2013; Su *et al.*, 2022) when applied to soil it can reduced permeability, improve mechanical properties and mitigate harmful element pollution (Warren *et al.*, 2001; Xue *et al.*, 2022). Most researchers use urea hydrolysis pathway to fulfill MICP process (DeJong, Fritzges and Nüsslein, 2006). In this pathway urea is decomposed to CO_3^{2-}/HCO_3^- and NH_4^+ (pH increase) by urease of urea catalytic bacteria (Hammes *et al.*, 2003). Utilization of MICP is limited by the byproduct ammonia NH_3/NH_4^+ .High-strength ammonia is pollutant that can accelerate eutrophication, deplete dissolved oxygen, and be toxic to aquatic life in water bodies (Karadag *et al.*, 2006) therefore the byproduct ammonia limits the wide application of the MICP technique. There are several biological procedures that can lead to calcite precipitation, however, hydrolysis of urea is the most preferred because the mechanism is straight forward and can produce up to 90% chemical conversion efficiency of precipitated amount of calcite in less than 24 hours (Al-Thawadi, 2008; Mujah, Shahin and Cheng, 2017). Granular soils are good candidate soils for MICP because of their geometric compatibility that enables the bacteria to freely move through the pore spaces of the soil during which bio-cementation and bio-clogging processes result in strength gain and reduction in void of the treated soil (Moravej *et al.*, 2018). Silt-sand is one of such soil types.

Silt-sand is one of the soil groups that are regarded as problematic. This is because, in most cases, they do not meet specifications for engineering applications, and therefore requires some modifications. This study focusses on adding zeolite to MICP treatment variables and optimizing MICP process factors to reduce excess ammonia generated during MICP process of silt-sand, evaluating the response in geotechnical properties improvement of silt-sand when stabilised trough MICP with zeolite using Response Surface Methodology (RSM).

2 MATERIALS AND METHOD

2.1 MATERIALS

The soil used in this study is a silt-sand soil. This soil was characterized form soil collected from three (3) trial pit in Girei local government area Adamawa state. Disturbed samples were collected, packaged, labelled and transported to Civil Engineering laboratory of Modibbo Adama University for geotechnical soil investigation similarly the bacteria used was isolated in the laboratory

from natural soil. The bacteria were identified and characterized using standard microbiological techniques that is biochemical confirmatory test and molecular identification, and their purity and viability were confirmed before using in the experiments. Design expert® software version 13 was used to generate experimental design and carry out data analysis. The software allows for the design of experiments and analysis of data using response surface methodology.

2.2 EXPERIMENTAL DESIGN

Response surface methodology was used to investigate the effect of independent variables which including bacterial suspension density, cementation reagent concentration, pH, compactive effort and zeolite on response variable (erodibility, permeability, ammonia content). Experimental Design was developed using expert design software version 13.0.1.0 for studying the interaction between different combinations of bacterial suspension density, cementation reagent concentration, pH, compactive effort and zeolite. The response variables were measured in a factorial design with the range and levels of the input variables determined based on experimental tests. RSM design with coded and un-coded levels developed with D-optimal (custom) design is presented in table 1. D-optimal design type and quadratic model were used to design the experiment. Thirty-one treatment were randomly performed according to D-optimal custom design. Real levels of the in-depended variables were coded based on the equation

$$Z = \frac{Z_{real} - Z_o}{\Delta Z} \quad (1)$$

were

Z: Actual value of the factor

Z_{real}: Actual (real-world) value of the factor

Z_o: Center point (mid-point of the real factor level in design)

ΔZ: Step size (half the range of the real factor levels)

Table 1 In-depended Variables with their corresponding levels for MICP Stabilisation of Silt-sand and based on D-optimal (custom) design.

