CHARACTERIZATION, SOIL-FORMING PROCESSES AND CLASSIFICATION OF WATERLOGGED SOILS IN OVIA NORTH EAST LOCAL GOVERNMENT AREA, EDO STATE

BY

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CERTIFICATION

We the undersigned certify that this project was carried out by **TEITEI STANLEY SEIYEFA** with matriculation number **SSC1708102** in partial fulfillment of the requirements for the award of Bachelor of Science (B.Sc.) Degree in the Department of Geography and Regional Planning of the University of Benin. Benin City, Nigeria.

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DEDICATION

To my mother, Boyous Teitei, and my great aunty, Mrs. Pauline Eyekeginren Laurentia APREZI (Nee BRISIBE) who has always supported me and believed in me. Your love and encouragement has been a constant source of strength and motivation throughout my academic journey. Thank you for everything.

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ABSTRACT

The study focused on the characterizing, classifying and identify the soil-forming processes in a waterlogged soil in Ovia North East Local Government Area, Edo State for the purpose of providing an understanding of the ecosystem and land-use sustainability. A soil profile of up to 180 cm was dug in the area, and six soil samples were drawn from the each of the horizons in the profile for laboratory analysis. The morphological properties of these soils: colour, soil structure, soil consistence, drainage, boundaries and root inclusions were recorded in the field. The soil samples collected were analyzed using standard laboratory procedures. The treatments were non-replicated and the data was analysed using different weathering indices. The results showed that the soil in the study area has a moderate, medium, sub-angular blocky structure in the topsoil, with colours ranging from dark reddish brown to red. The bulk density of the soil was found to be within acceptable limits. The water holding capacity (WHC) was highest in the subsurface horizon and lowest in the surface horizons, with the highest values found at the Bt_2 horizon and the lowest at the AB horizon. The pH of the soil was slightly acid to neutral and did not show a clear pattern throughout the profile. Available phosphorus was very low and not sufficient for crop production. The levels of micronutrients in the soil, including manganese, copper, zinc, and iron, were higher than necessary for crop plant growth, and crops sensitive to these micronutrients should not be planted. The soil contained high levels of heterogeneous bacteria and fungi, with microbial activity being particularly high at the topsoil. However, microbial activity decreased with soil depth. There is evidence of transformation, translocation of clay, eluviation, illuviation, and leaching. The soils were classified according to the USDA Soil Taxonomy as Typic Kandiudults. These findings provide important information for understanding the suitability of the soil for crop production and identifying potential management strategies. To improve the productivity of the soil in the study area, the study recommends putting in place a well-functioning drainage system and water management facilities, engaging in good organic matter management practices, including the use of farmyard manure, and periodically applying lime to the soil.

CHAPTER ONE

INTRODUCTION

1.0 Background to the study

The importance of soil has most often been underestimated. Most people are not aware that their lives and sources of livelihood, either directly or indirectly, are affected by the soil underneath their feet. Despite, this grave oversight, soil can be seen symbolically as the foundation of life and a medium of biodiversity. The environment within which any given soil is formed is revealed in its condition and nature (Gabler, Petersen, Trapasso, Sack, Sager, and Wise, 2007). The soil condition and nature are the characteristics of soil within the context of the various environmental factors that shape the soil. Functioning as a system, a set of interacting elements, soil reflects its surroundings by responding to various processes of nature within the environment. Therefore, soils are not only influenced by non-living matter but by organisms living in and on it. These organisms significantly contribute to the processes of soil formation and its overall characteristics (Arbogast, 2013).

For the most part, the uppermost layer of the earth's lithosphere which provides support for plant and animal life can be referred to as soil. According to Hess and Tasa (2013), soil is a layer of the earth's surface, made up of mineral matter and contains a high amount of organic compounds that supports plant life. In an online lecture video, Alizé Carrère (Crash Course, 2021) compared soil to a carrot cake where different ingredients are required in the right proportion in the baking process; emphasizing that, similarly, soil is a complex aggregate of minerals, air, water and organic matter for plants to flourish. Although classified as part of the lithosphere because most of its constituents are inorganic, soil is inseparably related to other Earth systems. Therefore, soil is a collection of natural bodies occupying portions of the earth's surface that support plants and that have properties due to the integrated effect of climate and living organisms acting upon parent materials as conditioned by relief over a period of time (Esu, 1999).

Although soils varies both locally and regionally all soils seem alike in various ways by having gas, liquid and solid phases having profiles of some kinds. A bit alternation of description of a soil is that reported by Birkeland (1974) as a natural body consisting of variable thickness, which differ from the parent materials in their morphology and biology. Thus, the lower limit of soil is usually the lower limit of biological activities which coincides with the rooting depth of perennial plants. Soil Survey Staff (2010) define it arbitrarily as 200cm. Each soil body has boundaries, and adjacent bodies often break into another forming a continuous mantle over the whole mass.

