# GEOGRAPHIC INFORMATION SYSTEM-BASED IRRIGATION SUITABILITY EVALUATION OF LAPAI-AGAIE IRRIGATION SCHEME, NIGER STATE, NIGERIA.

**By**

**JANKARO, Larai Saleh**
**PhD/SAAT/2016/956**

**DEPARTMENT OF SOIL SCIENCE AND LAND MANAGEMENT**
**FEDERAL UNIVERSITY OF TECHNOLOGY**
**MINNA**

**AUGUST, 2023**

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**A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHYLOSOPHY (PhD) IN SOIL CONSERVATION AND WATER MANAGEMENT**

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**ABSTRACT**

Irrigation is one of the most important inputs for an efficient and sustainable agricultural production. Many farmers are out of jobs during the dry season and prices of locally produced food are high as a result of food scarcity during this period. The objective of this study was to map potential irrigable areas based on soil physical properties and slope of the study area. To evaluate the land suitability for irrigation, parametric evaluation system was applied, using soil and land characteristics. Suitability classes were defined considering the value of suitability index. The overall soil suitability was estimated using the weightage of each factor (slope, soil pH, soil texture, Infiltration rate, Organic carbon, Effective soil depth, Available water capacity, Cation Exchange Capacity, exchangeable sodium percentage and drainage) to obtain potential irrigable sites. The ratings were selected for different qualities. Suitability classes were defined considering the value of suitability index. Land suitability index was calculated based on ratings of all factors using the equation of Rabia method of parametric evaluation system. The data were combined using a multi-criteria decision approach to select suitable sites for irrigation. Landsat imagery with 30m resolution was used for the overall land suitability classification. Using an overlay tool in ArcGIS 10.1, overlay (weighted) analysis of the above factors was performed to generate thematic maps for each factor to develop Land Suitability maps of the study site. The GIS maps after weighting maps of all the factors in Lapai-Agaie 1 shows 28.08 ha out of 86 ha of Lapai-Agaie 1 was marginally suitable for irrigation, 20.29 ha was moderately suitable and a small portion (3.6 ha) of the mapping unit was highly suitable. Marginally suitable class covered the largest area (52.46 ha out of 62 ha) of Lapai-Agaie 2. Lapai-Agaie 3 which occupies 52 ha of the study site had the largest portion (44.64 ha) of the mapping unit as moderately suitable (S2), followed by marginally suitable and a smaller portion (3.7 ha) was highly suitable. Generally, this study shows that sprinkler and drip irrigation will be preferable to surface irrigation since these irrigation methods were suitable for undulating slope without requiring land grading and may be reliable in improving yield. The effective soil depth, slope, organic matter and available water capacity were factors that posed a threat to surface irrigation suitability in the mapping units of the study site. Land suitability map would help in developing land use plans and formulating environmental planning policies that can enhance the development of agriculture and help in improving food insecurity in Nigeria. It was recommended that GIS system should be adapted when evaluating the suitability of soils for irrigation. Sprinkler and drip irrigation methods will be more profitable in the study site. Organic matter application will be required to improve the organic matter content of the soil.

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# CHAPTER ONE

# 1.0 INTRODUCTION

## 1.1 Background to the Study

Soil is an important factor in determining the suitability of an area for agriculture and irrigation (Sultan, 2013). Agriculture is the largest global consumer of water (Tadele and Zewde, 2021). All plants require water for their survival as it is essential for their growth and development (Emmanuel, 2020). Irrigation is one of the most important inputs for efficient and sustainable agricultural production (Praharaj *et al.*, 2016). Irrigation is used to assist in the growing of agricultural crops, maintenance of landscapes and re-vegetation of disturbed soils in dry areas and during periods of inadequate rainfall. It is a powerful tool for boosting the economy. It influences market prices thereby stabilizing farm economy (Delphine and David, 2019). However, food production via irrigated agriculture does not match the current rapid population growth (Bagherzadeh and Paymard, 2015). Irrigated lands produce approximately 40 % of the world's agricultural output (Albaji *et al.*, 2008), but only 4 % of Africa's total cultivated area is irrigated (Kadigi *et al.*, 2019).

Providing comprehensive, reliable and timely information on land suitability is very important in order to ensure food security (Tadele and Zewde, 2021). A piece of land without determination of its suitability has serious consequences and inadequate information of the degree or extent of its suitability constitutes a setback on the achievement of global security, particularly in developing economies such as Nigeria (Biag and Aldosan, 2013).

Land suitability is the process of evaluating and classifying specific areas of land based on their suitability for specific uses (Yonas *et al.*, 2022). Land suitability analysis is a method of land evaluation which allows identifying the main limiting factors of a crop production (Halder, 2013). At the same time, it enables decision makers to develop a crop management system for increasing land productivity. In order to manage land resources properly, land suitability classification is often conducted to determine the type of land use that is most appropriate for a location (Bodaghabadi *et al.*, 2015). Evaluation of land resources in an irrigation command area is a prerequisite for optimum utilization of land resources. Land suitability is essential for developing land use maps based on irrigation potential (Diallo *et al.*, 2016).

Computer based systems and tools help the decision maker to manage irrigation system quickly and efficiently. Few computer-based tools/systems have become popular among irrigation experts and authority. These tools were effectively applied in the past for irrigation management. Irrigation potentials can be assessed by incorporating Multi-Criteria decision analysis in the ArcGIS environment and employing the weight overlay rule (Hussein *et al.*, 2019; Gurara, 2020). The soil, terrain feature (Digital Elevation Models and its derivatives) and land use classification criteria are the basis used to define the suitability. Soil properties vary from place to place; therefore, the knowledge of soil chemical and physical characteristics is a vital criterion for land suitability analysis and mapping (Getachew and Solomon, 2015). Most of the data related to irrigation management are complex and spatially distributed in nature.

Geographic Information System is a very effective tool that can provide information to farmers and irrigation professionals in form of maps. These maps can be easily understood by farmers, planners and specialists for irrigation planning, management and research, providing information most effectively and accurately. It is a valuable tool to store, retrieve and manipulate huge amounts of data needed to compute and map different quality indices for land suitability (El Baroudy, 2016). It is important in managing and displaying spatial data and can be employed for decision making and management functions that lie at the heart of the planning and management of any irrigation scheme. Multiple-criteria decision making (MCDA) methods include the analytical hierarchy process (AHP), Topsis, Electre and Grey theory. Analytical Hierarchy Process is a Multiple-criteria decision making (MCDA) method used for assessing and analyzing land-use suitability (Yonas *et al.*, 2022).

With the rapid advances in computer technology, water agencies and researchers around the world are intensifying efforts to develop generalized computer models/tools for simulating irrigation management. Although, the development of software for improved management of irrigation systems has been moving very slowly as compared to other sectors, in the past, a number of simulation models, irrigation scheduling models and decision supporting system to support irrigation management have been developed (Roque *et al.*, 2020; Gaiqiang *et al.*, 2017; Mannini *et al.*, 2013). Hence, Multiple-criteria decision making (MCDA) methods would be deployed for this research.

## 1.2 Statement of the Research Problem

Farming system in Nigeria can still be regarded as subsistence and it is predominantly rain-fed, which makes it overly subject to weather fluctuations. Irrigated agriculture accounts for only one percent of the cultivated area (Food and Agricultural Organization, 2017). Many farmers are out of job during the dry season and local food prices are on the rise as a result of food scarcity during this period. However, the green revolution requires all-year-round farming. The role of irrigation cannot be ignored as it is the only way to achieve food security. In Nigeria, as in many developing countries, current land use practices are not based on suitability analysis. Increased pressure on the available land resources may result in land degradation. Reliable and accurate land evaluation is therefore indispensable to the decision-making processes that will support sustainable rural development. If self-sufficiency in agricultural production is to be achieved, land evaluation technique will be required for predicting land suitability for irrigated agricultural crops (Bakhtiar and Thomas, 2012). Irrigation represents an alteration of the natural conditions of the landscape by extracting water from  available source, adding water to fields where there was none or little before, and introducing man-made structures and features to extract, transfer and dispose of water (Vidya *et al*., 2013). Many irrigation projects, especially in the developing tropical regions are embarked upon without any land capability assessment, resulting in avoidable and undesirable ecological consequences (Umweni and Ogunkunle, 2014).

Several researchers have carried out irrigation land suitability evaluation using a geographic information system (GIS) in different parts of the world (Yared and Tewodros, 2014; Girma and Abdullahi, 2015; Worqlul *et al.*, 2017). There are small-scale irrigation activities taking place throughout the year close to the study site in Bakajeba, Niger State, but there is no study available which analysed the suitability of the Lapai-Agaie Irrigation Scheme for irrigation. Also, the extent and geographical locations of lands suitable for irrigation have not been identified.

### 1.3 Justification of the Study

Irrigation is an important factor that can boost agricultural productivity. It gives room for utilization of resources, which would otherwise remain idle (Zewdie *et al.*, 2021). The principal purpose of agricultural land suitability evaluation is to predict the potential and limitation of the land for crop production (Pan and Pan, 2012). With increasing demand for land, suitability evaluation of land for irrigation has become more important as people strive to make better use of the limited land resources. With its powerful capacity for management and analysis of spatial data, Geographic Information System has become an important tool in irrigation (Maina *et al.,* 2014), and would be deployed in this study.

Knowledge of the soils within a potential irrigation area is essential for economic and technical reasons. The high cost of development of irrigated agriculture requires justification by assessment of the risks and benefits. The design of an irrigation scheme itself is dependent on detailed knowledge of soils lying within the irrigable area. Proper use of land depends on the suitability or capability of land for specific purposes (Abdelrahman *et al.*, 2016); hence this study.

In agricultural context, finding optimal locations for crops can increase economic benefits, as well as reduce negative environmental consequences (Ashraf *et al.,* 2010). Proper recognition of land abilities and allocation of these to the best and most profitable and stable revenue operation system has special importance for prevention of ecosystem destruction. Excessive use of croplands and the resulting damage necessitates the best land management practices more than ever (Albaji *et al.,* 2009).

## 1.4 Aim and Objectives of the Study

The aim of the study was to carry out a Geographic Information System based irrigation suitability evaluation of Lapai-Agaie Irrigation Scheme and identify potentials of the land for arable crop production. The objectives of the study are to:

i. characterize the soil and topographic properties of the command area;
ii. map potential irrigable areas based on soil characteristics and slope of the command area;
iii. provide an integrated, geo-referenced irrigation suitability database that can be used for attracting irrigation investment opportunities;
iv. recommend appropriate irrigation methods for different sections of the study site;
v. compare the GIS-based method with parametric evaluation method.

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### 2.1 Irrigation Methods

Suitable irrigation method is essential for selecting a good irrigation farming to attain structured water use and to reduce land and water degradation for better nutrient and pesticide control in crop production (Davis *et al*., 2013). However, the practice of irrigation has the prospective to make a major impact on the land and water quality during comprehensive use. The intensive use of water in particular, alters distribution of water throughout the environment and powers transportation of pollutants, compaction, erosion, salinization and waterlogging (Ray *et al*., 2017). Soil and water compatibility are very important under irrigation, where soil acts as sponge to take up and retain water, giving room for infiltration and percolation (Iqbal *et al*., 2020). The basic understanding of soil, water and plant will help farmers during irrigation to effectively manage their crops, soil irrigation systems and water supplies for optimum crop yield. Various irrigation methods have been developed overtime to meet irrigation needs of certain crops in specific areas. The three main methods of irrigation are surface, sprinkler and drip.

#### 2.1.1 Surface irrigation system

Surface irrigation entails water flowing by gravity over the soil surface from water source through canals, pipes or ditches to the field. The efficiency of surface irrigation systems varies tremendously because of variations in soil type, field uniformity, crop type and management (Goncalves *et. al*., 2020). It is considered less efficient than sprinkler and drip irrigation system because of loss by evaporation, percolation and seepage. However, a properly managed surface irrigation system on a uniform soil with a runoff reuse system can approach 90 % application efficiency. In surface irrigation method, when the entire field is flooded, it is called basin irrigation; when the water is fed into small channels it is furrow irrigation, and water applied on strip of land is border irrigation. It is the oldest and still the most widely used method of water application to agricultural lands.

Surface irrigation offers several benefits for the less skilled and poor farmers. Under such circumstances, more than 90% of the world uses surface irrigation, even if local irrigators have least knowledge of how to operate and maintain the system (Kassaye *et al.*, 2019). Further, these systems can be developed at the farm level with minimal capital investment. The major capital investment on surface system is mainly associated with land grading, but if the topography is not too undulating, these costs are not high. Hence, surface irrigation development requires favorable topography and information on land and water resources for proper planning (Mandal *et al.*, 2018). Therefore, planning process for surface irrigation must integrate information about suitability of the land, water resources availability and water requirements of irrigable areas in time and place (Haile and Abebe, 2022). Determining the suitability of land for surface irrigation requires thorough evaluation of soil properties and topography (slope) of the land within field (Fasina *et al*., 2008).

The suitability evaluation for surface irrigation also provides guidance in cases of conflict between rural land use and urban or industrial expansion, by indicating which areas of land covers /uses are most suitable for irrigation (Shitu and Berhanu, 2020). The suitability of land must also be evaluated on condition that water can be supplied to it. The volume of water obtainable for irrigation will depend on the outcome of hydrological studies of surface water. The amount of runoff in river catchments with limited stream flow data can be determined from runoff coefficient of gauged river basin (Ma *et al.*, 2015; Ayele *et al.*, 2017). After the amount of river discharges both gauged and un-gauged are quantified, an important part of the evaluation is the matching of water supplies to water demand (requirement). Irrigation water supplies and their requirements are, therefore, important physical factors in matching the available supply to the requirements. However, these factors should be assessed in an integrated manner, geo-referenced and mapped for surface irrigation development possibilities.

### 2.1.2 Sprinkler irrigation system

Sprinkler irrigation applies water to soil by spraying or sprinkling water through the air on the soil surface. Water is pressurized and delivered to the irrigation system by a mainline pipe, which is often buried so that it does not interfere with farming operations. This irrigation method is used for a wide variety of plants, including field crops, vegetables and pastures (Chapman *et al*., 2012). Sprinkler is often more efficient than surface irrigation because water application is better controlled (Prathyusha and Suman, 2012). In hot and windy areas, sprinklers can have significant water losses to evaporation and wind drift. Maintenance is also important for efficient sprinkler irrigation; worn nozzles and leaking pipe connections can reduce water application uniformity and system efficiency.

### 2.1.3 Drip irrigation system

This irrigation method applies water at low rates and pressures to discrete areas so that irrigation water can reach the root zone with minimal losses (Galande and Agrawal, 2013). Water drip from emitters in plastic pipes or tapes, or sprays from small emitters that only wet a portion of the soil surface. Drip irrigation system are permanently installed systems that irrigate trees, vineyards and shrubs. This system is typically automated so that water is applied frequently to maintain optimum soil water content near the plants. Filtration is important for drip irrigation because sediments and algae can plug the small openings on drip emitters, bubblers and micro-sprays. Chemical treatment may also be necessary to reduce salt or mineral deposits that can plug emitters.

### 2.1.4 Research on the different irrigation methods

Soil evaluation for surface and drip irrigation systems have been used in different countries. Physical and chemical factors of the land are the main parameters that determine irrigation potential of a given land. The attributes are physical and chemical soil factors as slope, soil depth, soil texture, soil drainage and soil salinity, water resource factors as water availability, water quality and distance to water source (Temesgan and Yonas, 2016). The suitability factors that affect surface irrigation are soil, slope, land use and water sources (Abebe, 2014). Vertisols are characterized by their high clay content. They are often dark colored. As a result of their smectite clay mineralogy, they are very hard and crack when dry, but becomes sticky and plastic when wet (Somasundaram *et al.*, 2018). These are chemically rich soils, but they may develop on an undulating micro relief, which hampers mechanization. Vertisols have great agricultural potential, but special management practices are required. Slope is the incline or gradient of a surface and is commonly expressed as a percentage. Availability of water is one of the most limiting factors for implementation of irrigation systems. Water resources are estimated in accordance to three criteria: quantity, quality and location. Together they form water potential (Dagnenet, 2013). Quantities of water required for irrigation are considerable and depend on water deficit, crops and size of the area. All three characteristics must be met in order for water capture to satisfy long-term needs and if only one of them is not met, quantity, quality or accessibility of location, such source of water becomes questionable. Usual sources of water for irrigation are rivers, surface reservoirs, ground water table and in the more recent times various non-conventional sources (Lidija, 2012). Favourable conditions found in open water bodies for capturing of water for irrigation depend on their hydrological regime. It is important not to forget the global trends in the decrease of water quantities, increase of frequency and duration of low water regimes, which also cause droughts (Abebe, 2014).

Albaji *et al.* (2008) carried out a research to compare two different irrigation methods according to parametric evaluation system in an area of 77,706 ha in Shavoor region in Khuzestan province, southwest of Iran. After analyzing and evaluating soil properties by means of Geographic Information System, suitability maps were generated for both methods. The result showed that 14,952 ha of the studied area were highly suitable for drip methods, though not suitable enough for surface irrigation. It was also found that some series covering an area of 27,578 ha were not suitable for both irrigation systems. The main limiting factors in using both surface and drip irrigation methods were soil salinity and drainage.

Bienvenue *et al.* (2003) evaluated land suitability of surface and drip irrigation in the Thies, Senegal, using the parametric evaluation system proposed by Sys *et al.* (1991). Under surface irrigation, there was no area classified as highly suitable (S1). Only 20.4 % of the study area was classified as moderately suitable (S2). The study area had limitation factors of mainly the soil drainage and soil texture, which was sandy, while surface irrigation generally requires heavier soils. For drip irrigation, a good proportion (42.25 ha) of the area was suitable (S2), while 25.03 % was classified as highly suitable (S1) and only a small portion was almost suitable (N1; 5.83 %) or unsuitable (N2; 5.83 %). The limitation was attributed to the shallow soil depth and soil texture due to a large amount of coarse gravel and/or poor drainage. Barberis and Minelli (2005) provided land suitability classification for both surface and drip irrigation methods in Souyang county, Shanxi province, China where the study was carried out using a modified parametric system. The results indicated that due to the unusual morphology, suitability of the area for surface irrigation (34%) was smaller than the area suitable for drip irrigation (62%). The limiting factors included slope and soil depth.

Dengiz (2006) also compared different irrigation methods including surface and drip irrigation in the pilot fields of Central Research Institute, Ikizce research farm located in southern Ankara, Turkey. He concluded that the drip irrigation method increased land suitability by 38% compared to the surface irrigation method. The most important limiting factors for surface irrigation in the study area were soil salinity, drainage and soil texture whereas, the major limiting factors for drip or localized irrigation were soil salinity and drainage. Liu *et al.* (2006) evaluated land suitability for surface and drip irrigation in the Danling county, Sichuan province, China, using parametric evaluation systems. For surface irrigation, the most suitable areas (S1) represented about 24% of Danling county, 33% was moderately suitable (S2), 9% was classified as marginally suitable (S3), 7% of the area was found currently not suitable (N1 and 25% was very unsuitable for surface irrigation due to their high slope gradient. Drip irrigation was everywhere more suitable than surface irrigation due to the minor environmental impact that it caused. Areas highly suitable for this practice covered 38% of Danling county, about 10% was marginally suitable. Only the steeper reliefs of the study area (23%) were unsuitable for such practice.

Kumi-Boateng *et al.* (2016) suggested that GIS based Multi-Criteria Evaluation Land Suitability Analysis (MCELSA) techniques are possible ways of making optimal decisions in selecting suitable land for dam or surface irrigation. GIS based Multi-criteria evaluation (MCE) techniques are the numerical algorithms that define suitability of solution based on input criteria and weights together with some mathematical or logical means of determining trade- offs when conflicts arise. In this technique, weight can be assigned to the geospatial dataset from various sources to reflect their relative importance (Abeyou *et al.*, 2012) and overlaid using GIS-based multi-criteria analysis techniques in the ArcGIS software environment.

## 2.2 Land Use Planning

Land use planning is an iterative process based on dialogue amongst all stakeholders aiming at the negotiation and decision for a sustainable form of land use in rural and urban areas as well as initiating and monitoring its implementation (Merga, 2012). In order to manage land resources adequately, land suitability assessment is often conducted to determine which type of land use is most appropriate for a location (Bodaghabadi *et al.*, 2015). According to Joshua *et al.* (2014), land use planning involves making decisions regarding the use of land resources with the primary aim of achieving best use of land for maximum food production and profit. Yihenew *et al.* (2014) conducted a research at Yigossa watershed, Northwestern Ethiopia to characterize the soils using FAO criteria and evaluate their suitability to cereal crop production. The FAO guideline was used to evaluate land suitability for selected cereal crops and geographical information system (GIS) was employed to analyze and map soils within the watershed. From the results of their study, it was concluded that different soils were variably suitable for different crops. In some cases, the same soil could be suitable for different crops, bringing competing nature of crop land use types for the same parcel of land. However, yield per unit of land and return to investment dictate farmers' decision on land allocation for a particular use.

## 2.3 Land Suitability Classification

Land suitability is the fitness of a given type of land for a defined use. There are two land suitability orders represented by the symbols S (suitable) and N (unsuitable). Land suitability analysis is a method of land evaluation which allows identifying the limiting factor of crop production (Halder, 2013). The principal purpose of land suitability evaluation is to predict the potential and limitation of the land for crop production (Pan and Pan, 2012). Agricultural land suitability assessment for irrigation is defined as the process of land performance assessment when the land is used for alternative kinds of irrigation (Hoseini, 2018). Land evaluation, thus, presents itself as a suitable technique for identifying the different land use options for purposes of decision-making at all levels of governance (Abushnaf, 2014). Land evaluation, using a scientific method, is essential to recognizing the potential and limitation of a given land for specific use in terms of its suitability and certifies its sustainable use. It identifies the level and geographical patterns of biophysical constraints and evaluates potential capacity of land and its sustainable use (Teshome *et al.*, 2017).