Factor	A	B	C	D	E
Name	Bacteria	Cementation reagent	pH	Zeolite	Compactive effort
Type	Numeric	Numeric	Numeric	Numeric	Categoric
Sub type	Discrete	Discrete	Discrete	Discrete	Nominal
Minimum	1.500E+09	0.5000	3.50	2	BSH
Maximum	3.500E+09	1.0000	9.50	10	
Coded low	-1 ↔ 1500000000.00	-1 ↔ 0.50	-1 ↔ 3.50	-1 ↔ 2.00	BSL
Coded high	+1 ↔ 3500000000.00	+1 ↔ 1.00	+1 ↔ 9.50	+1 ↔ 10.00	WAS

2.2.1 MICP Specimen Preparation.

3000g of the soil was thoroughly mixed with zeolite and liquid containing soil pH buffer of wet optimum moisture content (OMC) containing 1/3 of its pore volume as the bacteria suspension density. And the mixture was compacted to BSH, BSL and WAS respectively. The compacted specimens were permeated with 2/3 of their pore volume of the cementation reagent under gravity in three 24 hours' circles intervals each to initiate and facilitate the MICP process. Following design of experimental, the concentration of all the input factors were varied according to experimental design. The soil was then cured for 72h before strength determination.

2.2.3 Data Analysis

The data obtained from the experiments was analyzed using the statistical software Expert Design Software version 13. The response surface methodology was used to investigate the relationship between the input variables and the measured responses of the MICP treated silt-sand soil. The optimal bacterial suspension density, cementation reagent concentration, pH, zeolite and the Compactive effort of MICP treated silt-sand soil was determined by identifying the maximum or minimum values of the response surface. In addition, the statistical significance of the effects of each input variable on the measured responses was evaluated using analysis of variance (ANOVA) and regression analysis.

3 RESULT AND DISCUSION

3.1 MATERIAL CHARCTERIZATION

The particle size distribution of the natural soil obtained by standard sieve test is presented in figure 1, the soil has 97.5% passing 2mm and 15.2% passing 0.075mm, the sample met the geometrical compatibility requirement for MICP soil (Sand: 0.075 mm – 2 mm, Silt: 0.002 mm – 0.075 mm). The soil was classified as Non-plastic silt-sands (NSM) described as Non-plastic silty sands, poorly graded sand-silt mixture using modified Unified Soil Classification system chart.

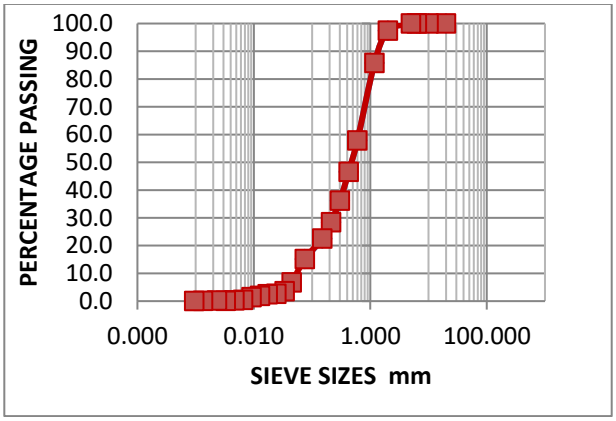


Figure 1 Particle Size Distribution Curve for Soil use for Soil used in the Study

3.2 MODEL FITTING

The responses for the influence of independent factors of MICP stabilized silt sand (bacteria concentration x_1, cementation reagent x_2, pH x_3, zeolite x_4 and compactive effort x_5) were predicted by the model equations. Coefficients of polynomial equation were computed from experimental data to predict the values of the response variable. Regression equations for each response variable, as obtained from response surface methodology were presented in Equations. 2, 3 and 4 respectively. Statistical analysis results of (ANOVA) indicates that the experimental data can best be represented with quadratic polynomial model with coefficient of determination R-square values of 0.8679, 0.8918 and 0.8643 for permeability, erodibility and ammonia content respectively, lack of fit was insignificant as the ($p \leq 0.05$) relative to pure error for all variables is less than 0.05, which shows that our model is statistically accurate. Table 2 present the model prediction error analysis, the predicted R^2 of 0.537, 0.5648 and 0.5141 are closer to the adjusted R^2 of 0.7170, 0.7628 and 0.7091for permeability, erodibility and ammonia content respectively as their differences is less than 0.2, also adequate precision of 12.2183, 10.5423 and 13.0213 for the permeability, erodibility and ammonia content is greater than 4 indicating that signal to noise ratio is desirable implying that the model can be used to navigate the design space.