Since soils are made up of different components combined at varied proportions, the practice of determining the properties of soil is very essential. It is so, not only because it is useful in determining the nature and extent of contamination in the soil, but knowledge of soil properties is important for crop production and in defining other suitable land use potentials (Yitbarek et al., 2016). The description of the distinctive nature or properties of soil is known as soil characterization. Soil property comprises structure, texture, moisture, porosity, and chemistry, and the integration of these various properties makes up soil type (Christopherson, 2011). According to GLOBE (Global Learning and Observations to Benefit the Environment) (2014), soil is characterized by its colour, structure, texture, consistence and abundance of roots, carbonates and rocks. The properties of soil are physical, chemical, and biological, and exert significant influence on the dispersal and growth of vegetation (Balasubramanian, 2017). The identification of these properties is important in the classification of the soil into appropriate taxa or soil groups (Soil Survey Staff, 1975).

Waterlogged soils are subjected to excessive wetness so much so that the wet condition influence landuse. Brinkmann and Blokhuis (1988) opined that in a waterlogged area, water is on or at the surface of the depressed land greater than two months of the agricultural and other vegetation growing season. Thus, the waterlogged area could be called wetland soils.

1.1 Statement of the Research Problem

Just as all areas do not have the same climate, not all areas have the same soil type. As such, the soil formation process of every area is not the same (Gabler et al., 2007). This is because factors responsible for soil formation do not operate uniformly across all geographic locations. Even soils classified into the same broad soil group do not have the same physico-chemical properties, possibly due to differences in the geology of parent materials, slope, and local climatic conditions (Food and Agriculture Organization of the United Nations et al., 1974). Ugwa, Orimoloye, Kamalu and Obazuaye (2017) stated that the major Nigerian soils have diverse physical, chemical and biological properties. The spatial variations of climate and geological phenomena correlate with characteristics and organic content of local soil types (Gabler et al., 2007).

Soils in Nigeria have been characterised and classified for different purposes. While some studies of soil in Nigeria were conducted to determine land use suitability, others have been conducted to assess the quality of land for agricultural productivity. Similar studies have been conducted in parts of Edo State to evaluate land suitability and assess the nature of soil contamination (Ugwa, Umweni and Bakara, 2016). Due to observed differences in scope and purpose among those studies, no acceptable generalization can be deduced from them.

However, studies in geomorphology have provided a general framework for understanding soils around Benin City. According to Ikhile (2016), geomorphic processes that may be related to the various soil types of the Benin region consist of deep weathering, fluvial and slope processes. One of the first inquiries on the geology of the Benin environ was done by Parkinson (1907) who referred to the reddish earth that has basal composition of sand, sandy clays and ferruginized sandstone as Benin Sand.

Subsequently, Tattam, (1943) used the term Coastal plain sands to portray the red soil underlain by clays and sands which depicts a prehistoric coastal plain exposed in most part of southern Nigeria. However, the same reddish-brown-yellow usually white sand was further described as Benin formation by Reyment (1965). After examining different literature written about the Benin landscape, Ikhile (2016) concludes that the Benin region which equally includes Ovia North East, the area of study in this research, comprises four land features of which the Benin formation is one.

Although enough literature seems to exist that attempt to describe the soil around the Benin environ, but not enough has been documented about the physical, chemical and biological properties of specific areas such as the unique nature of soils formed in waterlogged environment. It is not all areas that have the same soil characteristics even if they are classified into the same group. There are yet many flooded and waterlogged areas in Edo State that are undocumented, mapped nor studied. These soils occur largely in the inland valleys and associated with low-lying topography. It is a sizeable land as reported by Akamigbo (2001) as a large part of it permanently or seasonally flooded for a considerable period of the year that normally support hydrophilic plants and animals. These are some specific soil-related problems facing the environment and indeed the studied area. Flooding and waterlogging are very serious problems among others which should be addressed. Therefore, the characteristics and process of soil formation in a waterlogged area will be of significant interest in this study.

1.2 Aim and Objectives

There are some specific land-related problems facing the environment around Benin environs. It is therefore useful that continuous research is carried out at different locations to properly define the nature of surrounding soils and their properties. The main aim of this research is to evaluate the characteristics of soil in a waterlogged area in Ovia Northeast LGA and determine its process of formation for the purpose of providing an understanding of the ecosystem and land-use sustainability. Hence, the following specific objectives are instrumental to the pursuit of the aim which are to:

i. determine physical, chemical, and biological characteristics of the soil,
ii. explain the soil-forming processes at work,
iii. classify the soil into appropriate taxonomy, and
iv. recommend sustainable land use and management options suited to the soil type.

