GEOLOGICAL AND GEOTECHNICAL CONTROL OF GULLY EROSION, UNGOGO, KANO, NORTH WESTERN NIGERIA

BY

ALIYU, Hassan

MTech/SPS/2017/7415

DEPARTMENT OF GEOLOGY

SCHOOL OF PHYSICAL SCIENCES,

FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

OCTOBER, 2021

GEOLOGICAL AND GEOTECHNICAL CONTROL OF GULLY EROSION, UNGOGO, KANO, NORTH WESTERN NIGERIA

BY

ALIYU, Hassan
MTech/SPS/2017/7415

THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL
FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD
OF THE DEGREE OF MASTER OF TECHNOLOGY (MTech) IN GEOLOGY
(ENVIRONMENTAL GEOLOGY)

OCTOBER, 2021

ABSTRACT

Gully erosion is an environmental hazard that is ravaging the landscape of Ungogo area. This study was carried out to investigate the geological and geotechnical control of gully erosion in the study area. Geological field mapping was carried out to assess the causes and extent of erosion. Soil samples were collected from four (4) gully sites at depth between 0 - 5m, 0.5 - 1m and 1 - 1.5m for geotechnical analyses. Four (4) index properties of soil were determined: Specific gravity, sieve analysis, Atterberg test and compaction test both in accordance with British standard code: BS-1377-2, 1990. Specific gravity values were used to determine the probable risk of erosion. The grading index recorded from the sieve analysis showed that coefficient of uniformity ranged between 17.2 - 1.13 and coefficient of curvature ranged between 6.01 - 0.85. The coefficient of permeability falls between coarse sand and silt. The plasticity index of the soil samples were found to be 4%, 5%, 9%, 2%, 7%, 6% 2%, 20%, 9%, 11%, 3%, and 3% and all the soil samples from gully sites have their plot clustered within clay of low plasticity and silt of low plasticity indicating cohessionles properties thus the potential for the control of gully erosion formation in the area. The optimum moisture content and the maximum dry density of the soil indicated that soils are majorly loose sand and this could pave way for erosion susceptibility. Mitigation measures such as Landfilling, construction of check dam, geo-textile, fencing and stabilization are recommended for the control of gully erosion in the area.

TABLE OF CONTENTS

CONTENT **PAGE**

LIST OF TABLES

TABLE **PAGE**

LIST OF FIGURES

LIST OF PLATES

ABBREVIATION, GLOSSARIES AND SYMBOLS

NIMET: Nigerian Meteorological Agency

GSN: Geological Survey of Nigeria

NIMET: Nigerian Meteorological Agency

NBRRI: Nigerian Building and Road Research Institute

GS: Specific Gravity

Cu: Coefficient of Uniformity

Cc: Coefficient of Curvature

k**:** Coefficient of Permeability

I_0: Slope Intercept

LL: Liquid Limit

PL: Plastic Limit

PI: Plasticity Index

LI: Liquidity Index

OMC: Optimum Moisture Content

MDD: Maximum Dry Density

ρw: Wet Density

ρd: Dry Density

g: Gram

Mg/cm^3: Milligram Per Centimeter Cube

g/cm^3: Gram Per Centimeter Cube

mm: Millimeter

µm: Micron meter

°C: Degree Centigrade

Rn**:** Percentage of Soil Retain

w: Moist

Kg: Kilogram

Hrs: Hours

s: Second

%: Percent

cm: Centimeter

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Erosion is the gradual or quick geomorphologic process whereby surface layer of weathered rocks or sediment are removed, transported and deposited elsewhere by an agent of denudation thus leaving an exposure of lower soil horizon (Egboka, 2000). It is a worldwide phenomenon which ravages large areas of land particularly in high rainfall locations (Amangabara, 2012). Soil erosion has been documented from the earliest of times as severe environmental hazard (Poesen *et al*., 1998; Tebebu *et al*., 2010).

Gully erosion is a form of erosion that threatens roads, bridges, building, soil productivity and fence (Bruce, 2006). It occurs from region to region based on the mineral compositions of the soil. Soil erosion is mostly an accelerated process under which soil is bodily removed/displaced and transported away faster than it was formed. Soil erosion commences with rain droplets which displace soil particles, removing them and eventually depositing them at a new location entirely different from their original site of displacement. It occurs not constantly all over the year though, the formation of gully always begins by an increase in discharge at some point in the beginning of rainy season, while gullies tend to stabilize and fill up during the transition towards dry season where the discharge is drastically reduced.

The factors that contribute to control of gully erosion includes: geology, geomorphology, soil texture, biological diversity, vegetation cover and climate (Ofomata, 1988). It can be caused by other factors including climatic factors (precipitation, wind and storm), geological factor (porosity permeability and sediment types), physiography, hydrogeology, and geotechnical properties of the soil materials (John *et al*., 2015).

1.2 Statement of the Research Problem

Gully erosion is an epidemic environmental hazard in Nigeria and the area under study is no exception. The end result of the threat leads to destruction of farm lands, loss of natural habitat, loss of plant and animal diversity, deterioration of soil water quality, destruction of socio-infrastructural facilities, and displacement of people (Okoro *et al.* 2011). It causes destruction of soil quality farmland, collapse of buildings, roads and bridges (Bruce, 2006).

Erosion formation is a global problem causing threat to life and properties and it result is now serious problem in Ungogo area putting the residents in danger. The root causes of the problem have not been identified and studied despite the seriousness of gully erosion problems prevalent in the study area. No systematic work on the geological and geotechnical control of gully erosion is documented.

1.3 Justification for the Research

Investigation of the geological and geotechnical properties of soil has the potential to determine the factors and the causes of gully erosion formation. There is no systematic study of the geological and geotechnical control on erosion available in the study area, therefore, Knowledge of the geological and geotechnical conditions of the area under study is essential to provide basic information of the geologic condition and will help policy makers make informed decisions on possible mitigation measures and control.

1.4 The study Area

1.4.1 Location and Accessibility

The study area lies between Latitudes (12°7'30"N, 12°4'45"N) and Longitudes (8°28'30"E, 8°30'55"E). The map was enlarged to a scale of 1:12,500. Ungogo Arewa, Bakin Kasuwa, Daurawa and Tudun Murtala are the major settlements in the study area. The area is accessible by major road that runs through Ungogo Arewa to Nadara Doka (Figure 1.1). There is a minor road that linked from Bakin Kasuwa to Laying Maigari to Ungogo Arewa.

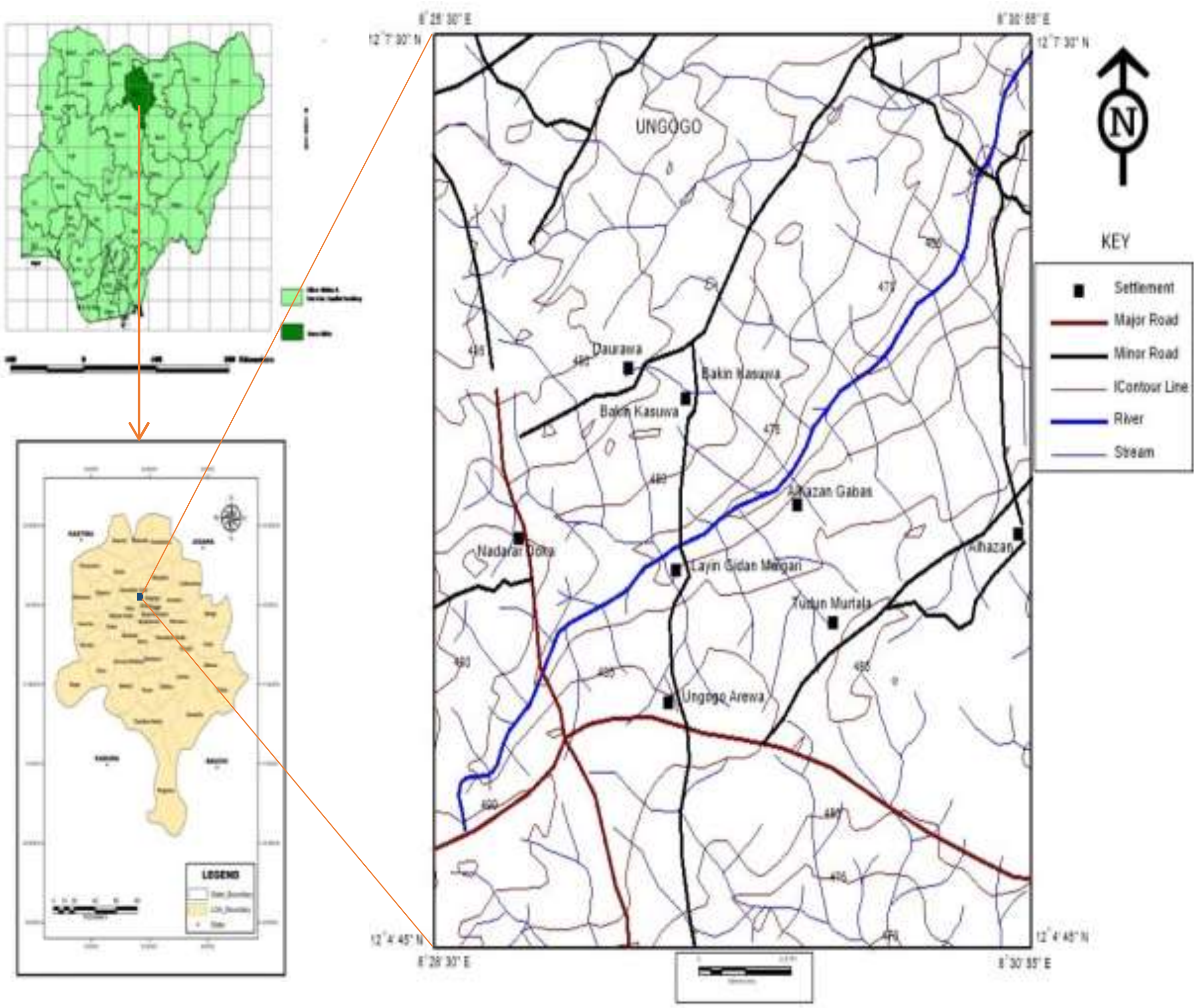


Figure 1.1: Location of study area

1.4.2 Climate

The climate of the study area is typical of tropics which is divided into two main seasons; the dry and wet seasons. The wet season lasts for about five to six months (May-September), while the dry season lasts from October to April. The average rainfall falls between May (63.3 - 48.2mm) to August (133.4 - 59mm) the wettest month. The temperature of Kano State usually ranges between 33-15.8^{0}C, although sometimes during the Hamattan, the temperature may drop as low as 10^{0}C (NIMET, 2015).

1.4.3 Vegetation

The vegetation of the area is typically of semi-arid savannah. The Sudan savannah is sandwiched by the Sahel savannah in the north and the Guinea Savannah in the south. The canopies of the trees are very wide and most of them are less than 20m tall. The following are the common trees widely scattered within the study area: baobab *Adanosi adigitata* (Hausa: kuka), *Sclerocary abirrea* (Hausa: danya), *Anogeissus leiocarpus* (Hausa: marke), *Vitex doniana* (Hausa: dinya), desert date *Balanties aegyptica* (Hausa aduwa), ebony *Diospyro smespiliformis* (Hausa: kanya), locust bean *Parkia clappertoniana* (Hausa: dorawa), *Acacia albida* (Hausa: gawo), *Neemazadirachta indica* (Hausa: dogonyaro), *Ziziphus spinachristi* (Hausa: kurna). These trees are very resistant to drought. Domesticated crops include groundnuts, sorghum, and, cowpeas, millet, beans, and rice.

1.4.4 Relief and Drainage

The study area forms part of the plains of the Hausa land with elevation not greater than 500m above mean sea level. The general relief of the study area is between 450m and 480m

(Figure 1.2). Kansuwa River is an ephemeral river which flows northeastward and linked to channels around the area.

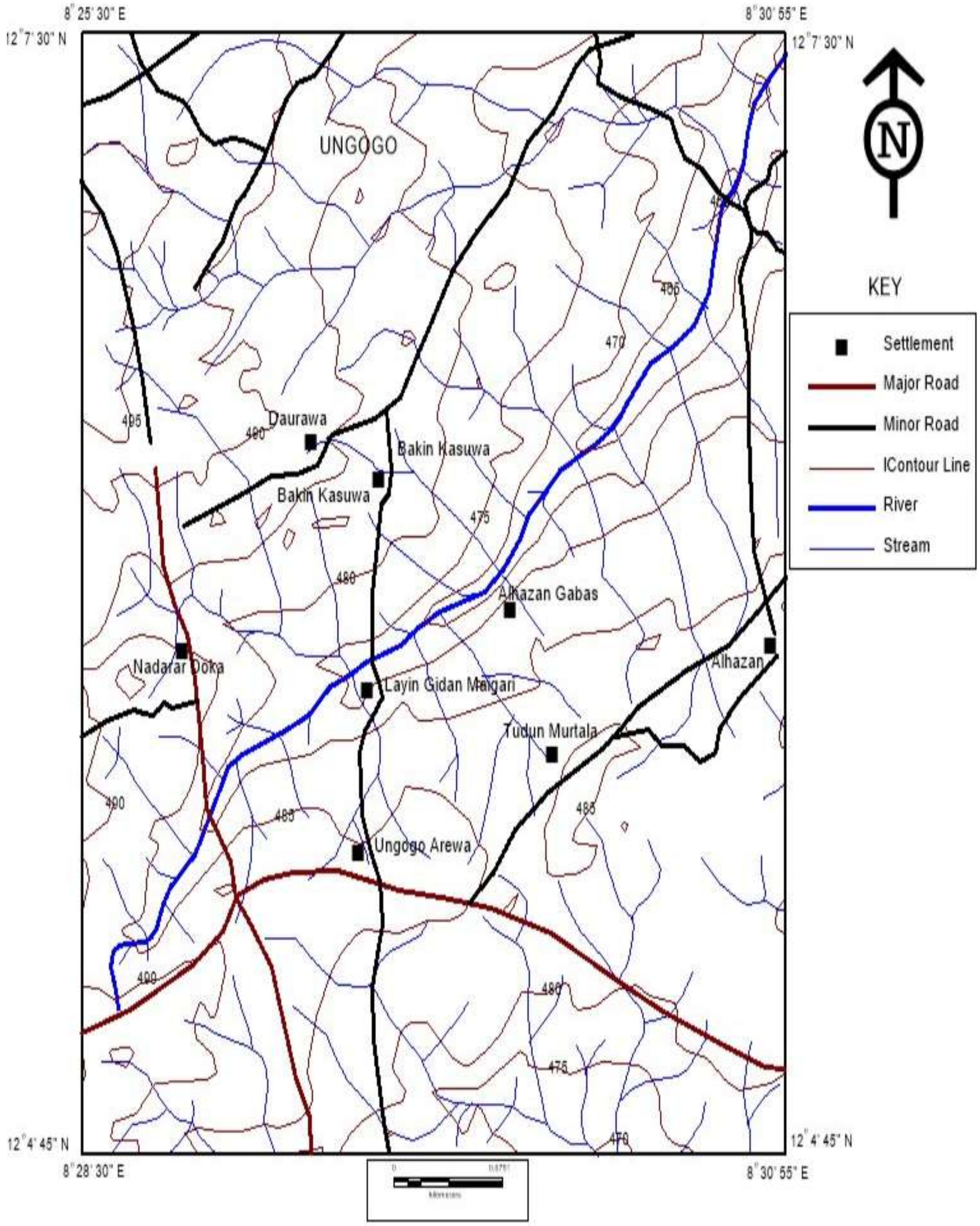


Figure 1.2: Relief and drainage map of the study area

1.4.5 Settlement and Land Use

Farming is the commonest land use in the study area. Farming is practiced by traditional methods, which involved the use of hand tools such as hoes, cutlasses, shovel and diggers. The common crops grown are maize (*Zea mays*), guinea corn (*Sorghum spp*.), beans (*Vigna unguculata*) and groundnuts (*Arachis hypogea)*.

1.5. Aim and Objectives

This work is aimed at investigating the geological and geotechnical control of gully erosion development in Ungogo area.

The objectives are:

i. To produce a geological map of the study area on a scale of 1:12,500.

ii. To determine the dimension of the gully sites of the study area.

iii. To determine the particle size distribution of the soil of the study area.

iv. To determine the plasticity of the soil of the study area.

v. To find out the optimum moisture content and maximum dry density of the soil.

1.6 Scope of the Research

This work covers the study of the geology of the area and investigating the contribution of geotechnical properties of soil to the formation and expansion of gully erosion in Ungogo of Kano, North Western Nigeria.

1.7 Organization of Study

This consists of five chapters. Chapter one is the introduction which presents the background of the study, statement of the problem, justification, climate and vegetation, relief and drainages, aim and objectives and scope of the research. Chapter two discuses the literature which includes the geology of Nigeria, gully erosion formation, causes of gully erosion formation, influence of geology, influence of soil factor and geotechnical index properties of the soil. Chapter three is the methodology adopted for the study. It includes field mapping, sample collection, sample preparation, and laboratory analyses. Chapter four presents the results and discussions. Chapter five is the conclusion and recommendations.

.CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Geology of Nigeria

The basement complex is among the lithological components of the Nigerian geology. It is divided into Western Nigerian basement complex, Central Nigerian Complex and the Eastern Nigerian Complex all of which the younger granites intruded into them and unconformably overlain by the Cretaceous and younger sediments (Falconer, 1911).

The petrological groups in the Nigerian basement complex have been identified (Rahman and Ocan, 1978): migmatite-gneiss-complex, slightly migmatise to non-migmatise metasedimentary and meta-igneous rocks, charnokitic, gabbroic and diorite rock, older granites, metamorphosed to unmetamorphosed calc-alkaline volcanic and hyperbysal rocks. Conversely, Grant (1978); Oyawoye (1972) identified three (3) lithological groups; the migmatite-gneiss complex, the schist belt and the older granites (Pan-African granitoids). They have been affected by three (3) major polycyclic events in nature; Liberian (2700±200Ma), Eburnean (2000±200Ma) and Pan-African (110±150Ma) and these cycles were characterised by deformation, metamorphism and migmatisation (Obaje, 2009).

2.1.1 The Migmatite-Gneiss Complex

This complex occupies about 70% of the Nigerian basement complex (Ajibade *et al*., 1987). There are relics of older metasediment and amphibolites that have resisted metamorphism and granitisation and are represented by high grade calcareous, peiltic, and quartzitic rocks belonging to lower amphibolites facies (Ajibade *et al*. 1987).

This rock type covers many areas (Figure 2.1) especially, in Nasarawa, Keffi and Akwanga (North Central Nigeria) Kaduna, Kano, Funtua (North Western Nigeria), Bauchi, and Das (North Eastern Nigeria) Obudu and Oban massif (South Eastern Nigeria and Ibadan, Akure, Ikerre (South Western Nigeria) (Obaje, 2009).

2.1.2 The Schist Belt

The schist belts in Nigeria trends NNE, parallel to the end between Pan-African province and the West African Craton at about 400km wide zone. It is regarded as the upper proterozoic supracrustal rocks which had been folded into migmatites-gneiss complex. The activity of the Pan-African Orogeny is related to this general trend and this fact is supported by the approximate north-south trending belt of metasediment large areas of the north western Nigeria (Truswell and Cope, 1963).

They are coarse to fine grained clastics, schist, phyllites, banded iron formation, carbonate rocks and met-volcanic rocks, and are known to be associated with gold mineralisation. They are exposed in almost western half of the country (Figure 2.1), predominantly outcropped in the south west (Lokaoje, Ibadan, Iseyin, Illesa) and in the North West (Minna, Bida, Birnin Guari, Maru, Anka, Zuru, Kebbi and Zungeru).

2.1.3 Older Granites

The Older granites were described as deep-seated, mostly concordant or semi-concordant granites of the basement from the high-level, highly discordant tin bearing granites of Northern Nigeria by Falconer (1911). The older granites are classified into syn-kinematics (concordant, foliated, indicating gradational contact they are mostly coarse grained) and late-kinematic (discordant with sharp contact, non-foliated and fined grained). However, based on the field relationship, they are divided into syntectonic group and late tectonic group. The late are considered to be the product of widespread mobilisation and reactivation of older basement rocks during Pan-African Orogeny (Ajibade *et al.*, 1987).

Dada *et al*. (1995) documented the mineralogical properties of the older granites given evidences of varying paragenesis with fine-grained leucocratic paraluminous biotite-muscovite granites to metaluminous biotite muscovite granites. They are outcropped in association with migmatite-gneiss complex and the schist belts. They are locally distributed around Zaria, Abuja, Bauchi (northern part) Ado Ekiti and Obudu areas (southern part).

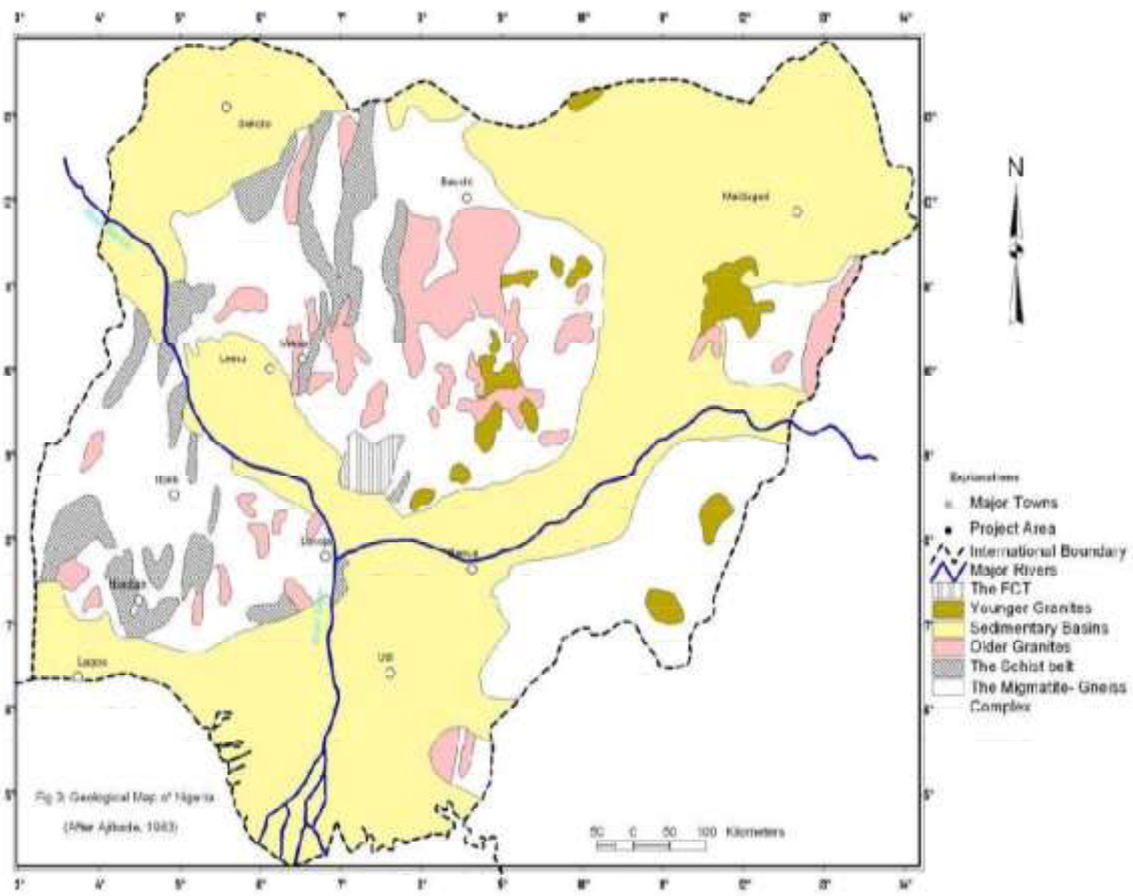


Figure 2.1: Geological map of Nigeria (GSN, 1994)

2.1.4 The Younger Granites

The younger granites intruded the basement complex during Jurassic period and were unrelated to structural deformation. They were described as cross-cutting alkali granites containing riebeckite or biotite characterized by chilled margins against their host rocks. They outcropped as rocky hill massif, sharply differentiated from the smoother topography of the surrounding basement rocks (Falconer, 1911).

They are grouped into province starting from the south (Benue trough) to the north (Jigawa and extend to air Niger). Over 50 granite complexes in Cameroon Republic, Central Sahara, Egypt and Sudan of West Africa have been discovered (Buchaman *et al*., 1971).

Bowden *et al*. (1976); Rahman *et al*. (1984) recorded the ages of the younger granites: Goure (264M.a), Metsena (258M.a), Dutse (213M.a), Fagam (191M.a), Ningi (183M.a), Banke (173M.a), Zaranda (186M.a), and Jos (161M.a), Pankshin (151M.a) and Mada (147M.a) and Afu (141M.a) along ENE-WSW direction with an overall south ward age decrease.

There are three (3) stages (Figure 2.2) in the development of Nigerian ring complexes (Kinnaird, 1981; Turner, 1983; Wright, 1985):

i. early volcanic stage (describes as the sign of evolution of the granitic cycle).
ii. caldera (period of extrusion of ash flow materials and tuffs that leads to the collapse of volcanic structure within the ring fault).
iii. ring stage and intrusive stage (the waning phase of igneous activity and the last stage of the evolution of younger granites).

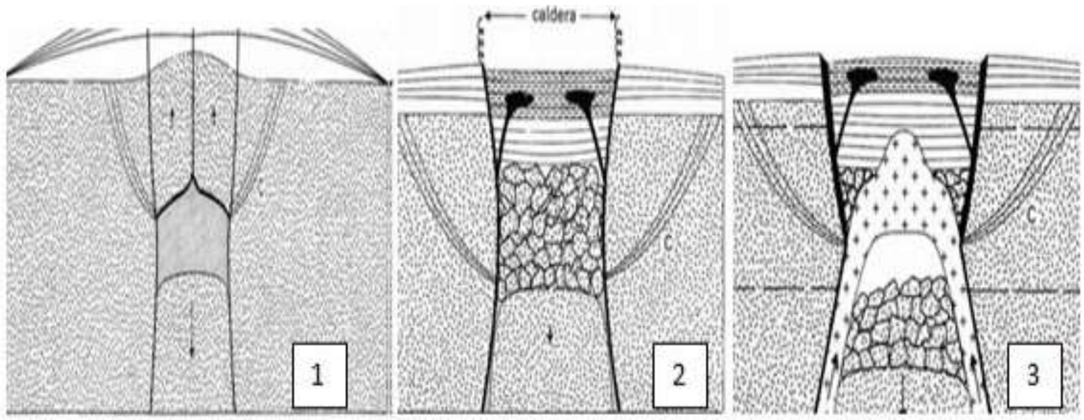


Figure 2.2: Different stages of the development of younger granites (Wright, 1985)

2.2 Gully Erosion Formation

Erosion is said to be the detachment and transportation of weathered soil particles from one place to another on the surface of the earth by the action of an agent of denudation (Aghayedo, 1996). Poesen *et al.* (2003) defined gully erosion as the process in which surface or runoff water accumulates and also reside in channels and then the soil is removed over short periods of time from that area at considerable depth.

Thomas (2004) had documented that gullies are unstable eroding channels formed at or close to valley heads, floors and sides. Poessen *et al*. (2003) carried out research on addressing gully erosion based on the understanding the formation of gullies, development of tools to locate channel initiation and appropriate measuring techniques.

2.2.1 Causes of Gully Erosion Formation

Gully erosion can occur at anywhere in a natural drainage system as runoff flows from within its catchment to its outlet. It is caused by a rapid expansion of the surface drainage in not usable site. According to Lakew and Belayneh, (2012) gully formation can be classified into two categories:

geological (geogenic) and anthropogenic (accelerated erosion-caused by mankind). Pathak *et al*. (2005) had classified the causes of erosion by geogenic factors (climate, topography, geology and soil properties) and anthropogenic factors (such as over grazing, road construction and lack of proper land management). The factors that result to the development of gully erosion and landslides are controlled by physiography, hydrogeology and engineering properties of the soil materials (Okengwo *et al*., 2015). Furthermore, Bocco *et al.* (1990) suggested that gullies erosion is caused by many factors, largely by rainfall, slope of the land surface, and human activities.

Okunlola *et al.* (2014) documented the natural causes of gully erosion which include climatic factor, uplift tectonism, and geotechnical properties. Additionally, Overgrazing, deforestation, mining activities civil works and faming are the anthropogenic cause of gully erosion development (Asiabaka, 1991). The gully erosion phenomenon is either naturally-induced or artificially-induced, or both (Okunlola *et al*., 2014).

Soils differ in terms of vulnerability to gully erosion. Soil with very coarse texture and highly permeable surface horizon is usually prone to gully erosion. The soil that is characterised by very low content of clay and organic matter and poor structural stability are most erodible (Osman, 2013).

Certain soils and landforms are easily subjected to gully formation. Soils with low cohesion, poor consolidation and weak cementation have more risk to erosion formation. Likewise, soils that are altered by physical, chemical or biological activity may develop weaknesses that may increase their erodibility and this varies with aggregate stability, shear strength, organic and chemical content, structure, degree of infiltration and soil texture, (Morgan, 1986; Bouyocous, 1951); nature of ground cover, soil infiltration capacity and characteristics of the underlying substratum characteristics (Amangabara, 2012).

2.2.2 Classification of Gully Erosion

Gully erosions are classified under several systems based on their different characteristics (Thomas, 1997)

i. Size- depth and drainage area: small gully, medium gully and large gully
ii. Shape: U-shaped, V- shaped gully and trapezoidal shaped gully and
iii. Continuation: continuous and discontinuous gully

2.2.3 Influence of Geology

The geology plays direct and indirect influence on the gully formation. The indirect effect is on the soil formation and the nature of soil which contribute significantly to erosion processes. High erosion risk is associated with units of loose and unconsolidated geological formations while least susceptible areas are within the consolidated lithology (Ofomata, 1981). The type of gully erosion with respect to their modes and conditions of formation is based on the nature of the underlying geology bearing on the initiation and propagation of gullies (Ezechi, and Okagbue, 1989). However, surface geology, soil types, topography anthropogenic factors are among the factors that lead to the formation and dimensional increase of the gullies (Thomas *et al*., 2004). Additionally, the nature of underlying geology contributes to the origin and distribution of gullies (Okagbue and Ezechi, 1988). It is documented that gully erosion is more predominant in the sedimentary terrain and perhaps in the basement/sedimentary contact areas (Abdulfatai *et al*., 2018).

2.2.4 Influence of Soil Factor

This is the measure of the resistance of soil to detachment and transportation by the agent of denudations (Amangabara, 2012). Generally, soils with high level of organic matter, high rate of infiltration, improved soil structures have a greater resistance to erosion. The erodibility process of soil is influenced by soil properties: structure, texture especially with respect to cohesiveness, organic matter, particle size distribution, structural stability, infiltration capacity, clay content and nature of the underlying substratum (Morgan, 1986; Amangabara, 2012). Soil erodibility is based on the physical characteristics of each soil. Sand, sandy loam and loam textured soils tend to be less erodible than silt, very fine sand, and certain clay textured soils (Wall *et al.,* 2003).

2.3 Geotechnical Index Properties of Soil

The initiation and propagation of gully erosion is mainly influenced by geotechnical properties of the soil (Okogbue and Ezechi, 1988). In most cases areas prone to severe gully erosion have varying geotechnical properties that favours gully erosion.

However, geotechnical properties of gully sites differ from place to place depending on the geologic conditions, soil formation and resulting sediment deposition. Geotechnical properties such as grain size distribution, Atterberg limit, moisture content and specific gravity are used to characterize gully sites (Omoru *et al*., 2015).

Zaman *et al*. (2016) conducted investigation on the geotechnical hazard analysis of river embankment of Bangladesh and argued that the geotechnical properties of the eroded river bank are important in controlling the river bank stability and many past works had indicated that these properties are spatially variable. Abdulfatai *et al.* (2018) conducted a research on the geological and geotechnical investigation of gully erosion along River Bosso and concluded that the geotechnical characteristics of the residual soils are from predominantly granitic rocks which make it to be vulnerable to gully erosion as it is supported by anthropogenic activities.

2.3.1 Specific Gravity

Various works considered specific gravity as causative agents in the formation of gully erosion. Soil with low specific gravity values favours erosion development (Charles *et al*., 2015; Okunlola *et al*., 2014). Das (2010) outlined the range of specific gravity of sand (2.63 - 2.67), silts (2.65 - 2.7), clay (2.67 - 2.9) and organic soil (<2). Gravel (2.65 - 2.68), sand (2.65 - 2.68), slit inorganic (2.62 - 2.68), clay organic (2.58 - 2.65) and clay inorganic (2.68 - 2.75) from the work of Bowel (1997). The specific gravity data were used in determining the probable risk of river bank erosion (Hasan *et al*., 2018).

2.3.2 Particle Size Distribution

This describes the relative proportion of the grain sizes of the soil. Soil densities, degree of paking, permeability, texture and structure have effect on the soil grading (Charles *et al*., 2015; Okunlola *et al.*, 2014; Omanayin, 2016). Many workers including (Thanappan *et al*., 2016; Okengwo *et al.*, 2015) studied gully formation based on the particle size distribution analysis by determining coefficient of uniformity (Cu), coefficient of curvature (Cc), and distribution of gravel, sand, silt and clay contents. Soil that are associated with poorly graded sands are likely to be easily eroded (Das, 2010) and highly susceptible to gully erosion (Okunlola *et al.,* 2014).