### 2.3.1 Land suitability classes

Land suitability classes are subdivisions of suitability orders that indicate the degree of suitability. The classes are; highly suitable (S1), moderately suitable (S2), marginally suitable (S3), unsuitable for economic reasons but otherwise marginally suitable (N1), N2 implies no limitations that cannot be corrected at any cost within the context of the land utilization type.

### 2.3.2 Land suitability subclasses

These are divisions of land suitability classes which indicate not only the degree of suitability but also the nature of limitations that make the land less than completely suitable. Suitability class S1 has no subclasses. The subclass code consists of suitability code, followed by a suffix, which indicates the nature of the limitation. There is a suggested list of suffixes in the guidelines of FAO (1976) as follows; 'S3e': marginally suitable (S3) because of erosion hazard (e), 'S3w': marginally suitable (S3) because of wetness (w).

Abraham *et al.* (2015) conducted a study to evaluate the current and potential suitability of Semaz dam, northern Ethiopia for irrigation purposes. The area was classified into six land mapping units and samples were taken from the representative sites of these land mapping units. The parametric evaluation system and Inverse Distance Weighted (IDW) interpolation provided in Arc GIS 10.1 software were used to perform the land suitability classification. Results of the study showed that the study area was moderately suitable for irrigated vegetable production. Soil texture was the only limiting factor and caused the area to be moderately suitable (S2).

Megersa (2020) carried out a research to evaluate suitable land resource potential for irrigation development for the Katar River watershed in the Rift Valley Basin in Ethiopia by using ArcGIS based on Multi-Criteria Evaluation (MCE) techniques. The steps undertaken were watershed delineation, characterizing the watershed by suitability parameters; such as slope, soil texture, soil depth, drainage classes, proximity to river and urban, land use and land cover. The re-classification and mapping according to suitability classification, identification of irrigable land, and estimation of surface water potential and irrigation water requirements followed. After re-classification, the parameters were classified based on suitability classes for irrigation development. The weighting analysis of all parameters showed that 34.08% was classified as highly suitable (S1), 58.08% was moderately suitable (S2), 3.8% was marginally suitable (S3), whereas 3.21% was not suitable (N) for surface irrigation development. The slope analysis indicated that about 41.34% of the watershed was covered with less than 2% slope class and 93.13% was covered with less than 8% slope and the land classified as highly suitable to marginally suitable for surface irrigation. Land area with slope greater than 8% was only 6.87% of the watershed area and was rated as permanently not suitable for irrigation. According to slope suitability classification for surface irrigation, most of the area of Katar River watershed was found to be suitable for surface irrigation regarding its work efficiency and cost of land leveling, canal construction and value for saving pumping system. In the same research, highly suitable (S1) was characterized by clay to clay loam soil texture, greater than 2 m soil depth and excellent soil drainage. It covered 34.91% of the study area. The moderately suitable class (S2) covered 58.08% in the study area and comprised of soil type having clay loam to sand clay loam soil texture, with a soil depth of 1 to 1.4 m, and moderate soil drainage. The limiting factor was drainage condition of these soils while the other factors were optimum for surface irrigation. Marginally suitability class (S3) covered around 3.8% of the total area of the watershed having sandy loam, with a soil depth of 50 - 100 cm and moderate soil drainage. Lastly, 3.21% of the study area were constrained by shallow soil depth and water bodies while other factors were optimum for surface irrigation. Majority of the soils of the Katar river watershed were found to be suitable for surface irrigation.

### 2.4 Parametric Methods of Land Suitability Assessment

Land suitability assessment methods can be divided into relative limitation scale approach and parametric approach. Parametric methods are widely used for land suitability evaluation. The parametric evaluation method is a technique that is based on morphology, physical and chemical properties of the soil (Ma *et al*., 2015). The properties considered include slope, drainage properties, soil texture and soil depth. Many researchers have conducted studies to compare studies between the different land suitability assessment methods. The outcome of the different land suitability assessment methods usually correlated with each other (Ashraf, 2010), the square root parametric method commonly gives higher results than the storie method. Sys *et al.* (1991) suggested a parametric evaluation system for irrigation methods which is primarily based upon physical and chemical soil properties. In the system, the factors affecting the soil suitability for irrigation purposes were subdivided into four groups; physical properties determining the soil-water relationship in the soil; such as permeability and available water content, chemical properties interfering with the salinity/alkalinity status; such as soluble salts and exchangeable sodium, drainage properties and environmental factors such as slope.

#### 2.4.1 Storie index

This is a method of soil rating based on soil characteristics that govern the potential utilization of land and productivity capacity. It was developed by Earl Storie at the University of California in the 1930s as a method that is independent of other physical or economic factors that might determine the desirability of growing certain plants in each location. The disadvantage of this method is that, if there is a value of zero in any category, then the result will be zero and will not be suitable for use. Another disadvantage is that the ratings are subjective (O'Geen *et al*., 2008). Storie index rating has been combined into six grade classes as follows: grade 1 (excellent), 100 to 80; grade 2 (good), 79 to 60; grade 3 (fair); 59 to 40; grade 4 (poor), 39 to 20; grade 5 (very poor), 19 to 10; and grade 6 (non-agricultural), less than 10.

Ali *et al.* (2020) evaluated land suitability for cultivating different crops in some soils of the Eastern part of Sohag Governorate, Egypt. The results of the study showed that, soils of the studied site ranged between poor to fair capability (using Storie index) and from very poor to fair capability (using Sys and Verheye index). Regarding soil suitability evaluation using the parametric method, the studied area ranged between marginally suitable (S3) and moderately suitable (S2) for cultivating wheat, maize, alfalfa, tomato, olives, and mango. Using the ALSE model, the soils ranged from non-suitable (N1) to moderately suitable (S2) for cultivating the evaluated crops. The limitations of these soils were soil texture, Ece and soil organic matter.

Vargahan *et al*. (2011) carried out a study to compare four land suitability methods (simple limitation, limitation regarding number and intensity, storie and square root). The study revealed that square root parametric method is better and more commonly used in qualitative evaluation. However, from the result, it was clear that the predicted values were always lower than the observed values. This gave the impression that both storie and square root parametric methods underestimates potentiality of the investigated land. The study also recommended that utilizing the outcome of this method in qualitative evaluation gives more realistic results.

The formula for this method is presented below

$$Si = A \times \frac{B}{100} \times \frac{C}{100} \times \frac{\text{D}}{100} \times \ldots$$

Where, Si is suitability index, A is the rating value for texture parameter and B, C, D are the remaining rating values for other parameters (Storie, 1978).

### 2.4.2 Square root method

This is a method which takes into consideration the entire land characteristics, but important consideration is given to the most limiting factor least scored among the parameters. It is represented by the formula below

$$Si = Rmin \times \sqrt{\frac{A}{100} X \frac{B}{100}} X \frac{C}{100} X \ldots$$

Where, Si is suitability index, Rmin is the minimum rating value of the parameters, and A, B, C are the remaining rating values for other parameters (Khiddir, 1986).

### 2.4.3 Rabia equation method

Rabia and Fabio (2013) introduced a new parametric concept (Rabia equation) of land suitability evaluation. The study compared result of the proposed method with two parametric methods; storie and square root methods. In the study, a land suitability assessment for wheat production was employed in order to compare the results of the three parametric methods. The results showed that in all land units in the study area, land suitability index was higher in case of Rabia method. The final suitability index value of the equation was based on the factor that had the maximum influence on land suitability with regards to other factors. In general, the result revealed that employing the outcome of the proposed method could give more realistic results. Below is the formula for Rabia and Fabio (2013) method;

$$Si = Wmax \times \sqrt{\frac{A}{100} X \frac{B}{100}} X \frac{C}{100} X \ldots$$

Where, Si is suitability index, Wmax is the rating value of the parameters that has the maximum weight and A, B, C are the remaining rating values for other parameters (Rabia and Fabio, 2013).

Rabati *et al.* (2012) conducted a research to evaluate qualitative and quantitative land suitability for the north-west of Iran based on FAO model for sunflower and maize. Qualitative evaluation was carried out using the square root of parametric method and quantitative evaluation was performed based on observed yield under an average management level. The results from their findings showed that in the surveyed area, climate was moderately suitability (S2) for maize. The major limitation factors were soil parameters like pH, $CaCO_3$, texture and coarse fragments, as well as topography and drainage in the study area.

## 2.5 Factors of Land Suitability Assessment

The land may be classified in its present condition or after improvement for its specified use. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (Rabia *et al.*, 2013). Land evaluation is primarily the analysis of data about the land, its soils, climate, vegetation, and so on in terms of realistic alternatives for improving the use of that land. For irrigation, land suitability analysis, attention is given to the physical properties of the soil, to the distance from available water sources and to the terrain conditions in relation to methods of irrigation considered (FAO, 2007). Below are some of the factors considered for land suitability evaluation.

### 2.5.1 Soil texture

Soil texture is an important factor of soil physical analysis for surface irrigation suitability evaluation (Weldeabzgi *et al.*, 2021). Soil textural characteristics, specifically the percentage clay and sand, affect infiltration, because they determine whether infiltration rate is dominated by gravity forces or capillarity forces, under a given rainfall intensity. Infiltration is gravity- driven in coarse-textured soil and capillarity- driven in fine-textured soil (Rahmati *et al.*, 2022) and is higher in the former than in the latter (Godwin and Dresser, 2003). In addition, soil texture directly affects soil moisture redistribution through its effect on soil permeability, which expresses how easily water flows through the soil, as well as the water holding capacity and ultimately the infiltration rate. Soil structure and its surrogate, soil aggregates, influence infiltration characteristics and have been used as a good indicator of changes in soil physical and biological properties (Bonettu *et al.*, 2021). Well-structured soils have optimum infiltration rates at varying moisture levels. Amusan and Anderson (2005) found that soil texture and infiltration rate declined due to changes in vegetation and soil structural characteristics in south-western Nigeria. Similar research results have been reported in south-eastern Nigeria. Eze *et al.* (2011) observed that the infiltration rate of a sandy soil under forest was higher than under sparse vegetation and bare cultivation. Also, Osuji *et al.* (2010) reported significant relationships between steady infiltration rates and soil organic matter, bulk density and total porosity. Medium-textured soils developed in uniform deposits are most desirable for irrigation. The degree to which soil texture deviates from this optimum determines their suitability for sustained irrigated agriculture.

### 2.5.2 Slope

Land slope is the most important topographical factor influencing land suitability for irrigation. The slope gradient of the land has great influence on selection of the irrigation methods and agricultural machine use. Slopes which are less than 2 % are very suitable for surface irrigation but slopes which are greater than 8 % are not generally recommended because they tend to runoff rather than reach the crop root zone. (Danbara and Zewdie, 2022).

Temesgen and Yonas (2016) conducted a study on land suitability for irrigation purpose in Abaya district, Ethiopia, on existing cultivated lands. Land evaluation was determined based on topography and soil characteristics. The topographic characteristics included slope. The result of land suitability of study area for the development of surface irrigation system indicated that 9.32 % (1,303 ha) was highly suitable, 32.5 % (4558 ha) were moderately suitable, 23.82 % (3,335 ha) marginally suitable and 34.30 % (4,802 ha) not suitable.

Slope gradient can affect the suitability of the land for surface irrigation in terms of land preparation for irrigation, moisture retention and erosion risk. The findings in the research of Asfaw *et al*. (2019) revealed that the steep slopes result in the less agricultural productivity. The general results from their research showed that physical factors like slope, soil depth, drainage, texture, highly determined the suitability of land for surface irrigation within the study area which was in line with the work of Albaji *et al*. (2009); Kassaye *et al*. (2019). From the research of Tadele and Zewde, (2021), slope was classified into four categories for surface irrigation namely: 0-2% as highly suitable (S1), 2-5% as moderately suitable (S2), 5 - 8 % as marginally suitable(S3) and >8% as not suitable (N2). Getachew and Solomon (2015) carried out a research on land suitability analysis for rice production in west central highlands of Amhara region, Ethiopia. The study was based on topography, soil physical and chemical properties of the study area. Their findings showed that highly suitable areas were characterized by slope level between 0 – 4 %. The result also showed that a considerable amount of the total area was marginally suitable (S3), with slope as the main limitation. Generally, areas classified as not suitable (N) were in mountainous areas with slope level of > 20 %.

### 2.5.3 Drainage

Soil drainage is one of the most important parameters for surface irrigation potential assessment. Drainage ensures that the soil is properly aerated. If you have excess water, there will be imperfect air circulation. Drainage reduces soil and nutrient loss from runoff and can help avoid soil erosion. Well-drained soils are good for agriculture and easy for cultivation, aeration, and crop nutrient. Good drainage of the site is essential to allow the continuous movement of water and salt through the profile (Nosetto *et al.*, 2012). From the research of Asfaw *et* al. (2019) on the suitability of Dirma river basin in Ethiopia, two soil drainage classes (well drained and imperfectly drained) were identified in the study area. Areas with high slope were under the well-drained soil class. Imperfectly drained soils were linked to lowlands (<5 %) of the river basin, mainly found under 0 – 2 % slopes. Soil drainage of the watershed (all land units) was classified as moderately drained.

Lawal *et al.* (2014) assessed some properties of basement complex rocks derived soils under a young teak (*Tectona grandis*) plantation in Minna, southern Guinea savanna of Nigeria. Three soil profiles sited at the upper, middle and lower slope positions along a toposequence were studied. Soil samples collected from their genetic horizons were analysed. Results showed that the colour of surface horizon differed. The upper horizon had very dark gray (10YR3/1), the middle had very dark brown (10YR 2/2) while the lower slope position was characterized by dark yellowish brown (10YR 3/4) coloration.

### 2.5.4 Available water capacity

Soil water is one of the principal factors limiting the growth of plants not only in the arid and semi-arid environment where total crop water requirement usually exceed water supply, but also in the sub-humid environment where poor rainfall distribution and water management result in occasional water stresses (Musa and Adeoye, 2010). An important soil ecosystem function is the enhancement of soil water storage and minimization of runoff and erosion (Lal and Shukla, 2005). This process is controlled by soil biophysical interacting forces which create a stable soil structure with enough macro-pores to rapidly transmit water. However, soil that is continually disturbed by tillage and other anthropogenic activities often loses its resilience and develops poor structural characteristics, including surface sealing and crusting, and consequently reduced infiltration and high runoff and erosion. This is because intensified land use primarily affects soil's intrinsic and dynamic properties including soil structure and structure-moderated soil properties.

### 2.5.5 Effective soil depth

Depth of soil profile from the top to parent materials or bedrock or layer of obstacles for roots is very important for the identification of land suitable for irrigation. The effective depth of a soil for plant growth is the vertical distance into the soil from the surface to a layer that essentially stops the downward growth of plant roots. It is also the thickness of the soil materials which provide structural support, nutrients and water for plants (Brantley *et al.*, 2017). Asfaw *et al.* (2019) conducted a study on GIS-Based surface irrigation potential assessment for Ethiopian river basin. In their study, the soil depth in the river basin varied from <25 to >150 cm. Further, the soil depth was reclassified into four classes (<50, 50–100, 100–150 and >150 cm). it is evident that most of the southern and central part of the river basin soil was categorized as highly to moderately suitable (73%) and the northern part is classified as not a suitable class for the use of surface irrigation development.

Kassaye *et al.* (2019) studied a GIS-Based multi-criteria land suitability analysis for surface irrigation along the Erer Watershed, Eastern Hararghe Zone, Ethiopia. Out of the total area of watershed which was 386,731 ha, a small portion of about 45,080 ha (11.7%) was assessed as highly suitable for surface irrigation due to factors such as gentle slope (0–2%), absence of obstacle to root up to 80 cm depth, absence of impermeable layer within 150 cm soil depth and soil depth greater than 100 cm. The barrier layer may be rock, sand, gravel, heavy clay, or a cemented layer.

Soils can be classified as very shallow (less than 25 cm), shallow (25 – 50 cm), moderately deep (50 – 90 cm), deep (90 – 150 cm) and very deep (more than 150 cm). Deep soils can hold more plant nutrients and water than can shallow soils with similar texture (Teshome and Halefom, 2020). Depth of soil and its capacity for nutrients and water frequently determine the yield from a crop, particularly annual crops that are grown with little or no irrigation. Plants growing on shallow soils also have less mechanical support than those growing in deep soils. Trees growing in shallow soils are more easily blown over by wind than are those growing in deep soils.

### 2.5.6 Infiltration rate

Infiltration is the entry of water into the soil through its surface (Lal and Shukla, 2005). Its rate is the flux density of water flowing into the soil per unit soil surface area and cumulative infiltration is the total quantity of water that enters the soil in each time. Infiltration is a primary factor in soil hydrology because it determines the amount of runoff during a rainstorm and the amount of water stored in the root zone and groundwater recharge (Pla, 2007). Bormann and Klassen (2008) and Haghighi *et al.* (2010) attributed changes in infiltration rates to soil hydraulic properties, porosity, soil organic matter, bulk density and different land use practices. Quantification of infiltration is necessary to determine the availability of water to crops and to estimate the amount of additional water needed for irrigation. Soil infiltration rate is the most essential process that affects the surface irrigation uniformity and efficiency because of its mechanism of transfer and distribution of water from surface to soil profile (Rashidi *et al.,* 2014). The measurement of infiltration of water into the soil is an important indication concerning the efficiency of irrigation and drainage, optimizing the availability of water for plants growth and metabolism, improving the yield of crops and minimizing erosion (Adeniji *et al.,* 2013).

Chen *et al.* (2003) studied water infiltration rate in cracked paddy soil surfaces of paddy fields of Loess plateau in China and found that a cracked paddy field has significantly increased rate of infiltration. Lake *et al.* (2009) developed the various pedo-transfer functions (PTFs) for Guilan Province of Iran to predict soil physico-chemical and hydrological characteristics using multi-layer perceptron (MLP), a feed forward artificial neural network (ANN) method. They found that ANN method was more accurate than multiple linear regression (MLR) method for the estimation of infiltration rate. Joshi and Tambe (2010) measured the effect of slope and grass-cover on infiltration rate, runoff and sediment yield under simulated rainfall condition in upper Pravara Basin in western India. They found the highest infiltration for grass covered area with gentle slope, and minimum for bare land surface with steep slope.

Hajiaghaei *et al.* (2014) estimated the infiltration rate using double-ring infiltrometer and predicted soil infiltration rate based on silt and clay content of soil. They developed a relation between soil infiltration rate and soil properties (silt and clay content). They found that double-ring infiltrometer was better than single ring infiltrometer. The knowledge about infiltration of water into soils is an important indication concerning the efficiency of irrigation and drainage, optimizing the availability of water for plants, improving the yield of crops, minimizing erosion and wastage of water. Double-ring infiltrometer test is often used for the measurement of infiltration rate, which is time consuming and laborious and practically difficult, particularly in the hilly terrain. This can be accomplished by the development of models based on the easily measurable soil properties because soil properties influence infiltration characteristics (Ghanshyam *et al.*, 2018). Rashidi *et al.* (2014) carried out a field experiment at the agricultural fields of Karaj (Iran) and developed a relation between soil infiltration rate and physical properties of soil. They predicted infiltration rate using silt content and clay content, bulk density (BD), organic matter (OM), and moisture content (MC) of soil.

Adeniji *et al.* (2013) estimated soil infiltration rate using soil texture at the University of Maiduguri, Nigeria. Azuka *et al.* (2013) evaluated the soil infiltration characteristics in South-Eastern Nigeria and predictions were done using the effect of organic matter content, micro-porosity, bulk density, coarse sand, silt and clay contents of soil. They reported that these soil properties had great influence on the infiltration characteristics of soils. The degree of soil organic matter stratification with depth has been suggested as an indicator of soil quality because surface organic matter is essential to control erosion, water infiltration, and conservation of nutrients (Franzluebbers, 2002).

### 2.5.7 Organic matter

Organic matter is the material in soil that is directly derived from plants and animals. It supports most important micro-fauna and micro-flora in the soil. Through its breakdown and interaction with other soil constituents, it is largely responsible for much of the physical and chemical fertility of a soil (Charman and Roper, 2007). Soil organic matter is a term that is usually used in broad sense to describe a wide range of organic components in the soil including living and non-living organic materials. The non-living organic matter can be broken down into dissolved organic matter, particulate organic matter, humus and inert organic matter (charcoal and charred plant materials). Organic carbon (C) refers to the carbon component of organic matter, which is about one-half the mass of organic matter. Organic matter is an important constituent of soils because it has a high capacity for absorbing water, nutrients and some agricultural chemicals such as herbicides. It also binds mineral particles together to form stable aggregates that give the soil favorable physical properties (Gizachew, 2014). There is a general relationship between the organic matter content of the surface horizon of a soil and its color and texture. One of the major suitability limitations reported for these soils were low organic matter and acidic pH. Another study in Iran also indicated that soils with low organic matter were non-suitable for maize production (Ali *et al*., 2020). Organic matter (OM) and organic carbon (OC) are usually expressed as a percentage of the soil by weight. When results are presented and interpreted, care should be taken to note whether organic matter or organic carbon levels are indicated.