Table 2 Model Fit Statistics and Prediction Accuracy

Fit Statistics	Permeability	Erodibility	Ammonia Content
Std. Dev.	3.049E-06	3.61	94.78
Mean	8.795E-06	23.1	641.45
C.V. %	34.76	15.35	14.78
R^2	O.8679	0.8918	0.8643
Adjusted R^2	0.7170	0.7628	0.7091
Predicted R^2	0.537	0.5648	0.5141
Adequate Precision	12.2183	10.5423	13.0213

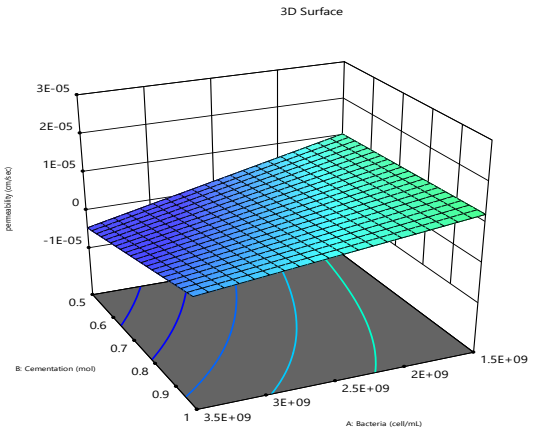
$$\boldsymbol{permeabilit} = +7.069X10^{-6} - 4.221X10^{-7}x_1 + 2.079X10^{-7}x_2 + 1.085X10^{-7}x_3 - 3.378X10^{-7}x_4 + 3.051X10^{-6}X_5[1] - 1.273X10^{-6}x_5[2] + 1.914X10^{-6}x_1x_2 + 3.734X10^{-6}x_1x_3 + 3.296X10^{-6}x_1x_5[1] - 5.145X10^{-6}x_1x_5[2] + 3.533X10^{-6}x_2x_3 - 5.146X10^{-6}x_2x_4 - 3.676X10^{-6}c_3x_4 + 3.839X10^{-6}x_3x_5[1] + 1.234X10^{-6}x_3x_5[2] + 3.059X10^{-6}x^2{}_3 \quad (2)$$

$$\boldsymbol{erodibility} = 23.106746039 - 0.3377333790776x_1 - 1.5578946164553x_2 - 0.39840698056329x_3 + 3.9074417026593x_4 + 4.0193588380924x_5[1] + 1.449430264647x_5[2] + 4.8053226116126x_1x_2 + 2.7896372750313x_1x_4 - 1.1127895553889x_2x_5[1] + 6.1903143356748x_22_5[2] - 5.7262417306138x_3x_4 - 9.5669241110838x_3x_5[1] + 3.4864529196912x_3x_5[2] - 8.9655122710829x^2{}_1 + 4.7650626273941x^2{}_2 + 3.567064265287x^2{}_4 \quad (3)$$

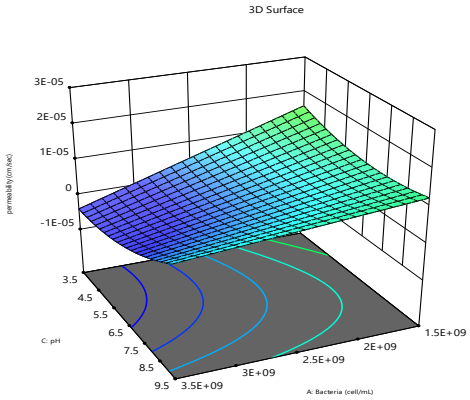
$$\boldsymbol{Amonia\ content} = 399.72330993848 - 76.20063188012x_1 + 61.3417444431389x_2 + 18.021404708982x_3 - 37.695537429494x_4 + 43.227153215702x_5[1] + 2.3920171362371x_5[2] - 125.61134610225x_1x_2 - 127.85331261958x_1x_4 - 130.22448790494x_1x_5[1] + 91.004216950547x_1x_5[2] + 91.761480428973x_2x_3 + 144.53198305631x_2x_5[1] - 312.06770124088x_2x_5[2] + 49.2271077420577x_4x_5[1] - 171.16115129125x_1x_5[2] + 313.55373782212x^2{}_1 \quad (4)$$