Soil with stable aggregates has low erodibility due to the fact that erodibility varies with aggregate strength, chemical composition, texture, degree of infiltration and impact value (Morgan, 1986). Tisdall and Oades (1982) documented that an aggregate hierarchy exists where micro aggregates consisting of clay pellets and organic molecules bind together to form micro aggregates which in turn bond to form macro aggregates. The micro aggregates are stabilised against disruption by several mechanisms wherein organo-mineral complexes play vital role. The aggregate hierarchy exists in soils where organic matter is the main stabilising agent of the aggregates (Oades and Waters, 1991).

The mechanical behavior of soil changes depending on its grain size distribution due to crushing during loading, unloading and reloading of particles during tectonic activities. The soil behaves either as cohesive or cohessionles reason for the change in coarse grains content ratio (Akpokodje, 2001). The textural behaviors of soil determine their mechanical responses to the erosive action of surface runoff (Hudec *et al.,* 2005).

2.3.3 Atterberg Limits

The water content at which the soil changes from one state to other is called Atterberg limits. The Atterberg limit determines that moisture content at which the soil will flow under its own height. It also defines the boundaries between several states of consistency. The Atterberg limit includes the Liquid Limit (LL), Plastic Limit (PL) and the Plasticity Index (PI). Atterberg limit is considered as causative agent in the study of gully formation (Ezechi and Okagbue, 1989; Ehiz and Uwadia, 2013; Valdon *et al*., 2010). From the work of Charles *et al*. (2015) it is deduced that soil from gullied areas or erosion prone region are non-plastic and non-cohesive, little amount of clay being the binding material (Chikwelu and Ogbuagu, 2014).

2.3.4 Compaction

This is the process by which moisture content of soil is controlled, reducing permeability, increase unit weight and shear strength. This makes the soil to be less susceptible to settlement under most especially repeated loading.

It is carried out to determine the relationship between moisture and density of soil. The methods include standard compaction method (proctor method), the modified method and the vibrating hammer methods. But proctor method has become the most widely method of compaction (BS-1377-2, 1990).

Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of soil have great relationship between particle sizes, grain shapes, mineral composition (importantly clay content) and specific gravity (Das, 2010).

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Materials

The following the materials were used for the research work

- Global positioning system
- Topographical map of the study area
- Compass clinometers
- Geological hammer, sampling bags
- Field note book
- Set of sieves, sieve shaker
- Mould, proctor rammer, bowl container
- Cone penetrometer
- Sledge hammer, digger, shovel

3.2 Field Work

3.2.1 Geological Mapping of the Area

The reconnaissance survey was carried out to locate erosion sites. The rock exposures, structural features and gully dimension were measured, recorded, and demarcated on the map. The rocks were observed in hand specimen based on the following macroscopic features: texture, colour and mineral composition. Moreover, careful observations of the lithologies were made by observing changes in the rock exposure, vegetation, topography and extent of weathering. More efforts were made to observe the textural variations of the soil along the gullied profiles.

3.2.2 Sample Collection

The soil samples were carefully collected from four (4) gully sites (Figure 3.1) by manual digging with simple implement such as digger, and shovel. Twelve (12) soil samples were collected and labeled for laboratory analysis: Sample 1T, 1M, 1B, 2T, 2M, 2B, 3T, 3M, 3B 4T, 4M, 4B. Where T, M, and B represents top, middle and bottom layer of the four (4) gully erosion sites respectively. Samples were stored in clean polythene bags and then transported to the geotechnical laboratory, Nigerian Building and Road Research Institute (NBRRI), Kano, Northwest Zonal Office for the laboratory analyses.

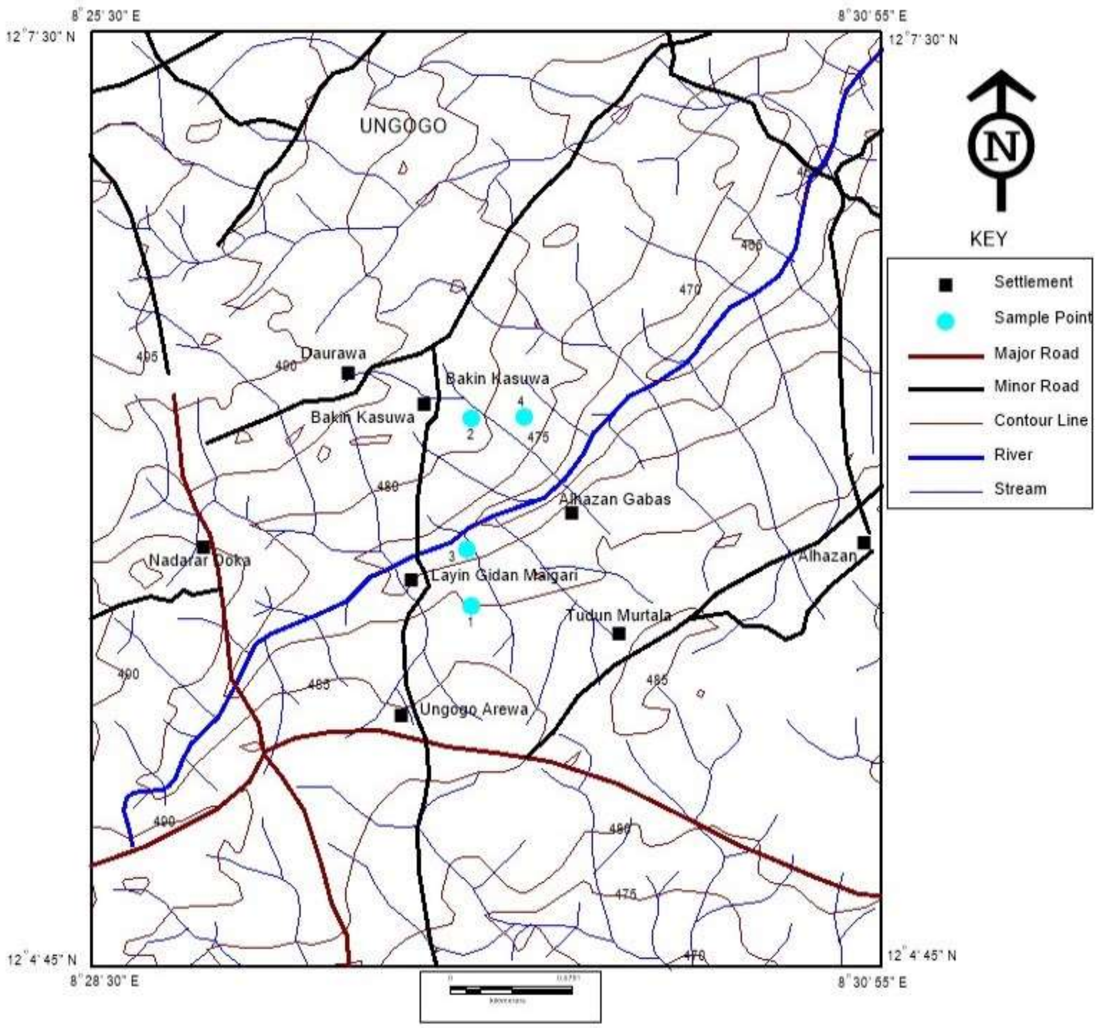


Figure 3.1: Sample points of the study area

3.3 Laboratory Analyses

The laboratory tests were carried out on the soil samples. Four (4) index properties of soil were determined: Specific gravity, granular-metric analysis (sieve method), Atterberg test and compaction tests. The physical characteristic of the soil is influence mainly by the distribution of particle sizes and plasticity associated with their mineralogical composition and the water content.

3.3.1 Sample Preparation

This involved air drying (until the water content is lost), pulverization and sieving of the soil samples to attain the required particle sizes for further analyses. Proper precautions were taken to avoid errors at the course of the analyses in order to obtain precise results.

3.3.2 Specific Gravity

This is the ratio of the unit weight of soil to the unit weight of water. It is required for the classification of the soil and determination of void ratio and density. The conical flask was clean and drying by rinsing blowing warm air through it at 105°C to110°C. The conical flask was weighed empty (M_1). The first soil specimen was transferred to the conical flask and then weighed (M_2). Sufficient air-free distilled water was added into the conical flask/dry soil and allowed it to settle for about 1hour and then weighed (M_3). The conical flask was then emptied, wiped, properly dried and then filled with water and weighed (M_4).

The procedures above were followed for the second specimen so as to determine the average of the particle density (BS-1377-2, 1990). Equation (3.1) was used to calculate the specific gravity of the soil.

$$GS = \frac{\qquad}{(\qquad)\ (\qquad)} \qquad (3.1)$$

Where GS= Specific Gravity

M_1= mass of conical flask [g]

M_2= mass of conical flask and dry soil [g]

M_3=mass of conical flask + soil + water [g]

M_4= mass of conical flask and water [g]

3.3.2 Sieve Analysis

This refers to gradation of particle size distributions of soil in an essentially cohesion less soil, down to the fine sand size. This experiment was employed to determine the grading of the geological materials in the soil and relative proportion of different soil particles.

About 500g weight of soil sample was soaked in water for 24hours and then washed thoroughly, the sample was then oven dried at temperature of 105-110^oC for 24 hours. The stack sieves were arranged serially from the larger opening to the finest. A bottom pan was placed under sieve 0.063(μm). The sample was then poured into the stak of sieves and then covered. The sieve shaker was then run for about 10-15mins. Thereafter, the shaker stops and the sieve removed. The amount of soil retained on each sieve and the bottom pan were weighed and recorded. The procedures above were repeated for other soil samples. The percentage of soils retained (Rn), cumulative percentage of soil retained and percentage finer were calculated from equation (3.2, 3.3 and 3.4) respectively.

$$Rn = \underline{\qquad\qquad\qquad} \times 100\% \qquad (3.2)$$

Cumulative (%) of soil retained = $\sum$ Rn (3.3)

Percentage finer= 100-$\sum$ Rn (3.4)

The percentage finer (passing) against sieves opening were plotted on semi-logarithmic graph. The D_{10}, D_{30}, D_{50} and D_{60} were read from the graph and coefficient of uniformity Cu (equation 3.5) and coefficient of curvatures Cc, (equation 3.6) were calculated.

$$\mathrm{Cu} = \frac{}{} \qquad (3.5)$$

$$\mathrm{Cc} = \frac{(\quad)}{(\qquad)} \qquad (3.6)$$

3.3.2.1 Permeability

The permeability is affected by the physical properties of the soil and the fluid passing through it. The grain size distribution controls the permeability of a soil layers. It is also favors by the fractures and porosity development (Pettijohn, 1975). The coefficients of permeability with respect to D_{10} were calculated from Equation (3.7) as adopted by Hazen (1983). The equation (3.7) only considered the D_{10} but equation (3.8) considered the difference between D_{10} and D_{50} and was also employed to calculate the coefficient of permeability of the gully soil (Odong, 2007).

$$k = \mathrm{C}(\mathrm{D10})^2 \qquad (3.7)$$

Where k = coefficient of permeability

C = constant (0.84)

D_{10}= grain size mesh equivalent to 10^{th} percentile

$$k=1.5046[I_0+0.025(D_{50}-D_{10})]^2 \quad (3.8)$$

Where k = permeability

I_0= slope intercept

D_{10}= grain size mesh equivalent to 10^{th} percentile

D_{50}= grain size mesh equivalent of the 50^{th} percentile.

3.3.3 Cone Penetrometer Test

This was carried out in order to determine the plasticity of the soil. It was used to show the effect of moisture content on fine grained soil. Cone penetrometer method was adopted because it is more satisfactory than the Casagrarnde method. It is easier to perform, easier to maintain in correct adjustment and the test procedure is less dependent on the judgment of the operator and it provides easy means of reproducing results.

3.3.3.1 Liquid Limit

This index practically established moisture content at which a soil passed from the liquid state to the plastic state. It provided a means of classifying a soil, especially when the plastic limit is known.

About 300g of soil paste prepared for the sieved soil was placed on the glass plate. The paste was mixed for at least 10min using the two palette knives. Some portion of the paste was placed into the cup with the pallet knife and smooth level surface was ensured. The cup was then placed under the tip of the cone and the cone was set in the correct position so that the cup marked the surface of the soil. The stem of the dial gauge was lowered to contact the cone shaft and the dial gauge was then recorded to the nearest 0.1mm. The cup was then released for about 5s. The differences between the beginning and the end of the drop as the cone penetration were recorded. The cone was cleaned and was lifted carefully to avoid scratching.

About 10g of paste was taken and placed on bowl from the area penetrated by the cone for the determination of moisture content. The water was been added at least three more times using the same specimen and the procedures above were repeated and each time soil was removed from the cup for the addition of water the cup was washed and dried.

The samples were then taken to oven for about 24hrs and the moisture content of the soil were calculated. The relationship between the moisture content and the cone penetration with the percentage content as abscissa and the cone penetration as ordinates, both linear scales and the best straight line fitting of the plotted points were drawn using excel. The penetration (mm) at 20 moisture content (%) is the liquid limit of the specimen.

3.3.3.2 Plastic Limit

The plastic limit is the established moisture content at which the soil is too dry to be plastic. It is used together with the liquid limit to determine the plasticity index which when plotted against the liquid limit on the plasticity chart providing a way of classifying cohesive soils.

It is performed on a proportion of the sample taken from that used for the liquid limit determination. About 20g of soil was taken from the paste prepared during liquid limit and rolled like a ball. The ball of wet sample was placed between the palms and rolled further to form a thread. The thread was rolled between the fingers, from the fingertip to the second joint with the glass rolling plate. Enough pressure was applied to reduce the thread's diameter to 3mm by the forward and backward movement of the hand.

The soil was picked up, molded between the fingers until the thread shears longitudinally and transversely. When the pieces of soil crumbled, in order to reform a thread and continue rolling; the first crumbling point is the plastic limit. The portion of the crumbled soil thread was gathered together and then transferred to three different moisture content containers and covered with the lid and then taken to oven for the determination of moisture content of the soil. The average moisture content values were calculated from equation (3.9) and expressed to the nearest whole number to be the plastic limit.

$$\mathrm{PL} = \overline{\qquad\qquad\qquad} \times 100\% \qquad (3.9)$$

3.3.3.3 Plasticity Index

This was obtained from the difference between liquid limit and the plastic limit. It is mathematically expressed in Equation (3.10).

$$\mathrm{PI} = \mathrm{LL} - \mathrm{PL} \qquad (3.10)$$

3.3.3.4 Liquidity Index

This was employed to determine the ratio of the difference between natural moisture (w) and plastic limit (PL) to the plasticity index (PI) of a clay soil in its natural state. It is mathematically expressed in equation (3.11). Over-consolidated clays may have LI <0 while unconsolidated clays may have LI >1.

$$Liquidity\ Index\ (LI) = \underline{\qquad} \qquad (3.11)$$

3.3.4 Compaction Test

This was adopted to examine the soil properties due to changes in moisture content. It determines the maximum dry density to which soil may be compacted by a given force and also showed when the material is wetter or drier than its optimal moisture content, (Nyles *et al*., 1999). Compaction by standard proctor method was employed (BS-1377-2, 1990).

About 5kg of air-dried soil on which compaction test is to be done was weighed. The water was then added and mixed thoroughly. Proctor mould and its base plate were weighed and then attached the top of the mold. The mixed soil was poured into the mold in three layers and each layer was compacted at 25 blows by the proctor hammer. The top attachment of the mould was removed from the mould and then trimmed the excess soil above the mould with straightedge.

The mold, base plate and compacted mixed (moist) soil were weighed altogether. The base plate was then removed from the mold. Small portion of sample was taken from top and bottom of the mold into the known mass moisture cans, weighed, and oven dried for about 24hrs for moisture content determination. The compacted soil was then removed from the mould, water was added to raise the moist content by about 2%, and then thoroughly mixed with the left over moist soil in the pan.

The procedures above were repeated for about 5 times until the weight of the mould and compacted soil reduced from the previous procedures. The percentage moist (w), wet density (ρw) and dry density (ρd) were calculated from equation (3.12, 3.13 and 3.14) respectively. The dry densities against moisture contents values were plotted on the graph.

$$\%\ \text{moist (w)} = \frac{\quad}{\quad} \times 100\% \qquad (3.12)$$

$$\text{Wet density } (\rho w) = \frac{(\quad)}{(\ )} \qquad (3.13)$$

$$\text{Dry density } (\rho d) = \frac{\quad}{\% \qquad (\ )} \times 100\% \qquad (3.14)$$

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Geology of the Study Area

The geological map of the study area indicated that the area is basically underlain by granitic rocks (Figure 4.1) of the basement complex of North Western Nigeria. However, geological activities were noted to have taken place in the area which includes jointing and fracturing of some rock exposures which could contribute to development of erosion of the area.

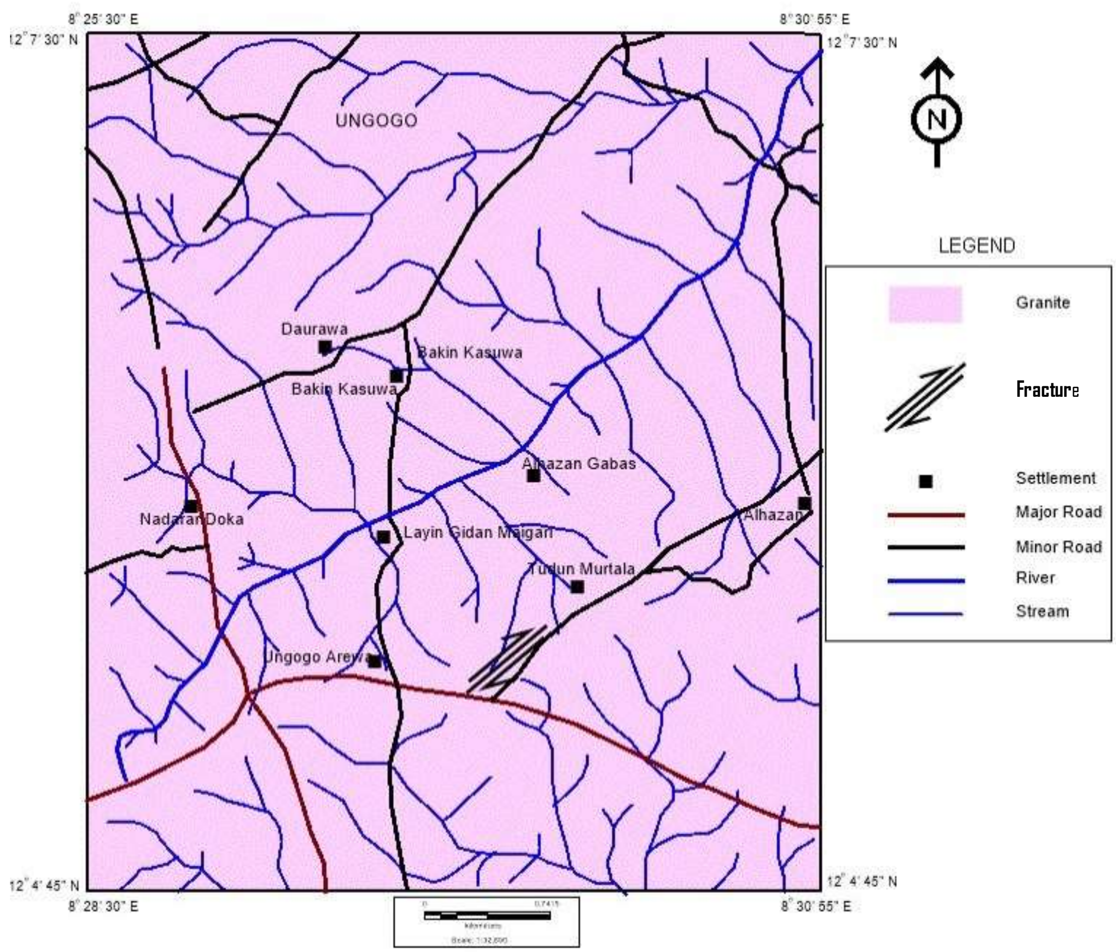


Figure 4.1: Geological map of the study area.

4.1.1 Older Granites

The older granites are poorly exposure mostly occurring as low laying scattered outcrops. They cover almost the entire study area. They are named coarse grained granites based on the textural properties. The texture appears to be 0.6mm - 0.9mm (Plate IVa) on hand specimen observations and compositionally consists of basically feldspars and quartz and biotites with some accessory minerals.

Plate IVa: Exposure of coarse grained granite (12˚5'40" N 8˚28'35" E)

4.2 Structural Geology

This is the relationship between different parts of a rock which is used to describe the overall relationships of the rock masses. The structures developed due to deforming forces that occur in response to different compressional and tensional forces during tectonic events (Whitten and Brooks, 1972).

The study area falls within the basement complex and had undergone various forms of tectonism leading the development of different structures. Veins, joints and fractures are the structural features identified in the study area.

4.2.1 Joints

The characteristics of the basement complex tectonics are the widespread of joints, a term used to describe a break or rupture in a rock that is either columnar or sheet. The joints and fractures could have developed from localized tectonic deformation and subsequent removal of the overburden by erosion and denudation from rock masses. They vary in sizes and orientations (Plate IVb and IVc).

Plate IVb: Joint on coarse grained granite (12˚5'30" N 8˚29'50"E)

Plate IVc: Fracture on coarse grained granite (12˚5'30" N 8˚29'50"E)

4.2.3 Veins

These are fractures filled with remobilized minerals including feldspar, quartz or both. The veins observed were in form of a sheet-like or tabular discordant, mineralized body formed by complete partial infilling of a fracture within the rock. The most noticeable vein was of quartz on highly weathered coarse grained granites (Plate IVd). The veins were seen occurring through the length of the rock with width of about 2 - 7cm.

Plate IVd: Quartz vein on coarse grained granite (12˚06'25"N 8˚28 40"E)

4.2.4 Gullies Dimension

The dimension of gullies are presented (Table 4.1) to give a picture of the level of erosion hazard and determine the soil horizon base on the spatial distribution of gullies using simple field assessments (Plate IVe and VIf). Location (1) is the widest gully measured but location (4) is the deepest gully. The gully depth ranges between 4.7 - 6.4m and width ranges between 3.4 - 4.6m.

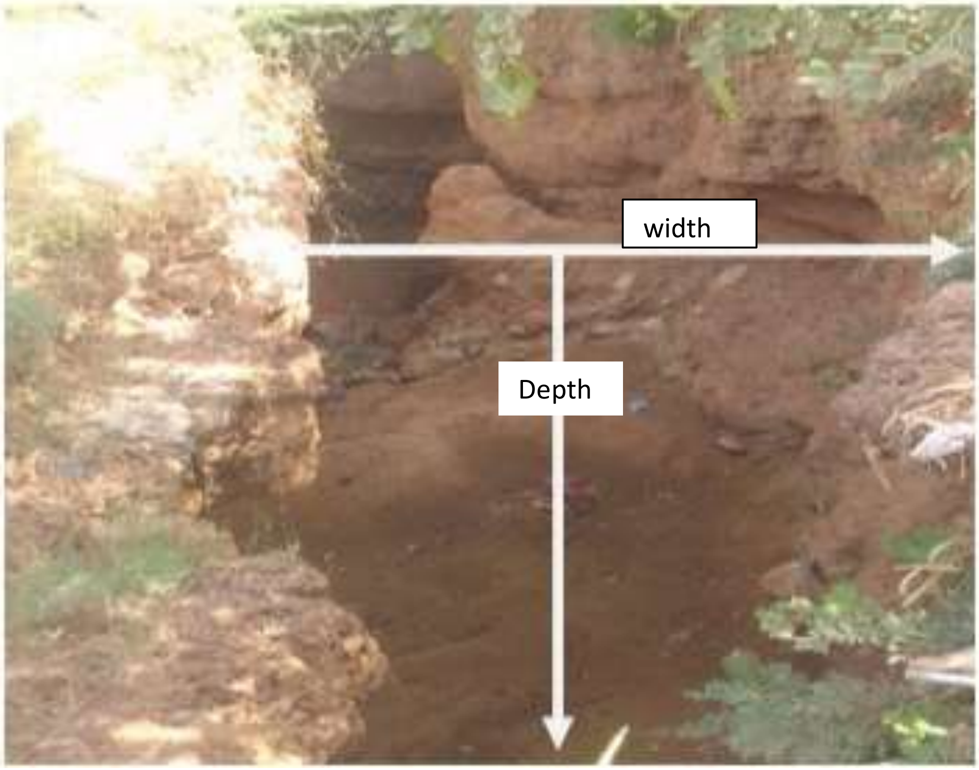


Plate IVe: Gully dimension of location 1 (12˚5'50"N, 8˚29'40"E)

Plate IVf: Gully dimension of location 4 (12˚6'22"N, 8˚25'50"E)

Table 4.1: Geometry of the gullies of the study area

Location	Cordinates	Depth (m)	Width (m)	Trend (˚)
1	12˚5'50"N, 8˚29'40"E	5.3	4.6	055
2	12˚6'22"N, 8˚29'40"E	4.7	3.4	120
3	12˚5'59"N, 8˚29'39"E	5.9	3.7	047
4	12˚6'22"N, 8˚25'50"E	6.4	3.8	110
	Total	22.3	15.5	-
	Range	4.7-6.4	3.4-4.6	047-110

4.3 Laboratory Analyses Results

4.3.1 Specific Gravity

The detailed specific gravity test results are presented (Appendix A), while the summary of the result is presented (Table 4.2 and 4.3). From the Table 4.3, it is seen that sample 2M has the highest specific gravity of 2.59 and sample 4T is the least with a value of 2.32. The specific gravity was used to determine soils that soil that are either cohesion or cohessionles, or even loose. This factor affects the erodibility of the soils hence, specific gravity results could be used to determine the probable risk of erosion loose that may affect the erodibility (by many factors) of the soil.

Table 4.2: Summary of geotechnical test results of the studied soil

S/N	Sample No.	SG	Sieve analysis				Atterberg limits				Compaction		
			Cu	Cc	K at D_{10}	K at D_{10}-D_{50}	LL (%)	PL (%)	PI (%)	LI	W (%)	OMC (%)	MDD(Mg/cm^3)
1	1T	2.48	12.67	4.25	2.3×10^{-4}	1.47×10^{-5}	23	19	4	1.01	23.04	7.89	2.17
2	1M	2.58	17.92	0.1	1.1×10^{-2}	7.9×10^{-4}	22	17	5	2.8	31.00	7.84	2.07
3	1B	2.54	2.57	0.96	1.0×10^{-2}	1.5×10^{-6}	19	10	9	1.2	20.98	10.67	2.13
4	2T	2.47	1.44	1.03	8.1×10^{-3}	8.5×10^{-7}	21	19	2	2.0	21.32	7.84	1.86
5	2M	2.59	10.1	0.14	1×10^{-4}	6.1×10^{-6}	21	14	7	1.14	22.17	10.38	2.07
6	2B	2.49	1.32	1.52	1.1×10^{-3}	5.4×10^{-7}	20	14	6	1.19	22.26	10.08	2.13
7	3T	2.40	1.38	1.14	6.4×10^{-3}	6.4×10^{-7}	24	23	1	1.0	24.00	11.17	1.92
8	3M	2.37	6.06	5.3	3.2×10^{-4}	1.1×10^{-3}	20	0	20	1.0	20.03	7.74	2.13
9	3B	2.48	7.06	5.3	2.9×10^{-4}	8.1×10^{-4}	26	17	9	1.32	24.86	6.72	2.12
10	4T	2.32	8.0	6.01	2.3×10^{-4}	8.5×10^{-6}	15	10	5	1.02	21.35	8.31	2.0
11	4M	2.53	1.3	0.93	1×10^{-2}	3.8×10^{-7}	23	21	2	0.03	20.34	11.38	2.03
12	4B	2.56	1.13	0.85	1×10^{-2}	7.9×10^{-4}	26	22	4	1.25	26.96	10.07	2.01

Table 4.3: Relationship between specific gravity and risk of erosion

S/N	Sample	Depth (m)	Specific gravity	Risk of erosion
1	1T	0-0.5	2.48	High
2	1M	0.5-1	2.58	Low
3	1B	1-1.5	2.54	Moderate
4	2T	0-0.5	2.47	Very high
5	2M	0.5-1	2.59	Moderate
6	2B	1-1.5	2.49	Moderate
7	3T	0-0.5	2.40	Moderate
8	3M	0.5-1	2.37	Moderate
9	3B	1-1.5	2.48	High
10	4T	0-0.5	2.32	Moderate
11	4M	0.5-1	2.53	Moderate
12	4B	1-1.5	2.56	Moderate

4.3.2 Particle Size Distribution

The percentage compositions of the grain sizes of the sieved soil samples are presented in Table 4.4, and the details are presented (Appendix B). The soils consist of high percentage of medium sand and low percentages of clay/silt. The underlying horizon contained high amount of coarse and medium sand except sample 1B and sample 3B. While, the middle horizons is compositionally made up of coarse grained sand except sample 3M. The upper horizon is of more fine sand except sample 1T.

The grain size distribution shows that the soils are predominantly sandy with low contents of clay materials which would serves as binding cementing materials. These fine particle contents in the soil established the presence of silts and clay sediments. Sediments with high sand or silt contents with less clay particle usually erode easily even under a flat terrain. Therefore, any runoff on the surface would intensify the intensity of the gully erosion in the area.

Table 4.4: Grain size distribution of the soil from the study area

S/N	Sample No.	Medium gravel (%)	Fine gravel (%)	Coarse sand (%)	Medium sand (%)	Fine sand (%)	Silt/clay (%)
1	1T	0.68	13.90	31.64	23.12	21.80	9.36
2	1M	3.60	32.24	31.38	18.52	12.08	2.18
3	1B	1.14	7.88	36.98	22.24	21.70	10.06
4	2T	0.0	3.52	18.84	44.72	25.40	7.52
5	2M	1.08	24.50	30.94	21.64	16.90	4.96
6	2B	0.08	10.80	21.68	44.54	17.96	4.94
7	3T	0	0.98	7.02	20.40	63.66	7.94
8	3M	0	0.68	4.82	19.96	69.36	5.18
9	3B	0.3	4.42	13.62	33.82	40.74	7.1
10	4T	0	4.96	16.04	31.04	36.72	11.24
11	4M	0.64	11.36	17.40	40.26	24.14	6.20
12	4B	1.7	15.44	19.48	36.96	21.82	4.60
-	Max	3.6	32.24	36.98	44.72	69.39	11.24
-	Min	0	0.68	4.82	18.52	12.08	2.18

4.3.3 Cone Penetration Test Result

The summary of the Atterberg limits is presented in Table 4.5, plasticity index chart (Figure 4.3) and detailed computation is presented (Appendix C).