1.3 Scope of the Study

This study focuses on analysing the physico-chemical and biological properties of a waterlogged soil, and to estimate the soil-forming processes at work. For this purpose, a soil profile of up to 180cm was dug in an area frequently inundated with water in Idunowina area, Ovia North East LGA. Samples were taken from its six horizons to a laboratory for analysis for the physical, chemical, and biological properties. Parameters to be taken into account include: textural class, bulk density, hydraulic conductivity, WHC, pH, OC, available phosphorus, potassium, sodium, calcium, magnesium, aluminium, soil reaction, exchangeable acidity, effective cation exchangeable capacity, iron, manganese, zinc, copper, total heterotrophic fungi count and bacteria counts. Appropriate statistical techniques were employed for the purpose of analysing the contents and to test whether there is significant relationship among properties. Some soil management options of the area shall be studied.

1.4 Significance of the Study

The need for the awareness that soils are essential components of the earth's biosphere has inspired studies on soil quality evaluation (Adeboye, 2011). As a result of improper use and poor management of land resources, the challenges of soil degradation and world food crisis among other issues have become worse due to lack of information on soil resources with respect to most regions (Esu, 2004). Adamu et al., (2015) believe that farmers cannot easily modify some physical characteristics such as texture and soil depth which condition the suitability of a soil for various activities. Soil water and air supplied to plant are largely determined by the physical properties of soil, therefore the adaptive ability of plants to cultivation and the amount of organic activity supported by the soil is equally influenced by them. Besides, soil productivity is dictated by its chemical properties, thus they are crucial among every other factors that define the ability of soil to deliver nutrients to plant microbes. A fertile soil may not necessarily be a productive soil. The reactions in the soil which result from these chemical properties also affect the soil-forming process and the gradual accumulation of soil fertility (Adamu et al., 2015). Similarly, the characterization of waterlogged soil will provide insight into the nature and functions of ecosystems in the area of study, and provide a knowledge base with which recommendations can be made about the type of soil. The data provided by this work can help scientists make important predictions on flooding and/or waterlogged areas. Furthermore, this study can help scientists and agencies come to a decision on the type of vegetation and land use practice best suited to the locale. According to GLOBE (2014), trends associated with soil moisture and temperature that have been observed from satellite imagery can be explained using soil characteristics. Therefore, this study provides valuable resources for future research in soil geography, geomorphology and pedology.

1.5 Study Area

The study was carried out in Ovia Northeast Local Government Area of Edo State, Nigeria (Fig. 1.1). It lies between latitude 6.43^{o}N and longitude 5.61^{o}E. This site is situated in Idunowina, Ovia Northeast LGA kilometre 11 in Benin-Sagamu expressway. Ovia Northeast L.G.A. is bounded by Uhunmwonde L.G.A. in the East, Ovia Southwest L.G.A. in the West, while being bordered by Egor L.G.A. and Oredo L.G.A. in Northeastern part. Idunowina has an elevation of 129m and an altitude of 127m above sea level.

The area is part of the terrain of Benin metropolis which is characterized by flat plains, and the northern fringes include Ugbowo and Isiohor. Oluku and Ekiadolor are at higher elevations ranging from 122m to about 155m above sea level respectively (Ikhile, 2016). Kamalu, Ugwa and Omenihu (2014) reported that the soil is made up of largely reddish-brown sandy laterite, as a result of unconsolidated sedimentary deposit of the Miocene-Pleistocene period. The soils are predominantly sandy texture, low total porosity, highly leached and therefore low in soil nutrients. Despite these views, these soils are known to support agriculture (Babalola and Obi, 1981). Idunowina is part of the coastal plain sands which is also part of Benin formation. According to Omosuyi, Ojo and Olorunfemi (2008) the coastal plain sands make up the major hydro-geologic units of the area. The high annual amount of rainfall (2255mm) geological and other favourable climatic conditions such as temperature (27^{o}C) positively affect adequate groundwater recharge in the area.

According to Atedhor et al., (2011), the areas surrounding Benin City belong to the Af category of Koppen’s classification of climate, and it is characterized by relatively wet and dry seasons. As tropical climate, the interaction of warm moist tropical maritime air mass and the hot and dry tropical continental air mass to determine the level of rainfall in the area. In the area, rainfall becomes heavier in April, and progressively peaks in August. However, rainfall becomes capriciously higher in September. The rainfall of Benin City and surrounding area which includes Ovia Northeast is intense in April and

October, although much heavier in June and July, however, with a break around August (Atedhor, Odjugo and Alex (2011). Ugwa et al (2016) reported that the area has a total of over 110 rainy days annually and could exceed 140 rainy days in some years.