3.3 EFFECT OF MICP INDEPENDENT FACTORS ON PERMEABILITY OF MICP TREATED SILT-SAND

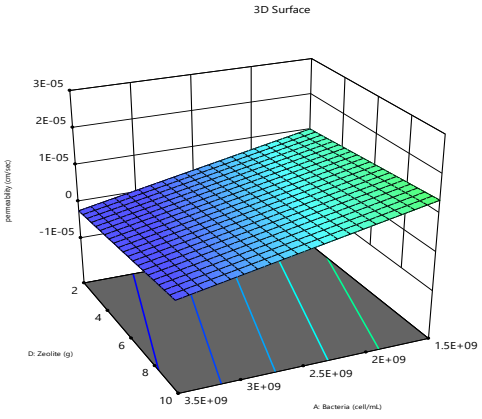
Figure 2(A) illustrate the influence of the concentration of Lysinibacillus fusiformis and cementation reagent concentration on permeability of MICP treated silt-sand soil. It can be observed that increase in both concentration of Lysinibacillus fusiformis and cementation reagent concentration leads to reduction in permeability, it can be inferred that at higher concentration of Lysinibacillus fusiformis more urease enzyme was produced and as the cementation reagent increase from 0.5 to 1mole there is sufficient urea and calcium that combine with the urease enzyme produced and precipitate calcium carbonate which in turn filled the pore spaces, there by clogging the soil and reduced permeability. Soon *et al.*,(2014) stated that for effective MICP treatment the preference concentration of cementation reagent should lies between 0.5-1.0 mol. Figure 2(B) show the combine effect of the Lysinibacillus fusiformis and soil pH on the permeability of MICP treated silt-sand soil. A saddle shape nature of the 3D surface plot shows upward curve in the direction of increasing soil pH indicating increase permeability and a downward curve in the direction of increasing concentration of Lysinibacillus fusiformis indicating decrease permeability it can be noticed that the optimal pH is located in the region were the soil pH is slightly acidic to basic at higher concentration of Lysinibacillus fusiformis, the reduction in permeability can be attributed to formation of uniform calcite which form during the MICP process as a result of change in the pH of the environment which favors the urease activities of Lysinibacillus fusiformis. Study from Liu, Li and Li, (2021) reveal that MICP process is favored in initial pH environment of 6.5–9.3 (neutral to basic condition). Figure 2(C) illustrate the combine effect for the interaction between Lysinibacillus fusiformis and zeolite, as indicated by the near flat surface of the 3D plot the relationship between Lysinibacillus fusiformis and soil pH is assume to be linear i.e. increase in both factors increase the permeability and the region of interest is located at the point where concentration of Lysinibacillus fusiformis is in the range 2.5E+09 - 3.0E+09cell/mL at higher zeolite content. Su and Yang, (2021) conducted a research on improving MICP technique with zeolite and found out that strength gain is positively correlated with zeolite dosage, in their study they use zeolite dosage of 0-10g and found the optimal zeolite dosage to be10g which is similar to the prediction of higher zeolite dosage of 10g in this study



A



B

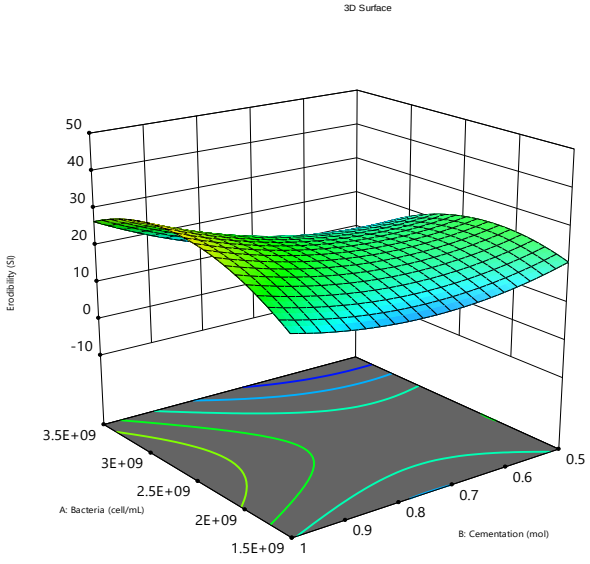


C

Figure 2 Response Surface plot of interaction between (A) Bacteria and Cementation reagent, (B) Bacteria and soil pH, (C) Bacteria and Zeolite for permeability.