Table 4.5: Summary of cone penetration test result

Sample no.	LL (%)	PL (%)	PI (%)	LI	W (%)	Soil classification
1T	23	19	4	1.01	23.04	CL
1M	22	17	5	2.8	31.00	CL
1B	19	10	9	1.2	20.98	CL
2T	21	19	2	2.0	21.32	MI
2M	21	14	7	1.14	22.17	CL
2B	20	14	6	1.19	22.26	CL
3T	25	23	2	1.0	24.00	MI
3M	20	0	20	1.0	20.03	CL
3B	26	17	9	1.32	24.86	CL
4T	21	10	11	1.02	21.35	CL
4M	24	21	3	0.03	20.34	MI
4B	25	22	3	1.25	26.96	MI
Max	26	23	20	2.8	31.00	
Min	19	0	2	0.03	20.03	

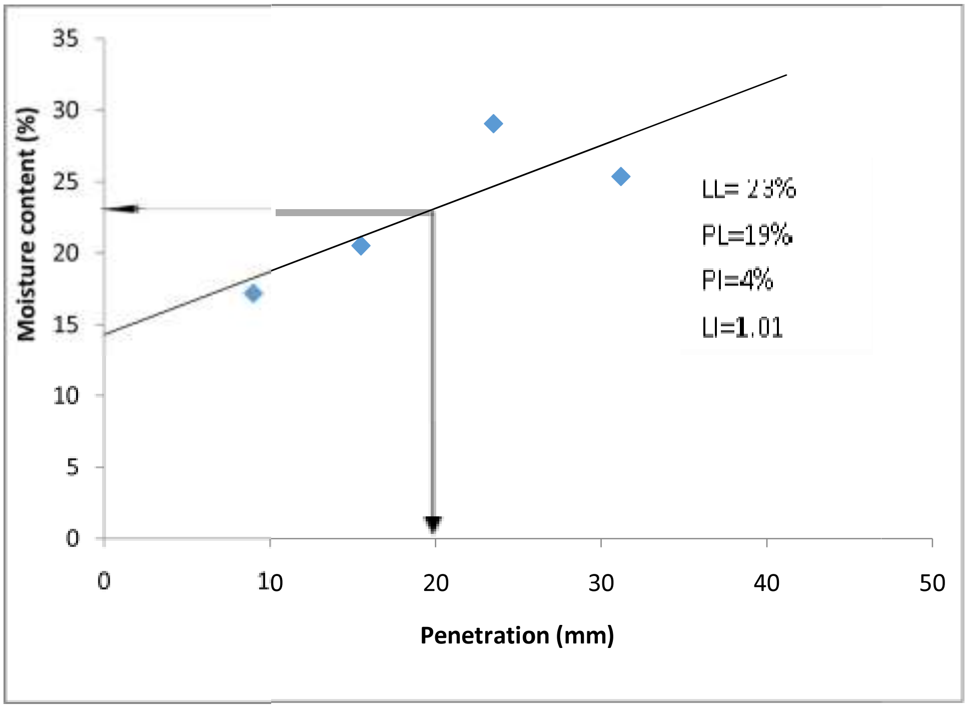


Figure 4.2: Liquid Limit of clay of low plasticity

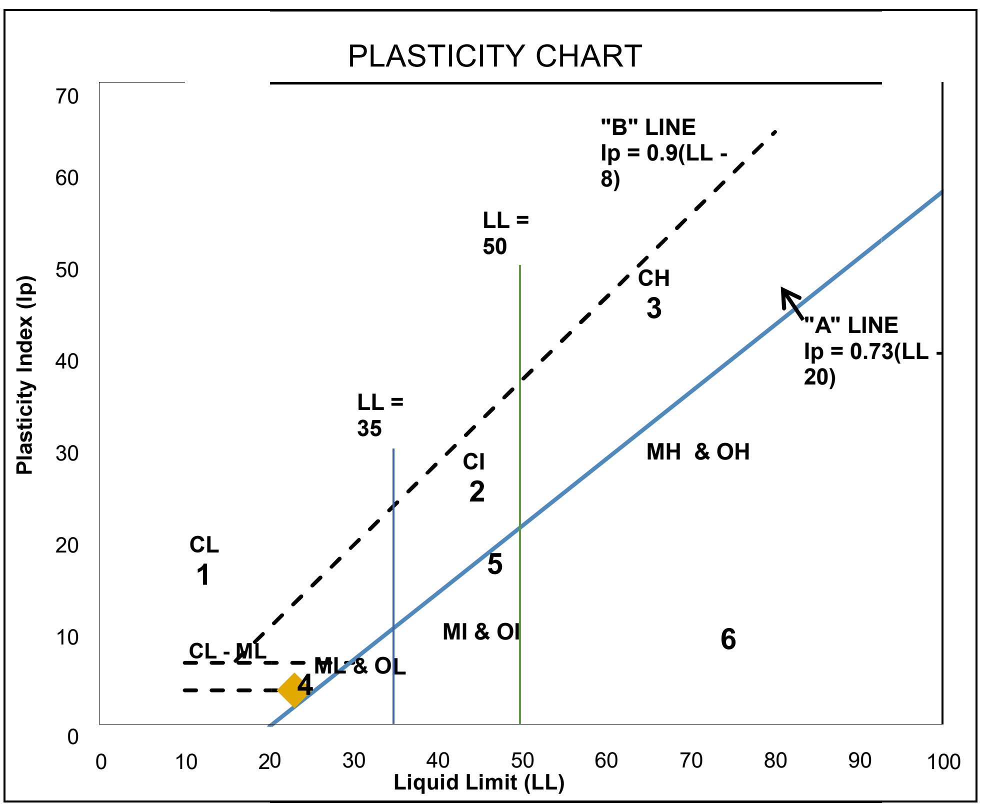


Figure 4.3: Plasticity Index of clay of low plasticity

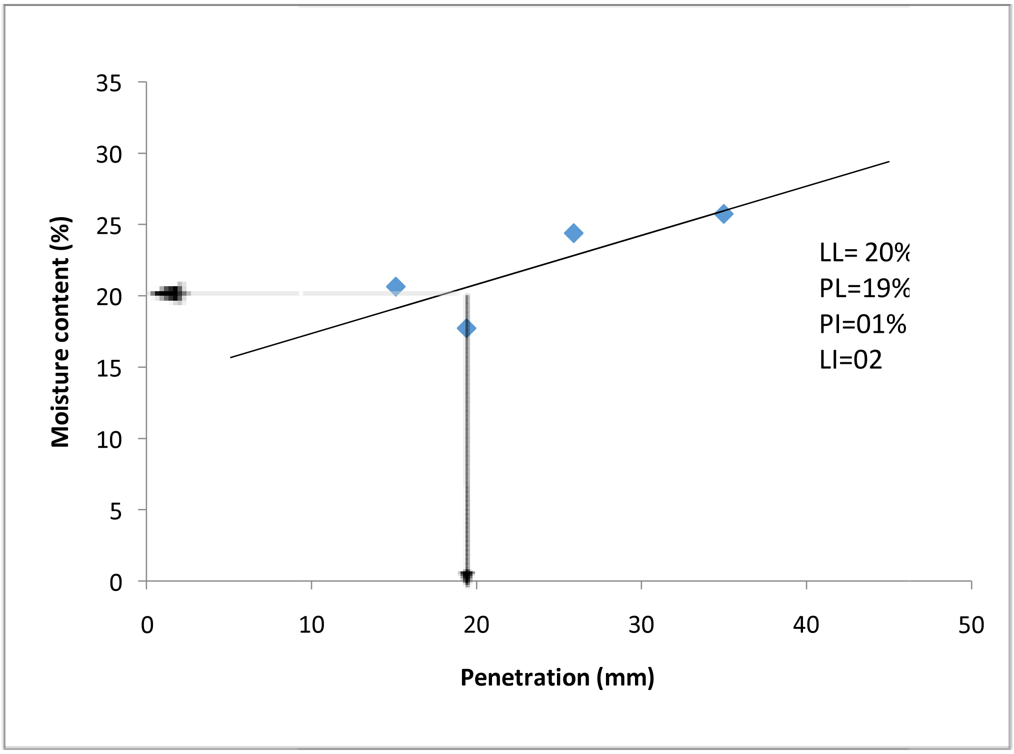


Figure 4.4: Liquid Limit of silt of low plasticity

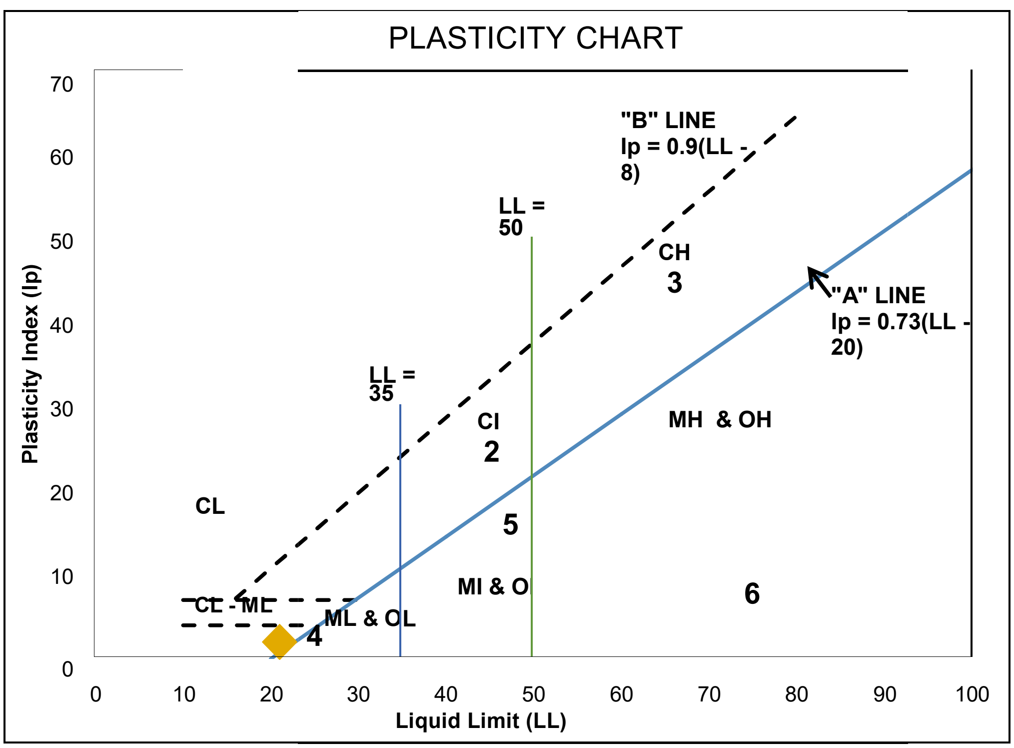


Figure 4.5: Plasticity Index of silt of low plasticity

4.3.4 Compaction Test Result

The compaction test result presented (Table 4.6) shows the maximum dry density and optimum moisture content values.

Table 4.6: Summary of compaction test results of the studied soil

S/N	Sample No.	Depth (m)	OMC (%)	(MDD) (Mg/cm^3)
1	1T	0-0.5	7.89	2.17
2	1M	0.5-1	7.84	2.07
3	1B	1-1.5	10.67	2.13
4	2T	0.05	7.84	1.86
5	2M	0.5-1	10.38	2.07
6	2B	1-1.5	10.08	2.13
7	3T	0-0.5	11.17	1.92
8	3M	0.5-1	7.74	2.13
9	3B	1-1.5	6.72	2.12
10	4T	0-0.5	8.31	2.0
11	4M	0.5-1	11.38	2.03
12	4B	1-1.5	10.07	2.01
-	**Max**	**-**	11.38	2.17
-	**Min**	**-**	6.72	1.86

4.4 Discussion of Results

4.4.1 Influence of Geology on Erosion

The soil erosion process are controlled by the influence of lithology and by directly resistant of the exposed bed rocks to the action of running water and also by the properties such as veins, and fractures of parent materials whose properties are given by the bed rock.

Some geological materials are less resistance to erosion than the other. High erosion risk matched with the weak, unconsolidated and highly weathered geological lithologies as in the case of the lithological condition of the outcrops in the studied area (Ofomata, 1981). The mode of erosion and its condition of formation is usually controlled by the nature of the underlying geology (Ezechi and Okagbue, 1989).

4.4.2 Impact of Gully Erosion in the Study Area

The field evidences had revealed that the study area has been affected by gullies erosion and these areas are potentially under threat of gully erosion. They have developed to extent of destroying bridge (Plate IVg), Lost of farm land (Plate IVh) The farmer could not be able to cultivate their crops due the fact that most of the vast areas affected by erosion within the studied area could not farm because the erosion has take an appreciable area and fertility is being lost leading to a decrease in agricultural productivity which may result to food shortage and can lead to famine. It leads to loss of vegetation (Plate IVi) within the studied area. Its continuous expansion encroaches into area where forests are cut and exposes the area for further gully activities.

Plate IVg: Impact of erosion the bridge (12˚6'24" N 8˚29'30" E)

Plate IVh: Impact of erosion on land (12˚5'48" N 8˚29'33" E)

Plate IVi: Impact of erosion on vegetation (12˚5'49" N 8˚29'34" E)

4.4.3 Geotechnical Assessment of the Gully Sites

4.4.3.1 Gradation Analyses

The grading index recorded from the sieve analysis showed that Cu ranged between 17.2 - 1.13 and Cc ranges between 6.01 - 0.85. Only samples 1M and 2M were found to be well graded, samples 1T, 3M, 3B and 4T were recorded as Gap graded sands but samples 1B, 2T, 2B, 3T and 4M were poorly graded. Well graded sands are more resistance to erosion due to increase in density and strength. The poor graded sands are vulnerable to erosion than its counterpart due to decrease in density, decrease in friction angles and increase in void ratio (Obiefuna *et al.,* 1999).

For sand to be well graded, Cu ≥ 6 & 1< Cc < 3 and if these criteria are not met, it is regarded as poorly graded. A soil is said to be well graded when the soil has wide range of sizes with good representation of all sizes from the least to the highest sieve. Conversely, poorly graded soil does not have good representation of the all size particles for the least to the highest sieve size (Das, 2010).

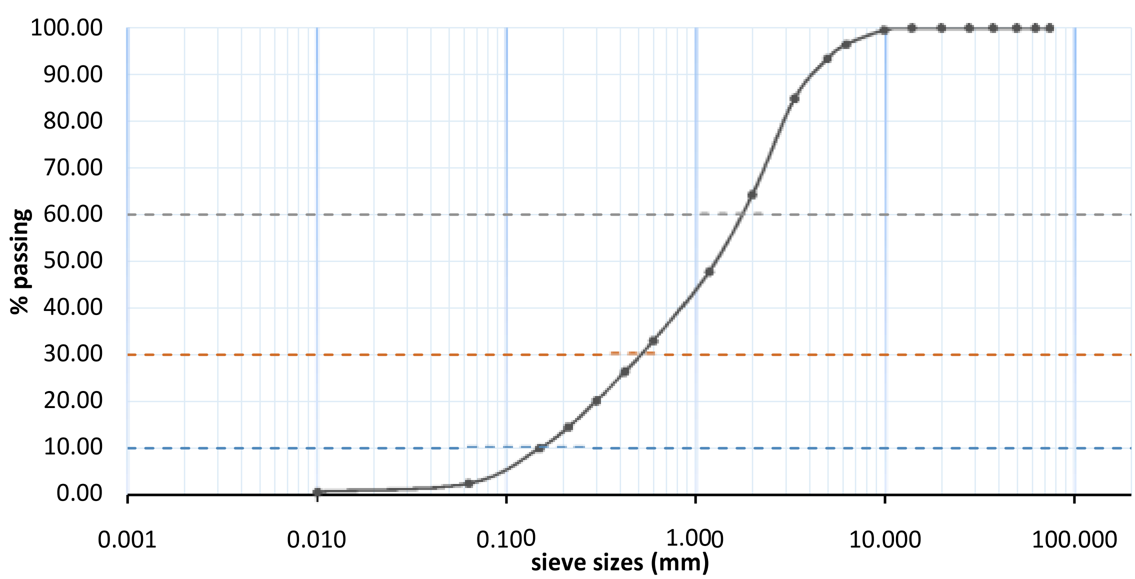


Figure 4.6: Particle size distribution curve of well graded sand

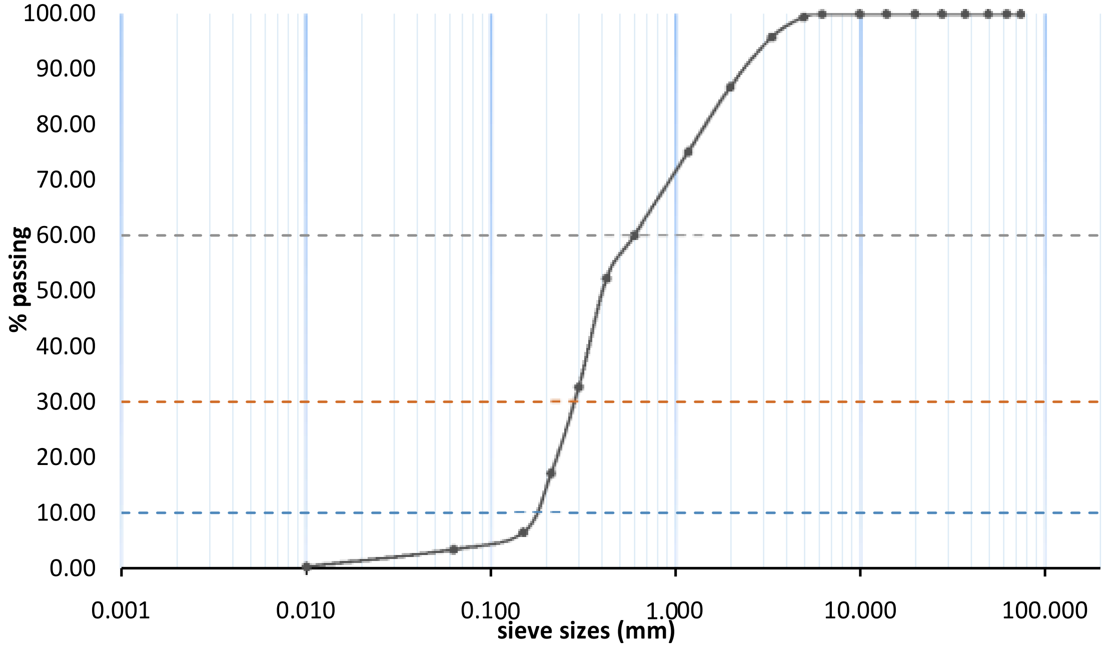


Figure 4.7: Particle size distribution curve of poor graded sand

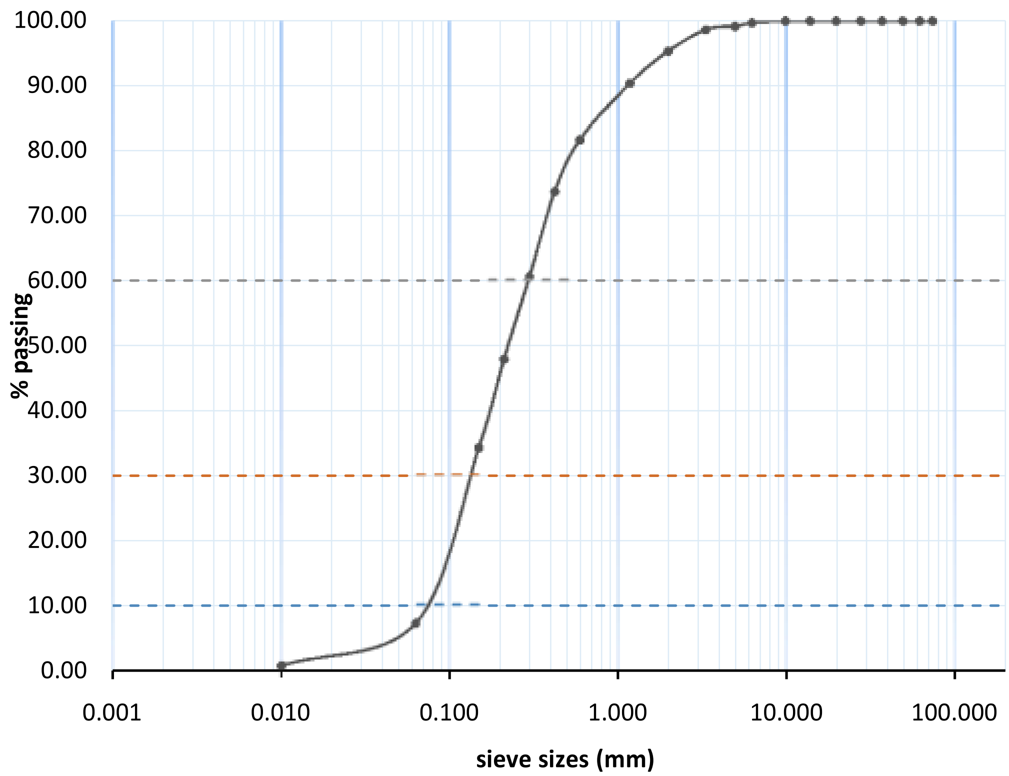


Figure: 4.8: Particle size distribution curve of gap graded sand

Table 4.7: Gradation analysis and calculated coefficient permeability of the soil sample of the study area

Sample No.	D_{10}	D_{30}	D_{50}	D_{60}	C_u	C_C	$K_{(D10)}$	$K_{(D10-D50)}$	Remark	Permeability
1T	0.015	0.11	0.14	0.19	12.67	4.25	1.9×10^{-4}	1.47×10^{-5}	Gap graded sand	Moderate
1M	0.106	0.14	1.02	1.09	17.92	0.1	9.4×10^{-3}	7.9×10^{-4}	Well graded sand	High
1B	0.1	0.11	0.14	0.18	2.57	0.96	8.4×10^{-3}	1.5×10^{-6}	Poorly graded sand	Moderate
2T	0.09	0.11	0.12	1.3	1.44	1.03	6.8×10^{-3}	8.5×10^{-7}	Poorly graded sand	Moderate
2M	0.1	0.12	0.18	1.01	10.1	0.14	8.4×10^{-3}	6.1×10^{-6}	Well graded sand	Moderate
2B	0.106	0.15	0.13	0.14	1.32	1.52	9.4×10^{-3}	5.4×10^{-7}	Poorly graded sand	Moderate
3T	0.08	0.1	0.106	0.108	1.38	1.14	5.4×10^{-3}	6.4×10^{-7}	Poorly graded sand	Moderate
3M	0.018	0.102	0.108	0.109	6.06	5.3	2.7×10^{-4}	$\times10^{-3}$	Gap graded sand	High
3B	0.017	0.104	0.11	0.12	7.06	5.3	2.4×10^{-4}	8.1×10^{-4}	Gap graded sand	High
4T	0.015	0.104	0.11	0.12	8.0	6.01	1.9×10^{-4}	8.5×10^{-6}	Gap graded	Moderate
4M	0.1	0.11	0.12	0.13	1.3	0.93	8.4×10^{-3}	3.8×10^{-7}	poorly graded sand	Moderate
4B	0.102	0.11	0.13	0.14	1.13	0.85	8.7×10^{-3}	7.9×10^{-4}	Poorly graded	High

4.4.3.2 Coefficient of Permeability of the Soil

Permeability is a complex property that is affected by physical properties of the soil and the liquid medium passing through it (DeGroot and Ostendorf, 2012). It is sometimes controlled by grain orientations, grain packing, cementation, clay content, mineral composition, fractures and porosity characteristics.

When compared with the work of Carter and Bentley (1991), it is confirmed that the coefficient of permeability of soils from the study area falls between gravel and sand (Figure 4.9). The coarse grained content of soil with low contents of fines could result to high flow rate of pore water and subsequent seepage pressure which implies that high amount of water will infiltrate to underground which could promote further expansion of the gullies (Onwuemesi and Egboka, 1991).

The well grade sands have all particle size of materials present in it and are more interlocking with high friction angles. The poorly graded sands are approximately of the same particle sizes and very high permeability than well graded sand. The gab graded having at least one of particle size is completely missing in it and considered moderate permeability; they are sometimes called poorly graded sand.

It is obvious that grain size distribution has impact on permeability. Coarse grained soils have large pores and larger interconnection between the pores while, smaller pores have very narrow interconnection. Additionally, fine particles fill the pore spaces between the larger grains thus decreasing the sizes of void and the associated interconnection. Considering sample 4B (1×10^{-2} & 7.9×10^{-4}) with the highest permeability as compared to sample 2T (8.5×10^{-3}& 8.1×10^{-3}), this indicated that the particle size distribution has significant effect on permeability which in turn induces gully erosion in the area.

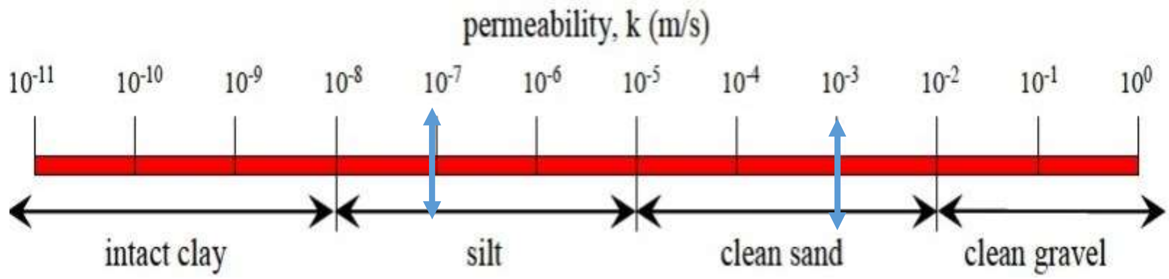


Figure 4.9: Relationship between grain size and permeability (Carter and Bentley, 1991)

4.4.3.3 Plasticity of Soil of the Study Area

Liquid limits and plastic limits were employed to determine the plasticity index which measures the cohesive properties of the soil (Onwemesi, 1990). Plasticity chats were plotted (Appendix C). The values of liquid limit ranges from 19 to 26% and mean 22.25%, Plastic limit ranges from 23 to 0% with a mean of 15.5%. While plasticity index ranges from 3 to 20% with a mean of 6.75%. This shows that the soils have low plasticity when compared with the chart (Figure 4.10) documented by Clayton and Jukes (1978).

The plasticity index of the soil from sample 1T - 4B were 4%, 5%, 9%, 2%, 7%, 6% 2%, 20%, 9%, 11%, 3%, and 3% respectively (Table 4.5). The sample 3M has the highest plasticity index of 20% and sample 2T recorded the lowest plasticity index of 2% and all the soil samples from gully sites have their plot clustered within the low plasticity range, indicating cohessionles properties. These cohessionles soils could be accountable for the gully erosion problems in the area. This is due to the fact that water flows through the soil with ease and soil particles are moved very easily down slope as the velocity of water increases.

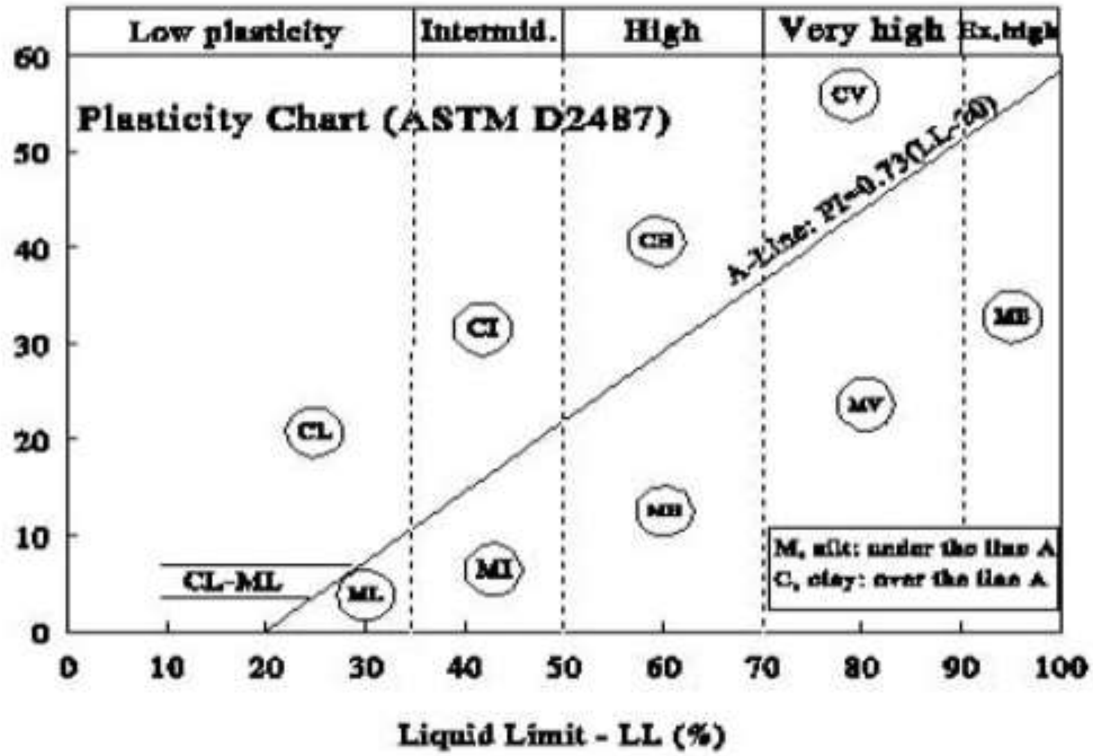


Figure 4.10: Plasticity chart **(**Clayton and Jukes, 1978)

4.4.3.4 Optimum Moisture Content and Maximum Dry Density

The OMC ranges from 6.72-11.38% and MDD ranges from 86-2.17Mg/cm^3 (Table 4.6). Sample 2T has the lowest MDD while sample 1T has the highest MDD. Sample 3M has the lowest OMC, while sample 4M has the highest OMC. The low values of the MDD imply that the soil are generally not compacted and are loosely bound.

A comparison of previous studies on the geotechnical analysis (Table 4.8) with the studied soil indicated that the studied soils are majorly loose sand with low maximum dry densities describing compacted properties of the soil and this could pave way for erosion susceptibility (Gabriel and Jibrin, 2012; Umoro *et al*., 2015). The values fell within the range classified to be sandy O'Flaherty (1988).

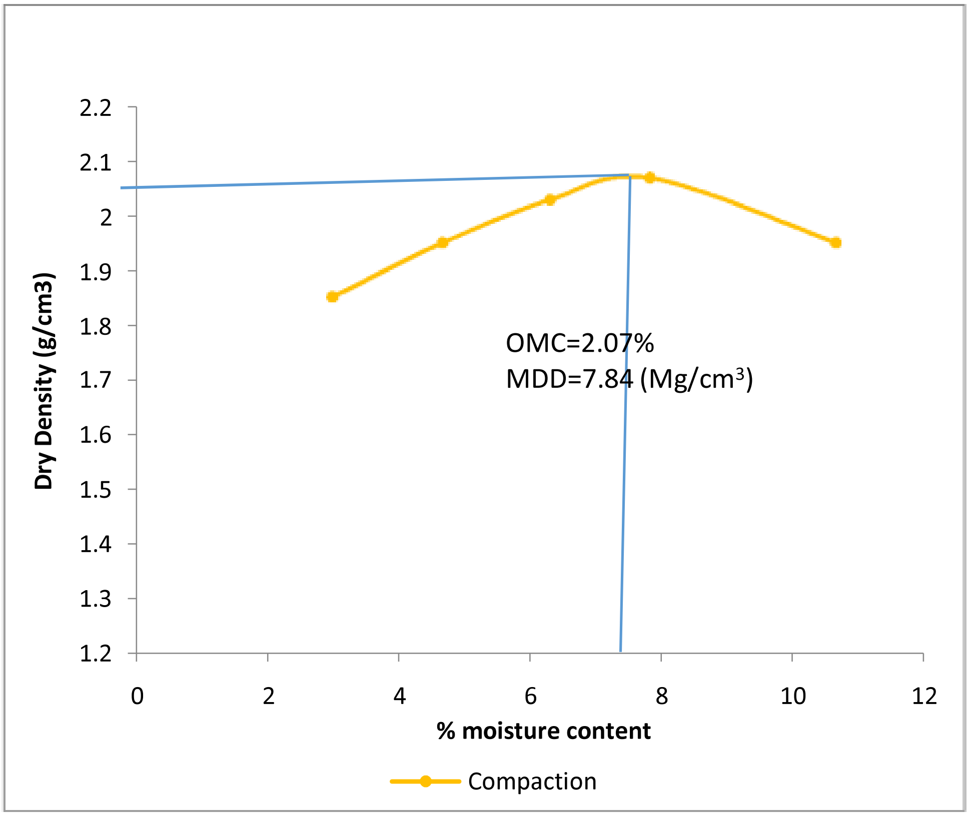


Figure 4.11: Graph of dry density against moisture content of the studied soil

Table 4.8: Comparison of OMC and MDD results with previous works

Authors	OMC (%)	MDD (Mg/cm^3)
Gabriel and Jibrin (2012)	6.4-12.4	1.82-2.15
Okunlola, *et al.* (2014)	8.9-14.85	1.88-2.09
Chikwelu and Ogbuagu, (2014)	7.90-11.0	2.0-3.91
Kamtchueng *et al*. (2015)	11.2-20.08	1.60-2.08
Umoro *et al*. (2015)	7.0-10.7	1.90-1.94
Omanayin (2016)	9.90-12.39	2.14-2.42
Current work	6.72-11.38	1.86-2.17

4.4.4 Mitigation Measures

The danger of gully erosion around Ungogo area has called for urgent measures to reduce the risk on the road and bridge collapse, farmland degradation, and building structures. There are basically two (2) methods of controlling gully erosion: biological method and engineering methods. The engineering practice requires stabilization of river banks and river flow, landfilling, construction of check dam and geo-textile.

a. Stabilization: Chemical stabilizer may be an effective technique to improve the erosion resistance of the soil along the gullied profiles. Sometimes, Ligno-sulfate is used to increase the critical shear strength which in turn reduces the soil erosion coefficient as a power function of the critical shear strength.

b. Landfilling: When reshaping the gullies, an excavator is more practicable due to the sizes of the gullies. During filling, each layer of the soil should be properly compacted otherwise non compacted layer will offer little resistance to gully erosion.

c. Check dams: This is aimed at stabilizing the river beds. They may reduce the rate of river banks expansion. It will also control erosion in the study area. Materials such as loose rock and wire-bound loose rock, brushwood check dams, rock/sand bag could be applied to control gully development in the study area.

i. Rock/sand bag checkdams are relatively low cost, easy to maintain and replaced when damaged and can be used to divert and slow reduce the flow velocity.

ii. Loose rock and wire-bound loose rock check dams are made up of relatively small rocks substituted across the gully in order to stabilize the gully bed and head.

iii. Brushwood check dams are important to be applied in the study area. It holds fine materials carried by runoff. They serve as shock absorber and to dissipate the runoff velocity during peak flows.

iv. Gabion check dam are prefabricated wire cages filled with loose rocks they are applicable in the gully floor and on the sides of the river banks.

d. Geo-Textiles: These are fabrics manufacture by weaving or bounding fibers made from synthetic materials like polyethylene, polyvinyl chlorides, glass and polyester. Geotextile can be used alone as matting to stabilize the flow along the channels.

e. Vegetation: This helps to protect the soil surface from rain-splash, increasing soil strength by reinforcing the soil with roots and moderate moisture content of the soil and reduce surface runoff. Vegetation alone can not be able to control an actively gully head but may reduce the rate of advancement by planting erosion-resistance grasses.

f. Fencing: This is cost-effective and more efficient when many gullies are included within the fence so that the dimension of gullies within the fence is increased to the dimension of the fence. It is applied to protect passive or active re-vegetation of gullies to prevent humans and animals from falling into the gullies.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The evaluation of the geological and geotechnical index properties (specific gravity, sieve analyses, compaction and Atterberg limits) that result to gully erosion in Ungogo has been carried out as a holistic approach for investigating the behavior of the earth materials and measurement of soil properties of the gully soils. The geological map of the study area was produced in order to have insight on surface and subsurface geology. The geometry of the gullies and the extent of degradation had been ascertained.