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Nemes *et al.* (2005) investigated the influence of organic matter on the estimation of saturated hydraulic conductivity. Their results showed a strong negative relationship between organic matter and saturated hydraulic conductivity. The researchers justified the fact that organic matter retains soil water well and does not allow water to flow freely. On the other hand, organic matter may also affect the pore size distribution of the soil through soil structural development which also affects soil hydraulic conductivity.

### 2.5.8 Soil salinity and sodicity

Sodicity occurs when exchangeable sodium on the cation exchange complex leads to clay dispersion in the soil. Sodic soils have the following problems: very severe surface crusting, very low infiltration and hydraulic conductivity, hard sub-soils, high susceptibility to severe gully and tunnel erosions (Hazelton and Murphy, 2016). The level of exchangeable sodium can be determined directly by measuring the concentration of all the exchangeable cations in the soil and expressing the amount of exchangeable sodium ($Na^{2+}$ cmol/kg), as a proportion of the sum of all the exchangeable cations known as cation exchange capacity (CEC). This proportion is called exchangeable sodium percentage (ESP). Three categories of sodicity corresponding to ESP values are as follows; 0 – 5 % is non sodic, 5 – 10 % is marginally sodic to sodic, and greater than 10 is strongly sodic. It is calculated using the formula below;

$$\mathrm{ESP} = \frac{\text{Exchangeable } Na^{+} \text{ (cmol } kg^{-1}\text{)}}{\text{Cation Exchange Capacity (cmol } kg^{-1}\text{)}} \times 100$$

### 2.5.9 Cation exchange capacity (CEC)

Cation exchange capacity is the capacity of the soil to hold and exchange cations. It provides a buffering effect to changes in pH, available nutrients, calcium levels and soil structural changes. As such, it is a major controlling agent of stability of soil structure, nutrient availability for plant growth, soil pH and the soil's reaction to fertilizers. A low CEC means the soil has a low resistance to changes in soil chemistry that are caused by land use. The CEC units are usually expressed as centimoles of positive charge per kg of soil [cmol(+)/kg)], which is numerically equivalent to the previously used unit of milli-equivalents per 100 g (me/100 g). The CEC is usually estimated by displacing exchangeable cations (Na, Ca, Mg, K) with another strongly adsorbed cation and then determining how much of the strongly adsorbed cation is retained by the soil. The strongly adsorbed cation is supplied by reagents such as ammonium chloride, ammonium acetate, silver thiourea, barium chloride and potassium chloride. Soils with CEC less than three are often low in fertility and susceptible to soil acidification. The CEC is rated as follows; <6 cmol $kg^{-1}$ is rated as very low, 6–12 cmol $kg^{-1}$ is low 12–25 cmol $kg^{-1}$ is moderate, 25–40 cmol $kg^{-1}$ high, and >40 cmol $kg^{-1}$ very high.

### 2.5.10 Soil pH

Soil pH is described as the "master soil variable" that influences myriads of soil biological, chemical, and physical properties and processes that affect plant growth and biomass yield. Dora (2019) in his paper discussed how soil pH affects processes that are interlinked with biological, geological and chemical aspects of soil environment and how these processes induce changes in soil pH. Unlike traditional discussions on the various causes of soil pH, particularly soil acidification, this paper focused on relationships and effects as far as soil biogeochemistry is concerned. Firstly, the effects of soil pH on substance availability, mobility and soil biological processes were discussed followed by the biogenic regulation of soil pH. It was concluded that soil pH can be applied in two broad areas, i.e., nutrient cycling and plant nutrition and soil remediation (bioremediation and physicochemical remediation).

Temesgen and Yonas (2016) conducted a study to evaluate land suitability for irrigation purpose in Abaya district, Borena zone, Ethiopia. One of the soil factors used as criteria for irrigation suitability analysis was soil pH. The soil pH ($H_2O$) values were found in the range of 5.6 to 6.3. Values of soil pH generally showed a slight increasing pattern with depth of the studied profiles. However, for both surface and subsoil horizons, soil pH values were below 7 and rated as weakly acidic to slightly acidic in reaction. Dagnenet (2013) conducted a research on assessment of irrigation land suitability and development of map for the Fogera catchment in south Gondor, Egypt, using GIS techniques. Soil pH results from the laboratory analysis showed that the average soil pH ($H_2O$) values were found in the ranges of 5.74 to 6.04, which was moderately acidic. Due to the moderately acidic nature of soils of the study area, it was inferred that there would not be any actual and potential salinity hazard in the soils of the study area.

## 2.6 Findings from Different Land Suitability Studies

Fasina (2008) carried out a detailed soil survey of about 120.89ha of land in Asu river basin to evaluate the suitability of soils for irrigated agriculture. The study revealed four major soil types namely; Ihuebe 1 and 2, Ameta 1 and 2. The soils were deep (>100 cm). The soil textures consisted of loam (Ihuebe 1), sandy clay loam (Ihuebe 2), clay loam (Ameta1) and loamy sand (Ameta2) on the surface. Three (Ihuebe 1, Ihuebe 2 and Ameta2) of the soils were imperfectly drained while one (Ameta1) was moderately well drained. The soils were classified into irrigation suitability classes for surface/gravity irrigation. Ihuebe1 and Ihuebe2 were classified as moderately suitable (S2) while Ameta1 was classified as highly suitable (S1). Their study recommended that for sustainable use of irrigation in the area, drip irrigation should be used to irrigate soils of the area.

Workat *et al.* (2020) also carried out a research to evaluate the suitability of Zamra irrigation scheme. For this study, about 195.16 ha of land were evaluated. The evaluation was carried out using a parametric evaluation method. The results of the study revealed that soil texture was sandy loam and sandy clay loam at the surface and subsurface soil and the soil depth varied from shallow to very deep. The soil of the scheme was free from salinity and the status of calcium carbonate was at a low level. The slope of the study area ranged from flat (0–3%) to sloping (8–15%). Due to major limiting factors of soil depth and slope, about 42.84 ha of the land (21.95%) were not suitable for irrigation. In the study area, the major limitations were slope and soil depth.

Geographic Information System-based land suitability analysis was conducted by Azemeraw (2021) using analytical hierarchy process methods. Eight factors like slope, elevation, distance to water source, land use, soil texture, depth and drainage were considered and therefore the weight of every parameter was estimated using 8x8 pairwise comparison matrix. Final land suitability map was generated using weighted overlay method under Geographic Information System tool. The area was classified into four suitable classes, using natural break classification method as highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable class (S4). The result showed that 13.9 % of the area was highly suitable, 46.9 % was moderately suitable, 26.9 % was marginally suitable and 12.2% was not suitable.

Amin (2012) investigated the impact of soil temperature and soil moisture. In the study, a land suitability evaluation was carried out for wheat (*Triticum aestivum*) cultivation in the Bastam region located in the north east of Iran. In order to find out the most correct method of physical land suitability evaluation, three methods of combining soil criteria for soil index calculation for wheat production were tested. These methods were based on parametric and maximum limitation approaches and the results of each method were compared with the observed yield. Ultimately, the maximum limitation method was found to be the best method and was used for classifying the study area for wheat cultivation. The varying results of applying different ways of evaluation in the study indicate that the accuracy of the method of land evaluation adopted should be checked before using the results for any purpose.

Mehdi *et al.* (2012) also conducted a research to compare different irrigation methods based on a parametric evaluation system in an area of 3011.9 ha in Mihel plain of Chahar Mahal and Bakhyari province, in the center if Iran. After analyzing and evaluating the soil properties, suitability maps were generated for surface, drip and sprinkler irrigation using Geographic Information System. From the result of their study, 73 ha (2.4 %) of the land was highly suitable for surface irrigation, while 1355.8 ha (45.01 %) and 907.6 ha (30.13 %) of the study area were highly suitable for drip and sprinkler irrigation, respectively. They also noted that, by applying drip and sprinkler irrigation instead of surface irrigation, land suitability classes of 2848 ha (94.56 %) of this plain improved. From their findings, the main limiting factor in using both drip and sprinkler irrigation methods in this area were soil texture, slope and calcium carbonate content, while the main limiting factors in using surface irrigation were slope and soil texture.

Ibrahim *et al.* (2015) carried out a study to evaluate land suitability for surface irrigation in the Almanaqil Ridge, Gezira State, Sudan, on an area about 220.000 acres. The evaluation was based on FAO (1985) guidelines and the method proposed by Sys *et al*. (1991). The area was divided into 3 mapping units. The units were classified according to the American System (Keys to Soil Taxonomy, 2010): Fine loamy, mixed, isohyperthermic, Typic Haplustepts (Unit1), Fine, mont, superactive, Isohyperthermic, Vertic Haplocambids (Unit2) and Fine, mont, superactive, isohyperthermic, Typic Haploustert (Unit3). The 30 m spatial resolution Digital Elevation Model was used to generate slope by using Spatial Analyst Tool Surface Slope in ArcGIS 9.3 environment. Land characteristics used as criteria were slope, texture, soil depth, calcium carbonate status, salinity, sodicity and drainage. The irrigation suitability map was compiled by matching reclassified land characteristics with irrigation land use requirements (LURs) using Geographic Information System tools. The results showed that Units 2 and 3 were slightly suitable.

Tadele and Zewde (2021) carried out a study with the objective of analyzing land suitability for surface irrigation in Humbo Woreda, Southern Ethiopia. For the suitability analysis of surface irrigation, soil type, slope, land cover, and distance from water supply were considered. The suitability factors data; such as soil data were obtained from Ethio-soil, slope was derived from DEM-20 meter resolution, land use/cover was classified from satellite image of 2019 (Landsat 7 ETM+), and distance from the River was obtained from Ethio-River map. For each of the criteria suitability map was developed.

## 2.7 Geographic Information System-based Multi-criteria Decision Approach for Irrigation

Otokiti and Adesina (2019) in their study adopted a GIS-based multi-criteria decision approach in mapping the inherent qualities and potentials of land peculiar to rice cultivation in Oye-Ekiti. An Analytical Hierarchical Process was used to assign weights to the selected factors with respect to their relative importance, while pairwise comparison was used to rank the factors. The priority generated was used to assign weights in ArcGIS 10.5 weighted overlay toolset in spatial analyst tool. The resulting weights were based on the principal eigenvector of the decision matrix. From the priority value derived from the pairwise comparison result, the criteria were reclassified according to their suitability level and weighted overlay toolset was used to merge the criteria from which the results were obtained. The study area was classified into three categories based on rice cultivation suitability, namely: Highly suitable-S1, moderately suitable-S2, marginally suitable- S3. The result indicated that 18 % (79.925 sq.km) of the total land area was highly suitable for cultivating rice, 70% (326.019 sq.km) was moderately suitable, while 12% (57.725 sq.km) was marginally suitable.

Multi-criteria irrigation land suitability analysis and mapping can play important role not only in sustainable use of scarce resources, but also in overcoming the global problem of water scarcity and crop production that resulted from high degree of rainfall variability and unreliability. Kassaye *et al.* (2019) carried out research to determine suitable sites for surface irrigation along the Erer Watershed of East Hararghe Zone, Ethiopia. The study employed Geographic Information System-based multi criteria land suitability evaluation method considering fifteen factors; namely, soil pH, soil type, soil drainage, soil depth, available water capacity, impermeable layer, cation exchange capacity (CEC), phase, organic carbon, texture classes, obstacle to root, land use/land cover, slope, and distance from the river outlets to find suitable land for surface irrigation. Each factor was standardized to a common measurement scale so that the results represent numeric range giving higher values to more suitable and lower values to less suitable attributes. Using the Weighted Overlay tool, the values of each dataset were weighted and combined to find the most suitable location for irrigation using the ArcGIS environment. Results of the study revealed that about 386,731 ha (11.7% of the watershed area) was highly suitable, while 140,308 ha (36.3%) was not suitable for surface irrigation. The remaining suitability classes were moderately suitable and occupied 50,223 ha (12.98%), while marginally suitable land occupied 151,120 ha (39.07%) of the watershed area, respectively.

Land suitability analysis using a scientific procedure is essential for assessing the potential and constraints of a given land parcel for agricultural purposes and suitability assessment is inherently a multi-criteria problem (Abushnaf, 2014). According to FAO (1976) methodology cited in Jovzi *et al.* (2012), land suitability is strongly related to “land qualities”. Land suitability analysis is a prerequisite to achieving optimum utilization of the available land resources (Gizachew, 2015).

Hillary *et al.* (2021) conducted a research on which land would be suitable for neglected and underutilized crop species. They observed modern approaches were gaining popularity over traditional methods. The MCDM methods; namely Analytical Hierarchy Process and fuzzy, are commonly applied to land suitability analysis while crop models and machine learning related methods are gaining popularity. A total of 67 parameters from climatic, hydrology, soil, socio-economic and landscape properties are essential in land suitability analysis. Unavailability and the inclusion of categorical datasets from social sources was a challenge.

Robert *et al.* (2019) assessed and mapped the potentials of 21,692.51 ha parcel of land in Ike-Bunu, Kogi State, using soil/land attributes for arable agriculture. Six mapping units were delineated, namely: MU-1 (3391.35 ha), MU-2 (1689.65 ha), MU-3 (1549.66 ha), MU-4 (5065.96 ha), MU-5 (4905.390 ha) and MU-6 (6,977.03 ha) based on soil properties and terrain analysis. Five (5) profile pits were dug across the study site and described according to FAO (2006) guidelines. The Geographic Information System database was generated for selected soil physical and chemical properties using ArcGIS 10.3 application. The results showed that dominant textural class of the soils was sandy loam underlain by sandy clay loam. Soil pH rated from strongly acidic to neutral (pH 4.8 to 6.9). Organic carbon (OC) was low (2.14 to 8.57 g $kg^{-1}$). All the mapping units had potentials for arable agriculture except the hilly terrain.

Gizachew (2014) used GIS to develop land suitability map in east Amhara region, Ethiopia. Land characteristics and crop requirements used as criteria for crop suitability analysis were soil depth, soil texture and pH, topographic (slope) and climatic (temperature) factors. Crop suitability map was made by matching reclassified LCs with crop LURs using GIS model builder. The results indicated that the largest portion of the region were unsuitable due to soil depth for sesame, cotton, Enset and mango production.

Chen *et al.* (2010) in their study presented a novel approach of examining multi-criteria weight sensitivity of a Geographic Information System-based MCDM model on the Loess plateau in China. The study explored the dependency of model output on the weights of input parameters, identifying criteria that were especially sensitive to weight changes and to show the impact of changing criteria weights on the model outcomes in spatial dimension. A methodology was developed to perform simulations where the weights associated with all criteria used for suitability modelling were varied one-at-a-time (OAT) to investigate their relative impacts on the final evaluation results. A tool which incorporated the OAT method with the Analytical Hierarchy Process (AHP) within the ArcGIS environment was implemented. It permitted a range of user defined simulations to be performed to quantitatively evaluated model dynamic changes, measures the stability of results with respect to the variation of different parameter weights and displays spatial change dynamics. A case study of irrigated cropland suitability assessment addressing the application of new Geographic Information System-based Analytical Hierarchy Process tool was described. It demonstrated that the tool was spatial, simple and flexible.

Goma *et al.* (2016) conducted a research and their objective was to provide an up–to date Geographic Information System-based land suitability evaluation for determining suitable agricultural land for rubber crops in Malaysia. Biophysical and ecological factors that were assumed to influence agricultural land use were assembled and the weights of their respective contributions to land suitability for agricultural uses were assessed using an analytic hierarchical process. The result of this study found Senawang, Mambau, Sandakan and Rantau as the most suitable areas for cultivating rubber; whereas Nilai and Labu were moderately suitable. Lenggeng, Mantin and Pantai were not suitable for growing rubber as the study foresaw potential environmental degradation of these locations from agricultural intensification. While this study could be useful in assessing the potential agricultural yields and potential environmental degradation in the study area, it could also help to estimate the potential conversion of agricultural land to non–agricultural uses.

El Baroudy (2015) carried out a research to develop a spatial model for land suitability assessment for wheat crop integrated with geographic information system (GIS) techniques. Organic matter, drainage, texture, depth, topography, surface stoniness, hard pan, hydraulic conductivity, water holding capacity, salinity, ESP, $CaCO_3$ and pH were recognized as factors affecting land suitability for wheat crop in the study area. Three thematic indicators were used in assessing land suitability, soil fertility, chemical and physical properties quality indices. The results of the proposed model were compared with the Square root and Storie methods. The results from the proposed model showed that most of the units fell within the highly suitable and moderately suitable classes which together represented 71 % of the total area. About 29% of the study area was marginally suitable and unsuitable for wheat crop due to adverse soil physical and chemical properties. The comparison of results of the three approaches used showed that GIS model had a high level of agreement with the Square root method, whereas all land units had the same classes of suitability with exception of one unit.

Rediet *et al.* (2020) evaluated the suitability for surface irrigation using GIS based weighted overlay analysis of individual parameters for better utilization of land resources in Omo-gibe river basin, southern Ethiopia. Factors considered included physical land features (land use/land cover, soil and slope), and proximity to water sources. Based on soil depth, 82.4 % of the study area was found to be potentially suitable for the intended use; the suitability index for drainage was 70 %; 80 % the soil texture was dominated by clay; hence, it was moderately suitable for surface irrigation. Considering the terrain, 11.75 % of the basin was suited for irrigation practice. The LULC classification revealed that 54.42 % was highly suitable and 16.7 % was found to be unsuitable. In reference to river proximity, around 81 % of the area was highly recommended for the intended use. Excluding the national parks, 7% was classified as S1 and 64 % was classified as S2. Hence, surface irrigation development was considered feasible.

In their research, Bakhtiar and Thomas (2012) investigated the optimal utilization of land resources for agricultural production in Tabriz County, Iran. A Geographic Information

System - based Multi Criteria Decision Making land suitability analysis was performed. Several suitability factors including soils, climatic conditions, and water availability were evaluated, based on expert knowledge from stakeholders at various levels. An Analytical Hierarchical Process was used to rank the various suitability factors and the resulting weights were used to construct the suitability map layers. In doing so, the derived weights were used, and subsequently land suitability maps for irrigated land were created. Finally, a synthesized land suitability map was generated by combining these maps and by comparing the product with current land use SPOT 5 satellite images. The resulting suitability maps indicated the areas in which the intensity of land use for agriculture should increase, decrease or remain unchanged. Their investigations revealed that 65,676 hectares was suitable for irrigation.

Mukhtar (2013) compared two approaches to land suitability evaluation; Parametric and Fuzzy Multi-Criteria Methods to model the opportunities for olive production in Jeffara Plain of Libya. A number of soil and landscape criteria were identified, and their weights specified as a result of discussions with local experts. The Fuzzy MCE approach was found to be better than the parametric approach. The Fuzzy MCE approaches accommodate the continuous nature of many soil properties and produce more intuitive distribution of land suitability value for olive. The results of Fuzzy MCE showed that most of the study area was highly suitable for olive production.

Mokarram *et al.* (2019) conducted a research to prepare land suitability evaluation maps for wheat using Fuzzy classification in Shavur area, Khuzestan province, Iran. In the model, non-physical factors were included. The results were compared to a Crisp classification using the parametric method of land evaluation which included non-physical parameters as well. In their study, eight soil parameters, such as soil texture, wetness (ground water depth and hydromorphy), cation exchange capacity (CEC) and exchangeable sodium percentage (ESP), gypsum (%), $CaCO_3$ (%), topography, soil depth and pH values, were chosen for crop-land suitability analysis and thematic maps were developed for each of the parameters with Idea of Design Works (IDW) model. Different Fuzzy membership functions obtained from literature (Con function) were employed and the weights for each parameter were calculated according to an Analytic Hierarchy Process (AHP) that relied on pair wise comparisons. Climatic requirements, landscape and soil requirements for selected crops were determined based on parametric method. Finally, classes of land suitability were provided for each land unit. The coefficient of Kappa was used for comparing these two methods and choosing the better one. The results with the parametric method showed 26% of the area as moderately suitable, 25% as marginally suitable and 49% as unsuitable. The results with the Fuzzy theory showed 31% of the study area as highly suitable for wheat, 29 % as moderately suitable, 19% as marginally suitable and 21% as unsuitable.

Gebre *et al.* (2021) evaluated the suitability of Gudina Wacho watershed Ethiopia, for surface irrigation development using parametric evaluation approach. The watershed was classified into four land mapping units. Three soil profile pits were dug in each land mapping unit. Slope analysis of the watershed was computed from the digital elevation model (DEM) using Geographic Information System technique. Results of the land suitability evaluation for surface irrigation showed that a total area of 3,064 ha (72.6 %) was slightly suitable (S3) and 1,154 ha (27.4 %) was currently not suitable (N1). The limiting factors were slope, soil texture and drainage. For all land mapping units, soil chemical parameters such as $CaCO_3$, ECe and pH, and physical parameter (soil depth) were not limiting for surface irrigation in the study watershed. Therefore, the area was suitable for irrigation with some limitations.

Emal *et al.* (2016) in their study, attempted to develop a land suitability model for saffron, an agronomic crop, which is economically viable, environmentally adaptable and socially equitable at Khost Province of Afghanistan. The objective was to determine different land suitability classes for saffron cultivation using Analytical Hierarchy Process and Geographic Information System. A decision tree was developed encompassing physical, economic and social criteria. They used secondary data (meteorological, remote sensing) from available sources and substantial primary data generated from soil survey, interviews and experts' opinion. A total of 30 physical and socio-economic factors were included in the analysis. The final land suitability result showed that out of the total land area of Khost Province, 1.5 % was highly suitable, 4.5 % was moderately suitable, 8.6 % was marginally suitable and 85.4 % was not suitable. Yigeltu (2022) carried out a study to analyze the potential application of weighted index overlay analysis for assessing land suitability evaluation for surface irrigation using Geographic Information System and Analytical Hierarchy Process technique. Based on the data, the irrigation water requirement was calculated using FAO-Penman-Monteith methods. By using Crop Wat version 8.0 model, the irrigation requirement of the selected crops was calculated They concluded from their findings that potential irrigable land was determined by comparing the gross irrigation demand of identified irrigable land with respect to available monthly river flow.