3.4 EFFECT OF MICP INDEPENDENT FACTORS ON ERODIBILITY OF MICP TREATED SILT-SAND

Figure 3 (A) present the surface plot of the effect of Lysinibacillus *fusiformis* bacteria and cementation reagent solution on erodibility of MICP treated silt-sand, the interaction between Lysinibacillus *fusiformis* and cementation solution exhibit a nonlinear relationship as indicated by convex nature of the plot. This pattern typically suggests that factor level low or high are less favorable and there exist a mid-range where erodibility can be maximized. At this point it is expected that Lysinibacillus *fusiformis* produced effective urease enzymes that combined with calcium from supply cementation solution and precipitated effective calcite with bind the soil together and resist soil loss due to resist soil movement. Study of Montoya, Do and Gabr, (2018) suggest that erodibility of MICP treated sand is affected by change in cementation level as a result of precipitated calcite. Figure 3 (B) depict the surface plot for the combine influence of Lysinibacillus *fusiformis* bacteria and soil pH on erodibility of MICP treated silt-sand, the plot suggest a nonlinear relationship between Lysinibacillus *fusiformis* and soil pH which was indicated by the concave curved nature of the surface plot, it can be observed that from the initial point erodibility increase with increasing both factor level which continuous until a region is reach within the deign space where any further increase in factor level leads to decrease in the erodibility value this region is consider as the region of optimality and upon amplifying the contour plot this region is predicted to be in the range of 6.5-9.5 pH and 2E+09-3E+09cell/mL Lysinibacillus *fusiformis* bacteria concentration. Do, Montoya and Gabr, (2020) found that erodibility of MICP treated sand reduced with increasing cementation level. Figure 3 (C) illustrate the effect of interaction between Lysinibacillus *fusiformis* bacteria and zeolite on erodibility of MICP treated silt-sand, the interaction between Lysinibacillus *fusiformis* bacteria zeolite follow similar pattern with the interaction between Lysinibacillus *fusiformis* bacteria and soil pH as indicated by the concave nature of the surface plot, this suggest that mechanism of interaction between Lysinibacillus *fusiformis* bacteria and zeolite for the erodibility of MICP treated silt-sand is as explain above.



A

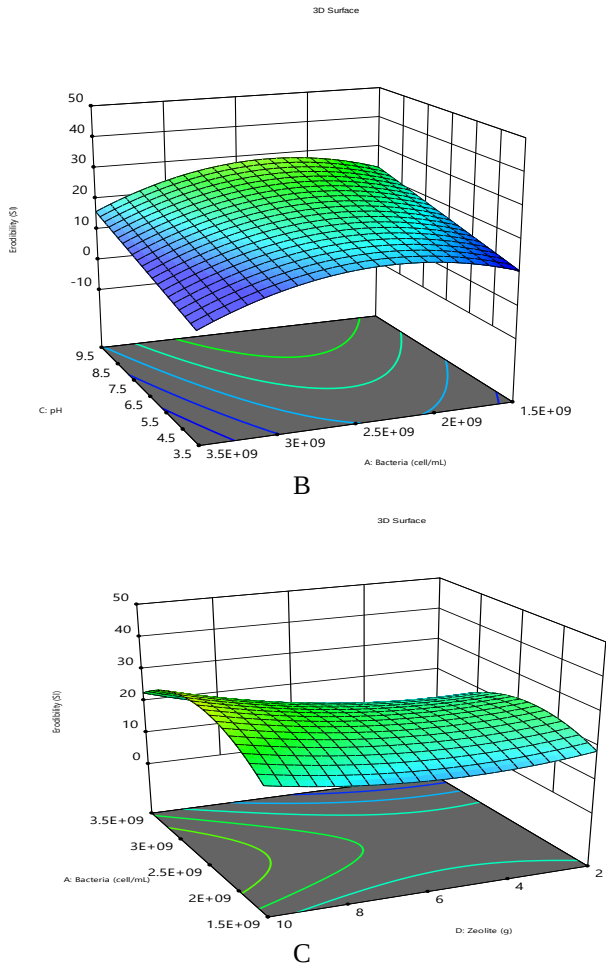
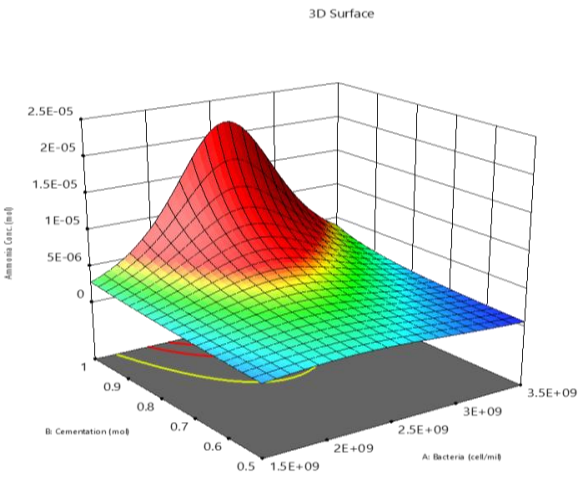