The study area is geologically underlain by coarse grained granites that are poorly exposed and intensely weathered. The presence of more poorly graded and gap graded soils within the soil layers may increase the voids thereby decrease the strength and densities of the soil. The soils are of low plasticity thus cohessionles which is an evidence of the causative factor for the growth of the gullies. The soils are majorly loose sand with low maximum dry densities showing un-compacted properties of the soils and could be responsible for gully formation in the area.

5.3 Recommendations

i. The anthropogenic activities responsible of exacerbation geomorphologic changes should be banned. Indiscriminate farming activities, grazing, construction activities on potential prone erosion sites should be check and control by the authorities.

ii. Channelization of runoff into nearby river to prevent ephemeral gully formation

iii. The information presented in this work should serve as a basis for minimizing the adverse effect of accelerated soil erosion and reduce the anthropogenic activities in the area.

iv. Further investigation by geophysical approach and continue monitoring gullies of the area is recommended.

REFERENCES

Abdulfatai, I. A., Okunlola, I. A., Akande, W. G., Momoh, L. O. & Ibrahim, K. O. (2018). Review of gully erosion in Nigeria: causes, impacts and possible solutions. *Journal of Geosciences and Geometrics,* 2(3), 125-129.

Aghayedo, N. (1996). Erosion and flooding in Edo State. Consensus building workshop for state environmental action plan by FEPA/EDSEPA, Benin City.

Ajibade A. C., Rahaman M. A. & Woakes, M. (1987). Proterozoic crustal development in the Pan-African. *Proterozic Lithospheric Evolution*, 17, 259-271.

Akpokodje, E. G. (2001). *Introduction to engineering geology*. Pam Unique Publications. 53-233.

Amangabara, G. T. (2012). Analysis of selected failed gully erosion control works in Imo State. *Nigerian Association of Hydrological Sciences*, 279-287.

Asiabaka, C. C. (1991). Socio-economic impact of erosion on flood and erosion in Cross River State, Calabar. 113-123.

Bocco, G., Blanco, J. L, & Morale, L. M. (1990). Computer-assisted mapping of gullies: A spatial database for a gully information system. *International Journal of Applied Earth Observation and Geoinformatics,* 45-50.

Bouyoucos, G. H. (1951). Method of determining particle sizes by the soil hydrometer. *Agronomy Journal,* 4(3)*,* 434 – 438.

Bowden, P., Van Breemen, O., Hutchison, J. & Turner, D. C. (1976). Palaeozoic and mesozoic age trends for some ring complexes in Niger and Nigeria. *Nature* 259*,* 297–299.

Bowles, J. E. (1997). *Foundation design and analysis*. New York. The McGraw-Hill Companies, Inc.

Bruce, C. (2006). Gully erosion: Natural resources and water managing Queensland's natural resources. *Continental Journal of Earth Sciences,* 5(1), 11-118.

BS-1377-2 (1990). Methods of test for soils for civil engineering purposes. British Standards Institution, 30-52.

Buchaman, M. S. Macleod, W. N., Turner, D. C. & Wright, E. P. (1971). The geology of the Jos Plateau. *Geological Survey of Nigeria, Bulletin,* 32, 1–170.

Carter, M., & Bentley, S. P. (1991). *Correlations of soil properties*. London, Pentech Press, 1-130.

Charles, U., Shuaibu, M., Umar, M. U. & Abdullahi, I. N. (2015). Geotechnical assessment of gully erosion at Ankpa area, North Central Nigeria. *Journal of Applied Chemistry,* 8(12), 36-48.

Chikwelu, F. & Ogbuagu, F. U. (2014). Geotechnical investigation of soil around Mbaukwu gully erosion sites, South-Eastern Part of Nigeria. *Journal of Applied Geology and Geophysics (IOSR-JAGG),* 2(4), 06-17.

Clayton, C. R. I., & Jukes, A. W. (1978). A one point penetrometer liquid limit test, geotechnique, 28, 469-472 Coduto, D.P., 1999. Geotechnical engineering principles and practice. Prentice Hall Inc. Upper Saddle River, New Jersey, 74-58.

Dada, S. S., Brique, L., Harms, U., Lancelot, J. R. & Mathies, G. (1995). Charnokitic and monozontic Pan-African series from North Central Nigeria. Trace elements and Nb-Sr-Pb isotope constraint on their petreogenesis, *Chemical Geology Journal of the European Association for Geochemistry.* 233-252.

Das, B. M. (2010). *Principles of geotechnical engineering* (7^{th} ed.). Stamford: London Press Publisher, 1-52.

DeGroot, D. & Ostendorf, J. A. (2012). In situ measurement of hydraulic conductivity of saturated soils. *Journal of Geotechnical Engineering,* 43(4)*,* 63-72.

Egboka, B. C. E. (2000). Erosion, its causes and remedies: A key note address on erosion control and stainable environment. University of Nigeria, Nsukka, Nigeria.

Ehiz, O. S., & Uwadia, N. O. (2013). Evaluating factors responsible for gully development. *Journal of Emerging Trends in Engineering and Applied Sciences,* 4(5)*,* 707-713.

Ezechi, J. I., & Okagbue, C. O. (1989). A genetic classification of gullies in Eastern Nigeria and its implications on control measures. *Journal of African Earth Sciences (and the Middle East)*, 9(34), 711-718.

Falconer, J .D. (1911). *The geology and geography of Northern Nigeria*. MacMillan London.

Gabriel, I. O. & Jibrin, A. (2012). Geological and geotechnical assessment of selected gully sites in Wuro Bayare area NE Nigeria, *Research Journal of Environmental and Earth Sciences,* 4(3)*,* 282-302.

Grant, N. K. (1978). Structural distinction between a metasedimentary cover and an underlying basement in the 600m.a old Pan-African domain of Northwestern Nigeria. *Geological Society, America,* 89, 50–58.

GSN (1994). *Geologic Map of Nigeria*. Abuja: Geological Survey Department, Ministry of Petroleum and Mineral Resources, Nigeria.

Hasan, M., Quamruzzman, C., Hassan, A., Methela, N. J., & Imran, A. S. (2018). Determination of River Bank erosion: vulnerability and risk in southern shoreline of Bangladesh. *International Journal of Energy and Sustainable Development,* 3(3), 44-51.

Hazen, A. (1983). Some physical properties of sands and gravels. Mass State Board Health, *24^{th} Annual Report*, 1-15.

Hudec, P. P. H., Simpson, F., Akpokodje, E. G., & Umennweke, M. O. (2005). Anthropogenic contribution of gully initiation and propagation, South Eastern Nigeria. *Geological Society of America*, 149-158.

John, U. J., Igboekwe, M. U. & Amos-Uhegbu, C. (2015). Geophysical evaluation of erosion sites in some parts of Abia State, Southeastern Nigeria. *Physical Science International Journal,* 6(2), 66-81.

Kamtchueng, B. T., Onana, V. L., Fantong, W. Y., Ueda, A., Ntouala, R. F. D., Wongolo, M. H. D., Ndongo, G. B., Ngo'oZe, A., & Ondoa, J. M. (2015). Geotechnical, chemical and mineralogical evaluation of lateritic soils in humid tropical area (Mfou, Central-Cameroon): Implications for road construction. *International Journal of Geotechnical Engineering,* 6(1), 1-21.

Kinnaird, J. A. (198l). Geology of the Nigerian anorogenic ring complexes 1:500,000 *Geological Map*, John Bartholomew and Sons.

Lakew, D. & Belayneh, A. (2012). A field guide on gully prevention and control. E. N. W. M. Project, Addis Ababa, 5-19.

Morgan, R. (1986). *Soil erosion and conservation*. Co published in the United States with John Wiley and Sons, New York, 286–291.

NIMET (2015). *Nigeria climate review bulletin*. A yearly publication of the Nigerian Metrological Agency.

Nyles, C., Brady, R. & Weil, R. (1999). The nature and properties of soils Upper Saddle River (12^{th} ed.). Prentice Hall, New Jersey, 1-745.

O'Flaherty, C. A. (1988). *Highway engineering.* London, UK: Edward Arnold Publishers.

Oades, J. M. & Waters, A. G. (1991). Aggregates hierarchy in soils, *Australian Journal of Soil Research,* 29, 815-828.

Obaje, N.G. (2009). *Geology and mineral resources of Nigeria*. Springer Publisher

Obiefuna, G. I., Nur, A. Baba, A. U., & Bassey, N. E. (1999). Geological and geotechnical assessment of selected gully sites, Yola area, Northeast Nigeria. *Journal of Environmental Hydrology,* 7(6), 13-20.

Odong, J. (2007). Evaluation of the empirical formulae for determination of hydraulic conductivity based on grain size analysis: *American Science,* 3, 54-60.

Ofomata, G. E. K. (1981). Impact of road building, urbanisation and general infrastructural development on the Nigerian rainforest ecosystem. *Landscape Planning*, 8(1), 21-29.

Ofomata, G. E. K. (1988). The management of soil erosion problems in southeastern Nigeria. *Proceeding International Symposium* on erosion in South Eastern Nigeria, 3-12.

Okagbue, C. O. & Ezechi, S. E. (I988). Geotechnical characteristics of soils susceptible to severe gullying in Eastern Nigeria. *International Association of Engineering Geologist,* 38, 111-419.

Okengwo, O. N., Okeke, O. C., Okereke, C. N. & Paschal, A. C. (2015). Geological and geotechnical studies of gully erosion at Ekwulobia, Oko and Nanka towns, Southeastern Nigeria. *Environmental Journal of Geosciences and Engineering,* 20(1), 113-122.

Okoro, E. I., Akpan, A. E. Egboka, B. C. E. & Odoh, B. I. (2011). Dimensional analysis and characterisation of the gully systems in parts of southeastern Nigeria. Water: ecological disasters and sustainable development, B. C. E. Egboka and B. I. Odoh,(Eds.), *Lambert Academic*, (pp. 237–246).

Okunlola, I. A. Abdulfatai, K. L. & Amadi, A. N. (2014). Geological and geotechnical investigation of gully erosion along River Bosso, Minna, North Central Nigeria, *Journal of Geosciences and Geomatics,* 2(2), 50-56.

Omanayin, Y. A. (2016). Investigation of some factors responsible for gully erosion activities along river Yashi, Minna, North-Central Nigeria. *Environmental Technology & Science Journal (ETSJ),* 7, 88 - 98.

Onwuemesi, A. G. & Egboka, B. C. E. (1991). Implication of hydrogeophysical investigations of the Agulu-Nankagullies area of Anambra State of Nigeria. *Journal of African Earth Science,* 13, 519.

Onwuemesi, A. G. (1990). Hydrogeophysical and geotechnical investigation of the Ajali Sandstone in Nsukka and environs with reference to groundwater resources and gully erosion problems. *Nigerian Association of Hydrogeologist,* 2(1), 25-32.

Osman, K. T. (2013). *Soils: principles, properties and management*. New York, London, Springer Dordrecht Heidelberg.

Oyawoye, M. O. (1972). The basement complex of Nigeria. In: Dessauvagie TFJ, Whiteman AJ (eds.), *African geology*, Ibadan University Press, 66–102.

Pathak, L., Wani, B., & Sudi, H. (2005). Gully control in SAT watersheds, global theme on *agroecosystems report*, 15, 28.

Pettijohn, F. J. (1975). *Sedimentary rocks* (3rded.). New York: Harper and Row.

Poesen, J., Nachtergaele, J., Verstraeten, G. & Valentin, C. (2003). Gully erosion and environmental change: importance and research needs. *Catena*, 50(2-4), 91-133.

Poessen, J., Vandele, K. & Van, W. (1998). Gully erosion Importance and Model implication. In: Boardman, J; Faris-Mortlock, D.T. (Eds.), *Modelling Soil Erosion by Water*, Springer-Verlag, Berlin NATO-AST series, 1-55, 285-311.

Rahaman, M. A. & Ocan, O. (1978). On relationships in the Precambrian migmatite-gneisses of Nigeria. *Nigerian Journal of Mining Geology,* 15, 23–32.

Rahaman, M. A., Van Breeman, O., Bowden, P., & Bennett, J. N. (1984). Age migration of anorogenic ring complexes in Northern Nigeria. *Journal of Geology,* 92, 173–184.

Tebebu, T. Y., Abiy, A. Z., Zegeye, A. D., Dahike, H. E., Easton, Z. M., Tiluhan, S. A., collick, A. S., kidnau, S., Mosges, S., Dadgari, F. & Steenhuis, T. S. (2010). Surface and subsurface flow effect on permanent gully formation and upland erosion near lake Yana in the Northern highlands of Ethiopia. *Hydrology and Earth system sciences,* 14(11). 2207-2217.

Thanappan, S., Vincent, P. & Nalanth, N. (2016). Geotechnical assessment of soil in erosion prone zone. *International Journal of Civil Engineering and Technology (IJCIET),* 7*(6),* 227–240.

Thomas, D. B. (1997). *Soil and water conservation*. Manual for Kenya.

Thomas, J. T., Iverson, N. R, Burkert, M. R. & Kramer, L. A. (2004). Long term growth of a valley-both gully, Western Iowa. *Earth Surface Process and Land Forms,* 29, 995-1009.

Tisdall, J. M. & Oades, J. M. (1982). Organic matter and water-stable aggregates in soils. *Journal of Soil Science,* 33, 141-163.

Truswell, J. F. & Cope, R. N. (1963). The geology of parts of Niger and Zaria Provinces, Northern Nigeria. *Geological Survey Nigeria,* 29, 1-104.

Turner, D. C. (1983). Structure and petrography of the younger granites complexes of Nigeria. *Rock View International*, 143-158.

Umoro, C. I., Shuaibu, A. M., Abdullahi, I. N. & Umar, M. U. (2015). Geotechnical assessment of gully erosion in Ankpa area, North Central Nigeria. *Journal of Applied Chemistry, 8,* 36-48.

Valdon, Y. B., Gabriel, I. O. & Emmanuel, A. (2010). Hydrogeological and geotechnical assessment of selected gully sites in Gombe area, Northeastern Nigeria. *Journal of Applied Sciences,* 5, 8-14.

Wall, W., Bergonse, R. V., & Reis, E. J. (2003). Theoretical constraints to gully erosion research: time for a re-evaluation of concepts and assumptions. *Earth Surface Processes and Landforms*, 36(11), 1554-1557.

Whitten, D. G. A. & Brooks, J. R. V. (1972). *The Penguin Dictionary of Geology*. Penguin Books Limited, Harmondsworth, 75-76.

Wright, J. B. (1985). *Geology and mineral resources of West Africa*. George Allen & Unwin, London, 45-80.

Zaman, W., Asik, T. Z., Rumi, Y. M., & Shahin, H. M. (2016). Geotechnical hazard analysis ofriver embankment of Bangladesh and Its protectability. *Journal of Geotechnical Engineering*, 5(3), 6-7.

APPENDIX A

Specific Gravity Test Results

Nigerian Building and Road Research Institute, Kano Zonal Office

TEST BY	Aliyu Hassan		
Project	MTech, 2019		
Sample No	1T	27/09/2019	
Depth (m)	0 - 0.5		
		1	2
Mass of conical flask (g		381	381
Mass of conical flask + dry soil (g)		464.6	441.1
Mass of conical flask + dry soil + water (g)		948.6	936.7
Mass of conical flask + water (g)		900	900
Specific gravity (GS)		2.39	2.57
Average Specific gravity (GS)		2.48	

TEST BY	Aliyu Hassan		
Project	MTech, 2019		
Sample No	1M	27/09/2019	
Depth (m)	0.5-1		
		1	2
Mass of conical flask (g		381	381
Mass of conical flask + dry soil (g)		492.4	497.5
Mass of conical flask + dry soil + water (g)		968.9	971.3
Mass of conical flask + water (g)		900.8	900.8
Specific gravity (GS)		2.57	2.53
Average Specific gravity (GS)		2.55	

TEST BY	Aliyu Hassan		
Project	MTech, 2019		
Sample No	1B	27/09/2019	
Depth (m)	1-1.5		
		1	2
Mass of conical flask (g		381	381
Mass of conical flask + dry soil (g)		554.5	529.2
Mass of conical flask + dry soil + water (g)		1008.2	990.4
Mass of conical flask + water (g)		900.8	900.8
Specific gravity (GS)		2.62	2.53
Average Specific gravity (GS)		2.58	

TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	2T	27/09/2019
Depth (m)	0 - 0.5	

	1	2
Mass of conical flask (g	381	381
Mass of conical flask + dry soil (g)	519.7	550.3
Mass of conical flask + dry soil + water (g)	984.7	999.5
Mass of conical flask + water (g)	900.8	900.8
Specific gravity (GS)	2.53	2.4
Average Specific gravity (GS)	2.47	

TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	2M	27/09/2019
Depth (m)	0.5-1	

	1	2
Mass of conical flask (g	381	381
Mass of conical flask + dry soil (g)	553.4	588.3
Mass of conical flask + dry soil + water (g)	1006.7	1028
Mass of conical flask + water (g)	900.8	900.8
Specific gravity (GS)	2.59	2.59
Average Specific gravity (GS)	2.59	

TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	1B	27/09/2019
Depth (m)	1-1.5	

	1	2
Mass of conical flask (g	381	381
Mass of conical flask + dry soil (g)	580.6	518
Mass of conical flask + dry soil + water (g)	1019.3	983.4
Mass of conical flask + water (g)	900.8	900.8
Specific gravity (GS)	2.46	2.52
Average Specific gravity (GS)	2.49	

TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	3T	27/09/2019
Depth (m)	0 - 0.5	

	1	2
Mass of conical flask (g	381	381
Mass of conical flask + dry soil (g)	572.9	557.8
Mass of conical flask + dry soil + water (g)	1012.7	1005.4
Mass of conical flask + water (g)	900.8	900.8
Specific gravity (GS)	2.4	2.45
Average Specific gravity (GS)	2.43	

TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	1M	27/09/2019
Depth (m)	0.5-1	

	1	2
Mass of conical flask (g	381	381
Mass of conical flask + dry soil (g)	539.7	516.6
Mass of conical flask + dry soil + water (g)	991.9	981.5
Mass of conical flask + water (g)	900.8	900.8
Specific gravity (GS)	2.35	2.47
Average Specific gravity (GS)	2.41	

TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	3B	27/09/2019
Depth (m)	1-1.5	

	1	2
Mass of conical flask (g	381	381
Mass of conical flask + dry soil (g)	672.6	561
Mass of conical flask + dry soil + water (g)	1070.5	1010.5
Mass of conical flask + water (g)	900.8	900.8
Specific gravity (GS)	2.39	2.56
Average Specific gravity (GS)	2.48	

TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	4T	27/09/2019
Depth (m)	0 - 0.5	

	1	2
Mass of conical flask (g	381	381
Mass of conical flask + dry soil (g)	502.5	479
Mass of conical flask + dry soil + water (g)	970.2	956.9
Mass of conical flask + water (g)	900.8	900.8
Specific gravity (GS)	2.33	2.34
Average Specific gravity (GS)	2.34	

TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	4M	27/09/2019
Depth (m)	0.5-1	

	1	2
Mass of conical flask (g	381	381
Mass of conical flask + dry soil (g)	564.1	510.5
Mass of conical flask + dry soil + water (g)	1013.6	979.3
Mass of conical flask + water (g)	900.8	900.8
Specific gravity (GS)	2.6	2.54
Average Specific gravity (GS)	2.57	

TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	4B	27/09/2019
Depth (m)	1-1.5	

	1	2
Mass of conical flask (g	381	381
Mass of conical flask + dry soil (g)	507.7	507.5
Mass of conical flask + dry soil + water (g)	977.3	978.8
Mass of conical flask + water (g)	900.8	900.8
Specific gravity (GS)	2.52	2.61
Average Specific gravity (GS)	2.57	

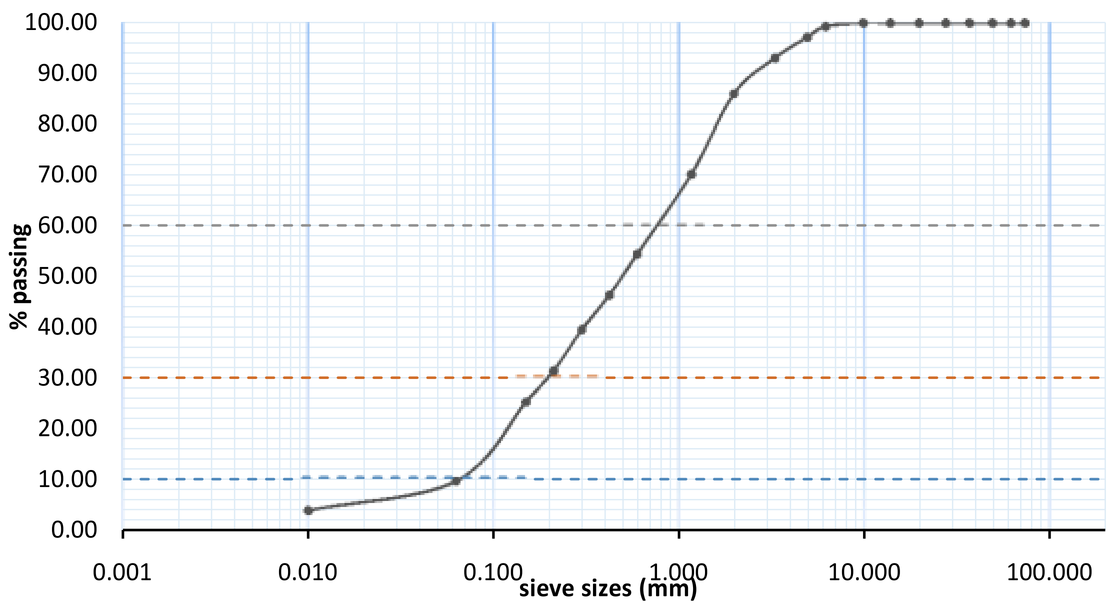
APPENDIX B

Sieve Analysis Test Results

Nigerian Building and Road Research Institute, Kano Zonal Office

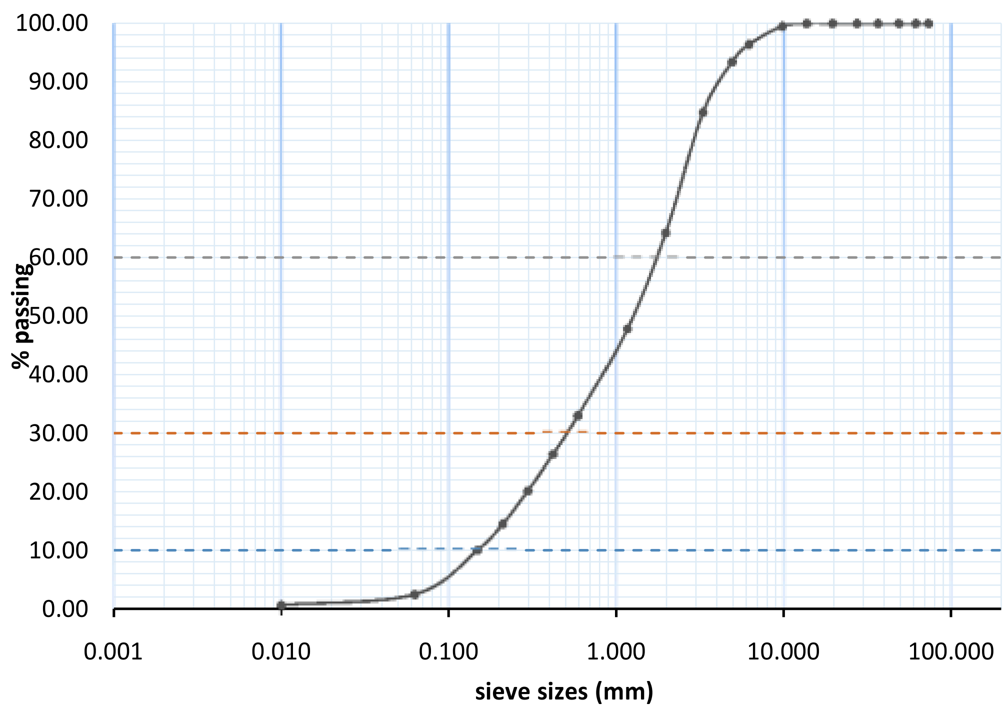
TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	1T	27/09/2019
Depth (m)	0 - 0.5	
		Weight 500g

Particle Description		Diameter (mm)	Weight (g)	Retained %	Cumulative Retained %	Passing %
Cobbles		75.000	0.0	0.00	0.00	100.00
		63.000	0.0	0.00	0.00	100.00
Gravel		50.000	0.0	0.00	100.00	100.00
		37.500	0.0	0.00	100.00	100.00
		28.000	0.0	0.00	100.00	100.00
	Coarse	20.00	0	0.00	100.00	100.00
		14.000	0	0.00	100.00	100.00
		10.000	0	0.00	100.00	100.00
	Medium	6.300	3.4	0.68	0.68	100.00
		5.000	10.7	2.14	2.82	100.00
		3.350	20.5	4.10	6.92	93.08
	Fine	2.000	35.8	7.16	14.08	85.92
Sand		1.180	78.9	15.78	29.86	70.14
	Coarse	0.600	79.3	15.86	45.72	54.28
		0.425	40.5	8.10	53.82	46.18
		0.300	34.6	6.92	60.74	39.26
	Medium	0.212	40.5	8.10	68.84	31.16
		0.150	30.7	6.14	74.98	25.02
	Fine	0.063	78.3	15.66	90.64	9.36
Silt/Clay		Pass 63 microns	29.2	5.84	96.48	3.52
			482.4	96.48		



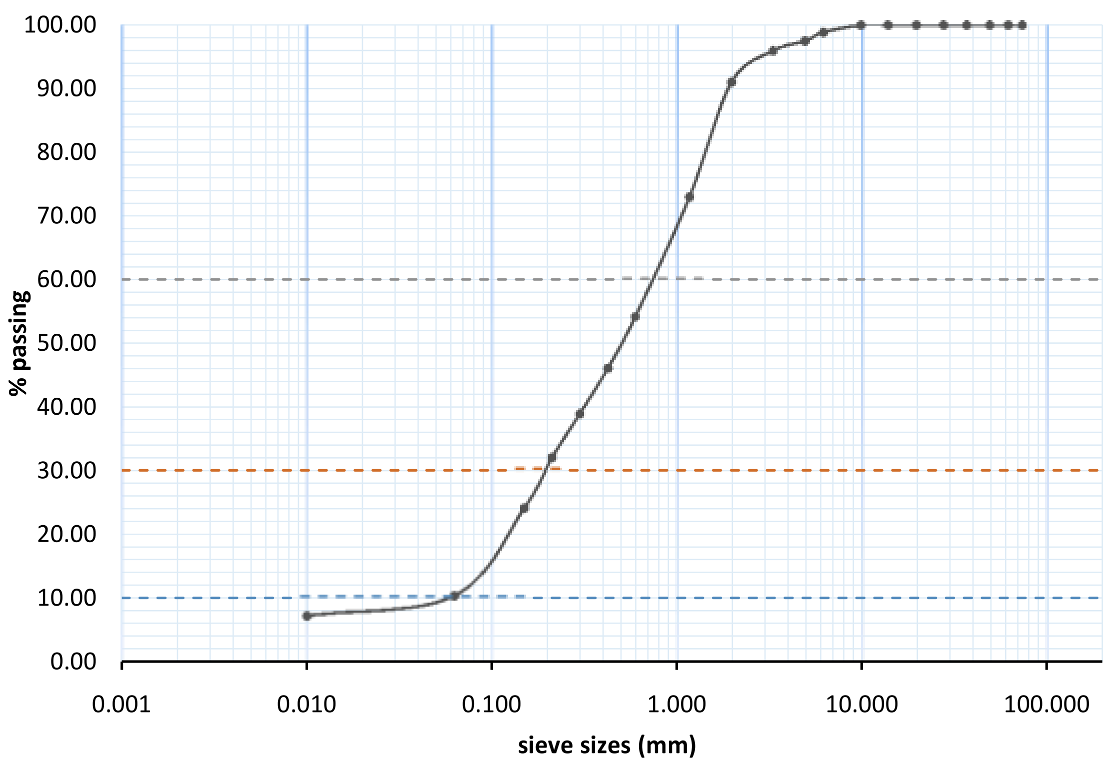
TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	1M	27/09/2019
Depth (m)	0.5-1	
		Weight 500g

Particle Description		Diameter (mm)	Weight (g)	Retained %	Cumulative Retained %	Passing %
Cobbles		75.000	0.0	0.00	0.00	100.00
		63.000	0.0	0.00	0.00	100.00
Gravel		50.000	0.0	0.00	0.00	100.00
		37.500	0.0	0.00	0.00	100.00
		28.000	0.0	0.00	0.00	100.00
	Coarse	20.00	0	0.00	0.00	100.00
		14.000	0	0.00	0.00	100.00
		10.000	2.5	0.50	0.50	99.50
	Medium	6.300	15.5	3.10	3.60	96.40
		5.000	15.2	3.04	6.64	93.36
		3.350	43	8.60	15.24	84.76
	Fine	2.000	103	20.60	35.84	64.16
Sand		1.180	82.7	16.54	52.38	47.62
	Coarse	0.600	74.2	14.84	67.22	32.78
		0.425	33.2	6.64	73.86	26.14
		0.300	30.9	6.18	80.04	19.96
	Medium	0.212	28.5	5.70	85.74	14.26
		0.150	22.4	4.48	90.22	9.78
	Fine	0.063	38	7.60	97.82	2.18
Silt/Clay		Pass 63 microns	9.2	1.84	99.66	0.34
			498.3	99.66		



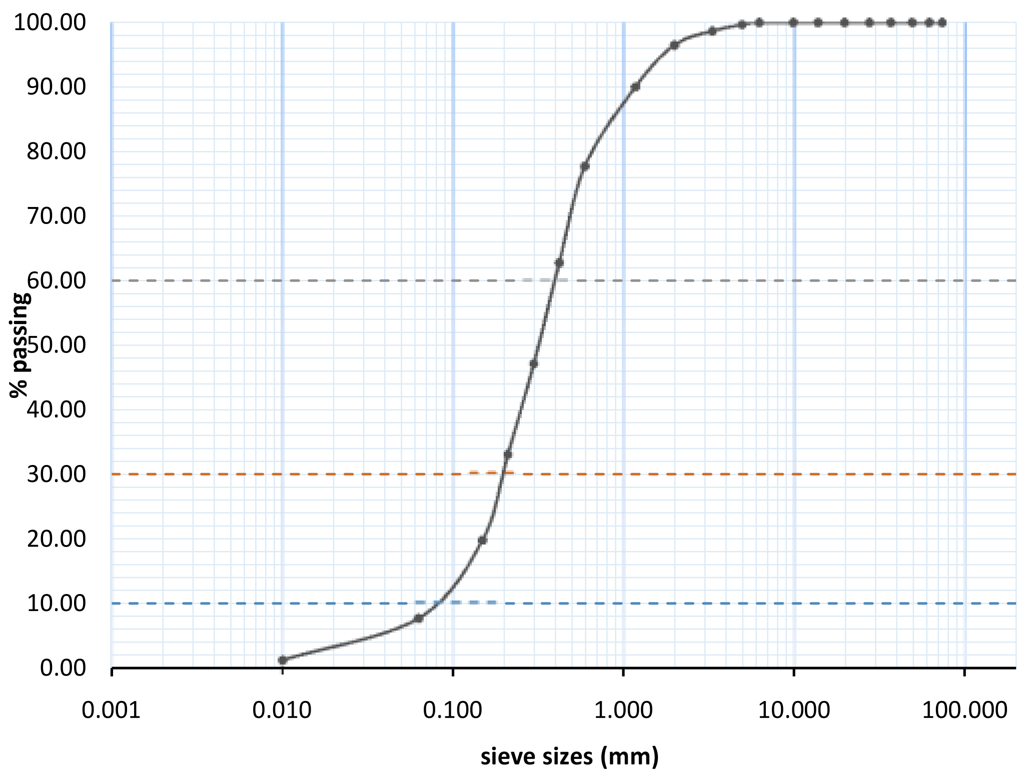
TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	1B	27/09/2019
Depth (m)	1.5-1	
		Weight 500g