## 2.8 Assessment of Water Resources

River basins are the geographic areas contained within the watershed limits of a system of streams and rivers converging toward the same terminus, generally the sea or sometimes an inland water body. Tributary sub-basins or basins more limited in size (typically from tens of square kilometers to 1,000 square kilometers) are often called watersheds, while catchment is frequently used in British English as a synonym for river basins, watershed being more narrowly defined as the line separating two river basins (Francois, 2017).

With declining productivity in rain-fed agriculture and with the need to double food production over the next two decades, water has been recognized as the most important factor for the transformation of low productive rain-fed agriculture into most effective and efficient irrigated agriculture (Alemu and Kidane, 2015). It is obvious that the utilization of water resources in irrigated agriculture provide supplementary and full season irrigation to overcome the effects of rainfall variability and unreliability. Hence, the solution to food insecurity could be provided by irrigation development and intensification of cropping by producing more than one crop per year. In this regard, sustainable food production that can be expected through optimal development of water resources, in conjunction with development of land depends on the method of irrigation considered (Mandal *et al.*, 2018). These methods, however, can be broadly classified into three categories: surface (basin, border and furrows), sprinkler, and drip /micro-irrigation/ methods.

## 2.9 Benefits of Geographic Information System Technology in Land Evaluation

Over the last decade, rapid advances in computer hardware and software, combined with the development of extensive digital database, have encouraged the application of GIS in irrigation management. The main uses of Geographic Information System in land evaluation include data restoration from various sources, updating data, their geometric conversion, modelling and overlapping (Haghighi *et. al.*, 2022). A Geographic Information System technique allows modeling of water demand with different scenario for soil, crop, weather and irrigation data. Liang and Wu, (2012) stated that Geographic Information System can be used as a powerful tool for the exploration of spatially distributed databases and evaluation of scenarios under different local conditions. The GIS is central to achieving a successful transition from traditional environmental and resource management practices, which assist to gain sustainable development because of the integrity of social, economic and environmental data (World Bank, 2016). The GIS can be used to represent geo-referenced laboratory analysis findings of soil properties as well as in identification and mapping of areas suitable for cultivation of crops.

The Geographic Information System technology is increasingly applied in mapping of soil properties and land attributes, as it hastens decision making processes (Robert *et al.,* 2019). With adequate database, Geographic Information System can serve as a powerful analytic and decision-making tool for irrigation development (Mandal *et al.*, 2018). Large area extent of Geographic Information System as well as its ability to collect, store and manipulate various types of data in a unique spatial database, helps to perform various kinds of analysis and thus, extract information about spatially distributed phenomena. In this kind of situation, the factors that are involved for irrigation potential assessment such soil, land cover/use, land slope and distance between water supply and suitable command area should be weighted and evaluated by use of Geographic Information System.

Tesfay and Shoeb (2017) conducted a study initiated to assess the land resources potential for irrigation and providing geo-referenced map of these resources using Geographic Information System (GIS). By delineating boundary of the study area, irrigation suitability of each physical land parameters was classified, and potentially irrigable sites were identified by weighting the factors of suitability. The main suitability factors used to identify existing and potential irrigable land were slope, soil texture, depth, drainage characteristics, soil type and land use/cover. By weighting analysis of all parameters, 9.1 % of the study area was found to be suitable, whereas about 1.3% was restricted for irrigation development. Negash (2004) conducted a study on irrigation suitability analysis in the Abaya-Chamo lake basin, Ethiopia. It was Geographic Information System based and had taken into consideration soil, slope, land use and water resource availability in perennial rivers in the basin to identify potential irrigable land. Meron (2007) carried out similar work on surface irrigation suitability analysis of southern Abay basin by using Geographic Information System techniques. The study considered soil, slope and land cover /use factors to find suitable land for irrigation with respect to location of available water resource and to determine the combined influence of these factors for irrigation suitability. There is need to monitor and assess the changes taking place on vegetation quality and productivity. Conventional ground survey method has proved to be highly tedious, laborious, and grossly limited; especially when large and densely forested regions are concerned (Onuigbo *et al*., 2015). Geographic Information System facilities were extensively used for this purpose. In this study, a physical approach to irrigation potential was understood as setting the global limit for irrigation development.

## 2.10 Geographic Information System Multi-Criteria Evaluation

Land use policy makers in developing countries often make little use of available technical information; and when doing so, they require it to be interpreted into concise statements with few technical details (Elaalem *et al.,* 2010). Geographic Information System spatial analysis is not a new concept but rather forms an important part of land use suitability mapping and analysis (Feizidadeh and Blascheke, 2013). In general, suitability analysis aims to identify the most appropriate spatial pattern for future land uses according to the requirements, preferences or predictions of activity (Collins *et al.,* 2001).

Geographic Information System is best suited for handling a wide range of criteria at multi-spatial, multi-temporal and multi-scale from different sources for a time-efficient and cost-effective analysis. (Chen *et al.,* 2010). The multi-criteria evaluation approach based on GIS decision rules (Reshmidevi *et al.,* 2009, Yu *et al.,* 2011) can reduce the number of factors used in land suitability analysis. One multi-attribute technique that has been incorporated into the GIS-based land use suitability procedure is the Analytical Hierarchy Process (AHP) (Malczewski, 2004). This is a twofold approach realized within a GIS environment. First, it can be employed to derive the weights associated with suitability (attribute) map layers. The weights can then be combined with the attribute map layers in a manner similar to that used in the linear additive combination methods (Malczewski 2004). The MCDM methods; such as the AHP method have been successfully applied to land evaluation techniques (Everest *et al.,* 2022). They used a GIS-based MCDM land suitability analysis method to classify Tabriz County with respect to the potential for irrigated agriculture.

Multi-criteria analysis (MCA) is one of the most important procedures for GIS-based decision making processes (Gizachew, 2015). The MCA can be used to define the most suitable areas for irrigation. In MCA technique, generation of the suitability maps for given purpose is the very first step. The integration of multi-criteria analysis method with GIS has considerably advanced the conventional map overlay approaches to the land- use suitability analysis. The GIS-based multi-criteria analysis can be thought of as a process that combines and transforms spatial and a spatial data (input), into a resultant decision (Gizachew, 2015).

Hamere and Teshome (2018) conducted a study aimed at evaluating land suitability analysis by using geographical information system-based multi-criteria approach in Andit Tid watershed. The analysis of land suitability for major crops (wheat and barley) revealed that though there was slight variation in suitable classes for each crop, most parts of the watershed were moderately suitable for both crops, with 266.55 ha (77.42 %) and only very small part of the land (2.43 ha 0.51 %) being highly suitable for both crops. On the other hand, 9.3 ha (2 %) and 3.6 ha (0.77 %) of the land was marginally suitable and not suitable respectively for both wheat and barley crops. The limiting factors were soil depth, texture, temperature, slope and erosion hazard. From their findings the spatial distribution showed that most of the cultivation was practiced in marginally suitable land in the lower part of the watershed. Most of the land parcel was being used against its suitability potential. Thus, it was established that the land-use pattern needed to be modified based on its suitability potential.

## 2.11 Weighted Overlay Analysis

Weighted overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. Geographic problems often require the analysis of many different factors using GIS. For instance, finding optimal site for irrigation requires weighting of factors such as land cover, slope, soil and distance from water supply (Haile and Abebe, 2022). To prioritize the influence of these factor values, weighted overlay analysis uses evaluation scale from least suitable factor to the most suitable factor. Weighted overlay only accepts integer rasters as input; such as, a raster of land cover, soil types, slope, and Euclidean (the straight-line from the center of the source cell to the center of each of the surrounding cells) distance output to find suitable land for irrigation. Different parameters of the field data can be used to compare the land suitability for different irrigation systems.

# CHAPTER THREE

## 3.0 MATERIALS AND METHODS

### 3.1 The Study Site

The study was conducted at Lapai-Agaie Irrigation scheme. It lies between latitude 09$^o$ 13.22.69" N and longitude 6$^o$35'10.68", latitude 09$^o$ 13.22.79" N and longitude 6$^o$35'51.37", latitude 09$^o$ 12.45.39" N and longitude 6$^o$35'17.24" and latitude 09$^o$ 12.45.39" N and longitude 6$^o$35'17.24" near Bakajeba village along Paiko-Lapai road in Niger State. It is about 40 km from Minna. The area is in a tropical climate which is characterised with two distinct seasons (Wet and Dry) annually. The rainy season is from April to October with heavy rainfall between July and September. The annual amount of rainfall varies from 1,300 to 1,800 mm. Cold and dry harmattan winds usher in the dry season between November and February. The temperature becomes relatively high with a peak in the dry season between 30 and 41 $^o$C during the period between December and April, while temperatures of between 25 and 30 $^o$C occur at mid-days between May and July (The Nigerian congress, 2007). The study site is in the southern part of Niger State (Figure 3.1) which is characterised by gentle slopes and have the vegetation of Guinea savanna. The size of the site surveyed for this research purpose was about 200 hectares.

### 3.2 Field Work

Soil identification and mapping was by rigid grid (100 x 100 m) method of soil survey with the aid of soil auger. Traverses were cut at 100 m apart along a baseline and observation points were at 100 m apart along each traverse. Auger observation holes were made along baselines and traverses at each point down to a depth of 100 cm or an impenetrable layer and soil was examined. A total of 200 auger borings were made. At each observation point,

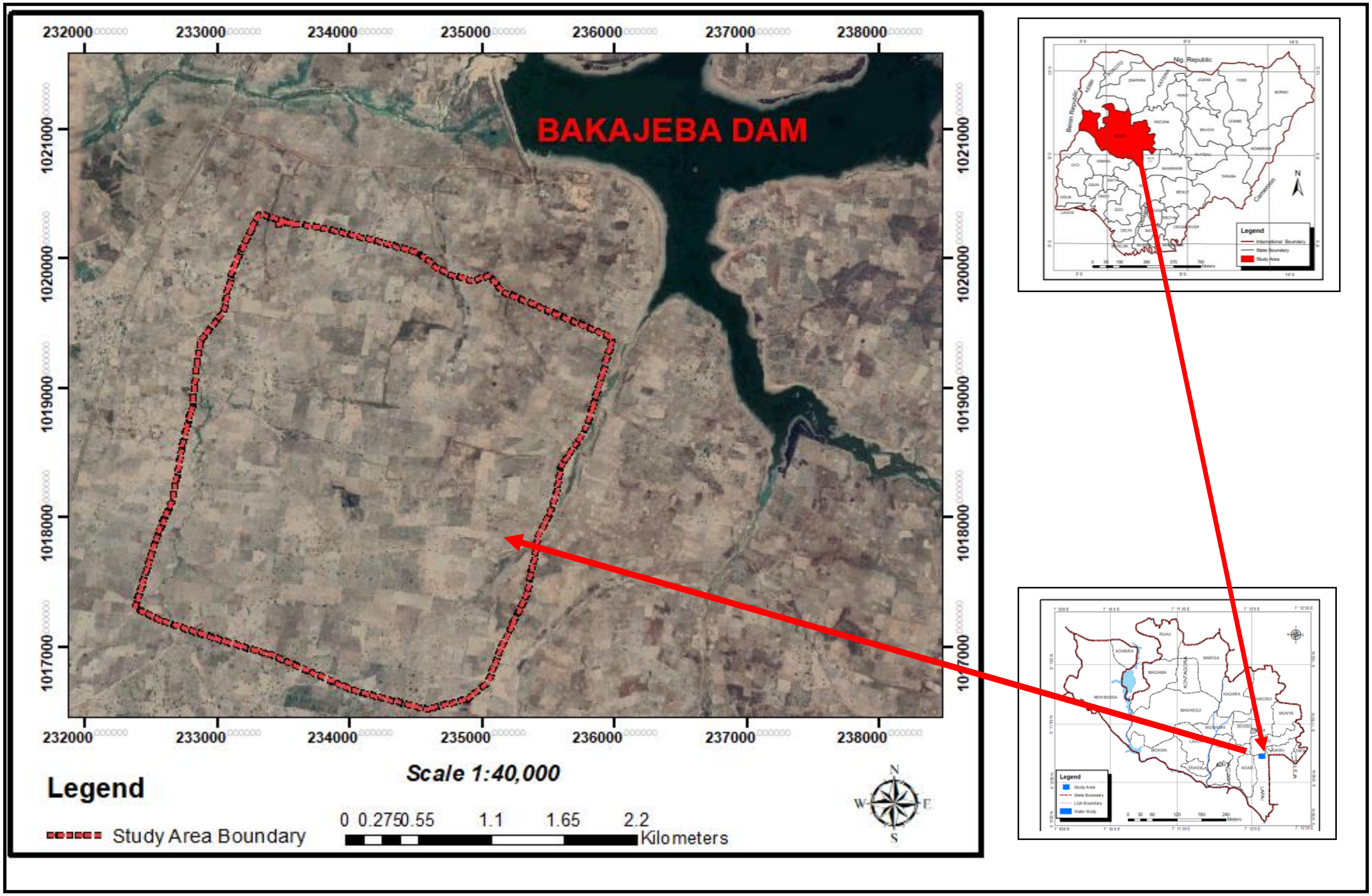


Figure 3.1: Location of the Study Site

selected soil morphological properties were recorded. These included soil texture, colour, consistence and other natural land features such as vegetation and evidence of rock outcrop. The recorded observations were further grouped based on similarities of morphological features. The concept of the mapping units was based on soils which shared similar morphological, topographic, and physical characteristics of depth, drainage, colour of soil matrix and mottles, texture, and structure. In each soil mapping unit that was identified in the study site, two soil profile pits were dug, described and sampled from bottom to the top, to minimize contamination. Each profile pit was described regarding its full range of morphological characteristics according to international standards of FAO (2006). These include soil depth, colour of matrix, structure, consistency, root distribution, texture, horizon boundary, vegetation/land use, topography and depth of water table. Soil samples collected from each identified genetic horizons were taken to the laboratory for analysis.

### 3.3 Land Evaluation Parameters

The data measured in the field were effective soil depth, drainage, infiltration rate and slope percent. Effective soil depth was determined by measuring from the soil surface to the upper boundary of the limiting horizon where roots were no longer visible. The nature and depth of the limiting horizon was also noted. Drainage characteristics were determined at each identified horizon of the soil profiles using Munsell Colour Charts. The basic infiltration rate was determined on the field using a double ring infiltrometer method. Three runs were carried out for each mapping unit at 2 hours 30 minutes per run. Slope percent was determined by levelling instrument (Automatic level). For available water capacity, core samples were collected in triplicate at each horizon. The samples collected were saturated in water for 24 hours, with a piece of muslin cloth placed at the bottom of the core ring immersed in water to prevent loss of soil material. The empty moisture cans were weighed. The core samples were transferred into the moisture cans and weighed, and were further oven dried at 105 $^{0}$C for 48 hours to a constant weight, allowed to cool, and weighed. The results obtained were used to determine, field capacity, permanent wilting point and available water capacity. Water retained at field capacity (FC) and permanent wilting point (PWP) were determined using the saturation water percentage-based estimation models of Mbagwu and Mbah, (1998).

$$FC = 0.79\,(SP) - 6.22 \quad (r = 0.972)$$

$$PWP = 0.51\,(SP) - 8.65 \quad (r = 0.949)$$

Where FC is field capacity, SP is saturation percentage on weight, PWP is permanent wilting point and r is correlation coefficient.

## 3.4 Soil Analysis

The soil samples were air-dried, gently crushed using a mortar and pestle, and passed through a 2 mm sieve and some were further passed through 0.5 mm sieve to obtain fine earth separates. The processed soil samples were analyzed for chemical properties which include; soil organic carbon, pH, exchangeable bases, exchangeable acidity and cation exchange capacity, following the procedures outlined by the International Institute of Tropical Agriculture (IITA, 2018).

Soil texture was determined using Bouyoucous hydrometer method with sodium hexametaphosphate as dispersing agent (Bouyoucous, 1962). The textural classes of the soils were further determined using International Union of Soil Science (IUSS) soil Textural Triangle. Soil pH was determined using a glass electrode pH meter (Olsen *et al*., 1954). Organic carbon was determined using Walkley-Black wet oxidation method (Walkley and Black, 1934). Soil sample for exchangeable bases ($Ca^{2+}$, $Mg^{2+}$, $K^+$ and $Na^+$) was extracted with 1N neutral ammonium acetate ($NH_4OAc$) solution and amounts of $K^+$ and Na+ in solution was measured using a flame photometer (Van, 1993) while $Ca^{2+}$ and $Mg^{2+}$ were measured using Atomic Absorption Spectrophotometer (Chapman, 1965). Exchangeable acidity ($H^+$ and $Al^{3+}$) was determined by titrimetric method. Cation exchange capacity (CEC) was determined by using Atomic adsorption spectrophotometer (Chapman, 1965). Exchangeable Sodium percentage was calculated using the formula below;

$$\text{ESP} = \frac{\text{Exchangeable Na} + \ (\text{cmol } Kg^{-1})}{\text{Cation Exchange Capacity (cmol } Kg^{-1})} \times 100$$

### 3.5 Land Suitability Classification

To evaluate land suitability for irrigation, parametric evaluation system of Sys *et al*. (1991) was applied, using soil and land characteristics. These characteristics concern environmental factors, drainage properties, soil physical and chemical properties. The ratings were selected for different qualities. Rating tables for each factor were prepared where each table has some values of a factor and the corresponding ratings for these values (usually range from 0 to 100). If the feature was highly suitable, a rating of 100 was assigned and if it is not suitable, a minimal rating was assigned to that feature (Rabia and

Fabio, 2013). Suitability classes were defined considering the value of suitability index (Table 3.1). In this study, the rating tables were adapted from the tables prepared by Sys *et al*. (1991). Land suitability index was calculated based on ratings of all factors using the equation of Rabia and Fabio (2013) method of parametric evaluation system explained below;

$$\text{Si} = Wmax \times \sqrt{\frac{A}{100} \times \frac{B}{100}} \times \frac{C}{100} \times \ldots$$

where Si = Suitability index for irrigation, Wmax = Maximum rating value of the parameters, A, B, C… = rating values for other parameters from the table

Below is table that was used to specify ratings for individual parameters in all the sampling sites in the study site.

### 3.6 Overall Land Suitability/Weighted Overlay

The data were combined using a multi-criteria decision approach to select suitable sites for irrigation. Landsat imagery with 30 m resolution was used. The imagery was subjected to digital image processing. The overall soil suitability was estimated using the weightage of each factor (slope, soil texture, infiltration rate, effective soil depth, available water capacity, drainage, sodium adsorption ratio, exchangeable sodium percentage, organic carbon and CEC to obtain potential irrigable sites. Using an overlay tool in ArcGIS 10.1, overlay (weighted) analysis of the above factors was performed to generate Thematic maps for each factor to develop Land Suitability maps of the study area for their irrigation suitability based on an overall score value (Ganole, 2010). Weighted overlay is a technique for applying a common scale of values to diverse and dissimilar input data to create an integrated analysis. The purpose of weighting in land suitability analysis is to determine the importance of each factor relative to other factors.

**Table 3.1: Suitability index (Si) for Irrigation Suitability Classes**

| Si | Symbol | Definition |
|---|---|---|
| 75 – 100 | S1 | Highly suitable |
| 50 – 75 | S2 | Moderately suitable |
| 25 – 50 | S3 | Marginally Suitable |
| 12.5 – 25 | N1 | Currently Not Suitable |
| 0 – 12.5 | N2 | Permanently Not Suitable |

Source: Javad *et al*. (2019)

# CHAPTER FOUR

## 4.0 RESULTS AND DISCUSSION

## 4.1 Results

### 4.1.1 Mapping units identified within the study site

Identified in the study site were three soil mapping units namely Lapai-Agaie 1, Lapai-Agaie 2 and Lapai-Agaie 3 The land area and proportion covered by each mapping unit are presented in Table 4.1. The distribution of soil mapping units in the study site is shown in Figure 4.1

### 4.1.2 Soil description of the mapping units

#### 4.1.2.1 Lapai-Agaie 1

This mapping unit was estimated to cover 86 hectares. It occupied an undulating landscape with estimated slope gradient of 4.5 %.

##### 4.1.2.1.1 Morphological properties of Lapai/Agaie 1

The mapping unit Lapai-Agaie 1 was characterized by dark greyish brown colour (10YR 3/3) at the topmost horizon. The greyish colour in the topmost horizon signifies imperfect drainage condition. The yellowish brown colour at the subsurface of the study site could be as result of accumulation of hydrated Fe compounds on top of plinthite horizon. There was presence of Fe and Mn concretions at the subsurface of Lapai-Agaie 1. Plinthic horizon was encountered and the roots did not penetrate below 50 cm depth in the horizons as result of the plinthite. The surface horizon had a moderate structure underlain by sub- angular blocky shaped structure at 30 to 50 cm and sub-rounded gravelly fragment and massive

**Table 4.1: Soil Mapping Units and Area Occupied**

| Mapping unit | Area (ha) | Area (%) |
|---|---|---|
| Lapai-Agaie 1 | 86 | 43 |
| Lapai-Agaie 2 | 62 | 31 |
| Lapai-Agaie 3 | 52 | 26 |
| **Total** | **200** | **100** |

structure at 50 to 80 cm. Ironstones were found on the surface of soils in this mapping unit (Plate I).