Fig. 3 Response Surface plot of interaction between (A) Bacteria and Cementation reagent, (B) Bacteria and soil pH, (C) Bacteria and Zeolite for erodibility

3.5 EFFECT OF MICP INDEPENDENT FACTORS ON AMMONIA CONTENT OF MICP TREATED SILT-SAND

Figure 4 (A), illustrate the combine influence of Lysinibacillus *fusiformis* and cementation reagent on ammonia reduction of MICP treated silt-sand the curvature nature of the surface plot suggests a nonlinear relationship implying that the response does not increase linearly with either factors, the color transition from lowest ammonia generated (blue region) to the highest ammonia generated (red region) indicate how changes in factor level influence the response. Thus, moving from lower Lysinibacillus *fusiformis* and cementation reagent concentration (blue) to higher concentration (red) ammonia reduction improve significantly. The optimal ammonia reduction is located in the red region where concentration of both factors is high. The red zone at the top of the curve signify the highest ammonia reduction achieved within the tested parameters, this suggest that the optimal combination of Lysinibacillus *fusiformis* and cementation reagent for effective ammonia reduction is located in the red zone. The interaction between Lysinibacillus *fusiformis* and zeolite follow the same trend as can be observed in Figure 4 (A). Similarly, the effect of Lysinibacillus *fusiformis* and soil pH is illustrated in Figure 4 (C), the surface plot exhibits a relatively flat and slightly slope pattern which indicate that ammonia reduction may not be highly sensitive to changes in the two factors level (Lysinibacillus *fusiformis* and pH), it can be observed from the color gradient that ammonia levels decrease with increasing Lysinibacillus *fusiformis* and pH concentration but the changes appear to be gradual and not rapid implying that the interaction is moderate. The gradual improvement in ammonia reduction at higher bacteria and pH level may be attributed to the activity of Lysinibacillus *fusiformis* and pH), it can be observed from the color gradient that ammonia levels decrease with increase Lysinibacillus *fusiformis* and pH concentration but the changes appear to be gradual which suggest that Lysinibacillus *fusiformis* activity breakdown the ammonia and the higher pH condition facilitate the conversion of ammonium ion NH_4^+ to ammonia gas NH_3. An overly acid or alkaline environment will reduce ammonia removal, and the optimum pH varies with zeolites. In many studies, the optimal pH is about 8, below which H^+ ions increase and compete with NH_4^+ for exchange sites. When pH>8, zeolite may dissolve and NH_4^+converts to NH_3, reducing the removal efficiency. (Huang *et al.*, 2010; Su *et al.*, 2022).



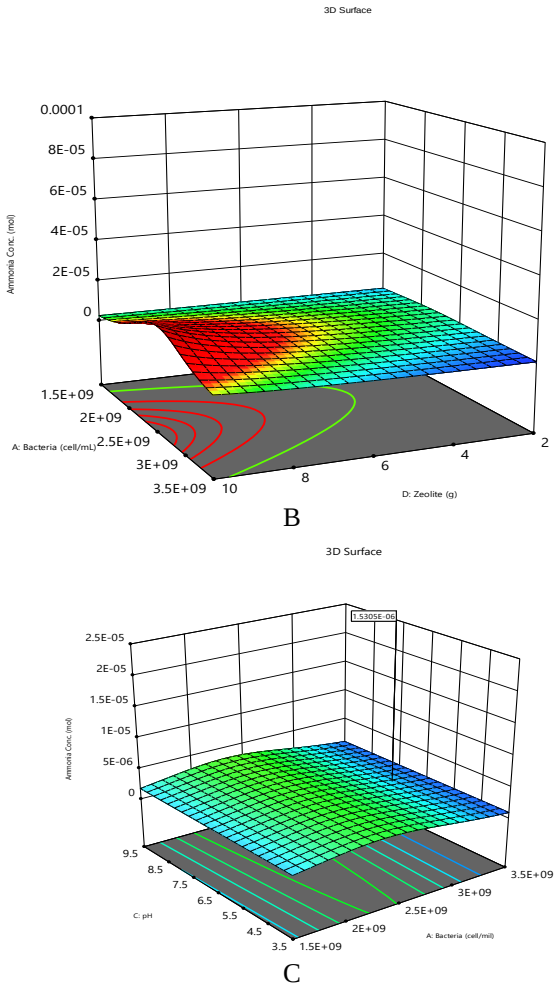


Figure 4 Response Surface plot of interaction between (A) Bacteria and Cementation reagent, (B) Bacteria and soil pH, (C) Bacteria and Zeolite for ammonia content