Particle Description		Diameter (mm)	Weight (g)	Retained %	Cumulative Retained %	Passing %
Cobbles		75.000	0.0	0.00	0.00	100.00
		63.000	0.0	0.00	0.00	100.00
Gravel		50.000	0.0	0.00	0.00	100.00
		37.500	0.0	0.00	0.00	100.00
		28.000	0.0	0.00	0.00	100.00
	Coarse	20.00	0	0.00	0.00	100.00
		14.000	0	0.00	0.00	100.00
		10.000	0	0.00	0.00	100.00
	Medium	6.300	5.7	1.14	1.14	98.86
		5.000	6.9	1.38	2.52	97.48
		3.350	7.8	1.56	4.08	95.92
	Fine	2.000	24.7	4.94	9.02	90.98
Sand		1.180	90.4	18.08	27.10	72.90
	Coarse	0.600	94.5	18.90	46.00	54.00
		0.425	40.9	8.18	54.18	45.82
		0.300	35.9	7.18	61.36	38.64
	Medium	0.212	34.4	6.88	68.24	31.76
		0.150	39	7.80	76.04	23.96
	Fine	0.063	69.5	13.90	89.94	10.06
Silt/Clay		Pass 63 microns	15.8	3.16	93.10	6.90
			465.5	93.10		



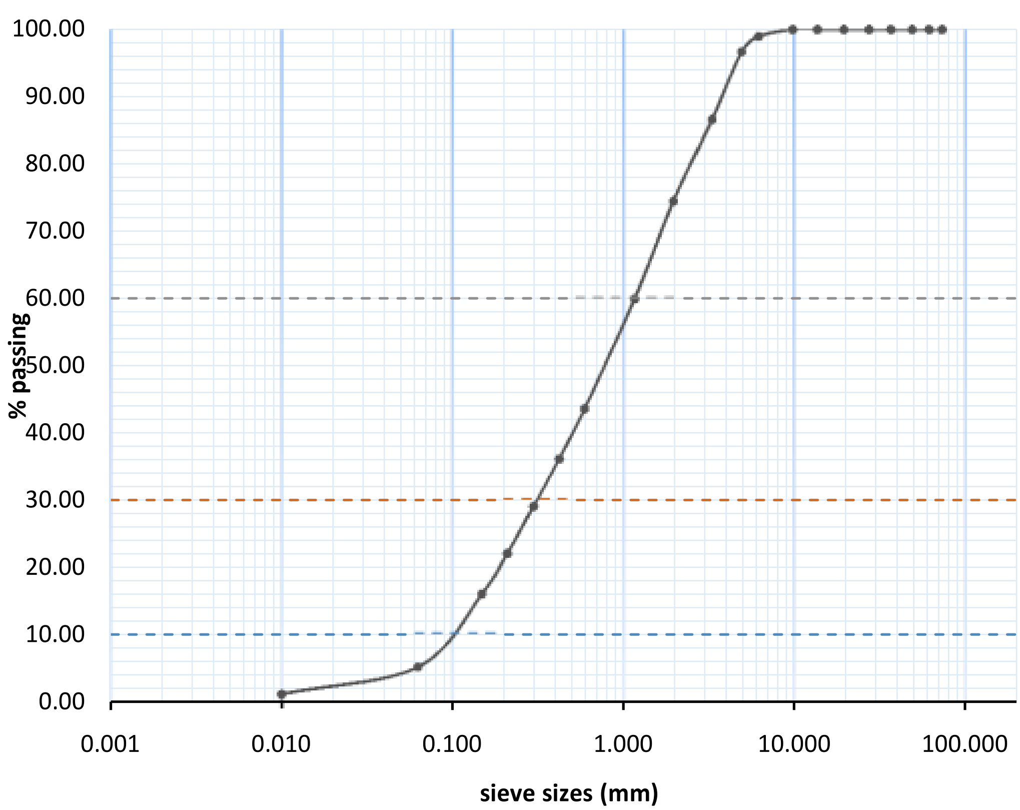
TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	2T	27/09/2019
Depth (m)	0 - 0.5	
		Weight 500g

Particle Description		Diameter (mm)	Weight (g)	Retained %	Cumulative Retained %	Passing %
Cobbles		75.000	0.0	0.00	0.00	100.00
		63.000	0.0	0.00	0.00	100.00
Gravel		50.000	0.0	0.00	0.00	100.00
		37.500	0.0	0.00	0.00	100.00
		28.000	0.0	0.00	0.00	100.00
	Coarse	20.00	0	0.00	0.00	100.00
		14.000	0	0.00	0.00	100.00
		10.000	0	0.00	0.00	100.00
	Medium	6.300	0	0.00	0.00	100.00
		5.000	1.6	0.32	0.32	99.68
		3.350	5.1	1.02	1.34	98.66
	Fine	2.000	10.9	2.18	3.52	96.48
Sand		1.180	32.4	6.48	10.00	90.00
	Coarse	0.600	61.8	12.36	22.36	77.64
		0.425	74.5	14.90	37.26	62.74
		0.300	78.7	15.74	53.00	47.00
	Medium	0.212	70.4	14.08	67.08	32.92
		0.150	66.4	13.28	80.36	19.64
	Fine	0.063	60.6	12.12	92.48	7.52
Silt/Clay		Pass 63 microns	32.6	6.52	99.00	1.00
			495	99.00		



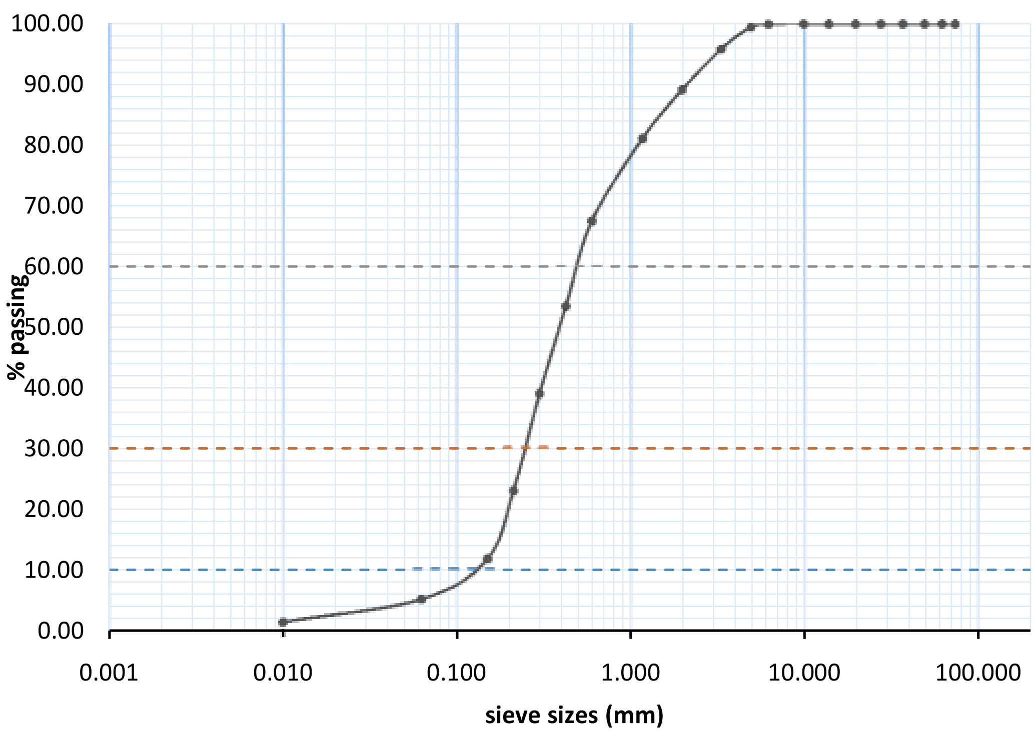
TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	2M	27/09/2019
Depth (m)	0.5-1	
		Weight 500g

Particle Description		**Diameter (mm)**	**Weight (g)**	**Retained %**	**Cumulative Retained %**	**Passing %**
Cobbles		75.000	0.0	0.00	0.00	100.00
		63.000	0.0	0.00	0.00	100.00
Gravel	**Coarse**	50.000	0.0	0.00	0.00	100.00
		37.500	0.0	0.00	0.00	100.00
		28.000	0.0	0.00	0.00	100.00
		20.00	0	0.00	0.00	100.00
	Medium	14.000	0	0.00	0.00	100.00
		10.000	0	0.00	0.00	100.00
		6.300	5.4	1.08	1.08	98.92
	Fine	5.000	11.3	2.26	3.34	96.66
		3.350	50.5	10.10	13.44	86.56
		2.000	60.7	12.14	25.58	74.42
Sand	**Coarse**	1.180	73.1	14.62	40.20	59.80
		0.600	81.6	16.32	56.52	43.48
	Medium	0.425	37.6	7.52	64.04	35.96
		0.300	35.3	7.06	71.10	28.90
		0.212	35.2	7.04	78.14	21.86
	Fine	0.150	30.2	6.04	84.18	15.82
		0.063	54.3	10.86	95.04	4.96
Silt/Clay		Pass 63 microns	20.4	4.08	99.12	0.88
			495.6	99.12		



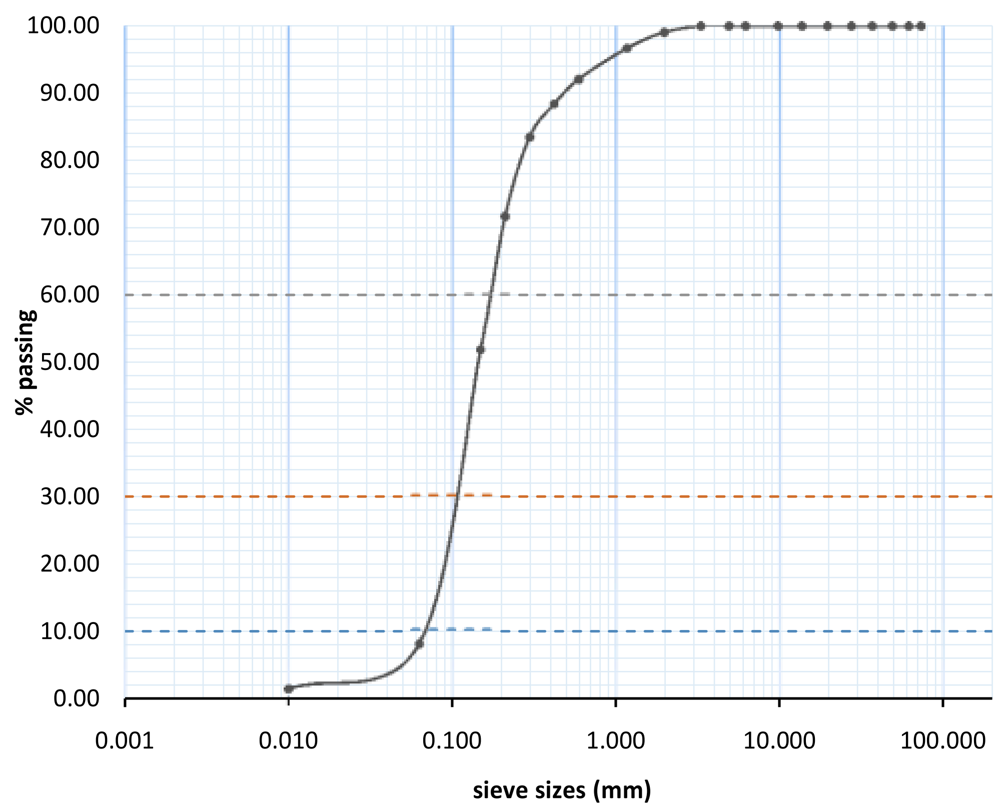
TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	2B	27/09/2019
Depth (m)	1-1.5	
		Weight 500g

Particle Description		**Diameter (mm)**	**Weight (g)**	**Retained %**	**Cumulative Retained %**	**Passing %**
Cobbles		75.000	0.0	0.00	0.00	100.00
		63.000	0.0	0.00	0.00	100.00
Gravel		50.000	0.0	0.00	0.00	100.00
		37.500	0.0	0.00	0.00	100.00
		28.000	0.0	0.00	0.00	100.00
	Coarse	20.00	0	0.00	0.00	100.00
		14.000	0	0.00	0.00	100.00
		10.000	0	0.00	0.00	100.00
	Medium	6.300	0.4	0.08	0.08	99.92
		5.000	2.4	0.48	0.56	99.44
		3.350	18.2	3.64	4.20	95.80
	Fine	2.000	33.4	6.68	10.88	89.12
Sand		1.180	40.3	8.06	18.94	81.06
	Coarse	0.600	68.1	13.62	32.56	67.44
		0.425	70.4	14.08	46.64	53.36
		0.300	71.8	14.36	61.00	39.00
	Medium	0.212	80.5	16.10	77.10	22.90
		0.150	56.3	11.26	88.36	11.64
	Fine	0.063	33.5	6.70	95.06	4.94
Silt/Clay		Pass 63 microns	18.9	3.78	98.84	1.16
			494.2	98.84		



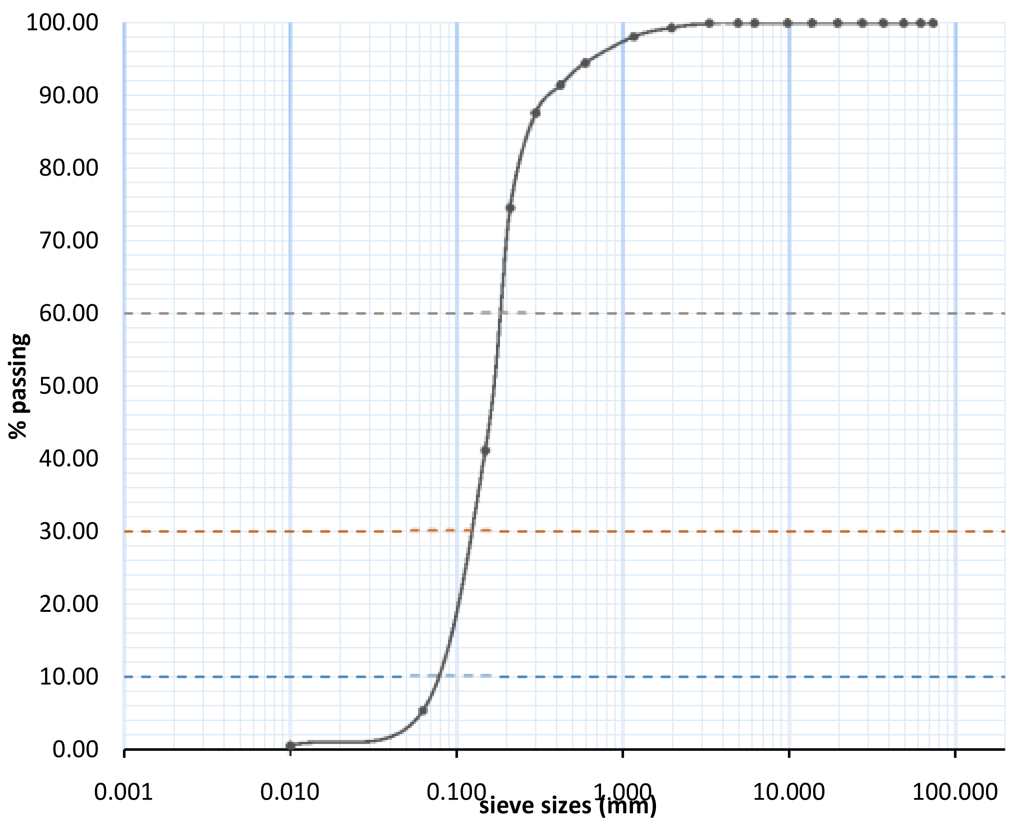
TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	3T	27/09/2019
Depth (m)	0 - 0.5	
		Weight 500g

Particle Description		**Diameter (mm)**	**Weight (g)**	**Retained %**	**Cumulative Retained %**	**Passing %**
Cobbles		75.000	0.0	0.00	0.00	0.00
		63.000	0.0	0.00	0.00	0.00
Gravel		50.000	0.0	0.00	0.00	100.00
		37.500	0.0	0.00	0.00	100.00
		28.000	0.0	0.00	0.00	100.00
	Coarse	20.00	0	0.00	0.00	100.00
		14.000	0	0.00	0.00	100.00
		10.000	0	0.00	0.00	100.00
	Medium	6.300	0	0.00	0.00	100.00
		5.000	0	0.00	0.00	100.00
		3.350	0	0.00	0.00	100.00
	Fine	2.000	4.9	0.98	0.98	99.02
Sand		1.180	11.9	2.38	3.36	96.64
	Coarse	0.600	23.2	4.64	8.00	92.00
		0.425	18.2	3.64	11.64	88.36
		0.300	24.6	4.92	16.56	83.44
	Medium	0.212	59.2	11.84	28.40	71.60
		0.150	99.4	19.88	48.28	51.72
	Fine	0.063	218.9	43.78	92.06	7.94
Silt/Clay		Pass 63 microns	29.2	5.84	97.90	2.10
			489.5	97.90		



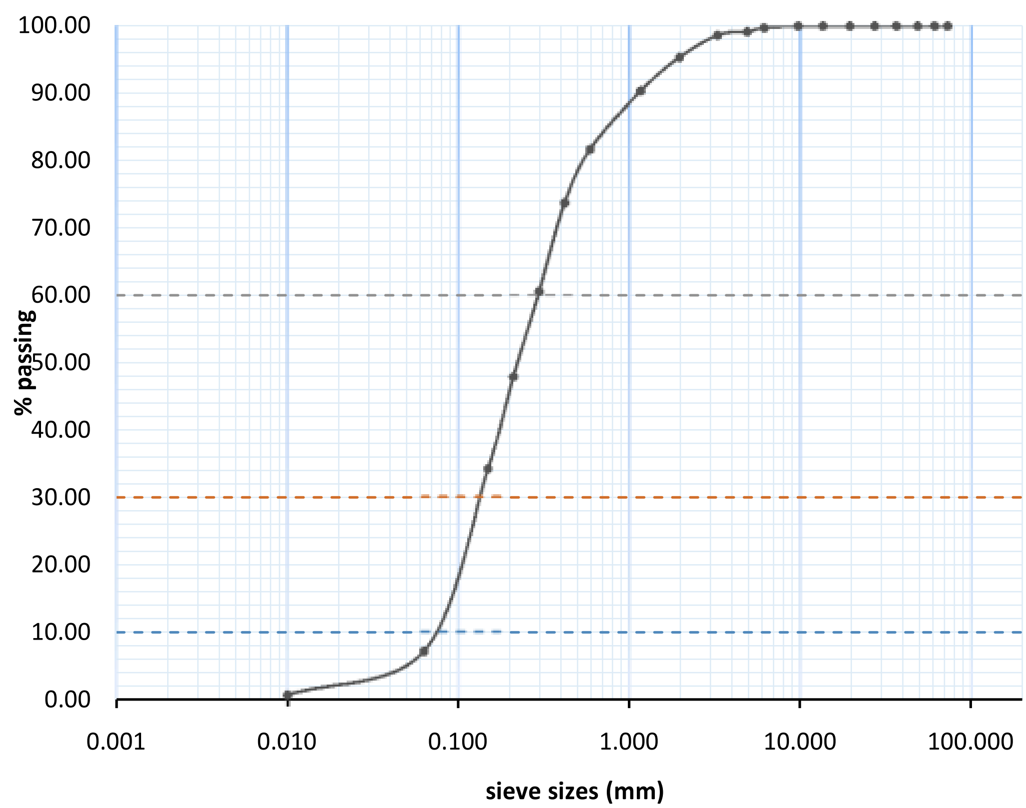
TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	3M	27/09/2019
Depth (m)	0.5-1	
		Weight 500g

Particle Description		Diameter (mm)	Weight (g)	Retained %	Cumulative Retained %	Passing %
Cobbles		75.000	0.0	0.00	0.00	100.00
		63.000	0.0	0.00	0.00	100.00
Gravel		50.000	0.0	0.00	0.00	100.00
		37.500	0.0	0.00	0.00	100.00
		28.000	0.0	0.00	0.00	100.00
	Coarse	20.00	0	0.00	0.00	100.00
		14.000	0	0.00	0.00	100.00
		10.000	0	0.00	0.00	100.00
	Medium	6.300	0	0.00	0.00	100.00
		5.000	0	0.00	0.00	100.00
		3.350	0.2	0.04	0.04	99.96
	Fine	2.000	3.2	0.64	0.68	99.32
Sand		1.180	6	1.20	1.88	98.12
	Coarse	0.600	18.1	3.62	5.50	94.50
		0.425	15.2	3.04	8.54	91.46
		0.300	19.4	3.88	12.42	87.58
	Medium	0.212	65.2	13.04	25.46	74.54
		0.150	167.3	33.46	58.92	41.08
	Fine	0.063	179.5	35.90	94.82	5.18
Silt/Clay		Pass 63 microns	24.2	4.84	99.66	0.34
			498.3	99.66		



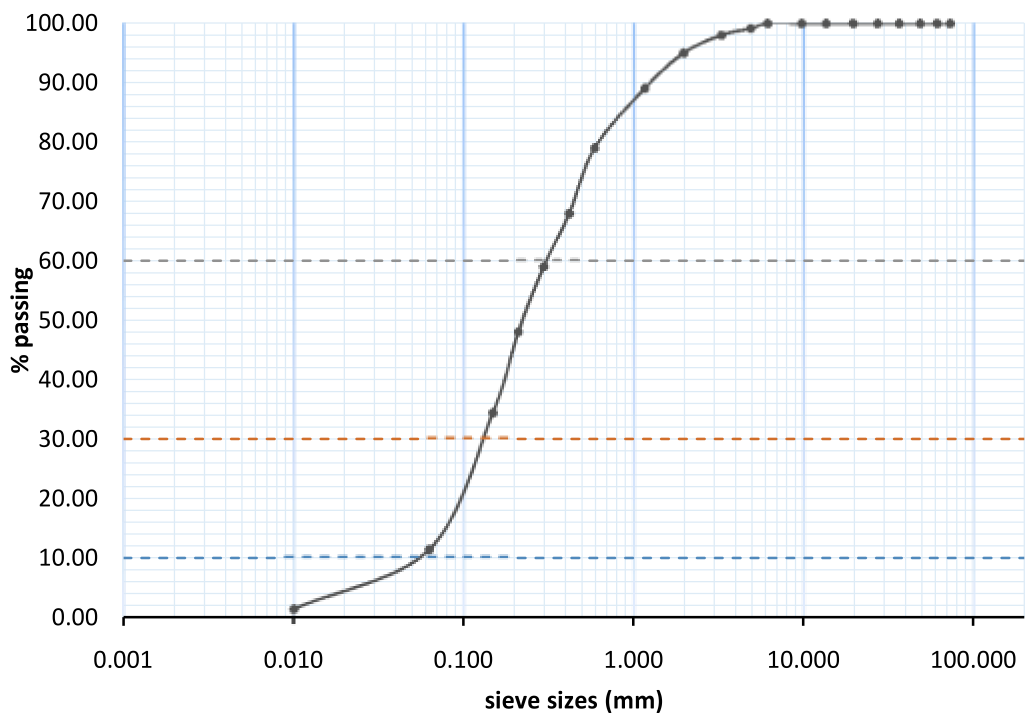
TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	3B	27/09/2019
Depth (m)	1-1.5	
		Weight 500g

Particle Description		Diameter (mm)	Weight (g)	Retained %	Cumulative Retained %	Passing %
Cobbles		75.000	0.0	0.0	0.00	100.00
		63.000	0.0	0.0	0.00	100.00
Gravel		50.000	0.0	0.00	0.00	100.00
		37.500	0.0	0.00	0.00	100.00
		28.000	0.0	0.00	0.00	100.00
	Coarse	20.00	0	0.00	0.00	100.00
		14.000	0	0.00	0.00	100.00
		10.000	0	0.00	0.00	100.00
	Medium	6.300	1.5	0.30	0.30	99.70
		5.000	2.7	0.54	0.84	99.16
		3.350	2.7	0.54	1.38	98.62
	Fine	2.000	16.7	3.34	4.72	95.28
Sand		1.180	24.8	4.96	9.68	90.32
	Coarse	0.600	43.3	8.66	18.34	81.66
		0.425	39.8	7.96	26.30	73.70
		0.300	65.7	13.14	39.44	60.56
	Medium	0.212	63.6	12.72	52.16	47.84
		0.150	68.4	13.68	65.84	34.16
	Fine	0.063	135.3	27.06	92.90	7.10
Silt/Clay		Pass 63 microns	32.8	6.56	99.46	0.54
			497.3	99.46		

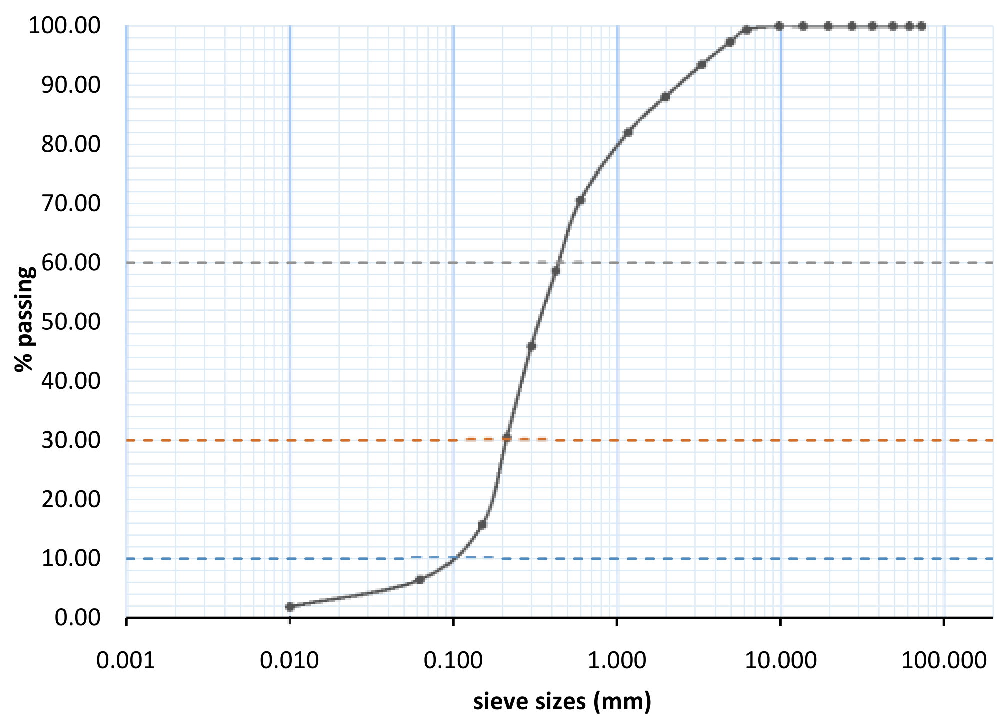


TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	4T	27/09/2019
Depth (m)	0 - 0.5	
		Weight 500g

Particle Description		**Diameter (mm)**	**Weight (g)**	**Retained %**	**Cumulative Retained %**	**Passing %**
Cobbles		75.000	0.0	0.0	0.0	100.00
		63.000	0.0	0.0	0.0	100.00
Gravel		50.000	0.0	0.00	0.00	100.00
		37.500	0.0	0.00	0.00	100.00
		28.000	0.0	0.00	0.00	100.00
	Coarse	20.00	0	0.00	0.00	100.00
		14.000	0	0.00	0.00	100.00
		10.000	0	0.00	0.00	100.00
	Medium	6.300	0	0.00	0.00	100.00
		5.000	4.3	0.86	0.86	99.14
		3.350	5.5	1.10	1.96	98.04
	Fine	2.000	15	3.00	4.96	95.04
Sand		1.180	30	6.00	10.96	89.04
	Coarse	0.600	50.2	10.04	21.00	79.00
		0.425	55.3	11.06	32.06	67.94
		0.300	45	9.00	41.06	58.94
	Medium	0.212	54.9	10.98	52.04	47.96
		0.150	68.3	13.66	65.70	34.30
	Fine	0.063	115.3	23.06	88.76	11.24
Silt/Clay		Pass 63 microns	50.5	10.10	98.86	1.14
			494.3	98.86		

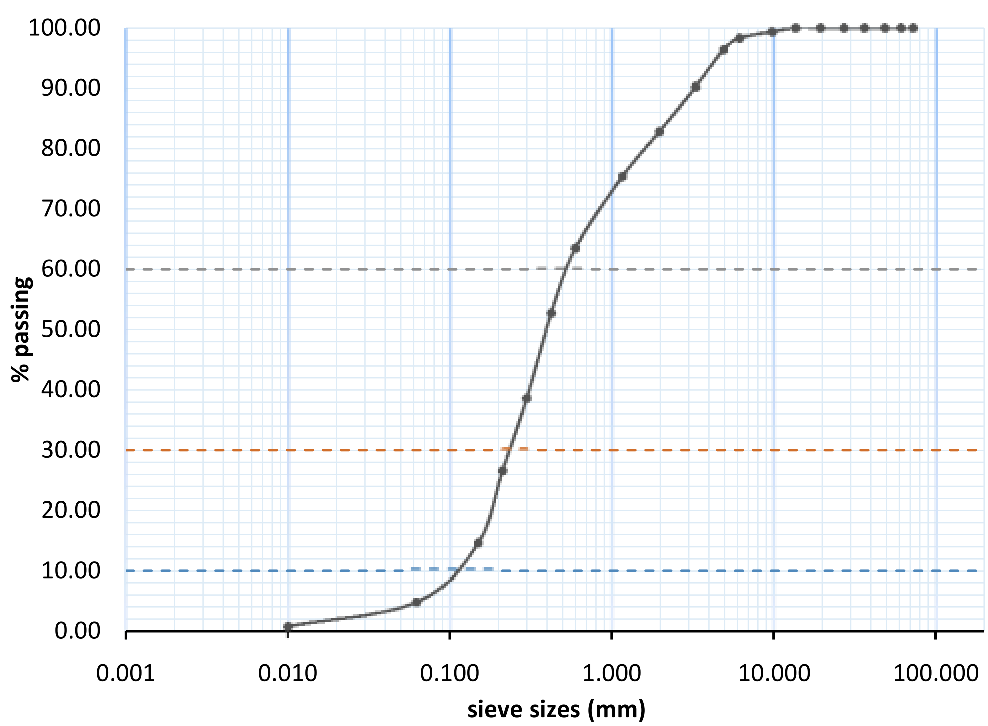


TEST BY	Aliyu Hassan					
Project	MTech, 2019					
Sample No	4M		27/09/2019			
Depth (m)	0.5-1					
			Weight 500g			
Particle Description		**Diameter (mm)**	**Weight (g)**	**Retained %**	**Cumulative Retained %**	**Passing %**
Cobbles		75.000	0.0	0.0	0.0	100.00
		63.000	0.0	0.0	0.0	100.00
Gravel		50.000	0.0	0.00	0.00	100.00
		37.500	0.0	0.00	0.00	100.00
		28.000	0.0	0.00	0.00	100.00
	Coarse	20.00	0	0.00	0.00	100.00
		14.000	0	0.00	0.00	100.00
		10.000	0	0.00	0.00	100.00
	Medium	6.300	3.2	0.64	0.64	99.36
		5.000	10.3	2.06	2.70	97.30
		3.350	19.2	3.84	6.54	93.46
	Fine	2.000	27.3	5.46	12.00	88.00
Sand		1.180	30.2	6.04	18.04	81.96
	Coarse	0.600	56.8	11.36	29.40	70.60
		0.425	60.1	12.02	41.42	58.58
		0.300	63.7	12.74	54.16	45.84
	Medium	0.212	77.5	15.50	69.66	30.34
		0.150	74	14.80	84.46	15.54
	Fine	0.063	46.7	9.34	93.80	6.20
Silt/Clay		Pass 63 microns	23.1	4.62	98.42	1.58
			492.1	98.42		



TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	4B	27/09/2019
Depth (m)	1-1.5	
		Weight 500g

Particle Description		**Diameter (mm)**	**Weight (g)**	**Retained %**	**Cumulative Retained %**	**Passing %**
Cobbles		75.000	0.0	0.0	0.0	100.00
		63.000	0.0	0.0	0.0	100.00
Gravel		50.000	0.0	0.00	0.00	100.00
		37.500	0.0	0.00	0.00	100.00
		28.000	0.0	0.00	0.00	100.00
	Coarse	20.00	0	0.00	0.00	100.00
		14.000	0	0.00	0.00	100.00
		10.000	3.2	0.64	0.64	99.36
	Medium	6.300	5.3	1.06	1.70	98.30
		5.000	9.6	1.92	3.62	96.38
		3.350	30.4	6.08	9.70	90.30
	Fine	2.000	37.2	7.44	17.14	82.86
Sand		1.180	37.4	7.48	24.62	75.38
	Coarse	0.600	60	12.00	36.62	63.38
		0.425	54.1	10.82	47.44	52.56
		0.300	70.4	14.08	61.52	38.48
	Medium	0.212	60.3	12.06	73.58	26.42
		0.150	60.4	12.08	85.66	14.34
	Fine	0.063	48.7	9.74	95.40	4.60
Silt/Clay		Pass 63 microns	20.3	4.06	99.46	0.54
			497.3	99.46		