#### 4.1.2.2 Lapai-Agaie 2

This mapping unit was estimated to cover 62 hectares. It occupies an undulating landscape with an estimated slope gradient of 5.0 %.

##### 4.1.2.2.1 Morphological properties of Lapai-Agaie 2

The mapping unit Lapai-Agaie 2 was characterized by dark brown colour (10YR 3/3) at the topmost horizon and yellowish brown (10YR 3/4) at subsurface horizon. The yellowish brown colour at the sub-surface of the study site could be as a result of accumulation of hydrated Fe compounds on the plinthite horizon. There was presence of stones at the subsurface horizon. Plinthic horizon was encountered and the fine roots were observed to penetrate below 50 cm depth in the horizons. The surface horizon had a granular structure, underlain by sub-angular blocky shaped structure in the subsurface horizon of the soil. The soil depth was deep and provides adequate volume of storage for water.

#### 4.1.2.3 Lapai-Agaie 3

This mapping unit covers the lowest slope of the study site and closest (80 cm) to the dam close to the study site. It was estimated to cover about 52 hectares and the smallest mapping unit in the study site. It occupies an undulating landscape with an estimated slope gradient of 4.3 %.

##### 4.1.2.3.1 Morphological properties of Lapai-Agaie 3

The mapping unit Lapai-Agaie 3 was characterized by very dark brown colour (10YR 3/3) at the topmost horizon and yellowish brown (10YR 3/8) and dark yellowish brown

**Plate I: Ironstone exposed on the surface of Lapai-Agaie 1**

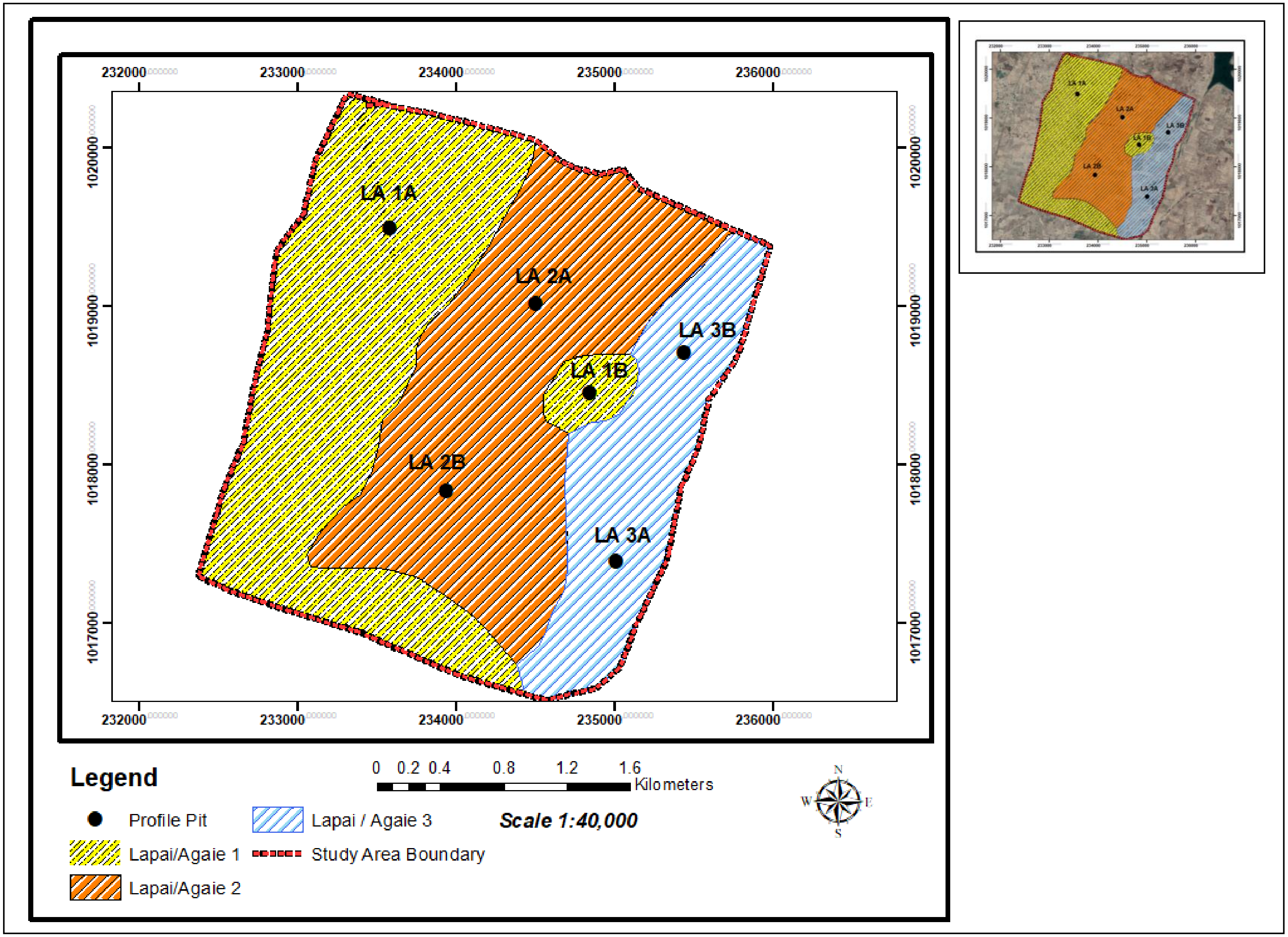


Figure 4.1: Map of the study site showing the three mapping units and pedon

horizon. There was presence of stones at the subsurface horizon. Plinthic horizon was encountered and fine roots were observed to penetrate to 85 cm depth in the horizons. The surface horizon had a fine crumb structure in the surface horizon underlain by sub-angular blocky shaped structure in the subsurface horizon of the soil. This mapping unit had deep soil depth and provides adequate volume of storage for water.

#### 4.1.3 Slope of the study site

The slope is presented on Table 4.2. The slope of Lapai-Agaie 1A was 4.6 % and Lapai-Agaie 1B was 5.2 %. Lapai-Agaie 2A was 3.6 % and LapaiAgaie 2B was 4.3 %. Slope of Lapai-Agaie 3A was 3.6 % while Lapai-Agaie 3B was 4.9 %. Lapai-Agaie 1 had the highest slope while Lapai-Agaie 3 had the lowest slope value. Slopes of the three mapping units were not suitable for surface irrigation method due to the risk of runoff and erosion. They were therefore, recommended for sprinkler and drip irrigation.

#### 4.1.4 Effective soil depth of the study site

Results of effective soil depth are shown on Table 4.3. In Lapai-Agaie 1, soil depth values were 80 cm and 82 cm at Lapai-Agaie 1A and 1B respectively and were classified as fair. Lapai-Agaie 2A had 100 cm and Lapai-Agaie 2B had 126 cm depth. The soils were classified as deep soil. Lapai-Agaie 3A and 3B had effective depth of 100 cm and 110 cm, respectively. Lapai-Agaie 2 was deeper than Lapai-Agaie 1 and 3 mapping units while Lapai-Agaie 1 was shallower Lapai-Agaie 2 and 3 mapping units. The limiting horizon found in Lapai-Agaie 1 and 2 as well as Lpai-Agaie 3B profiles comprises of plinthitic materials while dense clay was the nature of limiting horizon in Lapai-Agaie 3A.

**Table 4.2: Slope of the Study Site**

| Mapping unit | Value (%) | Grade |
|---|---|---|
| Lapai-Agaie 1A | 4.6 | Excess runoff and erosion risk, suitable for sprinkler/drip irrigation |
| Lapai-Agaie 1B | 5.2 | Excess runoff and erosion risk, suitable for sprinkler/drip irrigation |
| Lapai-Agaie 2A | 5.0 | Excess runoff and erosion risk, suitable for sprinkler/drip irrigation |
| Lapai-Agaie 2B | 4.3 | Excess runoff and erosion risk, suitable for sprinkler/drip irrigation |
| Lapai-Agaie 3A | 3.6 | Excess runoff and erosion risk, suitable for sprinkler/drip irrigation |
| Lapai-Agaie 3B | 4.9 | Excess runoff and erosion risk, suitable for sprinkler/drip irrigation |

**Table 4.3: Effective Soil Depth of the Study Site**

| Mapping unit | Value (cm) | Grade (Landon, 1991) | Nature of limiting horizon |
|---|---|---|---|
| Lapai-Agaie 1A | 80 | Fair | Plinthite |
| Lapai-Agaie 1B | 82 | Fair | Plinthite |
| Lapai-Agaie 2A | 100 | Good | Plinthite |
| Lapai-Agaie 2B | 126 | Good | Plinthite |
| Lapai-Agaie 3A | 100 | Good | Dense clay |
| Lapai-Agaie 3B | 110 | Good | Plinthite |

### 4.1.5 Soil texture and available water capacity of the study site

Results for soil texture are shown in Table 4.4. It shows that sand was the dominant fraction in soils of the study site. In Lapai-Agaie 1 soils, the highest sand value was 774 g $kg^{-1}$ at 24 – 70 cm and the lowest value was 724 g $kg^{-1}$ at 15 – 30 cm depth of Lapai-Agaie 1A. Clay had a higher value (170 g $kg^{-1}$) at surface soil Lapai-Agaie 1A and lower values at 50 – 80 cm and 24 – 70 cm of Lapai-Agaie 1A and 1B respectively. Lapai-Agaie 2 soils, the highest value for sand was 784 g $kg^{-1}$ found at subsurface soil (58 – 126 cm) of Lapai-Agaie 2B and the lowest value was 744 g $kg^{-1}$ at 30 – 50 cm depth of Lapai-Agaie 2A. Clay had a higher value (150 g $kg^{-1}$) at subsurface soil of Lapai-Agaie 2A and lower values of clay was at 0 – 34 cm and 58 – 126 cm of Lapai-Agaie 2B. Lapai-Agaie 3 soils, the highest value for sand was 794 g $kg^{-1}$ found at surface soil (0 – 65 cm) of Lapai-Agaie 3A and the lowest value was 734 g $kg^{-1}$ at 10 – 47 cm depth of Lapai-Agaie 3B. Clay had a higher value (160 g $kg^{-1}$) at 10 – 47 cm depth of Lapai-Agaie 3B and lower values of clay was at 65 – 85 cm of LapaiAgaie 3A, 0 – 10 cm and 47 – 110 cm of Lapai-Agaie 3B. The mineral fractions were irregularly distributed within the soil profile. Soil textural class of the study site shows that sandy loam (SL) texture dominate the surface and subsurface horizons of the three mapping units. Sandy loam soils are capable of quickly draining excess water but cannot hold significant amounts of water for plants. This soil requires more frequent irrigation than soils with higher concentration of clay. According to classification of USBR (1953), the texture was suitable for surface, sprinkler and drip irrigation systems. Available water capacity (AWC) is also presented in Table 4.3. In Lapai-Agaie 1A, available water capacity was highest (138 mm $H_2O$ $m^{-1}$) at 0 – 15 cm, while the lowest in this mapping unit was at 50 – 80 cm (125 mm $H_2O$ $m^{-1}$.)and 27 – 70 cm of Lapai-Agaie 1A and 1B

**Table 4.4: Soil Texture and Available Water Capacity of the Soils of the Study Site**

| Soil unit | Soil depth (cm) | Particle size distribution ($g\ kg^{-1}$) | | | Soil texture (Textural triangle) | Available water capacity ($mmH_2O\ m^{-1}$) | |
|---|---|---|---|---|---|---|---|
| | | Sand | Silt | Clay | | | |
| **Lapai-Agaie 1A** | 0-15 | 724 | 106 | 170 | Sandy loam | 138 | Moderate |
| | 15-33 | 724 | 116 | 160 | Sandy loam | 131 | Moderate |
| | 33-50 | 764 | 86 | 150 | Sandy loam | 126 | Moderate |
| | 50-80 | 764 | 106 | 130 | Sandy loam | 125 | Moderate |
| **Lapai-Agaie 1B** | 0-24 | 764 | 96 | 140 | Sandy loam | 126 | Moderate |
| | 24-70 | 774 | 96 | 130 | Sandy loam | 125 | Moderate |
| | 70-82 | 764 | 86 | 150 | Sandy loam | 135 | Moderate |
| **Lapai-Agaie 2A** | 0-30 | 764 | 96 | 140 | Sandy loam | 130 | Moderate |
| | 30-50 | 744 | 106 | 150 | Sandy loam | 127 | Moderate |
| | 50-100 | 754 | 96 | 150 | Sandy loam | 129 | Moderate |
| **Lapai-Agaie 2B** | 0-34 | 774 | 96 | 130 | Sandy loam | 123 | Moderate |
| | 34-58 | 774 | 86 | 140 | Sandy loam | 123 | Moderate |
| | 58-126 | 784 | 86 | 130 | Sandy loam | 135 | Moderate |
| **Lapai-Agaie 3A** | 0-33 | 794 | 66 | 140 | Sandy loam | 131 | Moderate |
| | 33-65 | 794 | 66 | 140 | Sandy loam | 128 | Moderate |
| | 65-85 | 794 | 76 | 130 | Sandy loam | 126 | Moderate |
| | 85-100 | 784 | 76 | 140 | Sandy loam | 128 | Moderate |
| **Lapai-Agaie 3B** | 0-10 | 774 | 96 | 130 | Sandy loam | 132 | Moderate |
| | 10-47 | 734 | 106 | 160 | Sandy loam | 124 | Moderate |
| | 47-110 | 774 | 96 | 130 | Sandy loam | 126 | Moderate |

respectively. In Lapai-Agaie 2A, available water capacity was highest (135 mm $H_2O$ $m^{-1}$) at the subsoil at a depth of 58 – 126 cm, while the lowest value (123 mm $H_2O$ $m^{-1}$) was found at 0 - 34 cm (125 mm $H_2O$ $m^{-1}$) and 34 – 70 cm of Lapai-Agaie 2B. The highest available water capacity value at Lapai-Agaie 3 was 132 mm $H_2O$ $m^{-1}$ at the topsoil 0 – 10 cm of Lapai-Agaie 3B, while the lowest value was 124 mm $H_2O$ $m^{-1}$ at 10 - 47 cm of Lapai-Agaie 3B. All depths in the three mapping units were rated as moderate.

### 4.1.6 Basic infiltration rates of soil mapping units

Result for basic infiltration rate are presented in Table 4.5. The result shows that the infiltration rate of Lapai-Agaie 1A was 8 cm $hr^{-1}$ and classified as moderately rapid. This value was rated as marginally suitable for surface irrigation. It is most suitable for sprinkler and drip irrigation systems. Infiltration rate of Lapai-Agaie 2A was 7 cm $hr^{-1}$. It was rated as moderately rapid and not suitable for surface irrigation. Soils of Lapai-Agaie 2B had infiltration rate of 4 cm $hr^{-1}$ and was rated as moderate. Lapai-Agaie 3A was 5 cm $hr^{-1}$. while Lapai-Agaie 3B had value of 6 cm $hr^{-1}$. Lapai-Agaie 1A, 2A and 3B were rated as moderately rapid. and therefore, not suitable for surface irrigation. They were best suited for sprinkler and drip irrigation methods, while Lapai-Agaie 1B, 2B and 3A were rated as moderate and suitable for surface, sprinkler and drip irrigation methods.

### 4.1.7 Drainage of soils of the study site

Soil drainage is one of the most important parameters for surface irrigation potential assessment. Results of soil drainage of the mapping unit are represented in Table 4.6 which shows that Lapai-Agaie 1A had the Hue and Chroma value of 10YR 3/3 and 10YR 3/6 respectively. They were both classified as well drained soils. The subsoils (33 – 50 cm and 50 to 80 cm) had values as 10YR 4/6 and 7.5YR 4/4 respectively and the soils were

**Table 4.5: Basic Infiltration Rates of Soil Mapping Units**

| Mapping units | Basic infiltration rate (cm $hr^{-1}$) | FAO infiltration category (Landon, 1991) | Suitability for irrigation (Landon, 1991) |
|---|---|---|---|
| Lapai-Agaie 1A | 8 | Moderately rapid | Marginally suitable for surface irrigation (too rapid) Suitable for sprinkler and drip irrigation |
| Lapai-Agaie 1B | 2 | Moderate | Suitable for surface irrigation |
| Lapai-Agaie 2A | 7 | Moderately rapid | Marginally suitable for surface irrigation (too rapid) Suitable for sprinkler and drip irrigation |
| Lapai-Agaie 2B | 4 | Moderate | Suitable for surface irrigation |
| Lapai-Agaie 3A | 5 | Moderate | Suitable for surface irrigation |
| Lapai-Agaie 3B | 6 | Moderately rapid | Marginally suitable for surface irrigation (too rapid) Suitable for sprinkler and drip irrigation |

**Table 4.6: Drainage of soils of the Study site**

| Depth (cm) | Mapping units | Hue/chroma (moist) | Drainage (Soil survey staff, 2010) |
|---|---|---|---|
| 0-15 | Lapai-Agaie 1A | 10YR 3/3 | Well drained |
| 15-33 | | 10YR 3/6 | Well drained |
| 33-50 | | 10YR 4/6 | Moderately well drained |
| 50-80 | | 7.5YR 4/4 | Moderately well drained |
| 0-24 | Lapai-Agaie 1B | 10YR 3/3 | Well drained |
| 24-70 | | 10YR 5/8 | Moderately well drained |
| 70-82 | | 10YR 4/6 | Moderately well drained |
| 0-30 | Lapai-Agaie 2A | 10YR 3/3 | Well drained |
| 30-50 | | 10YR 4/6 | Moderately well drained |
| 50-100 | | 10YR 4/6 | Moderately well drained |
| 0-34 | Lapai-Agaie 2B | 10YR 3/3 | Well drained |
| 34-58 | | 10YR 5/8 | Moderately well drained |
| 58-126 | | 10YR 4/6 | Moderately well drained |
| 0-33 | Lapai-Agaie 3A | 10YR 3/3 | Well drained |
| 33-65 | | 10YR 3/6 | Well drained |
| 65-85 | | 10YR 5/8 | Moderately well drained |
| 85-100 | | 7.5YR ¾ | Moderately well drained |
| 0-10 | Lapai-Agaie 3B | 10YR ¾ | Poorly drained |
| 10-47 | | 10YR 5/8 | Moderately well drained |
| 47-110 | | 10YR 5/8 | Moderately well drained |

classified as moderately well drained. Soils of Lapai-Agaie 1B at 0 – 24 cm while 24 – 70 cm and 70 -82 cm had values of 10YR 5/8 and 10YR 4/6 respectively and were classified as moderately well drained soils. were well drained (10YR 3/3).

Lapai-Agaie 2A soils were well drained (10YR 3/3) at 0 – 30 cm while 30 – 50 cm and 50 – 100 cm with value of 10YR 4/6 were moderately well drained soils. Lapai-Agaie 2B was well drained (10YR 3/3) at the topsoil (0 – 30 cm), while the subsoils (34 – 58 cm and 58 – 126 cm) were moderately well drained with values of 10YR 5/8 and 10YR 4/6 respectively. Soils of Lapai-Agaie 3A were well drained at the topsoil with values of 10YR 3/3 at 0 – 33 cm and 10YR 3/6 at 33 – 65 cm while the subsoils (65 – 85 cm and 85 – 100 cm) were moderately well drained (10YR 5/8 and 7.5YR 3/4). Lapai-Agaie 3B soils were poorly drained at the surface soil (0 – 10 cm) with value of 10YR 3/4 while the subsoils (10 – 47 cm and 47 – 110 cm) were moderately well drained (10YR 5/8). Poorly drained soils of Lapai-Agaie 3B topsoil could be due to soil compaction.

#### 4.1.8 Chemical properties of soils of the study site

Results of chemical properties of soils of the study site are shown on Table 4.7. The soil pH in Lapai-Agaie 1 shows that Lapai-Agaie 1A soils were neutral at 15 – 33 cm, 33 – 50 cm and 50 -80 cm with value of 6.55, 6.60 and 6.22 respectively, while Lapai-Agaie 1A at 0 – 15cm, and all three horizons of Lapai-Agaie 1B were slightly acidic with values ranging between 6.45 and 6.55. Lapai-Agaie 2 soils were neutral at 0 – 30 cm and 50 – 100 cm depth of Lapai-Agaie 2A and 34 – 58 cm of Lapai Agaie 2B with value of 6.71, 6.63 and 6.81, respectively. Slightly acidic soils were found at 30 – 50 cm of Lapai-Agaie 2A (6.42), Lapai-Agaie 2B at 0 – 34 cm (6.48) and 58 – 126 cm (6.31). Soils of Lapai-Agaie

3 were slightly acidic in all horizons of the mapping unit apart from 47 -110 cm of Lapai-Agaie 3B.

Cation Exchange Capacity (CEC) of soils of Lapai-Agaien1 was low in the topsoil (0-15 cm) of Lapai-Agaie 1A with a value of 3.12 cmol $kg^{-1}$. All other horizons within the mapping unit were classified as moderate except 70 – 82 cm which was rated high (35.4 cmol $kg^{-1}$). Lapai-Agaie 2A was moderate; 13.4, 14.4 and 20.0 cmol $kg^{-1}$ in soils of the three horizons. Lapai-Agaie 2B had low CEC (11.6 cmol $kg^{-1}$) in the topsoil (0 – 34 cmol $kg^{-1}$), while the subsoils were moderate. The CEC of Lapai-Agaie 3 shows that surface soils of Lapai-Agaie 3A and 3B were moderate while 65 – 85 cm of Lapai-Agaie 3A and 10 – 47 cm of Lapai-Agaie 3B were high. Generally, moderate CEC values were dominant in the soils of the study site.