The study area is near residential area surrounded by buildings. The location is covered by trees, shrubs, grasses such as dwarf oil palm (elaeis guineensis), interspersed with bamboos grass (dracaena sanderiana) which have the effect of covering and protecting the soil from sheet and rill erosion, and encourage build-up of nitrogen. At the northern part of the study area are scanty farms inter with yam, melon and vegetables. The people are mostly farmers, traders and few civil servants. Hunting and trap-settings for games take place in the locality.

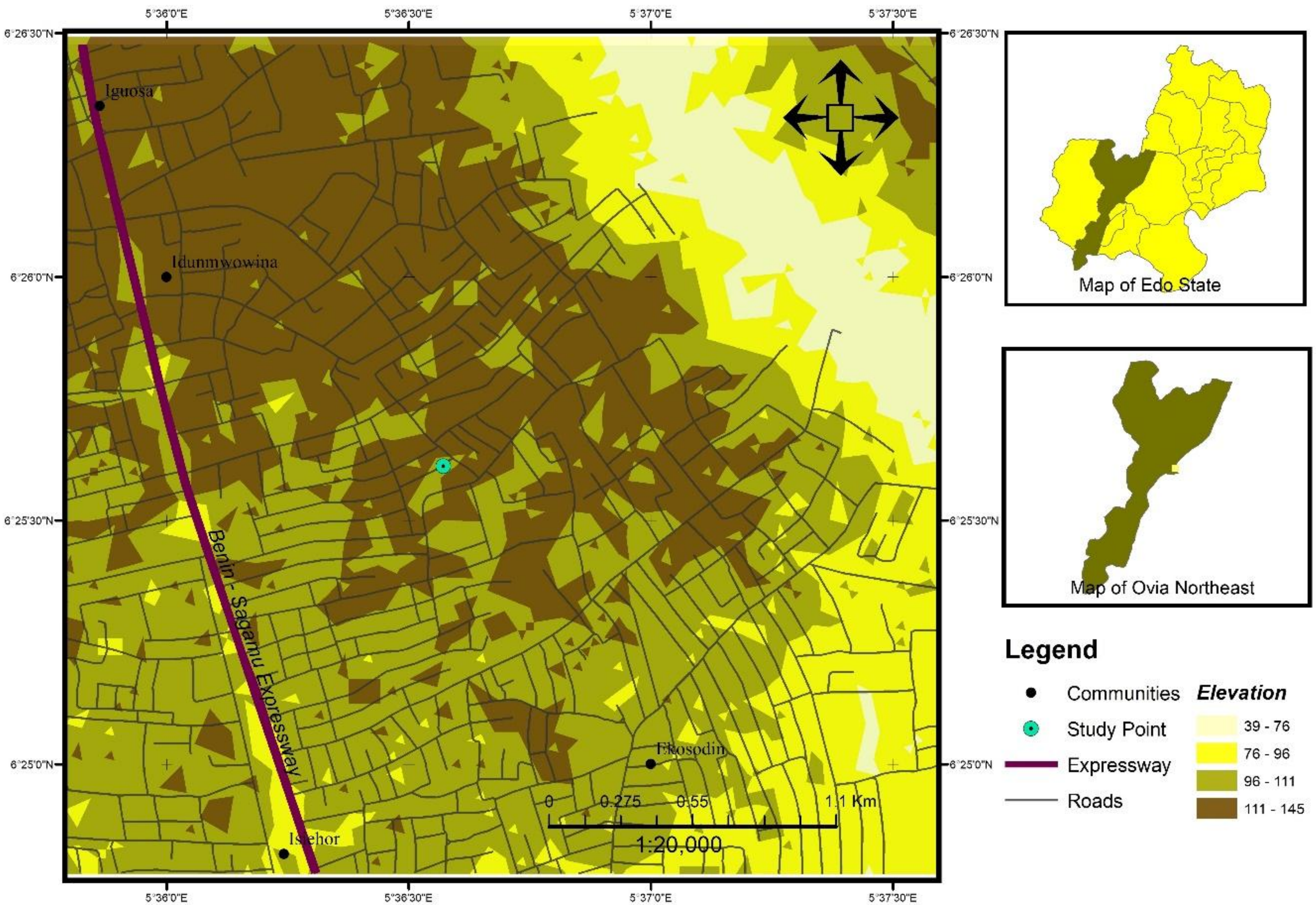


Figure. 1.1: Map of the Study Area

CHAPTER TWO

CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

2.0 Conceptual Framework

The ability of a particular soil to yield and retain plant nutrients is possible due to soil moisture, sunlight, microbes and good soil physical properties. As a functional basis of terrestrial ecosystems, soils are formed by different geomorphic processes. The formation of soils involves a slow process that usually takes several thousands of years through the interaction of climatic, biotic, and geological influences (Balasubramanian, 2017). Geologically, parent material, is either sediment transported from elsewhere by erosional agents or bedrock. Over time, the parent material breaks down and decomposes, creating the ingredients for soil formation. The amount of temperature and moisture influence the level and rate of breakdown of parent materials because chemical and biological processes are favourable in places of high temperature and great moisture content. Soil characteristics are also influenced by slope and drainage.