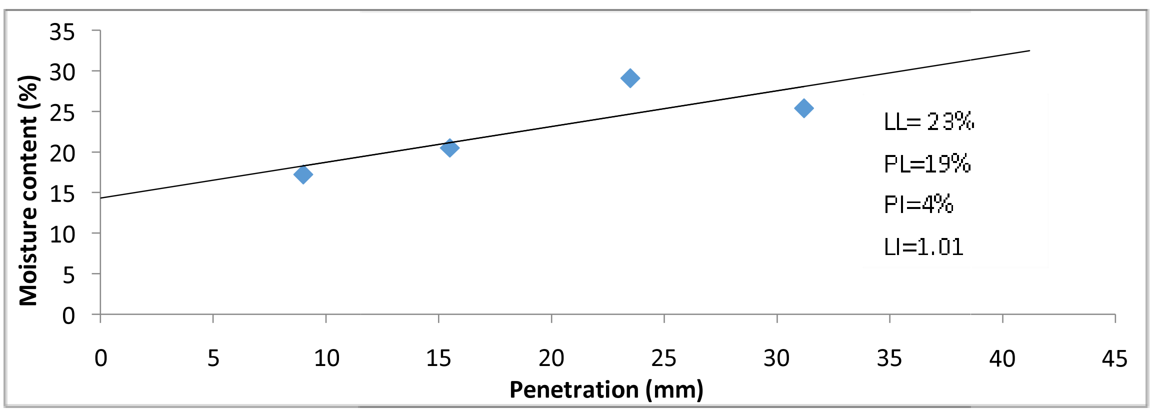


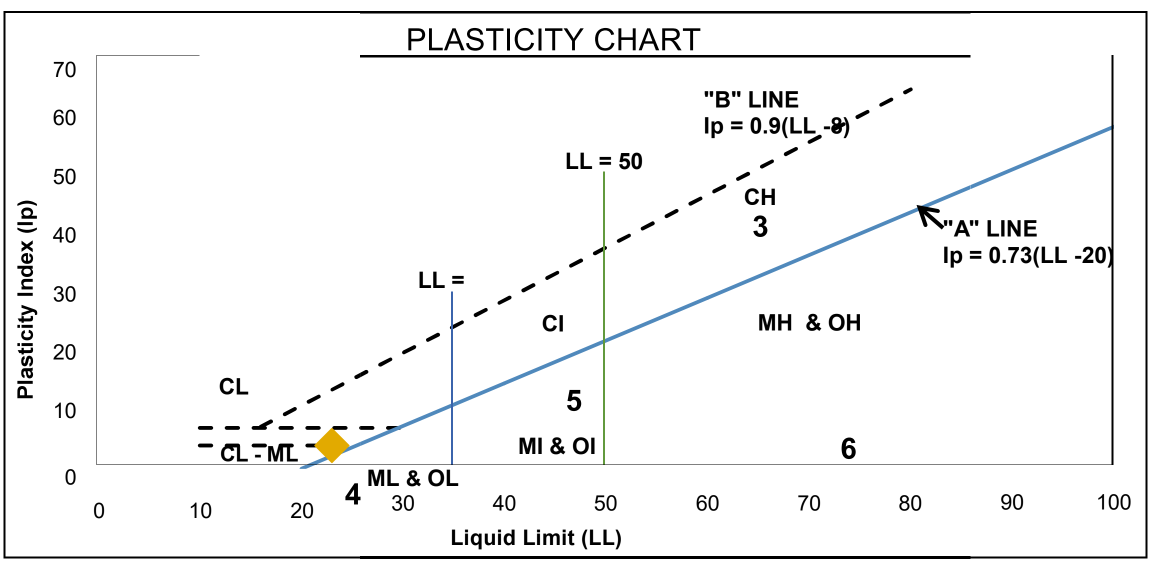
APPENDIX C

Compaction Test Results

TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	1T	27/09/2019
Depth (m)	0 - 0.5	

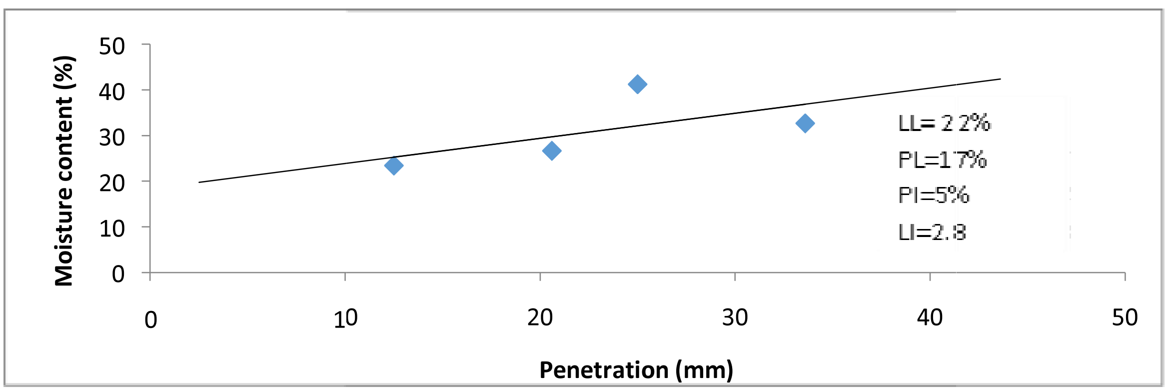
LIQUID LIMIT	**NATURAL M.C. (%)**					**PLASTIC LIMIT**	
Specimen number	1	2	3	4		1	2
Can number	810	91	k11	A39		201	93
Mass of empty can (g)	9.51	9.55	9.72	9.55		9.65	9.6
Mass of can & moist soil (g)	23.06	32.64	33.52	36.48		26.9	26.81
Mass of can & dry soil (g)	21.07	28.71	28.16	31.03		24.29	23.89
Mass of dry soil (g)	11.56	19.16	18.44	21.48		14.64	14.29
Moisture loss (g)	1.99	3.93	5.36	5.45		2.61	2.92
Water content, w%	17.21	20.51	29.07	25.37		17.83	20.43
Penetration (mm)	9	15.5	23.5	31.2			

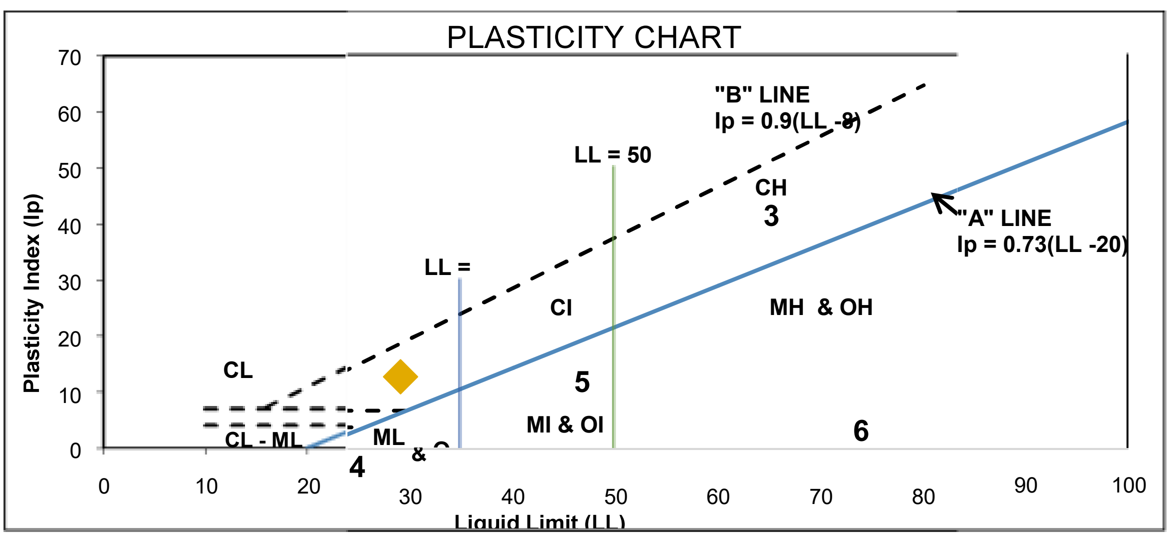




TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	1M	27/09/2019
Depth (m)	0.5-1	

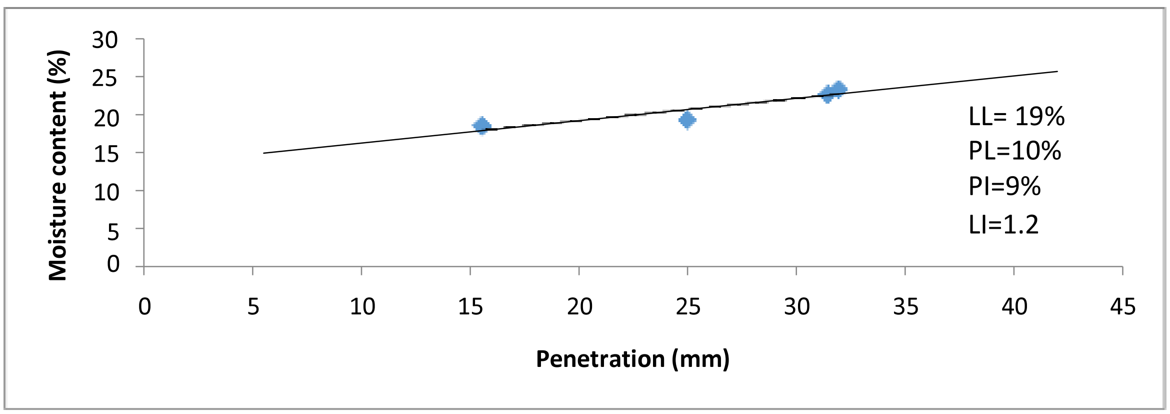
LIQUID LIMIT	**NATURAL M.C. (%)**					**PLASTIC LIMIT**	
Specimen number	1	2	3	4		1	2
Can number	M33	94	13	2		204	O38
Mass of empty can (g)	9.56	9.48	9.69	9.52		9.61	9.63
Mass of can & moist soil (g)	26.68	28.77	31.61	33.65		27	29.8
Mass of can & dry soil (g)	23.43	24.71	25.21	27.71		23.89	27.9
Mass of dry soil (g)	13.87	15.23	15.52	18.19		14.28	18.27
Moisture loss (g)	3.25	4.06	6.4	5.94		3.11	1.9
Water content, w%	23.43	26.66	41.24	32.66		21.78	10.4
Penetration (mm)	12.5	20.6	25	33.6			

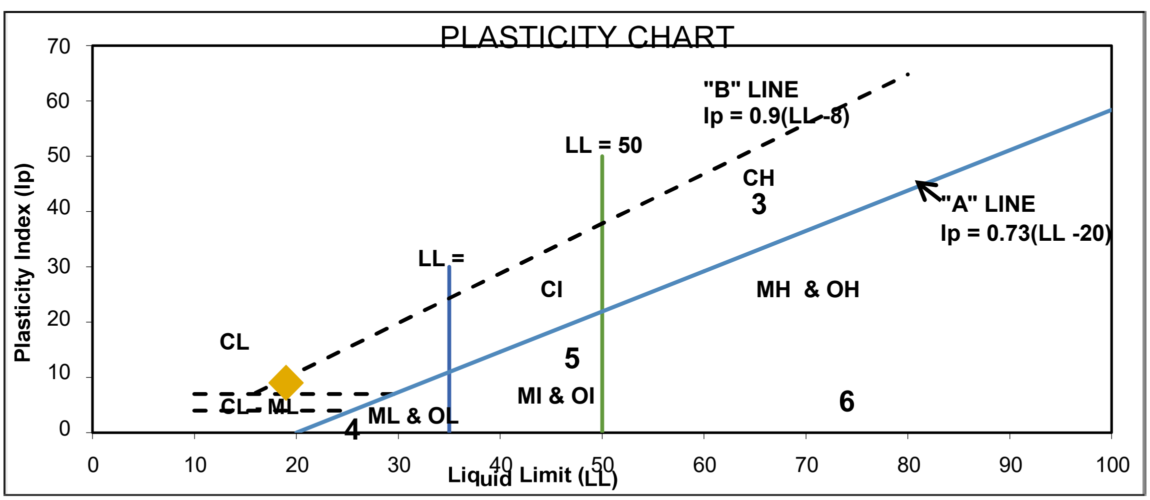




TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	1B	27/09/2019
Depth (m)	0 - 0.5	

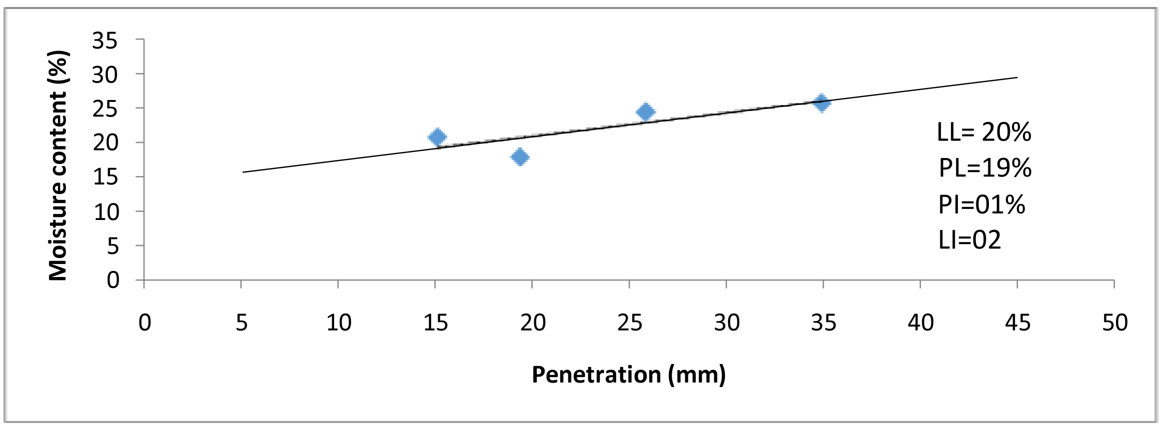
LIQUID LIMIT	NATURAL M.C. (%)					PLASTIC LIMIT	
Specimen number	1	2	3	4		1	2
Can number	O33	8	11	A22		A12	O38
Mass of empty can (g)	9.6	7.39	9.26	9.7		9.5	9.63
Mass of can & moist soil (g)	28.8	37.37	36.45	31.55		32.14	30.12
Mass of can & dry soil (g)	25.81	32.52	31.41	27.41		28.74	29.5
Mass of dry soil (g)	16.21	25.13	22.15	17.71		19.24	19.87
Moisture loss (g)	2.99	4.85	5.04	4.14		3.4	0.62
Water content, w%	18.45	19.3	22.75	23.38		17.67	3.12
Penetration (mm)	15.5	25	31.5	32			

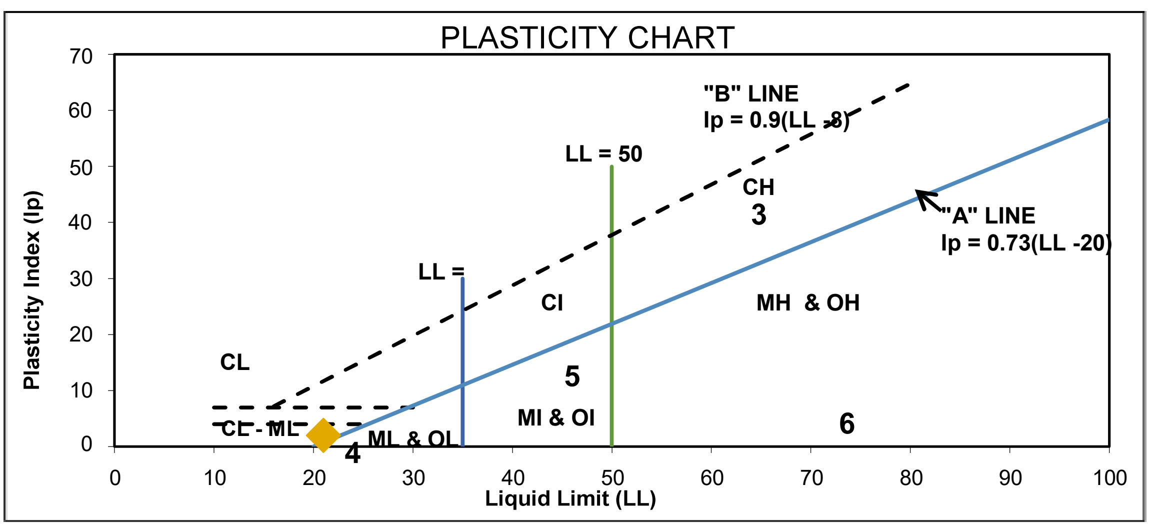




TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	2T	27/09/2019
Depth (m)	0.5-1	

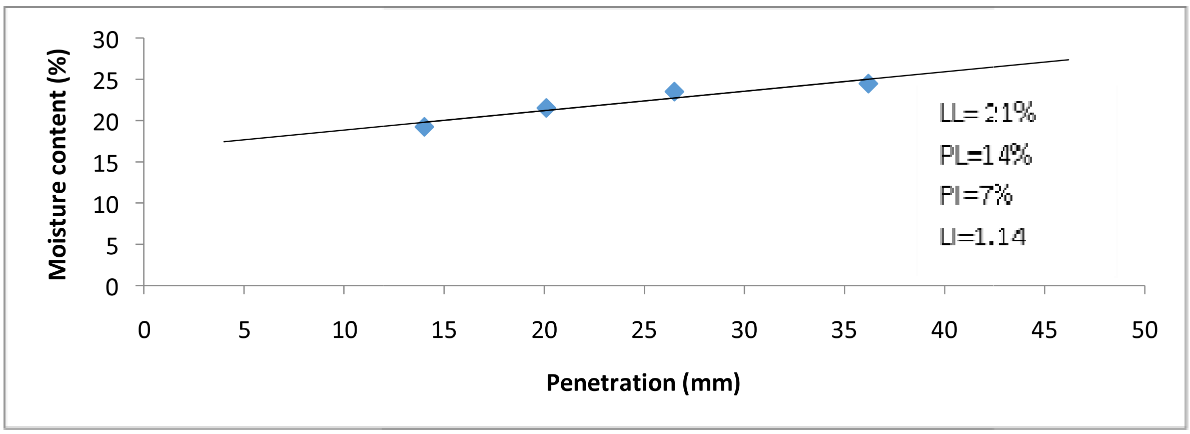
LIQUID LIMIT	NATURAL M.C. (%)					PLASTIC LIMIT	
Specimen number	1	2	3	4		1	2
Can number	3	A16	3A	23		7	A19
Mass of empty can (g)	9.45	9.47	9.26	9.52		9.33	9.26
Mass of can & moist soil (g)	29.0	36.58	38.38	53.19		30.17	30.18
Mass of can & dry soil (g)	26.1	32.5	32.67	44.25		26.84	26.89
Mass of dry soil (g)	16.65	23.03	23.41	34.73		17.51	17.63
Moisture loss (g)	2.9	4.08	5.71	8.94		3.33	3.29
Water content, w%	17.42	17.72	24.39	25.74		19.02	18.66
Penetration (mm)	15.1	19.4	25.9	35			

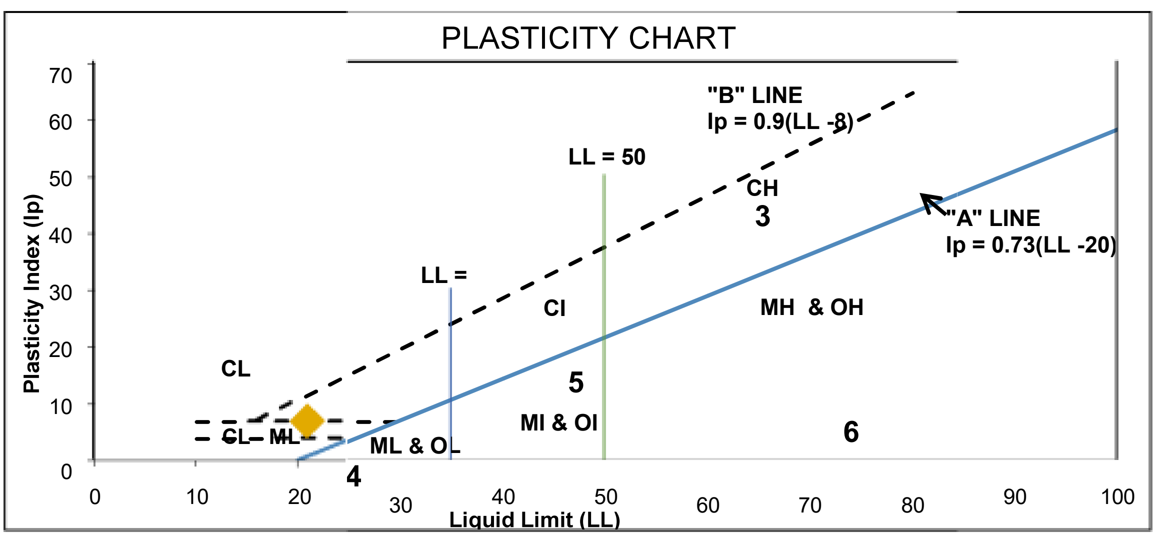




TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	2M	27/09/2019
Depth (m)	0.5-1	

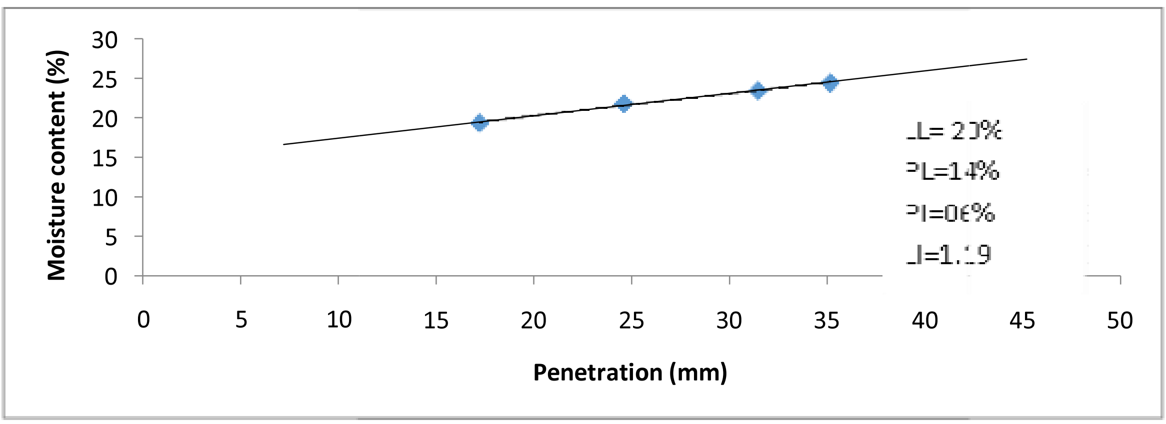
LIQUID LIMIT	NATURAL M.C. (%)					PLASTIC LIMIT	
Specimen number	1	2	3	4		1	2
Can number	19	47	A20	206		4A	B4B
Mass of empty can (g)	9.52	9.22	9.56	9.62		9.5	9.56
Mass of can & moist soil (g)	35.1	31.13	36.15	49.19		29.75	27.56
Mass of can & dry soil (g)	30.98	27.25	31.09	41.41		26.47	26.1
Mass of dry soil (g)	21.46	18.03	21.53	31.79		16.97	16.54
Moisture loss (g)	4.12	3.88	5.06	7.78		3.28	1.46
Water content, w%	19.2	21.52	23.5	24.47		19.33	8.83
Penetration (mm)	14	20.1	26.5	36.2			

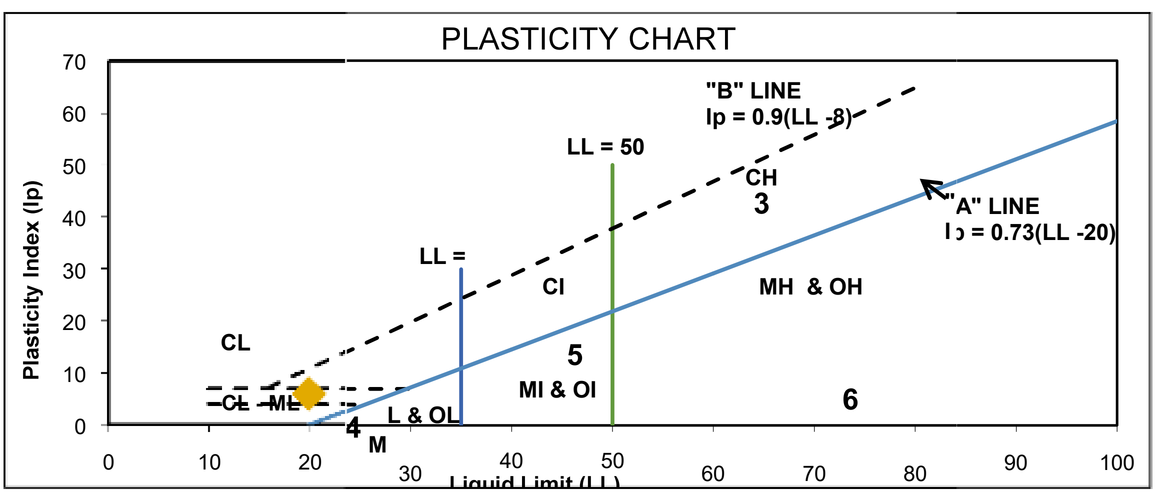




TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	2B	27/09/2019
Depth (m)	1-1.5	
		Weight

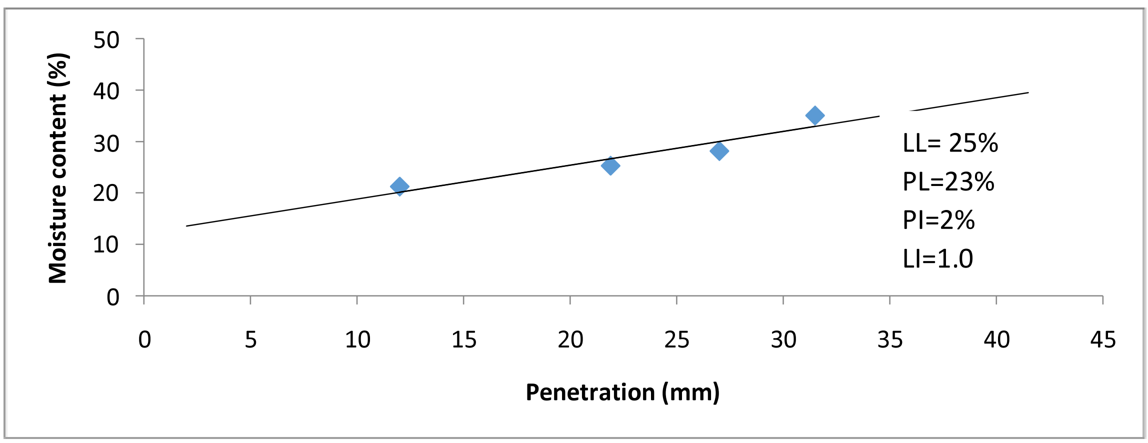
LIQUID LIMIT	**NATURAL M.C. (%)**					**PLASTIC LIMIT**	
Specimen number	1	2	3	4		1	2
Can number	428	1	02B	5XX		A21	B46
Mass of empty can (g)	9.62	9.46	9.52	9.63		9.6	9.7
Mass of can & moist soil (g)	35.1	31.13	36.15	49.19		31.38	28
Mass of can & dry soil (g)	30.98	27.25	31.09	41.41		27.4	26.94
Mass of dry soil (g)	21.36	17.79	21.57	31.78		17.8	17.24
Moisture loss (g)	4.12	3.88	5.06	7.78		3.98	1.06
Water content, w%	19.29	21.81	23.46	24.48		22.36	6.15
Penetration (mm)	17.2	24.6	31.5	35.2			

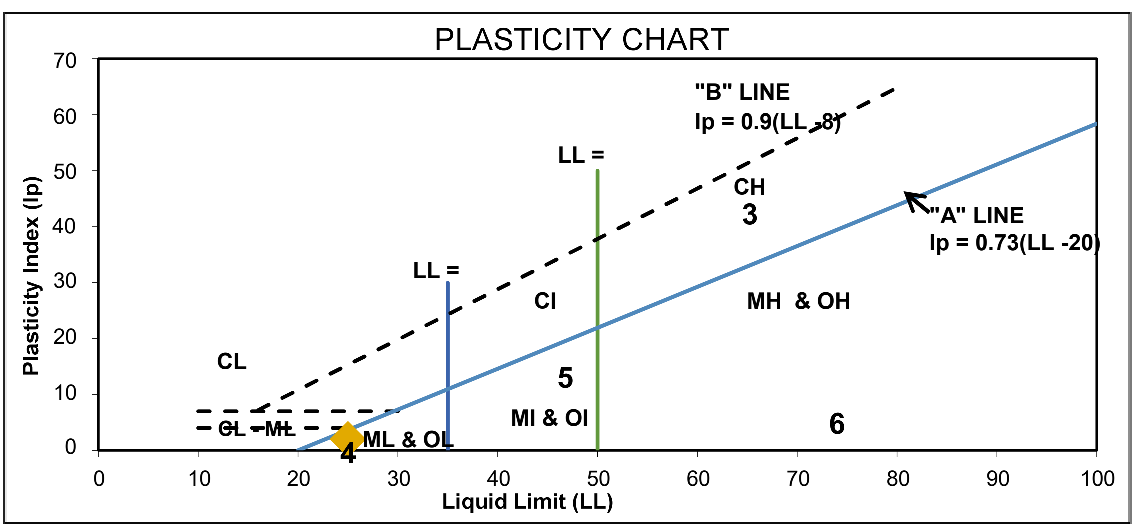




TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	3T	27/09/2019
Depth (m)	0 - 0.5	

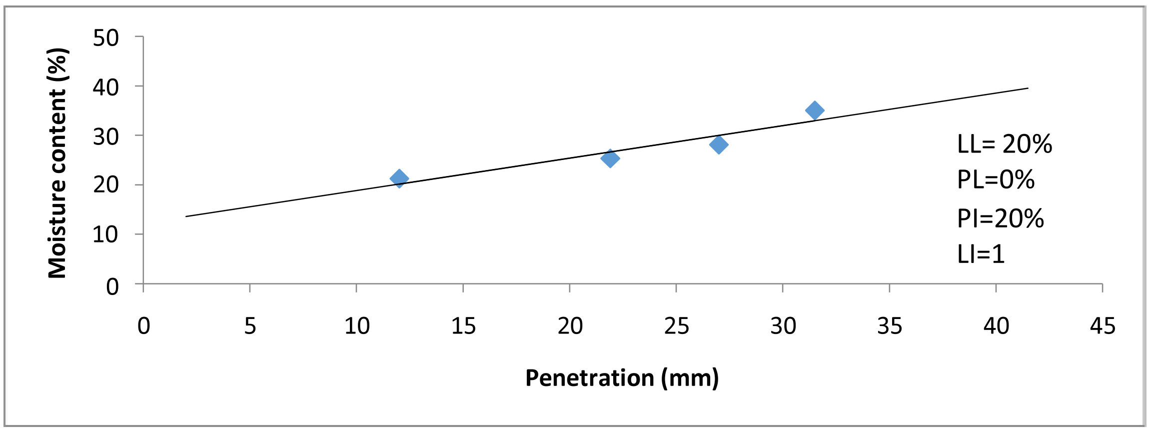
LIQUID LIMIT	**NATURAL M.C. (%)**					**PLASTIC LIMIT**	
Specimen number	1	2	3	4		1	2
Can number	12F	4	98	51		B1B	B2B
Mass of empty can (g)	9.6	9.46	9.46	9.55		9.71	9.55
Mass of can & moist soil (g)	30.27	33.18	31.92	37.36		31.56	31.55
Mass of can & dry soil (g)	26.65	28.39	26.99	32.47		27.4	27.39
Mass of dry soil (g)	17.05	18.93	17.53	22.92		17.69	17.84
Moisture loss (g)	3.62	4.79	4.93	4.89		4.16	4.16
Water content, w%	21.23	25.3	28.12	21.34		23.52	23.32
Penetration (mm)	12	21.9	27	31.5			

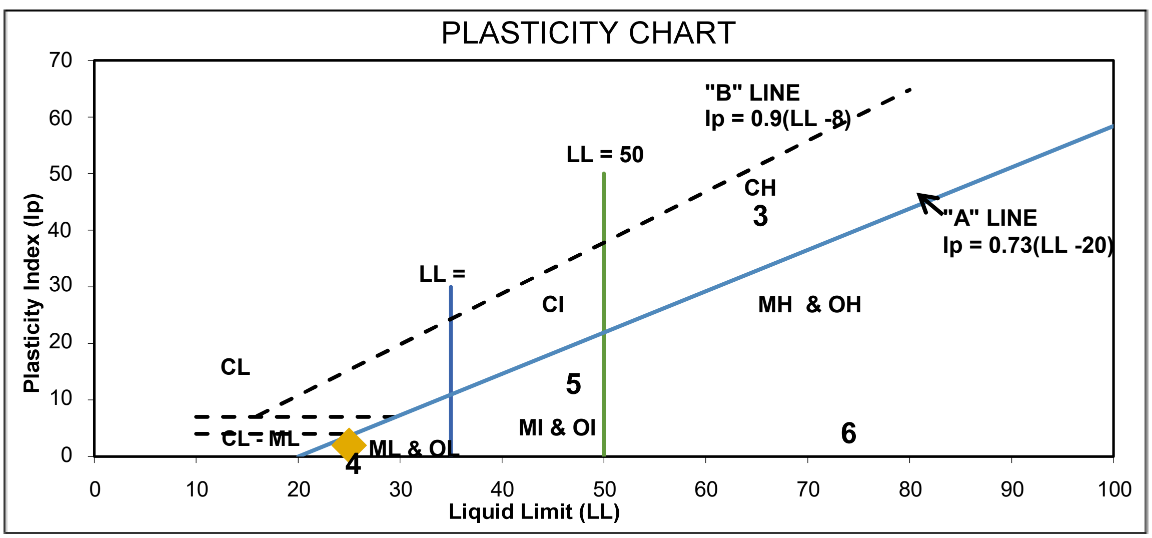




TEST BY	Aliyu Hassan		
Project	MTech, 2019		
Sample No	3M	27/09/2019	
Depth (m)	0.5-1		