Exchangeable sodium percentage was low (0.85 to 2.42 % in Lapai-Agaie 1, 1.50 to 3.54 % in Lapai-Agaie 2 and 1.16 to 3.07 % in Lapai-Agaie 3) in all horizons of the soils of the study site. The soils were classified as non-sodic. This implies that sodicity was not a problem for irrigation in soils of the study site. This was like findings of (Temesgan and Yonas, 2016) where Exchangeable Sodium Percentage values were found in very low amount. Generally, moderate CEC values were dominant in the soils of the study site.

Organic carbon is the carbon component of organic matter, which is about one-half the mass of organic matter. Organic matter is an important constituent of soils because it has a high capacity for absorbing water and nutrients. It also binds mineral particles together to form stable aggregates that give the soil favorable physical properties (Wuddivira and Camps-Roach, 2007). Organic carbon content of the soils of Lapai-Agaie 1A were medium

| Mapping units | Soil depth (cm) | Soil pH (1:2.5 $H_2O$) | | Organic carbon(g kg$^{-1}$) | | CEC(cmol kg$^{-1}$) | | Exchangeable sodium percentage (%) | |
|---|---|---|---|---|---|---|---|---|---|
| Lapai-Agaie 1A | 0-15 | 6.55 | Slightly acidic | 4.38 | Medium | 3.12 | Low | 1.54 | Non-sodic |
| | 15-33 | 6.68 | Neutral | 1.23 | Very low | 21.0 | Moderate | 2.42 | Non-sodic |
| | 33-50 | 6.60 | Neutral | 1.75 | Very low | 17.4 | Moderate | 2.18 | Non-sodic |
| | 50-80 | 6.22 | Neutral | 1.93 | Very low | 20.0 | Moderate | 0.85 | Non-sodic |
| Lapai-Agaie 1B | 0-24 | 6.51 | Slightly acidic | 2.10 | Low | 12.8 | Moderate | 2.11 | Non-sodic |
| | 24-70 | 6.45 | Slightly acidic | 1.50 | Very low | 16.8 | Moderate | 1.96 | Non-sodic |
| | 70-82 | 6.47 | Slightly acidic | 2.10 | Low | 35.4 | High | 1.21 | Non-sodic |
| Lapai-Agaie 2A | 0-30 | 6.71 | Neutral | 2.98 | Low | 13.4 | Moderate | 3.36 | Non-sodic |
| | 30-50 | 6.42 | Slightly acidic | 1.93 | Very low | 14.4 | Moderate | 3.54 | Non-sodic |
| | 50-100 | 6.63 | Neutral | 1.40 | Very low | 20.0 | Moderate | 1.50 | Non-sodic |
| Lapai-Agaie 2B | 0-34 | 6.48 | Slightly acidic | 1.75 | Very low | 11.6 | Low | 3.45 | Non-sodic |
| | 34-58 | 6.81 | Neutral | 0.70 | Very low | 18.0 | Moderate | 1.50 | Non-sodic |

**Table 4.7 Continued**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 58-126 | 6.31 | Slightly acidic | 3.15 | Low | 17.2 | Moderate | 2.03 | Non-sodic |
| Lapai-Agaie 3A | 0-33 | 6.20 | Slightly acidic | 2.28 | Low | 15.0 | Moderate | 3.07 | Non-sodic |
| | 33-65 | 6.38 | Slightly acidic | 1.58 | Very low | 16.4 | Moderate | 2.99 | Non-sodic |
| | 65-85 | 6.29 | Slightly acidic | 1.05 | Very low | 35.4 | High | 1.16 | Non-sodic |
| | 85-100 | 6.34 | Slightly acidic | 2.45 | Low | 13.6 | Moderate | 2.35 | Non-sodic |
| Lapai-Agaie 3B | 0-10 | 6.45 | Slightly acidic | 1.79 | Low | 15.6 | Moderate | 2.80 | Non-sodic |
| | 10-47 | 6.36 | Slightly acidic | 3.50 | Low | 32.2 | High | 1.46 | Non-sodic |
| | 47-110 | 6.84 | Neutral | 3.15 | Low | 14.4 | Moderate | 3.06 | Non-sodic |

**Table 4.7: Chemical Properties of Soils of the Study Site**

(4.38 g $kg^{-1}$) in 0 -15 cm, very low (2.10, 17.4 and 20.0 g $kg^{-1}$) in the subsoils. Lapai-Agaie 1B was low (2.10 g $kg^{-1}$) at the 0 – 24 cm and 70 – 82 cm. The topmost horizon of Lapai-Agaie 2A was low (2.98 g $kg^{-1}$) while the subsoils had very low organic carbon contents (1.93 and 1.40 g $kg^{-1}$). Lapai-Agaie 2B topsoil was very low (1.75 and 0.70 g $kg^{-1}$). Lapai-Agaie 3 had the lowest organic carbon content in the study site. Soil organic carbon of the soil was not suitable for surface irrigation, sprinkler and drip irrigation is recommended.

### 4.1.9 Land suitability of the study site (Parametric Method)

Results of land suitability are presented on Table 4.8. All factors; with exception of slope, organic carbon, and effective soil depth, had highly suitable ratings. In Lapai-Agaie 1 slope was rated 65 %, effective soil depth was rated as 65 % and organic carbon was rated as 70 %. Those value were limitations to the aggregate suitability of the mapping unit. Infiltration rate and available water capacity (AWC) were rated as 75. Soil texture, soil pH, Cation Exchange Capacity (CEC) and Exchangeable sodium percentage (ESP) were rated as 100. The aggregate suitability was rated S3 which meant that the mapping unit was marginally suitable, and the limitations were represented by “t” (slope), “e” (effective soil depth) and “n” (organic carbon).

In Lapai-Agaie 2, infiltration rate was 70 % and organic carbon was rated 65 %. These factors were the limitations found in the mapping unit. Available water capacity (AWC) was rated 80 %, slope and effective soil depth rated as 85 %, cation exchange capacity (CEC) had a rating of 90 %, drainage was given a rating of 95 % while soil texture, pH and exchangeable sodium percentage were rated as 100%. The aggregate suitability was rated

**Table 4.8: Land Suitability Classification (Parametric method) of the Study Site**

| Land qualities | Lapai-Agaie 1 | Lapai-Agaie 2 | Lapai-Agaie 3 |
|---|---|---|---|
| Slope | 65 | 85 | 85 |
| Soil texture | 100 | 100 | 100 |
| Effective soil depth | 65 | 85 | 85 |
| Infiltration rate | 75 | 70 | 75 |
| Drainage | 95 | 95 | 85 |
| AWC | 75 | 80 | 85 |
| Organic carbon | 70 | 65 | 65 |
| Soil pH | 100 | 100 | 100 |
| CEC | 100 | 90 | 100 |
| ESP | 100 | 100 | 100 |
| Aggregate class | **$S3_{ten}$** | **$S3_{in}$** | **$S2_{n}$** |

CEC: Cation Exchange Capacity, ESP: exchangeable sodium percentage, t- slope limitation, e- effective soil depth limitation, n- organic carbon limitation, i- infiltration rate limitation.

S3 (marginally suitable) and the limitation were represented by “i” (infiltration rate) and “n” (organic carbon).

Results of Lapai-Agaie 3 showed that organic carbon was rated 65 %. This was the only limiting factor found in the mapping unit. Infiltration rate was rates as 75 %, slope, effective soil depth, drainage and available water capacity were given 85 % rating while soil texture, cation exchange capacity, soil pH and Exchangeable sodium percentage were given ratings of 100 %. The aggregate suitability was rated S3 (moderately suitable) and the limitation was represented by “n” (organic carbon).

Lapai-Agaie 1 and 2 shared similar land suitability class (S3) but topography, effective soil depth and organic carbon were the limitations found in Lapai-Agaie 1 soils while infiltration rate and organic carbon were the limitations in Lapai-Agaie 3. On the other hand, Lapai-Agaie 3, had a different suitability (moderately suitable (S2)) from the first two mapping units and had organic carbon as the only limiting factor. Low organic carbon is the factor that is common with Lapai-Agaie 1, 2 and 3 in terms of limitation.  The map showing land suitability evaluation using parametric method is shown in Figure 4.2.

#### 4.1.10 Land suitability maps of the study site (Geographic Information System-based)

The total area covered by Lapai-Agaie 1 was 52 ha. Map of suitability for Lapai-Agaie 1 is shown in Figure 4.3 and the area covered by each suitability class is shown on the chart on Figure 4.4. The GIS maps after weighting maps of all the land suitability factors in this mapping revealed that the largest area 28.08 ha of the mapping unit was marginally suitable for irrigation, 20.29 ha was moderately suitable and a small portion (3.6 ha) of the mapping unit was highly suitable. Land suitability map for Lapai-Agaie 2 is shown in Figure 4.5 while the size of each suitability class is shown in Figure 4.6. It showed that 5.16 ha (6 %) of the mapping unit was highly suitable, 28.38 ha (39 %) was moderately suitable and 52.46 ha (61 %) was marginally suitable. Land suitability map for Lapai-Agaie 3 is shown in Figure 4.7 and the size of each suitability class is shown in Figure 4.8. It showed that 3.72 ha (6 %) of the mapping unit was highly suitable, 44.64 ha (72 %) was moderately suitable and 13.64 ha (22 %) was marginally suitable. Results from the maps showed that Lapai-Agaie 1 and 2 had the largest parts of the mapping units as marginally suitable while Lapai-Agaie 2 was moderately suitable in a larger portion of the mapping unit, making the results similar to the results of parametric method. Map of the overall land suitability evaluation using Geographic Information System is shown in Figure 4.9. Sprinkler and drip irrigation systems will be the best irrigation systems to be practiced in the study site.