3.6 OPTIMIZATION OF INDEPENDENT VARIABLES

Design expert software was used to create, 3D surface response graphs which show how the concentration of bacteria, cementation reagent concentration, soil pH level, zeolite dose, and compactive effort affected the response variables. These graphs were generated by varying two independent variables within experimental ranges while keeping the other variable at central point. (Fig. A) was generated by varying the concentration of Lysinibacillus fusiformis and cementation reagent at 6.39 pH, 3.92g zeolite and WAS compactive effort, (Fig. B) was generated by varying the concentration of Lysinibacillus fusiformis and soil pH level at o.66mol cementation reagent concentration, 3.92g zeolite and WAS compactive effort, while (Fig. C) was generated by varying the concentration of Lysinibacillus fusiformis and zeolite at 0.66mol concentration of cementation reagent concentration, 6.39 soil pH level and WAS compactive effort respectively. These graphs illustrate the complex interaction among independent variables. Furthermore, numerical optimization was executed by desirability function using Design Expert Software. The goals that were selected for the optimization of MICP stabilized silt-sand soil are concentration of Lysinibacillus fusiformis targeted at 3.0E+09cell/mil. Cementation reagent concentration targeted at 0.66mol, soil pH level targeted at 7.5 pH level, zeolite and compactive effort were in range of experimental data considered, the goal was set to obtain improved silt-sand soil that has lower soil permeability, lower soil erodibility and lower ammonia content generation of MICP process. Sixty-two different solution were found which contain different level of independent variable and the solution with maximum desirability was selected as the optimized MICP silt- sand improvement condition. Combined optimized condition for MICP stabilization of silt-sand were 3.2E+09cell/mil concentration of Lysinibacillus fusiformis, 0.65mol cementation reagent, 6.4 pH level, 3.9g zeolite and WAS compactive effort and the response at these optimized conditions were 6.3E-06cm/sec permeability, 15.93g soil loss (erodibility and 1.53E-06mol ammonia content respectively.

3. 7 VERIFICATION OF THE MODEL

Optimized MICP silt-sand stabilization conditions were used to check the suitability of the model for prediction of response values by performing experiments under the optimized condition. The predicted responses values at the optimized conditions were 6.3E-06cm/sec permeability, 15.93g soil loss (erodibility) and 1.53E-06mol ammonia content while the experimental response values at the optimized condition were 7.2E-06cm/sec permeability, 17.83g soil loss (erodibility and 1.68E-06mol ammonia content respectively.

4.0 CONCLUSION

In this study we have evaluated the influence MICP treatment factors on bio-stabilization of silt-sand and incorporated zeolite in the MICP treatment of silt-sand in order to improve geotechnical properties of silt-sand and reduce ammonia generated during MICP technique. MICP treatment of silt-sand were successfully prepared using experimental design. This study illustrates that response surface methodology is a useful tool to optimize the MICP treatment factors and explore the relationship between independent and response variables. The results of this study disclosed that MICP treatment with zeolite have significant effect on the bio improvement of silt-sand and can reduced the access ammonia generated during MICP treatment process. The current study demonstrates that the quadratic model was sufficient to describe and predict the responses of permeability, erodibility and ammonia content, with the change of independent variables (Lysinibacillus fusiformis, cementation regent, soil pH, zeolite and compactive effort). The optimum condition was obtained through numerical optimization using desirability function. Optimized MICP treatment factors were 3.2E+09cell/mL

concentration of Lysinibacillus fusiformis, 0.65mol cementation reagent, 6.4 pH level, 3.9g zeolite under WAS compactive effort respectively. It can be concluded that optimized MICP-zeolite techniques have the potential of improving geotechnical properties of silt-sand and reducing access ammonia generation during MICP process there by making MICP process to be effective and sustainable.

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