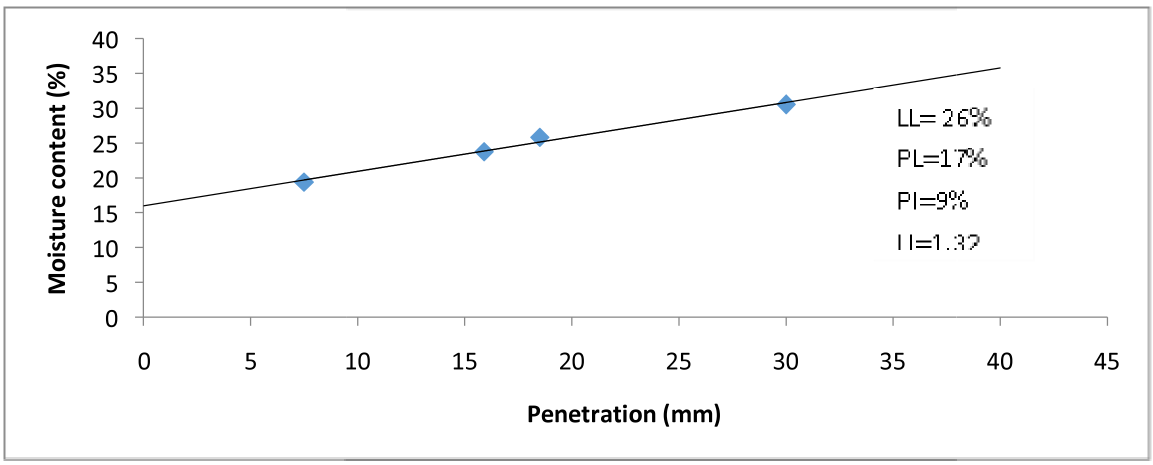
LIQUID LIMIT	**NATURAL M.C. (%)**					**PLASTIC LIMIT**	
Specimen number	1	2	3	4		1	2
Can number	18	A14	125	920		3	3M
Mass of empty can (g)	9.54	9.6	9.55	9.59		0	0
Mass of can & moist soil (g)	31.44	37.56	40.83	42.85		0	0
Mass of can & dry soil (g)	28.07	32.61	34.78	38.15		0	0
Mass of dry soil (g)	18.53	23.01	25.23	28.56		3.37	3.35
Moisture loss (g)	3.37	4.95	6.05	4.7		0	0
Water content, w%	18.19	21.51	23.98	16.46		0	0
Penetration (mm)	7.8	16.5	29.5	38			

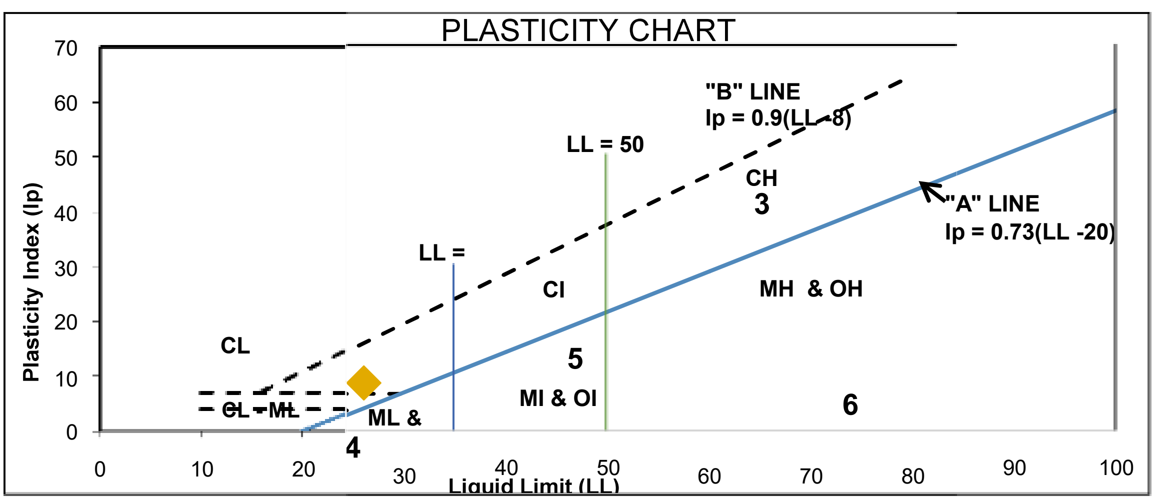




TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	3B	27/09/2019
Depth (m)	1-1.5	

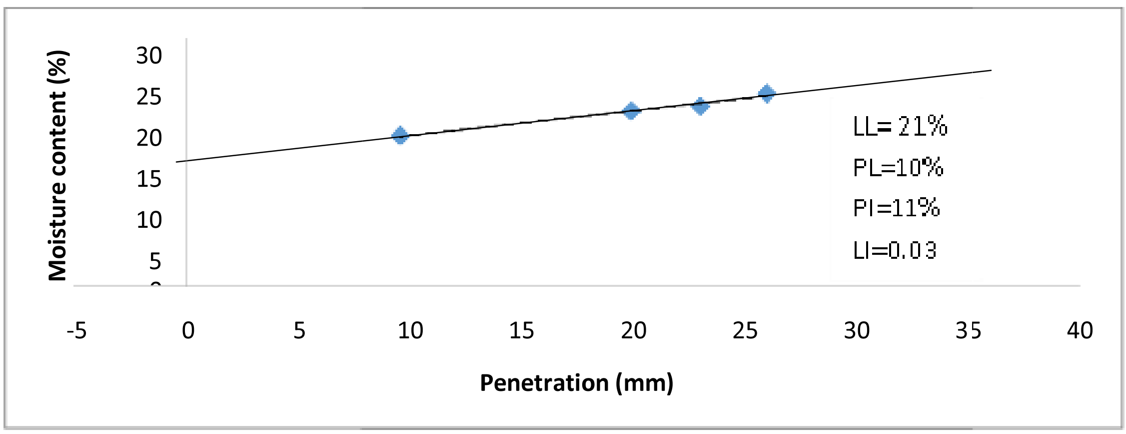
LIQUID LIMIT	**NATURAL M.C. (%)**					**PLASTIC LIMIT**	
Specimen number	1	2	3	4		1	2
Can number	58	GS	11	C1		3	3M
Mass of empty can (g)	28.89	29.26	29.28	18.37		9.5	9.51
Mass of can & moist soil (g)	53.59	56.71	53.71	60.25		19.93	19.9
Mass of can & dry soil (g)	49.58	51.44	48.7	50.46		18.38	18.39
Mass of dry soil (g)	20.69	22.18	19.42	32.09		8.88	8.88
Moisture loss (g)	4.01	5.27	5.01	9.79		1.55	1.51
Water content, w%	19.38	23.76	25.8	30.51		17.45	17
Penetration (mm)	7.5	15.9	18.5	30			

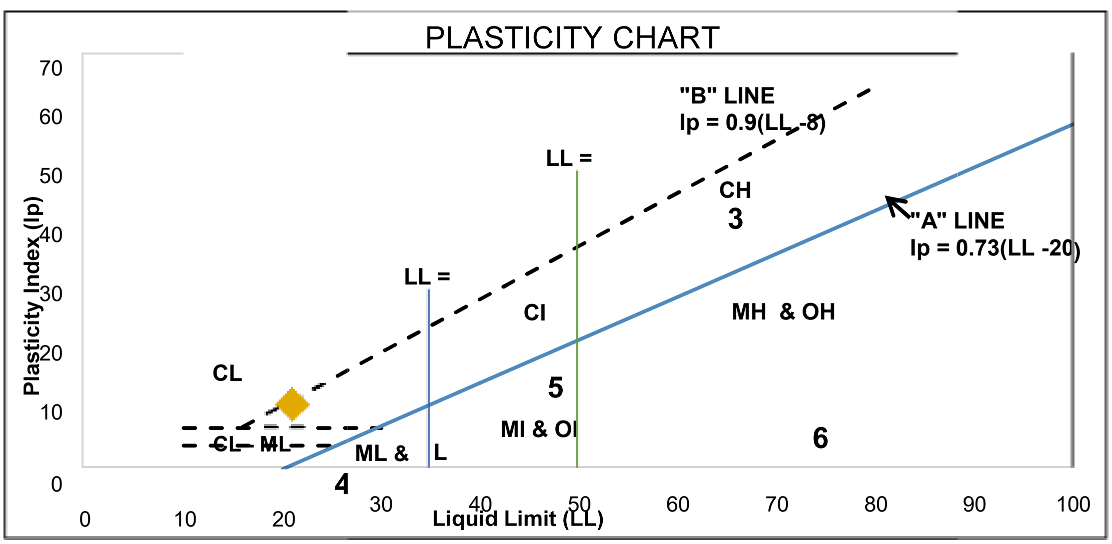




TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	4T	27/09/2019
Depth (m)	0-0.5	

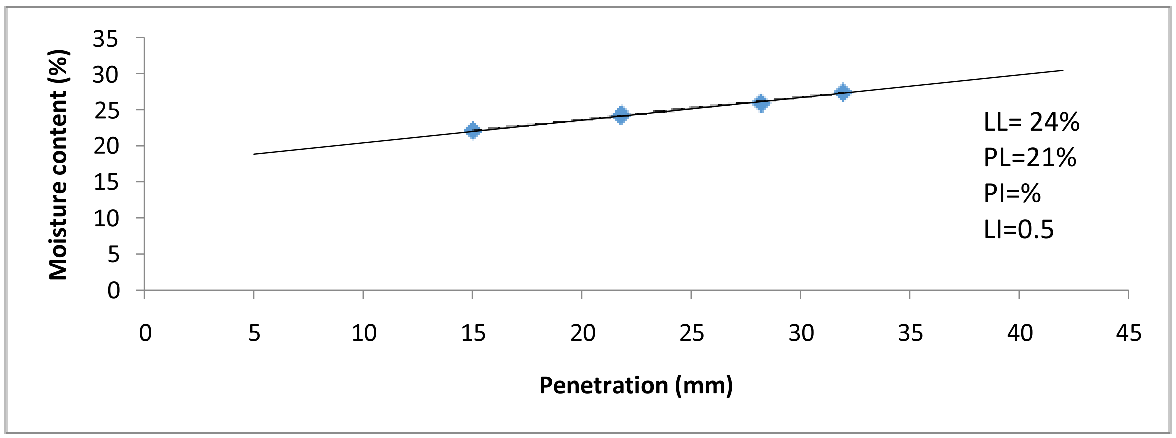
LIQUID LIMIT	NATURAL M.C. (%)					PLASTIC LIMIT	
Specimen number	1	2	3	4		1	2
Can number	B65	P3	49	11C		21	21C
Mass of empty can (g)	29.41	29.07	31.42	28.62		9.37	9.6
Mass of can & moist soil (g)	55.27	60.20	66.91	69.04		34.85	33.56
Mass of can & dry soil (g)	51.3	54.4	60.55	61.67		31.8	32.12
Mass of dry soil (g)	21.89	26.33	29.13	33.05		22.43	22.52
Moisture loss (g)	3.97	5.8	6.36	7.73		3.05	1.44
Water content, w%	18.14	22.03	21.83	23.39		13.6	6.39
Penetration (mm)	9.5	17.9	23	26			

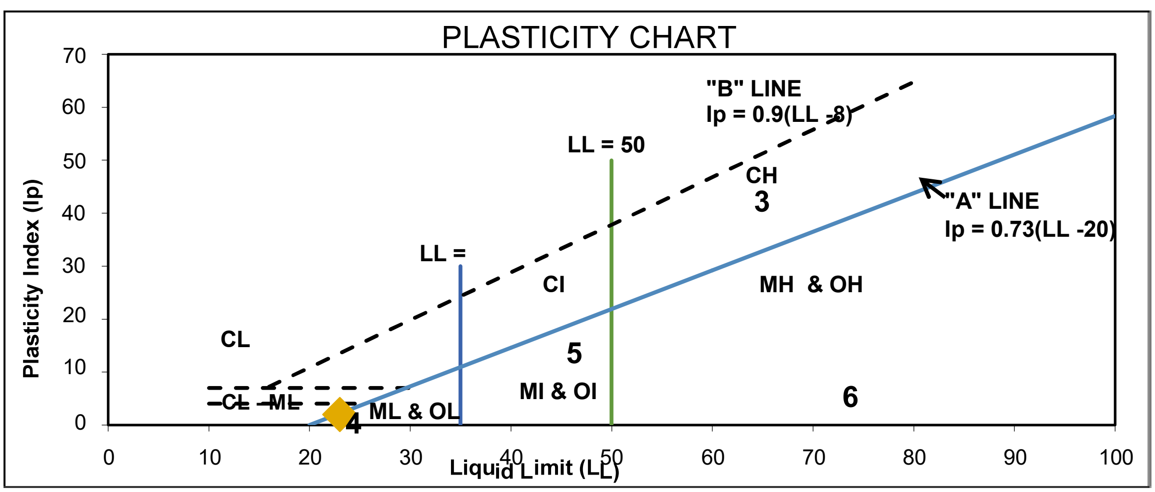




TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	4M	27/09/2019
Depth (m)	0.5-1	

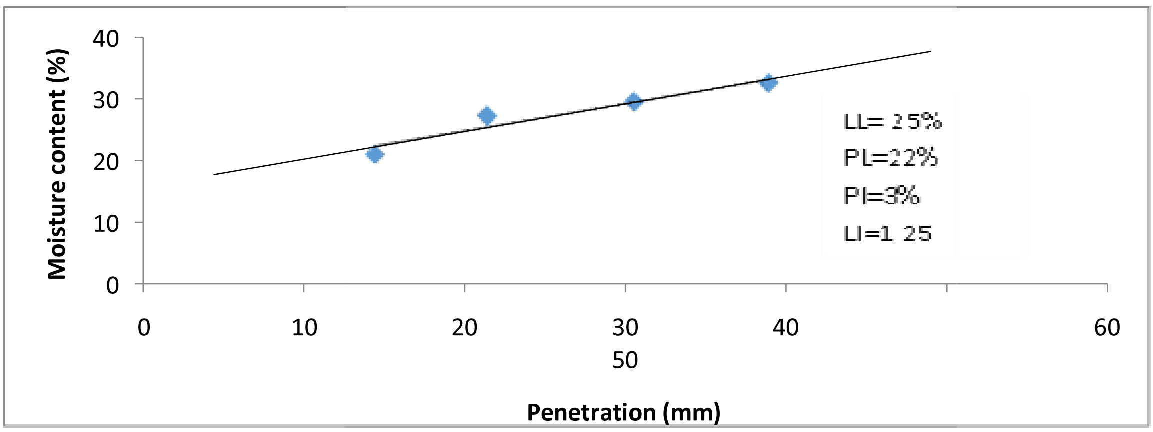
LIQUID LIMIT	NATURAL M.C. (%)					PLASTIC LIMIT	
Specimen number	1	2	3	4		1	2
Can number	6'1	31B	99	21A		07/SS	6'22
Mass of empty can (g)	29.42	27.35	27.57	29.52		28.66	28.64
Mass of can & moist soil (g)	61.57	58.79	68.36	69.29		57.24	57.89
Mass of can & dry soil (g)	55.78	52.66	59.98	62.23		52.56	52.5
Mass of dry soil (g)	26.36	25.31	32.41	32.71		23.9	23.86
Moisture loss (g)	5.79	6.13	8.38	3.06		4.68	5.39
Water content, w%	21.97	24.22	25.86	9.35		19.58	22.59
Penetration (mm)	15	21.8	28.2	32			

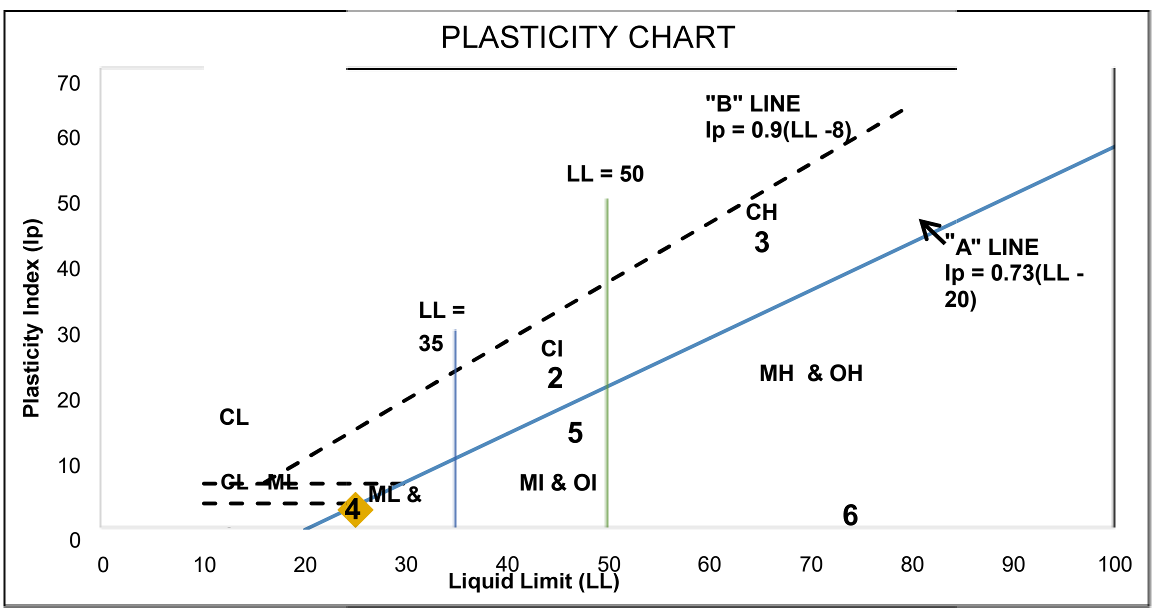




TEST BY	Aliyu Hassan	
Project	MTech, 2019	
Sample No	4B	27/09/2019
Depth (m)	1-1.5	

LIQUID LIMIT	NATURAL M.C. (%)					PLASTIC LIMIT	
Specimen number	1	2	3	4		1	2
Can number	3A	17	14	6A		4s/3	4s
Mass of empty can (g)	16.21	18.65	29.72	27.32		26.11	26.1
Mass of can & moist soil (g)	37	42.42	69.16	68.79		57.2	56.7
Mass of can & dry soil (g)	33.42	36.34	61.21	59.86		51.4	51.3
Mass of dry soil (g)	17.21	17.69	31.49	32.54		25.29	25.2
Moisture loss (g)	3.58	6.08	7.95	8.93		5.8	5.4
Water content, w%	20.8	34.37	25.25	27.44		22.93	21.43
Penetration (mm)	14.4	21.4	30.6	39			





APPENDIX D

Compaction Test Results

TEST BY	Aliyu Hassan		
Project	MTech, 2019	**Depth (m)**	0-0.5
Sample No	1T	27/09/2019	

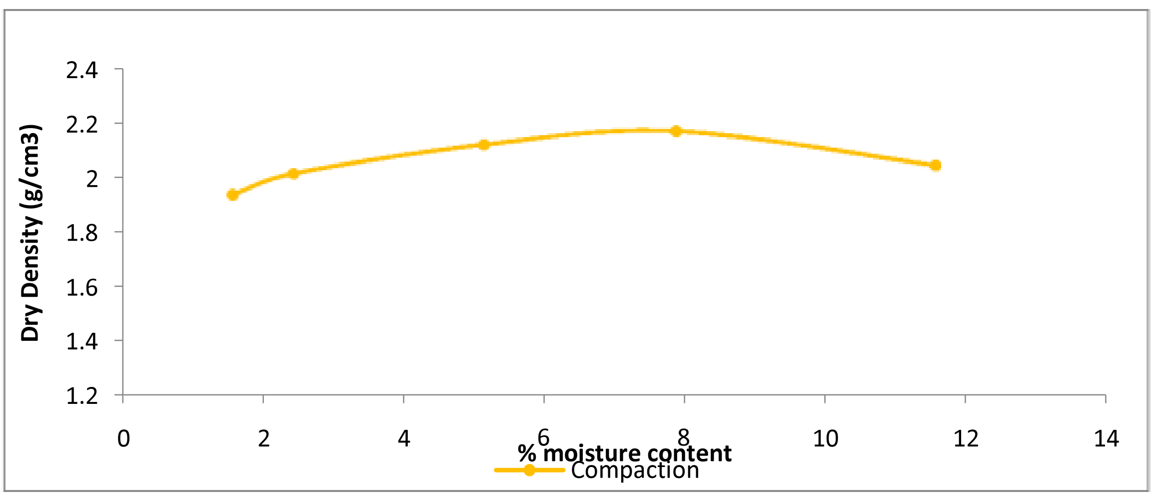
COMPACTYION TEST (MOISTURE CONTENT-DRY DENSITY)

WATER CONTENT DETERMIONATION

Compacted Soil - Sample no	1		2		3		4		5	
Moisture can no	E4	B5	O	H	E	E4	B5	O	H	E
Mass of empty, can + lid(g)	19	19	26.6	19	26.9	19	19	26.6	19	26.9
Mass of can, lid & moist soil (g)	45	45	75.2	51.3	69.8	45	45	75.2	51.3	69.8
Mass of can, lid & dry soil (g)	44.6	44.6	74.1	50.5	67.9	44.6	44.6	74.1	50.5	67.9
Mass of dry soil (g)	25.6	25.6	47.5	31.5	41	25.6	25.6	47.5	31.5	41
Mass of pore water (g)	0.4	0.4	1.1	0.8	1.9	0.4	0.4	1.1	0.8	1.9
Water content, w%	1.56	1.56	2.32	2.54	4.63	1.56	1.56	2.32	2.54	4.63
Average Water content, w%	1.56		2.43		5.15		7.89		11.59	

DENSITY DTERMINATION

Mould Volume (cm^3)	950	**Mass of Mould (1939)**			
Compacted Soil - Sample no	1	2	3	4	5
Mass of compacted soil and mould(g)	3800.5	3894.1	4053.5	4163.5	4109.5
Wet mass of soil (g)	1861.5	1955.1	2114.5	2224.5	2170.5
Wet density, ρw , (g/cm3)	1.96	2.06	2.23	2.34	2.28
Dry density, ρd , (Mg/m3)	1.93	2.01	2.12	2.17	2.04



MDD (2.17Mg/cm^3), **OMC** (7.89 %)

TEST BY	Aliyu Hassan		
Project	MTech, 2019	Depth (m)	0.5-1.5
Sample No	1M	27/09/2019	

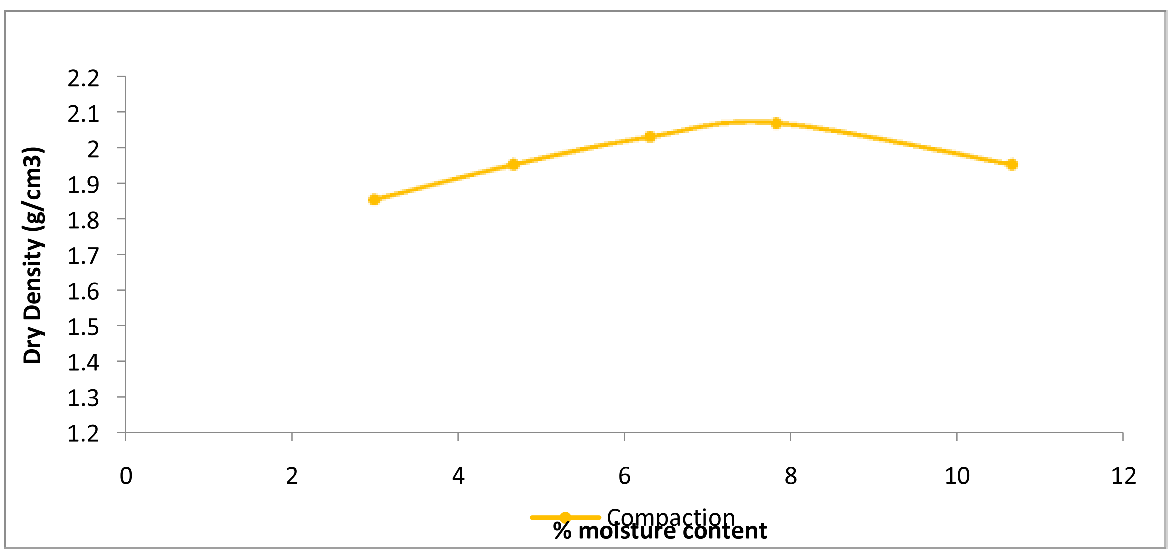
COMPACTYION TEST (MOISTURE CONTENT-DRY DENSITY)

WATER CONTENT DETERMIONATION

Compacted Soil - Sample no	1		2		3		4		5	
Moisture can no	L4	P	A4	B1	A5	L4	P	A4	B1	A5
Mass of empty, can + lid(g)	26.5	18.8	26.9	18.9	26.9	26.5	18.8	26.9	18.9	26.9
Mass of can, lid & moist soil (g)	78.9	63.6	55.7	51	75.4	78.9	63.6	55.7	51	75.4
Mass of can, lid & dry soil (g)	78.1	61.7	54.3	49.7	72.7	78.1	61.7	54.3	49.7	72.7
Mass of dry soil (g)	51.6	42.9	27.4	30.8	45.8	51.6	42.9	27.4	30.8	45.8
Mass of pore water (g)	0.8	1.9	1.4	1.3	2.7	0.8	1.9	1.4	1.3	2.7
Water content, w%	1.55	4.43	5.11	4.22	5.9	1.55	4.43	5.11	4.22	5.9
Average Water content, w%	2.99		4.67		6.31		7.84		10.68	

DENSITY DTERMINATION

Mould Volume (cm^3)	950	Mass of Mould (1939)			
Compacted Soil - Sample no	1	2	3	4	5
Mass of compacted soil and mould(g)	3756.9	3874.1	3992.5	4054.5	3994.8
Wet mass of soil (g)	1817.9	1935.1	2053.5	2115.5	2055.8
Wet density, ρw , (g/cm3)	1.91	2.04	2.16	2.23	2.16
Dry density, ρd , (Mg/m3)	1.85	1.95	2.03	2.07	1.95



MDD (2.07Mg/cm^3) **OMC (**7.84%)

TEST BY	Aliyu Hassan		
Project	MTech, 2019	**Depth** (m)	1-1.5
Sample No	1B	27/09/2019	

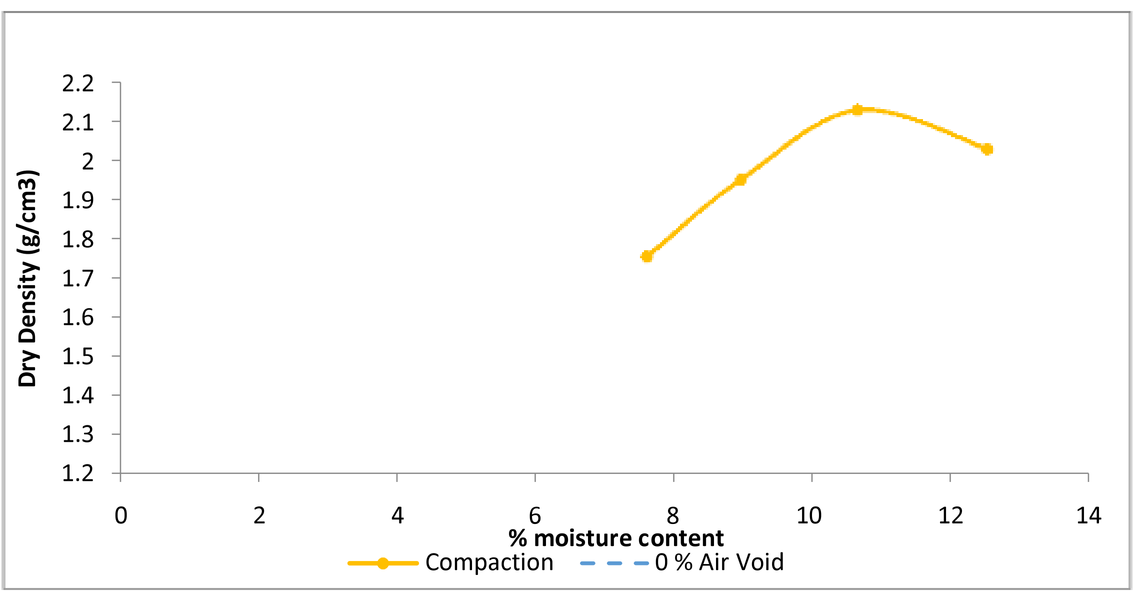
COMPACTYION TEST (MOISTURE CONTENT-DRY DENSITY)

WATER CONTENT DETERMIONATION

Compacted Soil - Sample no	1		2		3		4		5	
Moisture can no	B3	E5	D1	F	E3	B3	E5	D1	F	E3
Mass of empty, can + lid(g)	26.9	19	26.9	26.9	26.7	26.9	19	26.9	26.9	26.7
Mass of can, lid & moist soil (g)	55.4	64.7	67.9	64.1	83.8	55.4	64.7	67.9	64.1	83.8
Mass of can, lid & dry soil (g)	54.3	60.1	65.5	60.2	78.5	54.3	60.1	65.5	60.2	78.5
Mass of dry soil (g)	27.4	41.1	38.6	33.3	51.8	27.4	41.1	38.6	33.3	51.8
Mass of pore water (g)	1.1	4.6	2.4	3.9	5.3	1.1	4.6	2.4	3.9	5.3
Water content, w%	4.01	11.19	6.22	11.71	10.23	4.01	11.19	6.22	11.71	10.23
Average Water content, w%	7.6		8.97		10.67		12.56			

DENSITY DTERMINATION

Mould Volume (cm^3)	950	Mass of Mould (1939)			
Compacted Soil - Sample no	1	2	3	4	5
Mass of compacted soil and mould(g)	3723.6	3958.4	4181.4	4112.3	
Wet mass of soil (g)	1784.6	2019.4	2242.4	2173.3	
Wet density, ρw , (g/cm3)	1.88	2.13	2.36	2.29	
Dry density, ρd , (Mg/m3)	1.75	1.95	2.13	2.03	



MDD (2.13Mg/cm^3) **OMC** (10.67%)

TEST BY	Aliyu Hassan		
Project	MTech, 2019	Depth (m)	0-0.5
Sample No	2T	27/09/2019	

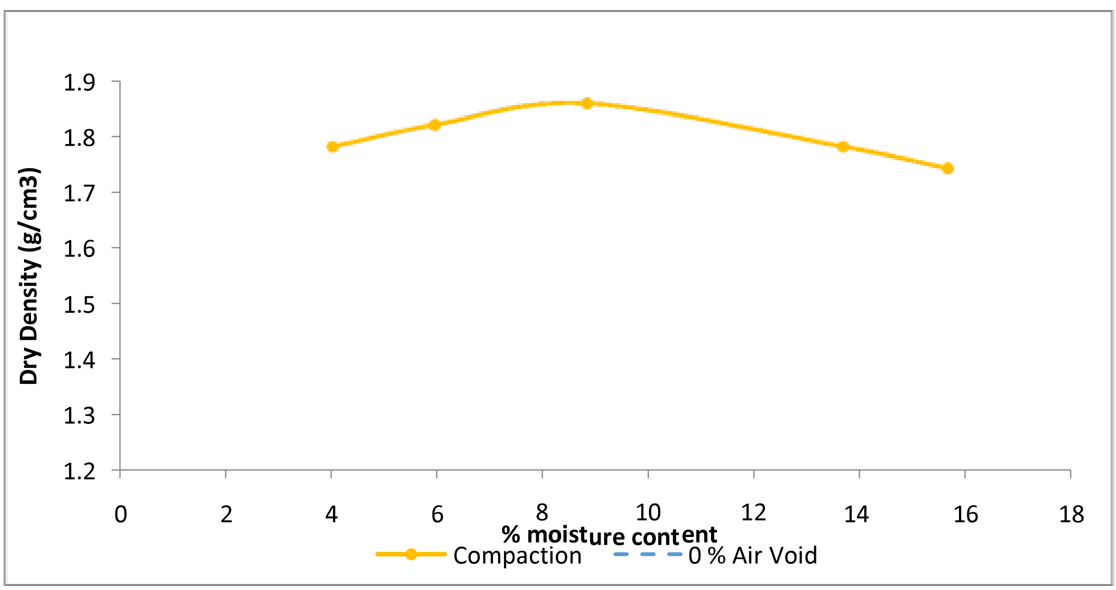
COMPACTYION TEST (MOISTURE CONTENT-DRY DENSITY)