According to GLOBE (2014), soils are characterized by their colour, texture, structure, consistence, carbonates, abundance of roots and rocks fragments which allow for the interpretation of their ecological functions, and provides the understanding with which recommendations for sustainable use of the soil can be made. Many soil classification systems have been advanced to sort soils based on their chemical, physical and morphological properties into various categories. Despite the fact that classifications are only systems developed to bring about consensus among scientists, it has proven useful in providing knowledge regarding relationships among soils and between soils and the factors that influence the various properties of soil (Soil Survey Staff, 1975).

Therefore, for the purpose of classification, some terms associated with the physical and chemical characteristics of soils have to be clarified, in order that relationships among them can be properly established.

2.1 Soil Physical Properties

2.1.1 Soil Colour

Colour is the most noticeable trait of soil, providing some clue to its chemical composition (Christopherson, 2011). Being the most visible, it is easy for people to notice how the colours of soils vary from one place to another. There is usually a variation in colour from black to brown, and to yellow, red and different shades of grey. In order to accurately identify colours and to standardize their descriptions, soils are compared with Munsell Colour Chart which shows 175 colours organised by *hue, value and chroma*. Black or brown is usually associated with humus (decomposed organic matter), therefore, soils containing a high amount of humus is usually dark. Soil colours fade to light brown or grey over time as their humus content declines due to the loss of organic matter through leaching. A high percentage of humus is often construed as highly fertile soil because humus provides bio-agents that stimulate chemical processes with which plants acquire nutrients from the soil. Some black and dark brown soil, however, do not have much humus content, because some other factors seem to be responsible for their dark colour (Gabler et al., 2007).

2.1.2 Soil Texture

Soil texture, often an unalterable attribute of soil, can be referred to as the distribution of the sizes of particles that constitute the soil (Gabler et al., 2007). Christopherson (2011) describes soil texture as the combination of sizes of soil particles and the ratio of their different sizes. All particles with a diameter smaller than 2 millimetres are considered part of the soil, while larger particles, such as cobbles, gravel or pebbles are separate from the soil. The three main soil textures are sand, silt, and clay which are mixed in different proportions. Sand particles are rough to the touch and have sizes between 0.05 and 2.0 mm (visible to the unaided eye). When wet, silt is smooth and slick to the touch, and its individual particles range in size from 0.002 to 0.05 mm (much smaller than those of sand). Clay is sticky when moist and has a size of less than.002 mm. (Gabler et al., 2007)

Soil texture is an essential physical property for characterizing soil (Pattison et al., 2008). This is because soil texture defines the capacity of a soil to preserve air and moisture, and the rate at which water moves through the soil which in turn contributes to its overall fertility. Soils with a high ratio of larger particles tend to be aerated and allow for quick infiltration of water, making it hard for plants to absorb and utilize the water. The reverse seems to be the case with clay soils because their smaller pore spaces hinder the movement of water which results in waterlogging and air deficiency. (Gabler et al., 2007).

2.1.3 Soil Structure

Soil structure refers to the arrangement of soil particles in small clumps or clusters known as ped which can alter the impact of soil texture (Christopherson, 2011). The structure of any soil is defined by the peds, and are categorised based on their shape into platy, blocky, spheroidal, or prismatic. These four classes have led to seven conventionally known types of soil structure. (Hess and Tasa, 2013). Not all soils develop a true structure, because some soils especially those composed mainly of sand, do not amass into peds. Silt and clay particles mostly amass into peds. The formation of peds usually occurs in moist soils and is less likely in dry ones. The shape, size and relative firmness of peds have a clear effect on how easily air, water, and organisms including plant roots penetrate the soil. Hence, the influence of structure on soil fertility (Hess, and Tasa, 2013).

2.1.4 Soil Consistency

In pedology, soil consistency is used to define the cohesion of soil particles resulting from the texture and structure of the soil. The consistence of soil describes how the particles of the soil stick together, and its inherent ability to resist breaking apart under various wet conditions (Brady and Weil, 2002). Measurement of soil consistence is taken for moist, dry, and wet soil separately because soil's response to pressure is determined by how wet it is. Consistence is measured in the field by feeling how easy it is when soil is crushed between thumb and forefinger (Schoonover and Crim, 2015). Moist soil is occupied to almost half of field capacity – the usable water volume of soil, and its consistence is evaluated from *loose* (free), to *friable* (easily crushed), to *firm* (not easily crushable between the thumb and forefinger) (Christopherson, 2011).