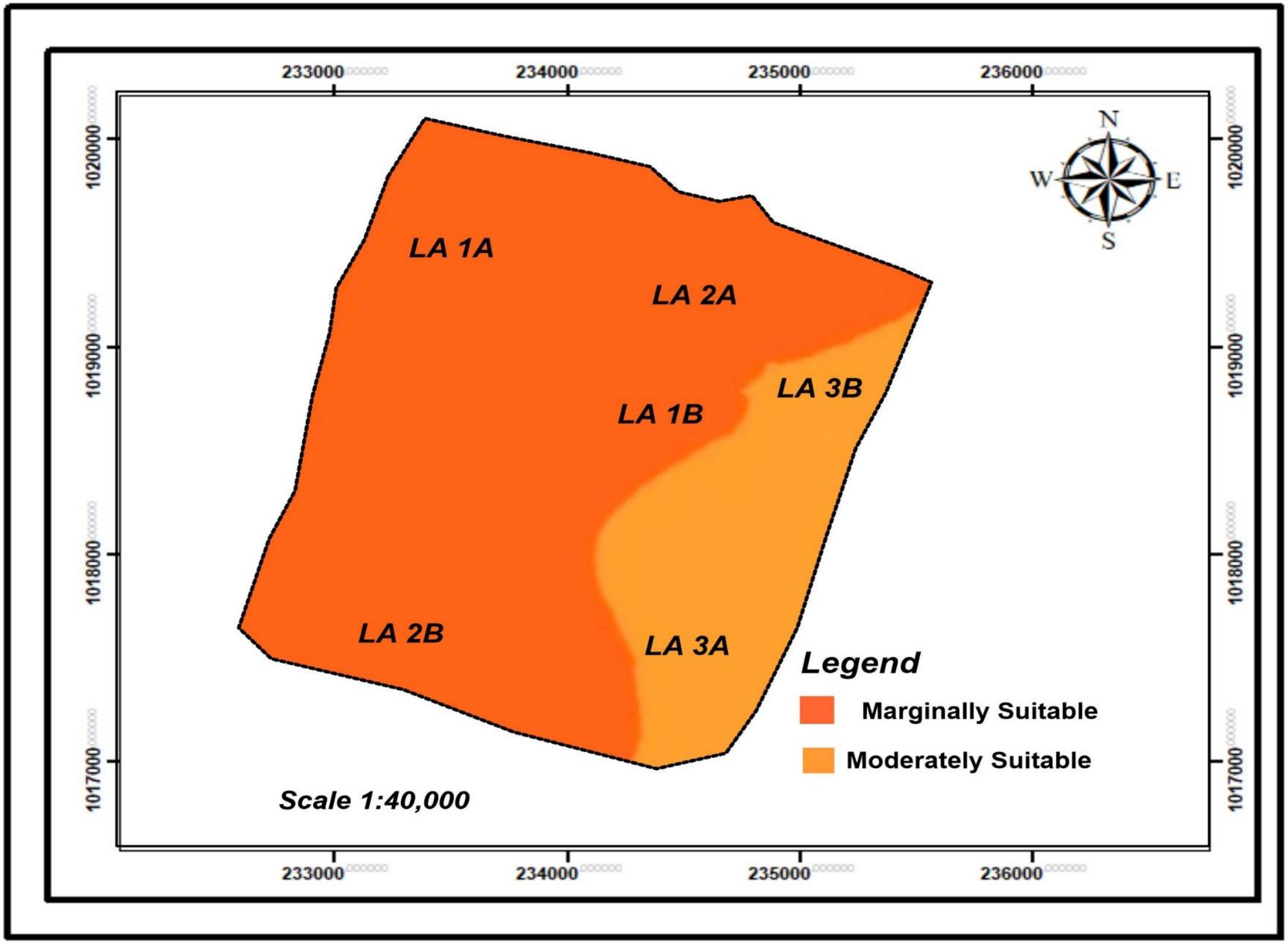


**Figure 4.2: Land suitability (parametric method) map of the study site**

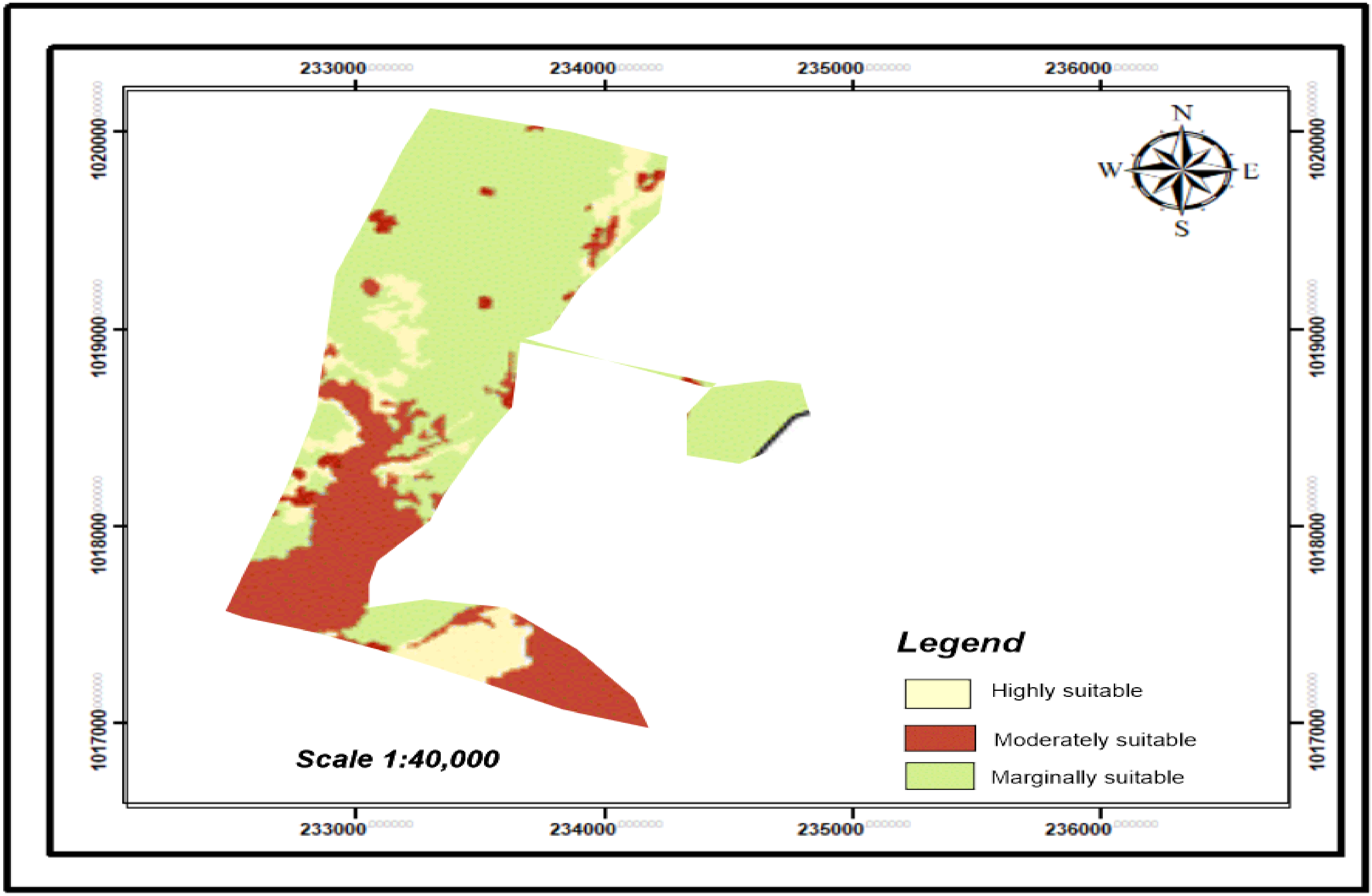

**Figure 4.3: GIS Land Suitability Map of Lapai-Agaie 1**

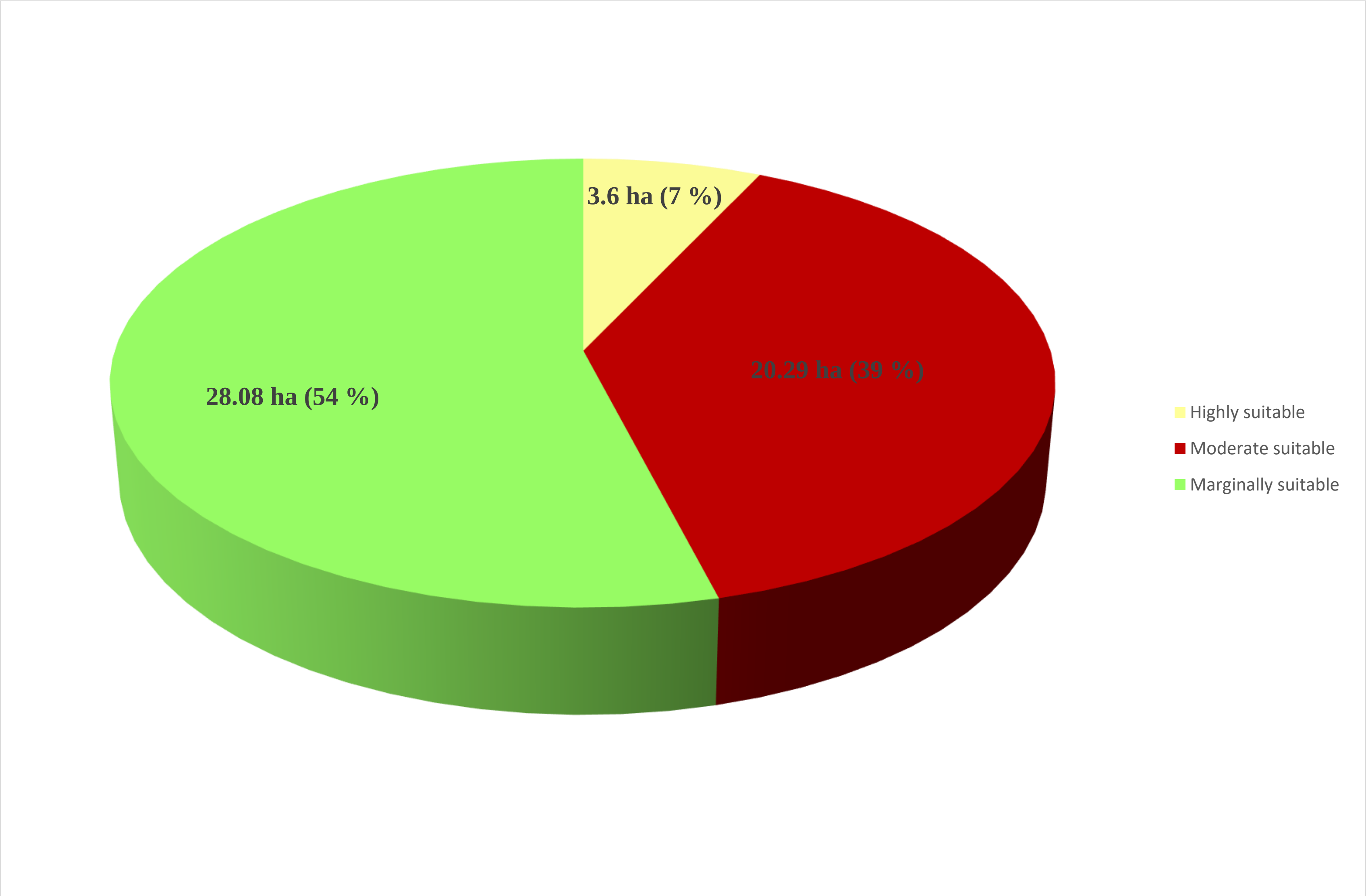


**Figure 4.4: GIS Land Suitability Chart of Lapai-Agaie 1**

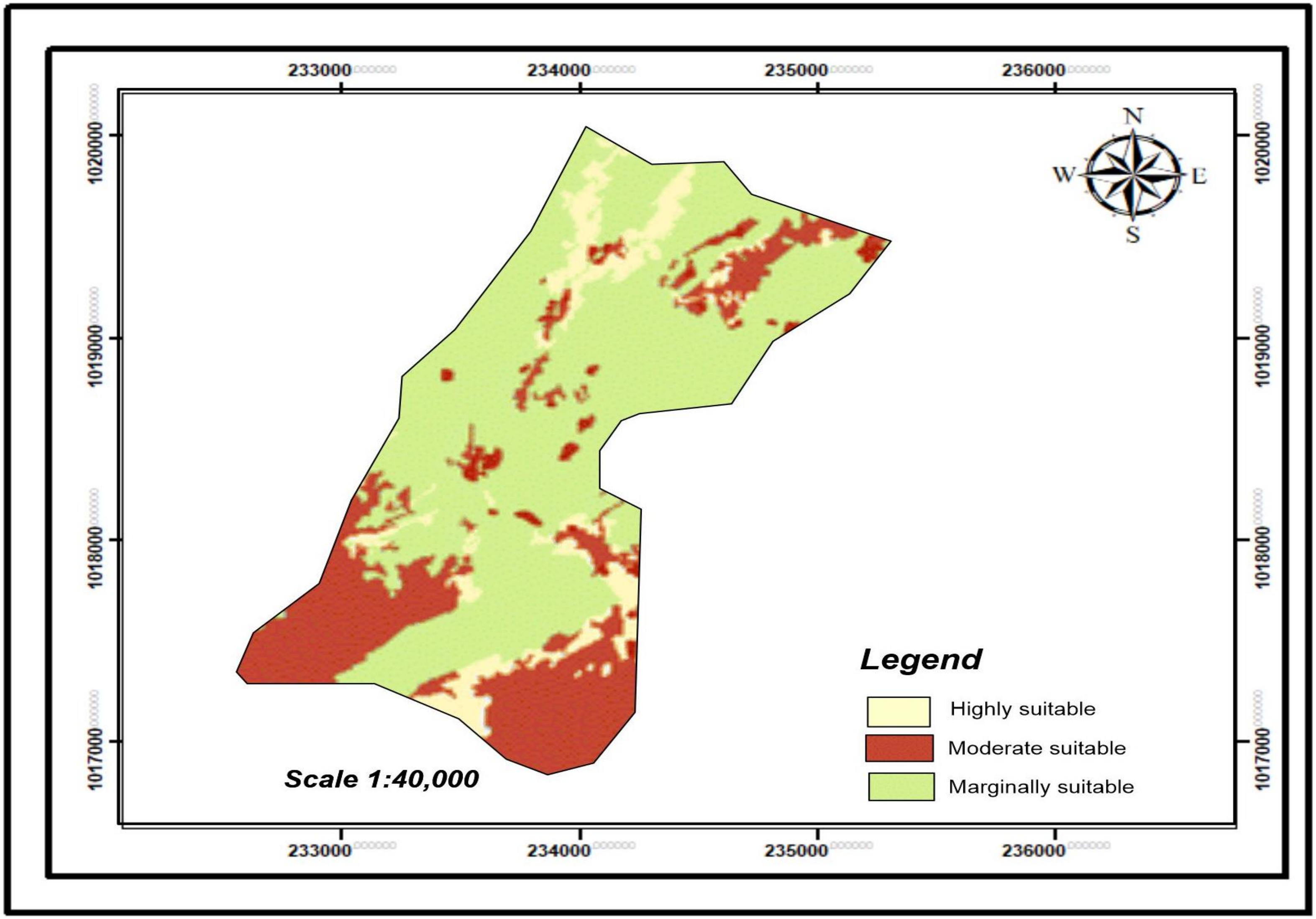


**Figure 4.5: GIS Land Suitability Map of Lapai-Agaie 2**

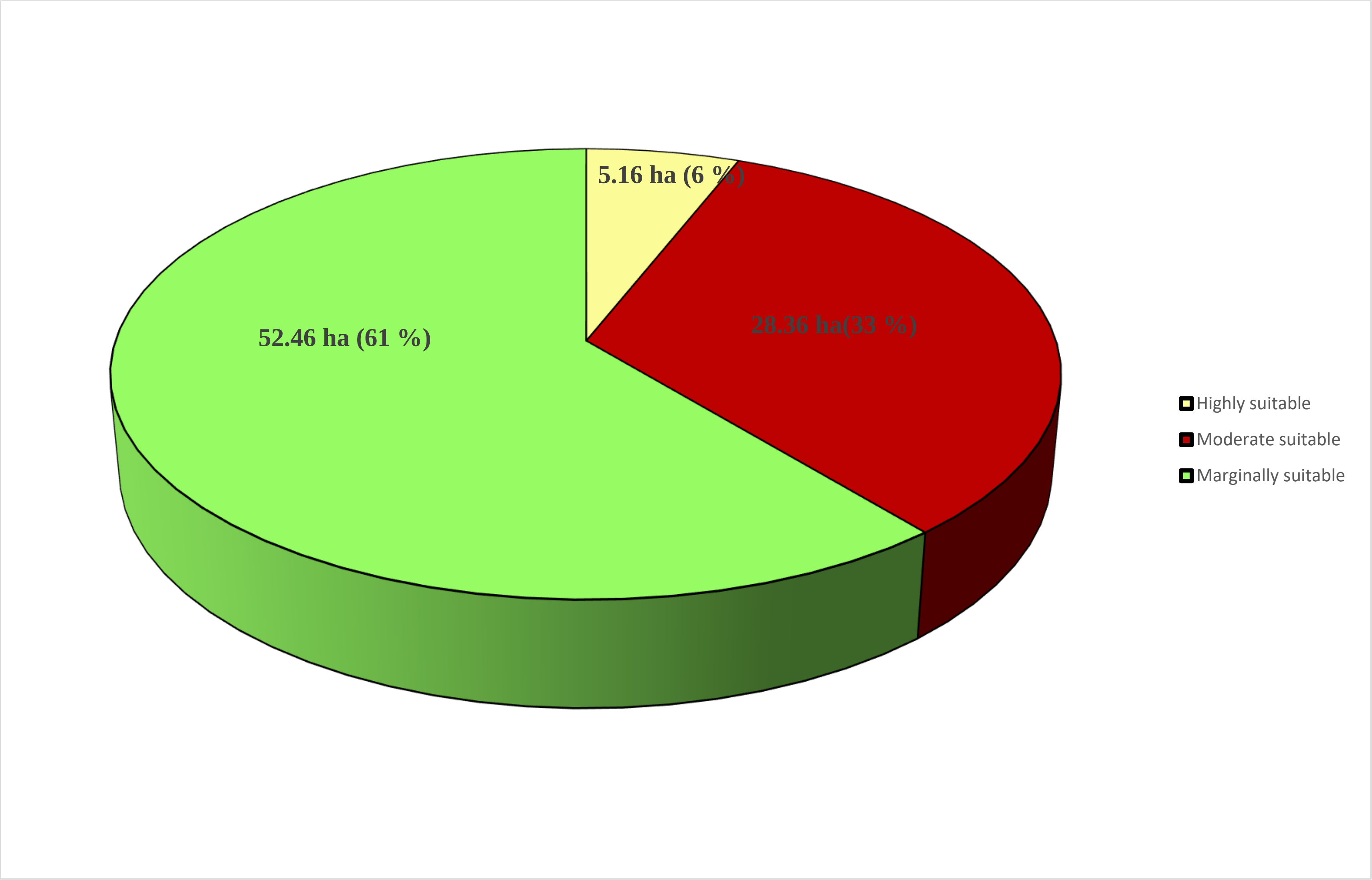


**Figure 4.6: GIS Land Suitability Chart of Lapai-Agaie 2**

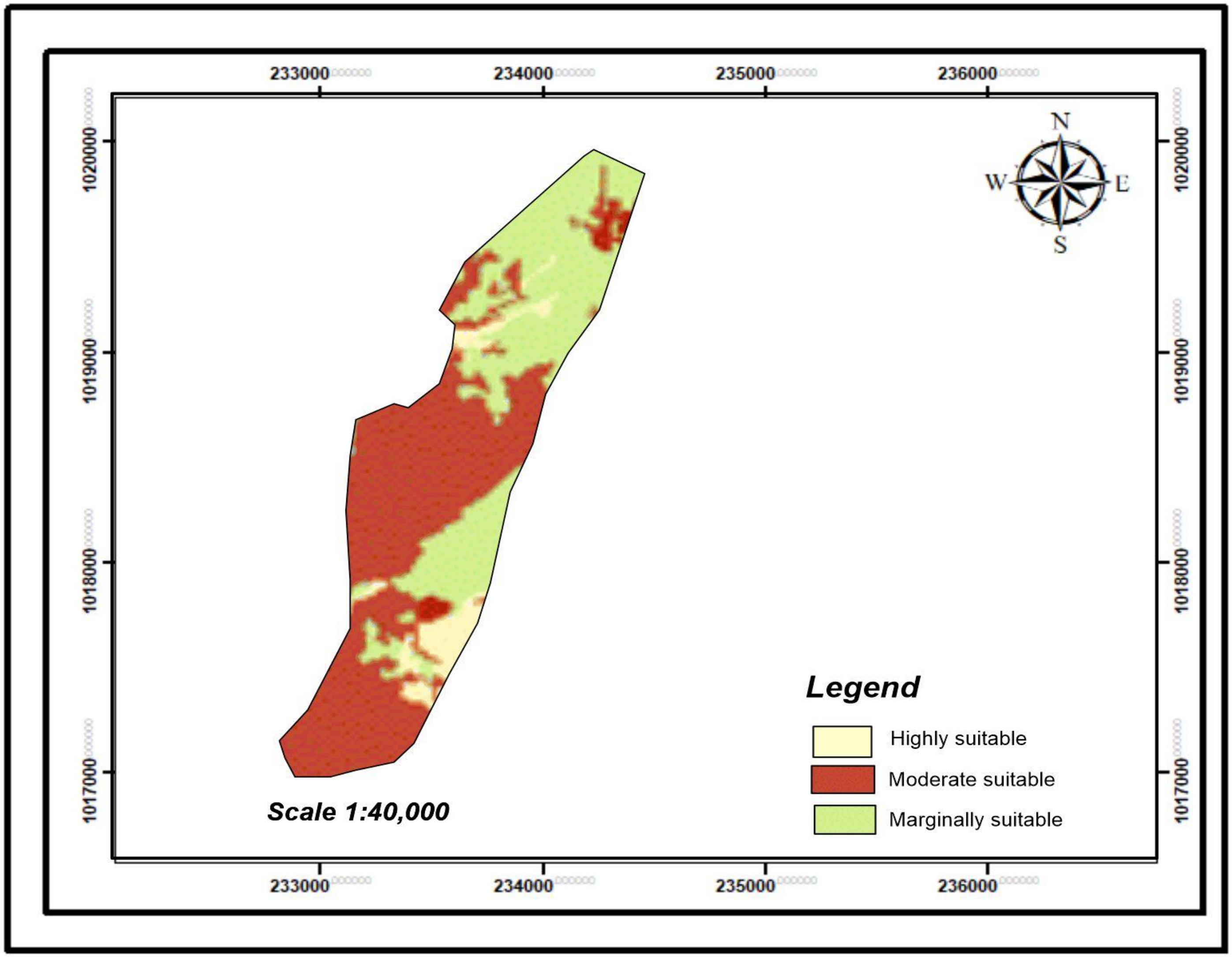


**Figure 4.7: GIS Land Suitability Map of Lapai-Agaie 3**

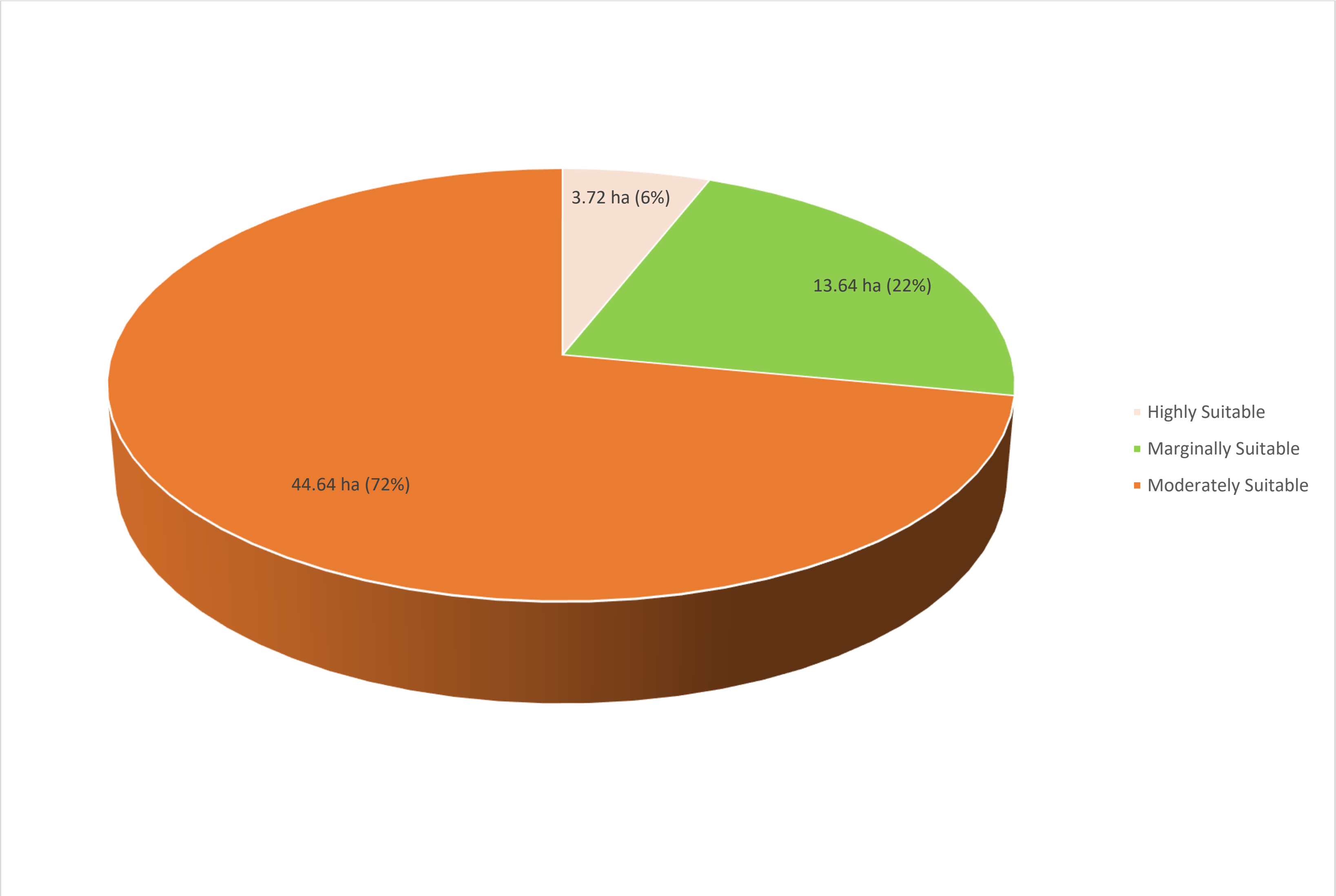


**Figure 4.8: GIS Land Suitability Chart of Lapai-Agaie 3**

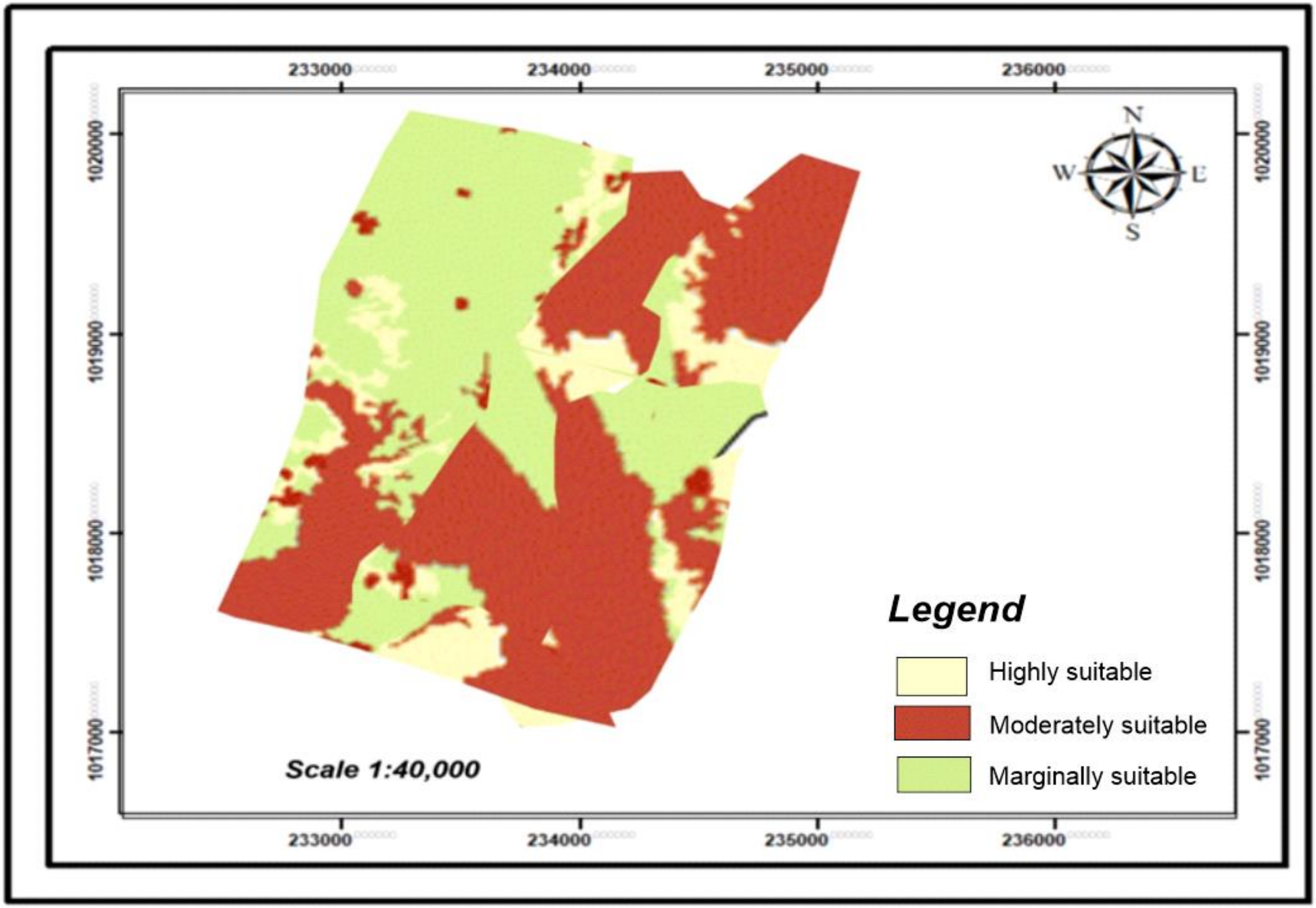


**Figure 4.9: GIS Overall Land Suitability Map of the Study Site**

## 4.2 Discussion

In comparison of the two approaches used (parametric evaluation system and Geographic Information System techniques), both approaches can be said to have high level of agreement. The factors for selection of land suitability for irrigation using parametric method were the same as criteria considered in preparing thematic layer of factors in Geographic Information System environment to produce the suitability maps. The analysis confirms the credibility of parametric evaluation method as well as the GIS. The availability of database plays a vital role in irrigation. GIS may be considered for easy identification of suitable areas in the study site. The GIS indicated points suitable for irrigation by using colours for easy identification by farmers and it gave the total number of areas in hectares and percentage so that the farmer would know what to expect on the field. It could be concluded that both methods employed in this study showed reasonably good accuracy in finding suitable areas.

Geographic Information System revealed better behavior in spatial distribution of various factors. It also showed that in one mapping unit, some areas could perform better than others in terms of irrigation suitability. For example, the GIS approach showed that Lapai-Agaie 1 had 7 % of the soil as highly suitable (S1), 39 % as moderately suitable (S2) and 54 % was classified as marginally suitable (S3), while the parametric approach only classified the mapping units using one suitability class in each mapping unit and indicated the limiting factors for suitability in each of the mapping units. Geographic Information System allows for better record keeping of the results for further analysis. It saves cost and time spent in visiting the site to make decisions about strategic locations (Mandal *et al.*, 2018). It improves communication to farmers by use of pictures to indicate areas found suitable for irrigation.

Slope gradient of the land has great influence on selection of irrigation methods. Slope of the study site was gently undulating according to the rating of Ritung *et al*. (2007). This slope can lead to low infiltration and high runoff of irrigation water and is not suitable for surface irrigation. Surface irrigation systems require uniform grades. Land with steep slopes need to be levelled prior to irrigation. Levelling is an integral part of an irrigation system to enhance the conservation of soil and water resource (Hargreaves and Merkley, 2004). Slopes which are less than 2 % are considered very suitable for surface irrigation (Danbara and Zewdie, 2022). To accommodate sprinkler irrigation systems, land smoothing can be used to modify the slope in a field. Although, areas of shallow soils may be levelled to provide adequate irrigation grades or an alignment, levelling may expose subsurface soil materials. The places where topsoil is removed are likely to have yield reductions and special management using increased organic matter may be required to accelerate soil building in these areas (Thomas *et al*., 2013).