WATER CONTENT DETERMIONATION

Compacted Soil - Sample no	1		2		3		4		5	
Moisture can no	Q	M	B4	A2	A1	Q	M	B4	A2	A1
Mass of empty, can + lid(g)	26.6	18.9	19	26.6	19	26.6	18.9	19	26.6	19
Mass of can, lid & moist soil (g)	65.8	48.5	57	59.8	51.2	65.8	48.5	57	59.8	51.2
Mass of can, lid & dry soil (g)	64.1	47.5	54.9	57.9	48.5	64.1	47.5	54.9	57.9	48.5
Mass of dry soil (g)	37.5	28.6	35.9	31.3	29.5	37.5	28.6	35.9	31.3	29.5
Mass of pore water (g)	1.7	1	2.1	1.9	2.7	1.7	1	2.1	1.9	2.7
Water content, w%	4.53	3.5	5.85	6.07	9.15	4.53	3.5	5.85	6.07	9.15
Average Water content, w%	4.02		5.96		8.86		13.73		15.71	

DENSITY DTERMINATION

Mould Volume (cm^3)	950	Mass of Mould (1939)			
Compacted Soil - Sample no	1	2	3	4	5
Mass of compacted soil and mould(g)	3693.4	3775.2	3859.5	3855.7	3852.1
Wet mass of soil (g)	1754.4	1836.2	1920.5	1916.7	1913.1
Wet density, ρw , (g/cm3)	1.85	1.93	2.02	2.02	2.01
Dry density, ρd , (Mg/m3)	1.78	1.82	1.86	1.78	1.74



MDD 1.86 (Mg/cm^3) **OMC** 7.84 (%)

TEST BY	Aliyu Hassan		
Project	MTech, 2019	**Depth (m)**	0.5-1
Sample No	2M	27/09/2019	

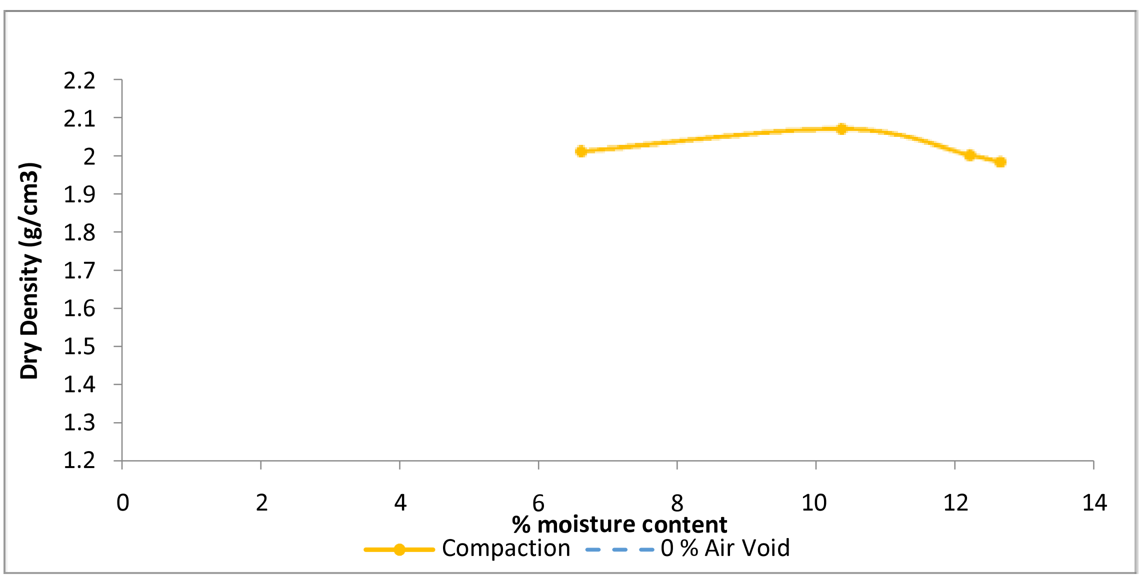
COMPACTYION TEST (MOISTURE CONTENT-DRY DENSITY)

WATER CONTENT DETERMIONATION

Compacted Soil - Sample no	1		2		3		4		5	
Moisture can no	E	B5	D	D4	O	E5	X1	B		
Mass of empty, can + lid(g)	27	19	26.5	19	26.5	19	26.9	27		
Mass of can, lid & moist soil (g)	72.3	57.9	70.7	58.7	69.2	60.7	53.9	68.9		
Mass of can, lid & dry soil (g)	69.6	55.4	66.4	55.1	64.7	56	50.3	65.1		
Mass of dry soil (g)	42.6	36.4	39.9	36.1	38.2	37	23.4	38.1		
Mass of pore water (g)	2.7	2.5	4.3	3.6	4.5	4.7	3.6	3.8		
Water content, w%	6.34	6.87	10.78	9.97	11.78	12.7	15.4	9.97		
Average Water content, w%	6.61		10.38		12.24		12.68			

DENSITY DTERMINATION

Mould Volume (cm^3)	950	**Mass of Mould (1939)**			
Compacted Soil - Sample no	1	2	3	4	1
Mass of compacted soil and mould(g)	3975	4106.2	4069.7	4057.3	3975
Wet mass of soil (g)	2036	2167.2	2130.7	2118.3	2036
Wet density, ρw , (g/cm3)	2.14	2.28	2.24	2.23	2.14
Dry density, ρd , (Mg/m3)	2.01	2.07	2	1.98	2.01



MDD (2.07Mg/m^3) **OMC** (10.38%)

TEST BY	Aliyu Hassan		
Project	MTech, 2019	Depth (m)	1-1.5
Sample No	2B	27/09/2019	

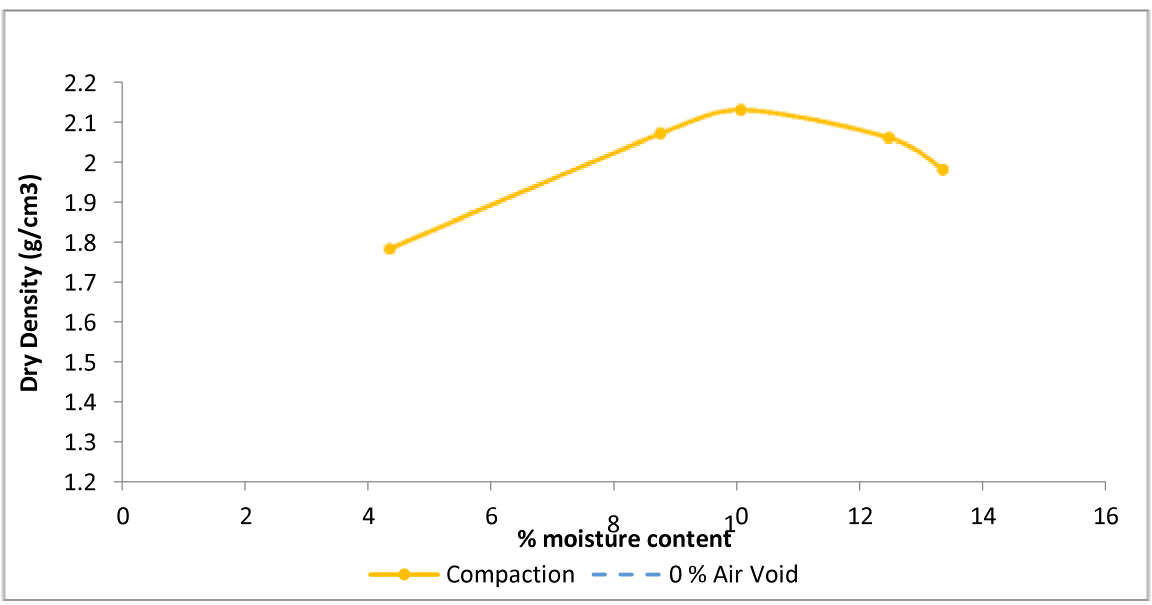
COMPACTYION TEST (MOISTURE CONTENT-DRY DENSITY)

WATER CONTENT DETERMIONATION

Compacted Soil - Sample no	1		2		3		4		5	
Moisture can no	P	H13	L4	T12	M0	P	H13	L4	T12	M0
Mass of empty, can + lid(g)	18.9	18.8	26.4	26.8	19	18.9	18.8	26.4	26.8	19
Mass of can, lid & moist soil (g)	55	54.8	55.2	55.1	64.7	55	54.8	55.2	55.1	64.7
Mass of can, lid & dry soil (g)	53.3	53.5	52.9	52.8	61	53.3	53.5	52.9	52.8	61
Mass of dry soil (g)	34.4	34.7	26.5	26	42	34.4	34.7	26.5	26	42
Mass of pore water (g)	1.7	1.3	2.3	2.3	3.7	1.7	1.3	2.3	2.3	3.7
Water content, w%	4.94	3.75	8.68	8.85	8.81	4.94	3.75	8.68	8.85	8.81
Average Water content, w%	4.35		8.77		10.08		12.5		13.38	

DENSITY DTERMINATION

Mould Volume (cm^3)	950	Mass of Mould (1939)			
Compacted Soil - Sample no	1	2	3	4	5
Mass of compacted soil and mould(g)	3703.9	4080.9	4169	4143.4	4068.7
Wet mass of soil (g)	1764.9	2141.9	2230	2204.4	2129.7
Wet density, ρw , (g/cm3)	1.86	2.25	2.35	2.32	2.24
Dry density, ρd , (Mg/m3)	1.78	2.07	2.13	2.06	1.98



MDD (2.13Mg/m^3) OMC (10.08%)

TEST BY	Aliyu Hassan		
Project	MTech, 2019	**Depth (m)**	0.-0.5
Sample No	3T	27/09/2019	

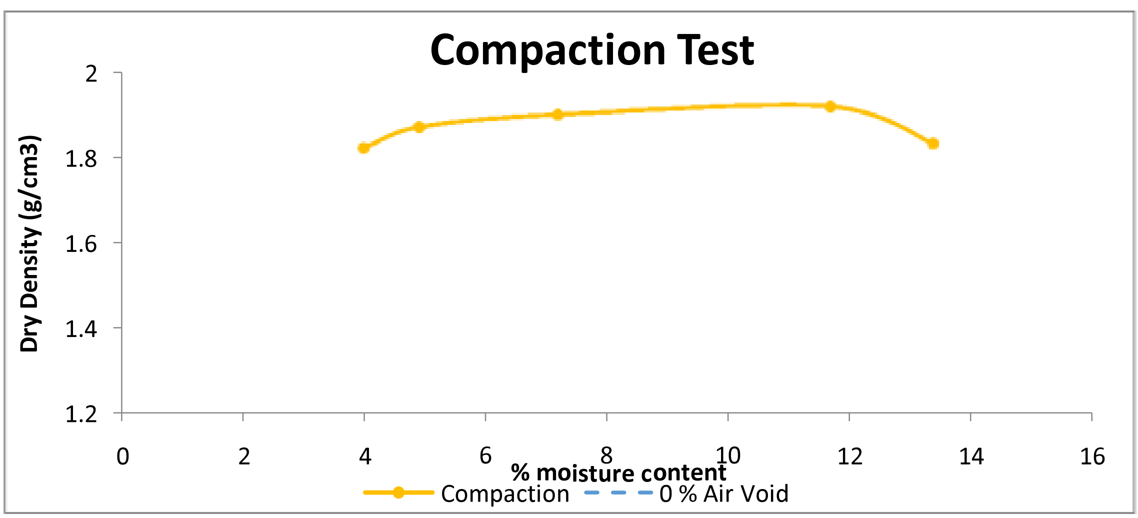
COMPACTYION TEST (MOISTURE CONTENT-DRY DENSITY)

WATER CONTENT DETERMIONATION

Compacted Soil - Sample no	1		2		3		4		5	
Moisture can no	B4	D4	A1	A	C3	B4	D4	A1	A	C3
Mass of empty, can + lid(g)	19	19	19	19	19	19	19	19	19	19
Mass of can, lid & moist soil (g)	46.3	55.5	43.3	40.7	48	46.3	55.5	43.3	40.7	48
Mass of can, lid & dry soil (g)	45.3	53.3	42.1	39.5	46	45.3	53.3	42.1	39.5	46
Mass of dry soil (g)	26.3	34.3	23.1	20.5	27	26.3	34.3	23.1	20.5	27
Mass of pore water (g)	1	2.2	1.2	1.2	2	1	2.2	1.2	1.2	2
Water content, w%	3.8	6.41	5.19	5.85	7.41	3.8	6.41	5.19	5.85	7.41
Average Water content, w%	5.11		5.52		7.74		9.88		11.43	

DENSITY DTERMINATION

Mould Volume (cm^3)	950	**Mass of Mould (1939)**			
Compacted Soil - Sample no	1	2	3	4	5
Mass of compacted soil and mould(g)	3848.8	3923.4	4127.3	4150.7	4069.9
Wet mass of soil (g)	1909.8	1984.4	2188.3	2211.7	2130.9
Wet density, ρw , (g/cm3)	2.01	2.09	2.3	2.33	2.24
Dry density, ρd , (Mg/m3)	1.91	1.98	2.13	2.12	2.01



MDD (1.92Mg/m^3) **OMC** (11.17%)

TEST BY	Aliyu Hassan		
Project	MTech, 2019	**Depth (m)**	0.5-1
Sample No	3M	27/09/2019	

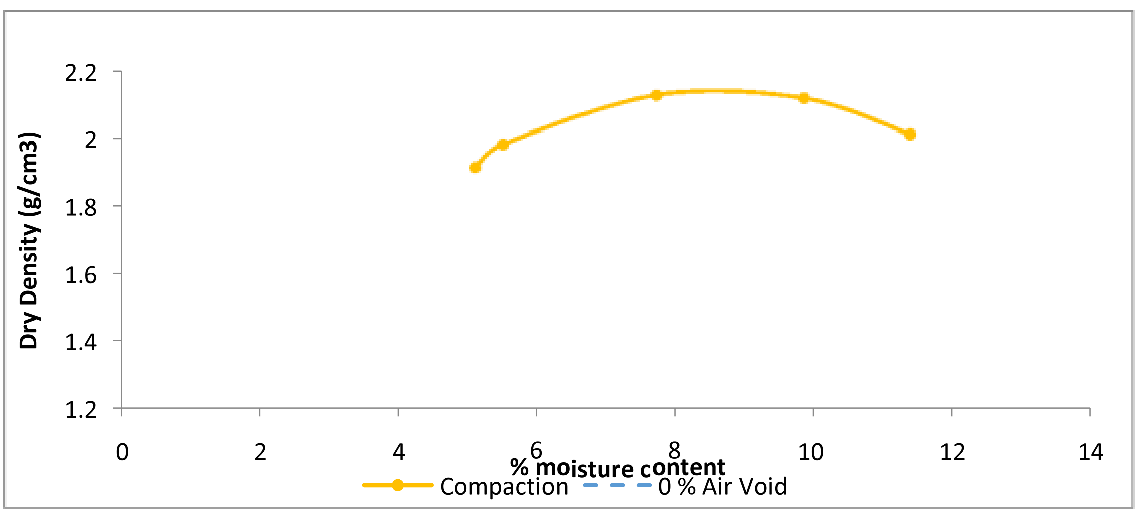
COMPACTYION TEST (MOISTURE CONTENT-DRY DENSITY)

WATER CONTENT DETERMIONATION

Compacted Soil - Sample no	1		2		3		4		5	
Moisture can no	B4	D4	A1	A	C3	B4	D4	A1	A	C3
Mass of empty, can + lid(g)	19	19	19	19	19	19	19	19	19	19
Mass of can, lid & moist soil (g)	46.3	55.5	43.3	40.7	48	46.3	55.5	43.3	40.7	48
Mass of can, lid & dry soil (g)	45.3	53.3	42.1	39.5	46	45.3	53.3	42.1	39.5	46
Mass of dry soil (g)	26.3	34.3	23.1	20.5	27	26.3	34.3	23.1	20.5	27
Mass of pore water (g)	1	2.2	1.2	1.2	2	1	2.2	1.2	1.2	2
Water content, w%	3.8	6.41	5.19	5.85	7.41	3.8	6.41	5.19	5.85	7.41
Average Water content, w%	5.11		5.52		7.74		9.88		11.43	

DENSITY DTERMINATION

Mould Volume (cm^3)	950	**Mass of Mould (1939)**			
Compacted Soil - Sample no	1	2	3	4	5
Mass of compacted soil and mould(g)	3848.8	3923.4	4127.3	4150.7	4069.9
Wet mass of soil (g)	1909.8	1984.4	2188.3	2211.7	2130.9
Wet density, ρw , (g/cm3)	2.01	2.09	2.3	2.33	2.24
Dry density, ρd , (Mg/m3)	1.91	1.98	2.13	2.12	2.01



MDD (2.13Mg/cm^3) OMC (7.74%)

TEST BY	Aliyu Hassan		
Project	MTech, 2019	Depth (m)	1-1.5
Sample No	3B	27/09/2019	

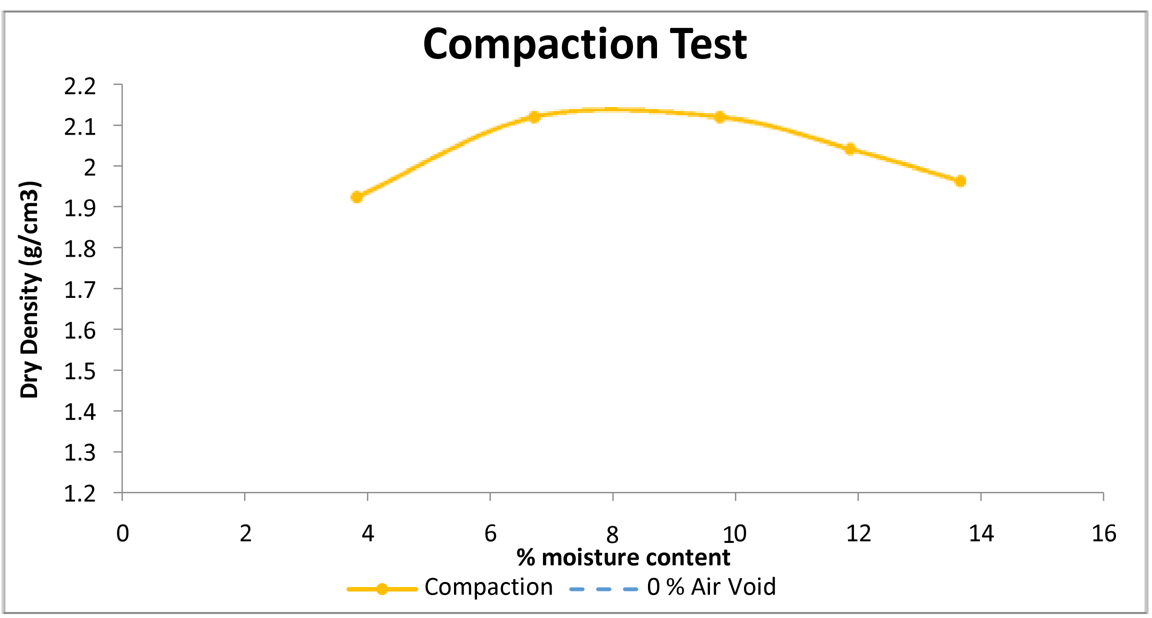
COMPACTYION TEST (MOISTURE CONTENT-DRY DENSITY)

WATER CONTENT DETERMIONATION

Compacted Soil - Sample no	1		2		3		4		5	
Moisture can no	E2	B5	E1	B1	B	E2	B5	E1	B1	B
Mass of empty, can + lid(g)	19	18.9	26.6	18.9	27	19	18.9	26.6	18.9	27
Mass of can, lid & moist soil (g)	38.7	43.9	56.7	43.1	78	38.7	43.9	56.7	43.1	78
Mass of can, lid & dry soil (g)	38.2	42.7	54.9	41.5	73.5	38.2	42.7	54.9	41.5	73.5
Mass of dry soil (g)	19.2	23.8	28.3	22.6	46.5	19.2	23.8	28.3	22.6	46.5
Mass of pore water (g)	0.5	1.2	1.8	1.6	4.5	0.5	1.2	1.8	1.6	4.5
Water content, w%	2.6	5.04	6.36	7.08	9.68	2.6	5.04	6.36	7.08	9.68
Average Water content, w%	3.82		6.72		9.75		11.89		13.69	

DENSITY DTERMINATION

Mould Volume (cm^3)	950	Mass of Mould (1939)			
Compacted Soil - Sample no	1	2	3	4	5
Mass of compacted soil and mould(g)	3831.1	4090.5	4156.7	4100.6	4053.4
Wet mass of soil (g)	1892.1	2151.5	2217.7	2161.6	2114.4
Wet density, ρw , (g/cm3)	1.99	2.26	2.33	2.28	2.23
Dry density, ρd , (Mg/m3)	1.92	2.12	2.12	2.04	1.96



MDD (2.12Mg/m3) **OMC** (6.72%)

TEST BY	Aliyu Hassan		
Project	MTech, 2019	Depth (m)	0-0.5
Sample No	4T	27/09/2019	

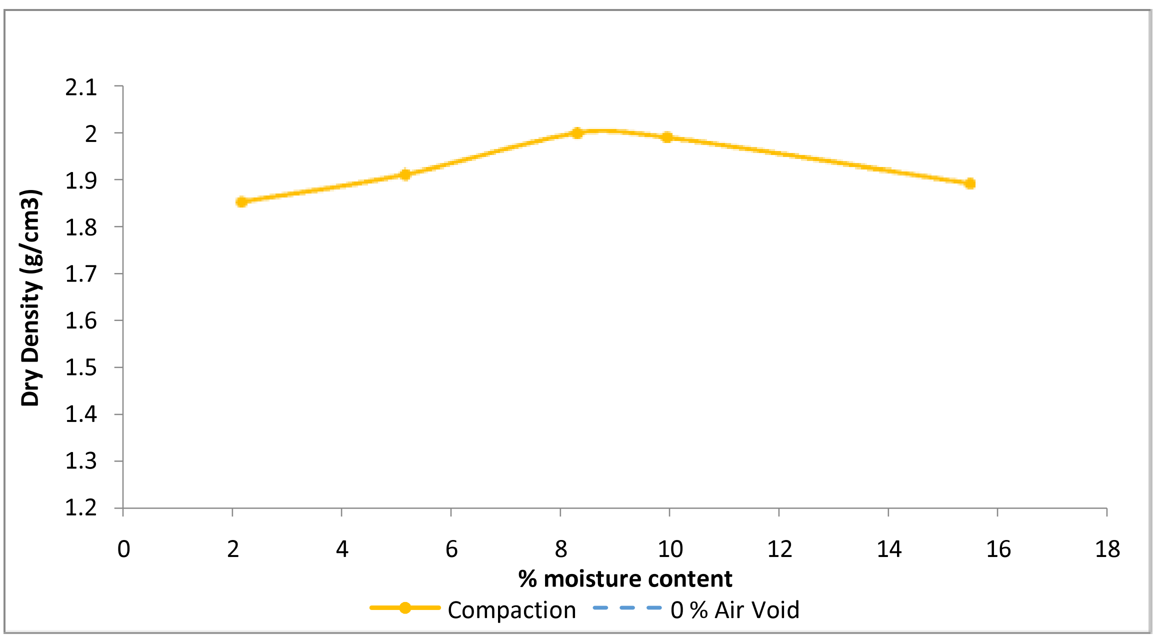
COMPACTYION TEST (MOISTURE CONTENT-DRY DENSITY)

WATER CONTENT DETERMIONATION

Compacted Soil - Sample no	1		2		3		4		5	
Moisture can no	E12	D5	L4	F	C2	E12	D5	L4	F	C2
Mass of empty, can + lid(g)	26.6	19	26.5	26.6	26.5	26.6	19	26.5	26.6	26.5
Mass of can, lid & moist soil (g)	53.1	56.4	68.4	50.1	55.1	53.1	56.4	68.4	50.1	55.1
Mass of can, lid & dry soil (g)	52.4	55.8	65.4	49.5	53	52.4	55.8	65.4	49.5	53
Mass of dry soil (g)	25.8	36.8	38.9	22.9	26.5	25.8	36.8	38.9	22.9	26.5
Mass of pore water (g)	0.7	0.6	3	0.6	2.1	0.7	0.6	3	0.6	2.1
Water content, w%	2.71	1.63	7.71	2.62	7.92	2.71	1.63	7.71	2.62	7.92
Average Water content, w%	2.17		5.17		8.32		9.97		15.51	

DENSITY DTERMINATION

Mould Volume (cm^3)	950	**Mass of Mould (1939)**			
Compacted Soil - Sample no	1	2	3	4	5
Mass of compacted soil and mould(g)	3732.5	3851.9	4001.6	4021	4013.6
Wet mass of soil (g)	1793.5	1912.9	2062.6	2082	2074.6
Wet density, ρw , (g/cm3)	1.89	2.01	2.17	2.19	2.18
Dry density, ρd , (Mg/m3)	1.85	1.91	2	1.99	1.89



MDD 2.0(Mg/cm^3) **OMC** (8.32%)

TEST BY	Aliyu Hassan		
Project	MTech, 2019	Depth (m)	0.5-1
Sample No	4M	27/09/2019	

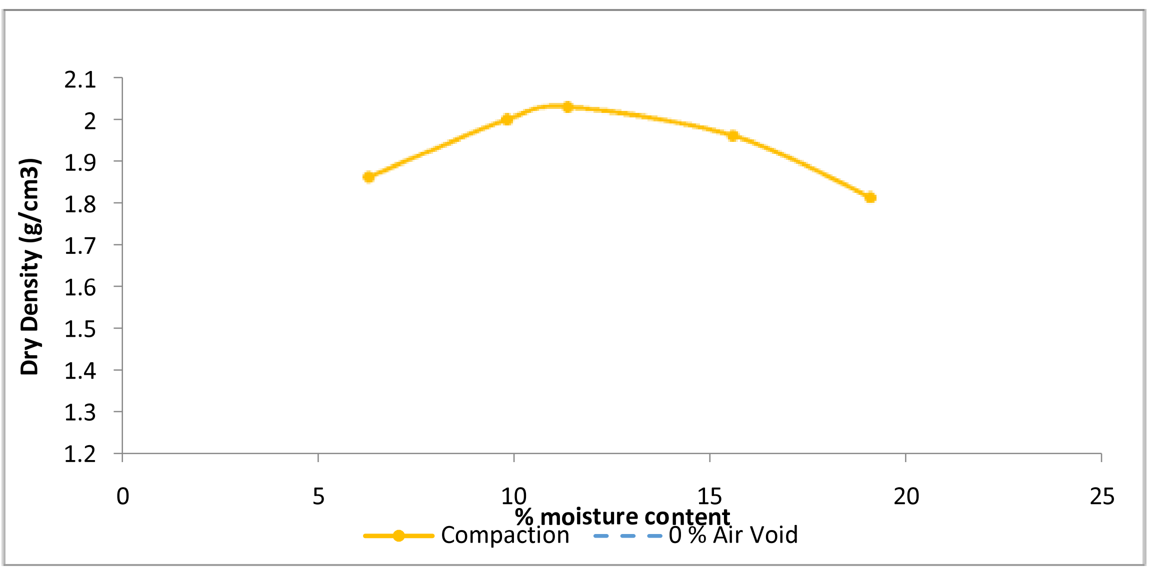
COMPACTYION TEST (MOISTURE CONTENT-DRY DENSITY)

WATER CONTENT DETERMIONATION

Compacted Soil - Sample no	1		2		3		4		5	
Moisture can no	B4	D3	A10	O	M	B4	D3	A10	O	M
Mass of empty, can + lid(g)	19	26.6	19	26.7	19	19	26.6	19	26.7	19
Mass of can, lid & moist soil (g)	68.3	62.9	59	87.3	57.8	68.3	62.9	59	87.3	57.8
Mass of can, lid & dry soil (g)	65.6	60.6	55.6	81.6	53.4	65.6	60.6	55.6	81.6	53.4
Mass of dry soil (g)	46.6	34	36.6	54.9	34.4	46.6	34	36.6	54.9	34.4
Mass of pore water (g)	2.7	2.3	3.4	5.7	4.4	2.7	2.3	3.4	5.7	4.4
Water content, w%	5.79	6.76	9.29	10.4	12.8	5.79	6.76	9.29	10.4	12.8
Average Water content, w%	6.28		9.84		11.38		15.63		19.15	

DENSITY DTERMINATION

Mould Volume (cm^3)	950	**Mass of Mould (1939)**			
Compacted Soil - Sample no	1	2	3	4	5
Mass of compacted soil and mould(g)	3820.3	4032.3	4083.6	4096.9	3988.1
Wet mass of soil (g)	1881.3	2093.3	2144.6	2157.9	2049.1
Wet density, ρw , (g/cm3)	1.98	2.2	2.26	2.27	2.16
Dry density, ρd , (Mg/m3)	1.86	2	2.03	1.96	1.81



MDD (2.03Mg/cm^3), **OMC** (11.38%)

TEST BY	Aliyu Hassan		
Project	MTech, 2019	Depth (m)	1-1.5
Sample No	4B	27/09/2019	

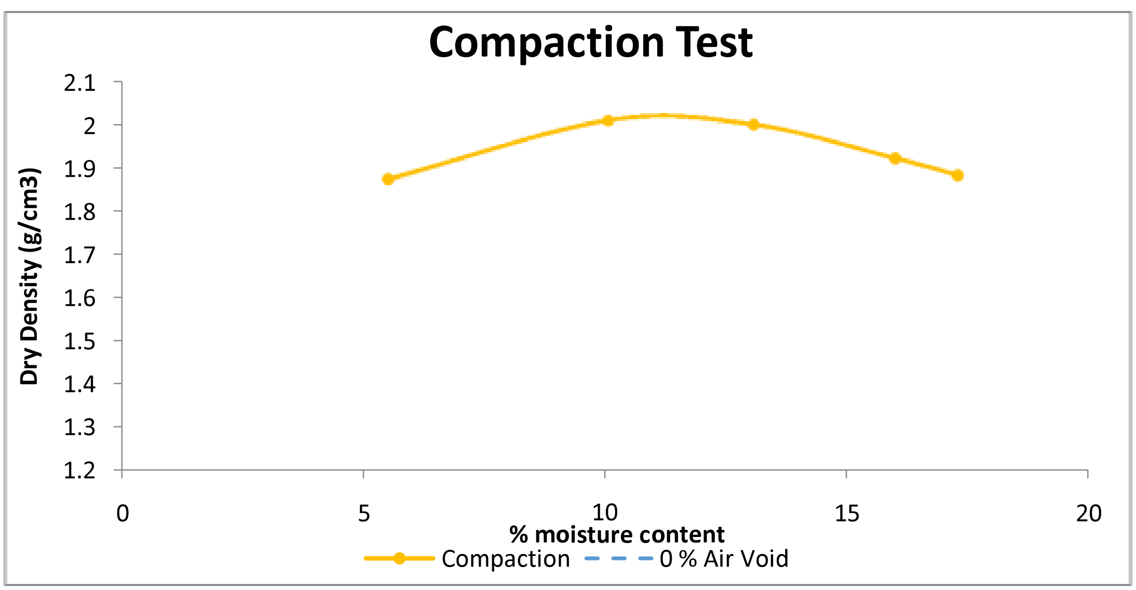
COMPACTYION TEST (MOISTURE CONTENT-DRY DENSITY)

WATER CONTENT DETERMIONATION

Compacted Soil - Sample no	1		2		3		4		5	
Moisture can no	B13	M3	F3	A8	N1	B13	M3	F3	A8	N1
Mass of empty, can + lid(g)	19	26.6	19	26.7	19	19	26.6	19	26.7	19
Mass of can, lid & moist soil (g)	67.3	63	58.4	87.3	56.8	67.3	63	58.4	87.3	56.8
Mass of can, lid & dry soil (g)	65.6	60.5	54.9	81.6	52.7	65.6	60.5	54.9	81.6	52.7
Mass of dry soil (g)	46.6	33.9	35.9	54.9	33.7	46.6	33.9	35.9	54.9	33.7
Mass of pore water (g)	1.7	2.5	3.5	5.7	4.1	1.7	2.5	3.5	5.7	4.1
Water content, w%	3.65	7.37	9.75	10.4	12.2	3.65	7.37	9.75	10.4	12.2
Average Water content, w%	5.51		10.07		13.09		16.04		17.34	

DENSITY DTERMINATION

Mould Volume (cm^3)	950	Mass of Mould (1939)			
Compacted Soil - Sample no	1	2	3	4	5
Mass of compacted soil and mould(g)	3810.6	4040	4084.7	4059.5	4038.5
Wet mass of soil (g)	1871.6	2101	2145.7	2120.5	2099.5
Wet density, ρw , (g/cm3)	1.97	2.21	2.26	2.23	2.21
Dry density, ρd , (Mg/m3)	1.87	2.01	2	1.92	1.88



MDD (2.01Mg/cm^3) **OMC** (10.07%)