2.1.5 Soil Porosity

Porosity is defined as the amount of space between peds and pore space between soil particles. The structure of any given soil is often considered an important indicator of its porosity and permeability. The capacity of soil to hold water and air is determined by its porosity. The dividing line between permeability and porosity is not clear, and it is because some materials that are considered to be porous are not really so permeable (Hess and Tasa, 2013). Unlike porosity which is the amount of space that can store liquids, permeability is the rate at which liquids such as water can move through the soil (Brady and Weil, 2002).

Porosity is enhanced by the biotic activity of plant and the actions of animals such as the boring of worms and agricultural activities of humans such as ploughing, adding of humus and preparatory work done by farmers before planting (Christopherson, 2011).

2.1.6 Soil Bulk Density

The weight of soil relative to a known volume of soil is referred to as bulk density, and it is usually employed as a measure of soil compaction (Schoonover and Crim, 2015). Plants ability to penetrate through the soil is often decreased by soil compaction. Bulk density is often measured as the dry weight of soil divided by its volume. The volume involves the size of pores among soil particles and the size of soil particles themselves, and it is expressed in g/cm^3 (National Resources Conservation Service, 2008). The mass of a unit volume of dry soil is measured to determine the compaction, soil structure and total porosity of soil (Barauah and Barthakulh, 1997). Bulk density depends on the texture of the soil, the concentration of soil minerals (sand, silt and clay) and the organic matter within the soil as well as soil structure. For plant growth, the ideal bulk densities range from < 1.10 g cm^{-3} for clays to < 1.6 g cm^{-3} for sands (Schoonover and Crim, 2015).

2.1.7 Water Holding Capacity (WHC)

The water holding capacity (WHC) of a soil is the amount of water retained by the soil, which largely depends on the texture, structure and organic content of the soil, as well as how pore spaces are arranged in the soil (Schoonover and Crim, 2015). A high amount of micro-porosity is associated with organic matter giving the ability to retain more water. Thus, soils with a high amount of organic matter have micropores that can hold more water. Soil water quantity is adversely impacted by soil compaction, because it weakens soil structure and closes the pores, reducing the ability of the soil to hold water (Schoonover and Crim, 2015).

2.2 Soil Chemical Properties

Soil fertility is largely determined by soil chemistry which involves the chemical properties, composition, and chemical reactions that take place within the soils. Just as minerals are dissolved under the right condition when water comes in contact with them, when water combines with carbon dioxide and other organic compounds, it results in the respective formation of carbonic and organic acids which result in further changes within the soil. These chemical processes produce chemical ions that are absorbed by plants (Arbogast, 2013).

2.2.1 Soil pH

A vital aspect of soil chemistry is the tendency of the soil to sway from neutrality to either alkalinity (baseness) or acidity, which are measured on a scale of 0 to 14, widely known as the pH scale (Gabler et al., 2007). Measuring soil pH – the relative concentration of hydrogen ions (H^+) in a solution – is one of the ways of describing the chemical makeup of soil. Soil pH is used in measuring the hydronium ion in the soil solution, which defines the alkalinity or acidity of the soil (Schoonover and Crim, 2015). In the pH scale, lower values indicate acidic conditions while higher values indicate alkaline (basic) conditions. Neutrality is shown at about 7, which is the same as the pH of clean water (Arbogast, 2013). Acidic soils have more H^+ ions and fewer OH^- ions, and can be formed when excess decomposition of organic matter occurs due to insufficient leaching or drainage, while alkaline soils, having fewer H^+ ions and more OH^- ions sometimes, have limestone parent materials. With regard to the dissolution of minerals and making them available for plant uptake, a highly alkaline soil proves more effective. In contrast, acidic soils promote continuous leaching of minerals, thereby leading to loss of important plant nutrients. Therefore, soil pH is a useful indicator of soil fertility.

2.2.2 Effective Cation Exchange Capacity

The effective cation exchange capacity of a soil refers to its capability to react with positively charged molecules (ECEC). The soil has a stronger negative charge and may hold more cations when the ECEC is higher. The ECEC typically declines with rising sand content and is typically higher in soils with more clay silt and organic matter. The total moles of charge that can be displaced by an extracting solution per unit mass of soil is what is used to measure the amount of negative charge per unit mass of soil, or ECEC (White, 2003). In acidic soils, Al^{3+} and occasionally Mn^{2+} must also be added (Rengasamy and Churchman, 2001). The cation exchange capacity, a measure of a soil's ability to retain and exchange cations, is primarily influenced by the colloidal fraction of the soil, which includes clay and organic matter particles. However, silt-sized particles may also contribute significantly to this property (Landon, 1991).

2.2.3 Exchangeable Acidity

Exchangeable acidity refers to the amount of acidity in soil that is reversible and can be exchanged with other cations in the soil. It is a measure of the concentration of hydrogen ions (H^+) and aluminum ions (Al^{3+}) that can be exchanged with cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+) in the soil. Exchangeable acidity is an important factor in soil pH, which influences plant growth and soil fertility.