Soil texture is one of the most important soil characteristics considered for land suitability evaluation as it determines pore spaces of the soil and it directly affects soil moisture redistribution. All mapping units of the study area had sandy-loam soil texture. This could be attributed to similar parent materials and environment in which the soils were developed. According to Sys *et al*. (1991), soils of all textural classes; with exception of coarse sand, can be successfully irrigated if proper irrigation method is chosen. Considering the soil texture in the study site, the soil can be said to be highly suitable for any kind of irrigation. Soil texture affects the water holding capacity of soils (Bonetti *et* *al.*, 2021). Soil moisture-holding capacity, intake rate and soil depth are principal criteria affecting type of irrigation system selected. Available water capacity (AWC) was classified as moderate for irrigation in all mapping units in the study site, this could be as a result of the sandy loam texture of the soil. The soils have some level of ability to hold water for a reasonable period thereby preventing the adverse effect of moisture stress on crop growth and the possible death of crop through agricultural drought spell. In terms of rating for irrigation, all the mapping units, available water capacity did not pose a threat to surface irrigation. This means that surface, sprinkler and drip irrigation can be practiced in the study site.

Soil infiltration rate is an essential factor that affects surface irrigation uniformity and efficiency because it distributes water from surface to soil profile. Surface irrigation may be difficult in soils with high infiltration because of rapid infiltration of water, while soils with low infiltration rates absorb water too slowly for surface irrigation, leaving irrigation methods that require the application of little amount of water frequently; such as sprinklers as options. The basic infiltration rate was moderate and moderately rapid which suggests the use of sprinkler and drip irrigation. The result shows that the study site is not suitable for surface irrigation. Infiltration rate was higher in Lapai-Agaie 1. This could be related to the lower values of soil organic matter because increased organic matter results in increased aggregation and improved soil structure, leading to improved infiltration rates. It is also related to the findings of Osuji *et al.* (2010) where they reported significant relationships between infiltration rates and soil organic matter. Azuka *et al.* (2013) evaluated infiltration rate by using the effect of organic matter content.

Effective soil depth is significant in irrigation as it enhances the volume of water the soil can hold, and the volume of soil plant roots can exploit. Deep soils have high water storage capacity and suggests surface irrigation with large amounts of water applied infrequently. They also permit levelling which is essential for surface irrigation. Shallow soils on the other hand, have low water storage capacity and so require frequent application of smaller amounts of irrigation water and is limited to irrigation systems that require little or no leveling; such as sprinklers and drip.

Umweni and Ogunkunle (2014) explained that in levelling of land for irrigation purposes, this characteristic (effective soil depth) is a major consideration so as not to expose unfavourable subsoil layers after the operation. The soils of Lapai-Agaie 1 are not as deep as those of Lapai-Agaie 2 and 3 and so leveling of the soil is not advisable. This poses a threat to surface irrigation in Lapai-Agaie 1 and renders the soil suitable for sprinkler and drip irrigation to conserve the soil. Experience has shown that most crops produce excellent yields with an effective root zone depth of 90 to 100 cm (Sys *et al.*, 1991).The low depth of the Lapai-Agaie 1 could be as a result of the high slope of the mapping unit because slope has great influence on soil depth because soil thickness decreases with increasing slope gradient. Generally, the plinthite which was observed from 33 cm depth of the horizon in the soil profile is one of the factors responsible for the shallow nature of the soil depth in the study site. Temesgan and Yonas (2016) and Albaji *et al*. (2014) had a similar result and they reported that stoniness and slope were limitations to surface irrigation and rendered the soil unsuitable for surface irrigation.

Colour of subsoil is a very important indication of natural drainage. If the subsoil is uniform brown, yellowish-brown, or reddish-brown, the soil was well drained. If the subsoil was mottled with gray, red or rust coloured spots, this soil is poorly drained. If the subsoil was almost entirely gray, it may indicate poor drainage conditions and a cold, wet soil. However, there were some soils with gray colour that have moderate or higher permeability (USDA, 2010). The mapping unit Lapai-Agaie 1 was characterized by dark greyish brown colour (10YR 3/3) at the topmost horizon. The greyish colour in the topmost horizon signifies an imperfect drainage condition. The yellowish brown colour at the subsurface of the study site could be as a result of accumulation of hydrated Fe compounds on top of plinthite horizon. There was presence of Fe and Mn concretions at the subsurface of Lapai-Agaie 1 and 3. Lapai-Agaie 2 was characterized by very dark brown colour (10YR 3/3) at the topmost horizon and yellowish brown (7.5YR 4/4) at the subsurface horizons. The Lapai-Agaie 3 was characterized by very dark brown colour (10YR 3/3) at the topmost horizon. The soils at Lapai-Agaie 1 had suitability index as 95 while Lapai-Agaie 2 was rated 95 and Lapai-Agaie 3 was 80. Lapai-Agaie 3B was poorly drained at the topmost horizon. This could be because the mapping unit was located at the lowest slope and the mapping unit is closest to the water body at the study site. According to the findings of Asfaw *et* al. (2019), well-drained soils are good for agriculture and easy for cultivation.

Barberis and Minelli (2005) and Workat *et al*. (2020) also had slope and soil depth as limiting factor in their findings and suggested that to increase production and productivity of the soil, land improvement operations and use of drip and sprinklers irrigation should be practiced. This implies that the use of surface irrigation method in this mapping unit may not be profitable due to these major limitations. The grading of soil to uniform slope for surface irrigation to be practicable may be difficult as a result of ironstones exposed in most areas of the mapping unit. The use of machines also could further expose the subsurface soil thereby reducing the rooting depth and reducing the organic matter of the soil which was already a limitation in the mapping unit. Lapai-Agaie 2 was also rated marginally suitable (S3) and the limitation factors include infiltration rate and soil organic carbon. Infiltration was very important in irrigation as it affects drainage of the soil and affects the surface irrigation uniformity and efficiency. When infiltration is too rapid it can lead to soil erosion. All other factors considered did not pose a threat to surface irrigation in the mapping unit. On the other hand, Lapai-Agaie 3 had a rating of moderately suitable (S2) and organic matter was the sole limiting factor to irrigation in the mapping unit, as other factors favour irrigation practice. Lapai-Agaie 3 was the mapping unit with the highest suitability rating and it was the only mapping unit in the study site with very little exposure of ironstone, unlike Lapai-Agaie 1 and 2. From the field survey, soils of the study site were characterized to be gently undulating type of landform and has plinthite exposed into hardpan on the surface. Generally, stones and hardpan were found to be a limiting factor in relation to mechanization and crop production through surface irrigation. This further qualifies the site to be more suitable for sprinkler than surface irrigation system.

Soil pH generally ranged between 6.2 to 6.8. This was interpreted to range between neutral to slightly acidic. Soil pH within the range of 5.6 to 6.5 is considered by Ritung *et* al. (2007) as slightly acid and the range of 6.6 to 7.7 is neutral. The result of exchangeable sodium percentage shows that the values ranged between 0.85 to 3.07 % and it was rated as non-sodic in soils of the study site. The result of CEC shows that the values ranged from 3.2 to 33.2 cmol $kg^{-1}$. Most horizons in the mapping units were moderate except for the topmost horizon of Lapai-Agaie 1A and 2B which had low CEC values. Soil organic carbon result shows that the organic carbon ranged between 1.23 to 4.38 g $kg^{-1}$ and this was classified as very low to medium.

Marginally suitable class covered the largest (86 ha) area of Lapai-Agaie 2. Lapai-Agaie 3 which occupies 62 ha of the study site had the largest portion of the mapping unit as moderately suitable followed by marginally suitable and a smaller portion (3.7 ha) was highly suitable. Based on the result from the maps, since the suitability class had moderate and marginal suitability, sprinkler and drip irrigation is preferable in the study site. Results obtained from use parametric method showed that two mapping units (Lapai-Agaie 1 and 2) of the study site were marginally suitable (S3) with the following limitations; organic carbon, slope, infiltration rate and effective soil depth, while Lapai-Agaie 3 was moderately suitable (S2) and GIS specified the size of suitable areas and location of suitability for each mapping unit and the difference between the two approaches was that GIS showed a small portion (21.5 ha) as  highly suitable (S1) while the parametric did not indicate any area as highly suitable. The GIS model allows obtaining results that seems to be corresponded with the current conditions in the study site and makes it is easier for farmers to detect suitable sites for any kind of irrigation practice. Geographic Information System was highly efficient for modeling and developing land suitability maps.

# CHAPTER FIVE

## 5.0 CONCLUSION, RECOMMENDATIONS AND CONTRIBUTION TO KNOWLEDGE

### 5.1 Conclusion

In conclusion, parametric method and Geographic Information System-based multi-criteria decision making analysis were adopted to evaluate the irrigation suitability of the study area. The GIS was used to generate land suitability map for irrigation in Lapai-Agaie irrigation scheme. The study shows that GIS based suitability evaluation could ease the identification and mapping of suitable land for irrigation purpose. The parametric approach and GIS maps can be said to agree, but GIS gave a better and more specific details about the land suitability. Important management information for the study area can be deduced from the land suitability maps for enhancing sustainable development of agriculture in the country. The Soils of Lapai-Agaie 1 had 28.08 ha out of 86 ha as marginally suitable (S3) for irrigation, 20.29 ha was moderately suitable (S2), and a small portion (3.6 ha) of the mapping unit was highly suitable (S1). Marginally suitable class covered the largest area (52.46 ha out of 62 ha) of Lapai-Agaie 2. Lapai-Agaie 3 which occupies 62 ha of the study site had the largest portion (44.64 ha) of the mapping unit as moderately suitable (S2) followed by marginally suitable and a smaller portion (3.7 ha) was highly suitable. The major limiting factors were organic matter, effective soil depth, slope and infiltration rate.

Generally, this study shows that sprinkler and drip irrigation may be preferable to surface irrigation since these irrigation methods are suitable for undulating slope without requiring land grading and may be reliable in improving yield. The effective soil depth, slope, organic matter, and available water capacity were factors that posed a threat to surface irrigation suitability in soils of all mapping units in the study site. Land suitability map would help in developing land use plans and formulating environmental planning policies that can enhance the development of agriculture and help in improving food insecurity in Nigeria. Concerned investors should incorporate GIS-based multi-criteria decision making analysis in selecting sites for irrigation. This will help to maximize potentials of the land thereby generating maximum returns from agricultural land.

## 5.2 Recommendations

i. It is recommended that GIS system should be adapted when evaluating suitability of soils for irrigation.

ii. Sprinkler and drip irrigation methods will be more profitable in the study site

iii. Organic matter application may be required to improve organic matter content of the soil.

## 5.3 Contribution to knowledge

i. GIS based suitability evaluation could ease the identification and mapping of suitable land for irrigation purpose.

ii. Important management information can be easily deduced from the land suitability maps for enhancing development of agriculture.

iii. Parametric evaluation and Geographical Information System approach agreed by 95 %.

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# APPENDICES

## Appendix A

Pedon: Lapai-Agaie 1A

Soil classification

**Site information**

Location: Lapai-Agaie Irrigation scheme, Bakajeba, Niger state

Geographic coordinates: 09$^{o}$13'17.3" N and longitude 06$^{o}$35'3.4" E

Topography and position: 4.5%

Geology: Basement Complex

Parent materials: Colluvial deposits

Vegetation/Land use: Southern Guinea savannah/Arable crops

Erosion hazard: low

Presence of salt and Alkali: nil

Drainage: well drained surface, imperfectly drained subsurface

Depth of water table: within 80cm

Author: Jankaro Larai Saleh

Date described/sampled: 15$^{th}$ May, 2020

Note: soil colours were described under moist condition unless otherwise indicated.

**PROFILE DESCRIPTION**

| **Horizon** | **Depth(cm)** | **Description** |
|---|---|---|
| Ap | 0-15 | Dark greyish brown (10YR 3/3) Sandy loam; weak crumbs;, no visible cracks, very porous horizon, non-sticky and non-plastic when wet, very friable when moist and soft |
| Bt | | |

| | | |
|---|---|---|
| | | wen dry; very good distribution of fine roots, clear wavy boundary. pH 6.6. |
| Btv1 | 13-33 | Dark brown (10YR 3/6) Sandy clay loam; moderate, sub-angular blocky, no visible cracks, sticky and slightly plastic when wet, firm when moist and slightly hard when dry; good distribution of fine and medium roots; diffuse smooth boundary. pH 6.7. |
| | 33-50 | Yellowish brown (10YR 4/6) Sandy clay loam, presence of Fe and Mn concretions, sub-rounded coarse gravelly fragments; concretions and pisolith. Moderate peds, sub-angular blocky shape; no visible cracks; little porous horizon, sticky and non- plastic when wet, firm when moist loose when dry; some fine badly distributed roots, no biological activities; diffuse smooth boundary; pH 6.6. |
| Btv2 | 50-80 | Yellowish brown (10YR 4/4) Sandy clay loam; presence of Fe and Mn concretions; sub-rounded gravelly fragment; massive structure with no visible cracks; sticky and non-plastic when wet, very firm when moist, very hard when dry; neither roots nor biological activities were visible; pH 6.2. |

Pedon: Lapai-Agaie1 B

Soil classification

**Site information**

Location: Lapai-Agaie Irrigation scheme, Bakajeba, Niger state.

Geographic coordinates: 09°12'50.6" N and longitude 06°35'42.7" E

Topography and position: 5.2%

Geology: Basement Complex

Parent materials: Colluvial deposits

Vegetation/Land use: Southern Guinea savannah/Arable crops

Erosion hazard: low

Presence of salt and Alkali: nil

Drainage: well drained surface, imperfectly drained subsurface

Depth of water table: within 82cm

Author: Jankaro Larai Saleh

Date described/sampled: 15th May, 2020

Note: soil colours were described under moist condition unless otherwise indicated.

**PROFILE DESCRIPTION**

| **Horizon** | **Depth(cm)** | **Description** |
|---|---|---|
| Ap | 0-24 | Very dark brown (10YR 3/3) Sandy loam; weak crumbs; no cracks; slightly sticky and slightly plastic when wet, firm when moist and soft wen dry; very good distribution |
| Btv1 | | |

| | | |
|---|---|---|
| | | of many fine and medium roots; medium biological activities, no cracks, clear smooth boundary; pH 6.5. |
| Btv2 | 24-70 | Yellowish brown (10YR 5/8) Clay loam; presence of Fe and Mn, concretions;moderate sub-angular blocky; no visible cracks, sticky and slightly plastic when wet, very firm when moist and slightly hard when dry; good distribution of many fine and medium roots; slight biological activities; no visible cracks; diffuse boundary with smooth topography; pH 6.5. |
| | 70-82 | Yellowish brown (10YR 4/6) Clay loam; presence of Fe and Mn, concretions; moderate sub-angular blocky peds; no visible cracks; very little porous horizon; sticky and non-plastic when wet, very firm when moist and very hard when dry; no visible roots and biological activities; pH 6.5. |

Pedon: Lapai-Agaie 2A

Soil classification

**Site information**

Location: Lapai-Agaie Irrigation scheme, Bakajeba, Niger state.

Geographic coordinates: 09$^o$13'01.3" N and longitude 06$^o$35'28.4" E

Topography and position: 5.0%

Geology: Basement Complex

Parent materials: Colluvial deposits

Vegetation/Land use: Southern Guinea savannah/Arable crops

Erosion hazard: low

Presence of salt and Alkali: nil

Drainage: well drained surface, imperfectly drained subsurface

Depth of water table: within 100cm

Author: Jankaro Larai Saleh

Date described/sampled: 15th May 2020

Note: soil colours were described under moist condition unless otherwise indicated.

**PROFILE DESCRIPTION**

| **Horizon** | **Depth(cm)** | **Description** |
|---|---|---|
| Ap | 0-30 | Very dark brown (10YR 3/3) Sandy loam; moderate; no cracks, porous horizon, non-sticky and non-plastic when wet, friable when moist and soft when dry. Very good distribution of many fine and medium roots, no cracks, clear wavy boundary; slight biological activities. pH 6.7. |
| AB | 30-50 | Yellowish brown (7.5YR 4/4) Sandy clay loam, moderate sub-angular blocky; no visible cracks, slightly sticky and plastic when wet, firm when moist and slightly hard when dry; good distribution of some fine roots; Slight biological activities; diffuse wavy boundary; pH 6.4. |
| Btv | 50-100 | Yellowish brown (7.5YR 4/6) Clay; Strong ; sub-angular blocky; no visible cracks; sticky and plastic when wet, |

extremely firm when moist and very hard when dry; slight biological activities. pH 6.6.

Pedon: Lapai-Agaie 2B

Soil classification

**Site information**

Location: Lapai-Agaie Irrigation scheme, Bakajeba, Niger state.

Geographic coordinates: 09$^{o}$12'48.5" N and longitude 06$^{o}$35'17.8" E

Topography and position: 3.6%

Geology: Basement Complex

Parent materials: Colluvial deposits

Vegetation/Land use: Southern Guinea savannah/Arable crops

Erosion hazard: low

Presence of salt and Alkali: nil

Drainage: well drained surface, imperfectly drained subsurface

Depth of water table: within 126cm

Author: Jankaro Larai Saleh

Date described/sampled: 16$^{th}$ May 2020

Note: soil colours were described under moist condition unless otherwise indicated.

**PROFILE DESCRIPTION**

| Horizon | Depth(cm) | Description |
|---|---|---|
| Ap | 0-34 | Very dark brown (10YR 3/3) Sandy clay loam; moderate; granular; no visible cracks; sticky and non-plastic when wet, friable when moist and soft when dry; very good |
| Bt | | |

| | | |
|---|---|---|
| | | distribution of many fine and medium roots; Abrupt wavy boundary; medium biological activities; pH 6.5. |
| Btv | 34-58 | Yellowish brown (10YR 5/8) Sandy clay loam; moderate, sub-angular blocky, no visible cracks; sticky and plastic when wet, firm when moist and slightly hard when dry; some fine roots with good distribution; slight biological activities; diffuse wavy boundary; pH 6.8. |
| | 58-126 | Yellowish brown (10YR 4/6) Clay; Strong; sub-angular blocky; no visible cracks; sticky and plastic when wet, extremely firm when moist and very hard when dry; slight biological activities; pH 6.3. |

Pedon: Lapai-Agaie 3A

Soil classification

**Site information**

Location: Lapai-Agaie Irrigation scheme, Bakajeba, Niger state.

Geographic coordinates: 09°12'43.8" N and longitude 06°35'47.3" E

Topography and position: 4.3%

Geology: Basement Complex

Parent materials: Colluvial deposits

Vegetation/Land use: Southern Guinea savannah/Arable crops

Erosion hazard:low

Presence of salt and Alkali: nil

Drainage: well drained surface, imperfectly drained subsurface

Depth of water table: within 100cm

Author: Jankaro Larai Saleh

Date described/sampled: 16th May 2020

Note: soil colours were described under moist condition unless otherwise indicated.

**PROFILE DESCRIPTION**

| **Horizon** | **Depth(cm)** | **Description** |
|---|---|---|
| Ap | 0-33 | Very dark brown (10YR 3/3) Sandy clay loam; no visible cracks; slightly sticky and non-plastic when wet, firm when moist and slightly hard when dry; very good distribution of many fine and medium root; clear wavy boundary; slight biological activities. pH 6.2. |
| AB | 33-65 | Dark brown (10YR 3/6) Sandy clay loam; no visible cracks; sticky and slightly plastic when wet, firm when moist and slightly hard when dry; good distribution of some fine and medium roots; medium biological activities; diffuse wavy boundary; pH 6.4. |
| Btv1 | 65-85 | Yellowish brown (10YR 3/8) Sandy clay loam; presence of Fe and Mn ; gravelly; no visible cracks; sticky and non-plastic when wet, very firm when moist and hard when dry; |
| Btv2 | | |

good distribution of some fine roots; slight biological activities; diffuse wavy boundary; pH 6.3.

| | |
|---|---|
| 85-100 | Dark yellowish brown (10YR 3/4) Clay loam; presence of Fe and Mn; gravelly; no cracks, very little porous horizon, sticky and non-plastic when wet, extremely firm when moist and very hard when dry; slight biological activities. pH 6.3. |

Pedon: Lapai-Agaie 3B

Soil classification

**Site information**

Location: Lapai-Agaie Irrigation scheme, Bakajeba, Niger state.

Geographic coordinates: $09^{o}12'52.6''$ N and longitude $06^{o}35'52.2''$ E

Topography and position: 3.9%

Geology: Basement Complex

Parent materials: Colluvial deposits

Vegetation/Land use: Southern Guinea savannah/Arable crops

Erosion hazard: low

Presence of salt and Alkali: nil

Drainage: well drained surface, imperfectly drained subsurface

Depth of water table: within 110cm

Author: Jankaro Larai Saleh

Date described/sampled: 16th May 2020

Note: soil colours were described under moist condition unless otherwise indicated.

**PROFILE DESCRIPTION**

| **Horizon** | **Depth(cm)** | **Description** |
|---|---|---|
| Ap | 0-10 | Very dark brown (10YR 3/4) Clay loam; moderate; granular; no visible cracks; slightly sticky and non-plastic when wet, firm when moist and soft when dry; good distribution of few fine roots; clear wavy boundary; slight biological activities. pH 6.3. |
| Btv1 | 10-47 | Yellowish brown (10YR 5/8) Sandy clay loam; presence of Fe and Mn; gravelly; little porous horizon with no cracks, sticky and non-plastic when wet, very firm when moist and very hard when dry; good distribution of some fine roots; medium biological activities. diffuse wavy boundary; pH 6.3. |
| Btv2 | 47-110 | Yellowish brown (10YR 5/8) Clay; No cracks; non-sticky and plastic when wet, extremely firm when moist and very hard when dry. Slight biological activities. sticky and non-plastic when wet, very firm when moist and very hard when dry; good distribution of some fine roots; medium rate biological activities. pH 6.3. |