The concept of exchangeable acidity has been studied extensively in the literature. For example, Jackson (1958) introduced the concept of cation exchange capacity, which is related to exchangeable acidity, as a measure of the soil's ability to retain and exchange cations. Landon (1991) also explored the role of exchangeable acidity in soil pH and its effect on plant growth. Other researchers have focused on the relationship between exchangeable acidity and soil organic matter (SOM) content (e.g., Sánchez et al., 1997). SOM is known to influence exchangeable acidity through its ability to buffer soil pH and adsorb cations (Six et al., 2000). Overall, exchangeable acidity is a complex and multifaceted concept that is influenced by a variety of factors, including soil type, pH, and SOM content. Understanding the dynamics of exchangeable acidity is important for managing soil fertility and promoting optimal plant growth.

2.2.4 Soil Organic Matter

The organic component of soil known as soil organic matter (SOM) is made up of plant and animal remains in various states of decomposition, soil organism cells and tissues, and compounds produced by soil organisms. The physical, chemical, and ecosystem services that the soil may give are all greatly improved by the presence of organic matter in the soil (Brady and Weil, 1999). For soil function and soil quality, the presence of organic matter in the soil is seen as essential. The term "soil organic matter" refers to a variety of organic materials found in soil, including living things, slightly altered plant and animal organic residues, and thoroughly decomposed plant and animal tissues. These materials differ greatly in terms of stability and susceptibility to further degradation.

Microorganisms in the soil surpass complex multicellular organisms in numbers and are continually moving and providing the soil with air. They yield waste products that are important in nutrient cycling. Therefore, the knowledge of soil's water, mineral, and organic components and their relative proportions can assist in determining its productivity and what the best use for that particular soil might be (Gabler et al., 2007)

2.2.5 Soil micronutrients

Soil micronutrients refer to essential elements that plants need in small amounts for proper growth and development, including iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), boron (B), and molybdenum (Mo). These elements are typically present in soil in trace amounts and can be limiting factors in plant growth if not present in sufficient quantities.

The availability of soil micronutrients is influenced by a number of factors, including soil pH, organic matter content, and the presence of other nutrients such as calcium (Ca) and phosphorus (P). For example, high levels of Ca and P can inhibit the uptake of micronutrients by plants, leading to micronutrient deficiency (Blevins and Wauchope, 1988). Similarly, soil pH can affect the solubility and availability of micronutrients, with most micronutrients being more available at neutral to slightly acidic pH levels (Marschner, 1995).

Soil management practices can also impact the availability of micronutrients in soil. For example, the use of fertilizers and manure can introduce micronutrients into soil, while tillage and erosion can remove them (Marschner, 1995). The use of cover crops and green manures can also contribute to the supply of micronutrients in soil (Pimentel et al., 1999).

Overall, soil micronutrients play a vital role in plant growth and soil fertility. Understanding the factors that influence their availability and developing effective management practices are important for optimizing crop productivity and soil health.

2.3 Soil-forming Processes

The literature is quite consistent on the major soil-forming processes. Although, Gabler et al (2007), opined that there is almost an endless number of factors involved in the development of soil, they can be grouped into a few general soil-forming processes. Four main processes are involved in the formation of soil. There are those that add to the soil; those that deplete; translocate or move; and those that transform and change (Arbogast, 2013).

In soil enrichment or addition, organic matter and minerals are added to the soil. On the surface, silt may be added by river floods or dust may settle down due to heavy wind. Below the surface, organic enrichment may occur when humus is carried from the O horizon to the A horizon by gravitational water (Strahler, 2013).

Concerning the soil-forming processes that deplete, materials are being removed from the soil body through the action of streams and rivers that continuous erode the soil. It can also occur in the form of leaching, which loss of colloids and other soluble substances from the upper horizons of soil by the percolation of water (Strahler, 2013).

In translocation, materials are moved upward and downward within the soil. Particles especially colloids and clay particles are moved downward leaving behind coarse silt or grain sand. This process is commonly referred to as eluviation and it occurs in the E horizon of most soils. Materials carried down from the E horizon which usually includes clay particles, sesquioxides of iron and aluminium, and humus are gradually deposited in the B horizon. This depositional process of translocation within the soil is known as illuviation (Arbogast, 2013).

The final class of soil-forming processes are those that bring about changes to minerals and organic matter within the soil. Decomposition of minerals and organic matter result in their transformation into other forms in the soil. The decay of leaf and animal litter which leads to the formation of humus, properly exemplify this phenomenon (Arbogast, 2013). According to Strahler (2013), the transformation of organic matter to carbon dioxide and water can occur in warm humid climates in a way that would leave no organic matter behind in the soil.

2.4 Literature Review

The practice of describing the unique nature and attribute of a given soil is of great importance because such knowledge is useful in determining the extent and nature of soil pollution, and in deciding suitable land use potential (Yitbarek, Beyene and Kibret, 2016). This process, known as soil characterization is important in classifying soil into proper soil groups. It, therefore, provides an understanding of the nature and functions of ecosystems in various places, as well as an insight into various soil types (GLOBE, 2014). Consequently, many studies have been carried out with the view of characterisation and classification of different soil types, and in the process, determine the various chemical activities responsible for their formation.

To determine the chemical and mineralogical composition of lateritic iron deposits in Auchi, Edo State, Nigeria, Irabor and Iwu (2010) collected 15 samples each from different soil profiles with the purpose of providing certainty of a source of iron and aluminium mineral in the study area. The study revealed that the laterite has a high amount of iron oxide, a considerable amount of aluminium oxide and clay minerals. Despite the detailed results in the research, it concluded without making any recommendation concerning a proper use the soil should be put to.

Similarly, in a rather recent study conducted by Imasuen, and Onyeobi (2013), thirty-eight sample units were chosen from places in Edo state, close to Benin City to ascertain whether there is any variance in the level of soil productivity in the area. The result from examining the chemical and mineralogical content of the soil samples revealed that the samples consist mainly of kaolinite, quartz, goethite, feldspar and sesquioxides of aluminium and iron. Collectively, the soils are acidic, with a considerably low ability to hold cations, further showing that in the savannah area, a high concentration of CaO, MgO and K_2O, while none of those oxides was recorded in the rainforest area. Evaluation of the fertility status revealed soils in the first group are comparatively more productive than the third group. By way of improving the productivity of the soils, the use of powder from rock containing magnesium was recommended. The above studies revealed similar mineral composition even though the former (Irabor et al. 2010) was conducted in only lateritic iron ore deposits while the latter (Imasuen and Onyeobi, 2013) was carried out to provide a general knowledge of soil productivity in the area. Since both studies were conducted by geologists, they were more in line with their focus, and therefore, had some level of discrepancies with what soil geographers' interests are, which will always involve defining the physical, chemical and biological characteristics of the soil, classifying and noting their spatial significance.

However, in another study conducted in India, Meena, Balpande, Babhulkar and Madhumita Mandle (2011) made effort to understand the issue of waterlogging and to classify the soil in part of Wardha river valley, in the state of Maharashtra, India. Using six soil profiles, samples were collected from different horizons for morphological, physical and chemical analysis. The soil was observed to be of clayey texture, sub-angular blocky to angular blocky structure and slightly alkaline. The result of the study shows high Cation Exchange Capacity (CEC) revealing the presence of smectite in clay fraction, low saturated hydraulic conductivity which indicated poor internal drainage, varied exchangeable sodium percentage (ESP) at different horizons, the calcium-magnesium ratio reduces with depth. Based on these properties, the soil was classified under vertisol, usterts, haplusterts and sodic haplusterts in order, sub-order, great group and subgroup respectively. Meena et al. (2011), asserted that the problem of waterlogging has worsened due to an increase in water-table resulting from canal seepages and careless irrigation practices. Despite the study's usefulness in providing clues to the nature of soils in waterlogged areas, it did not take into account the soil-forming processes, and insight about soil properties around the Benin region cannot be drawn from it because the study was conducted far from our area of interest.

A similar study was conducted by Sharu, Yakubu, Noma and Tsafe (2013) to characterise and classify the soils of Dingyadi District in Sokoto State, Nigeria in order to provide information that would be useful for agricultural planning. Three soil mapping units were employed on the basis of texture, and samples were taken to a laboratory for analysis. The morphological properties of the three soil mapping units varied with the first being deep, poorly drained and a texture of loamy sand; the second being well-drained with a texture that varies from loamy sand on the surface to sandy clay loam below, and the third being impermeable with generally gravelly sand texture. The physical properties of the soils show a considerably high bulk density and low porosity, while chemically being neutral to moderately basic in reaction. The soils were low in organic matter and other important compounds. Hence, the three soil mapping units were classified respectively into the Typic Endoaqualfs, Typic Haplustepts and Lithic Ustorthents following the USDA Soil Taxonomy System. Sharu et al. (2013) concluded by noting that the soils in Dingyadi District were products of colluvium-alluvial processes which explains their low fertility. The study was well detailed in its presentation of data and explanation which is relevant in guiding decisions on the sustainable use and proper handling of the soils in the surrounding areas. However, the scope of the study was limited to only characterising and classifying the soil in the

Dingyadi District without taking note of the various processes involved in the soil development.

Efforts have been made to study soils in some parts of southern Nigeria with the aim of characterisation and classification. Esu, Akpan-Idio, Otigbo, Aki, and Ofem (2014) conducted a study in Okitipupa Local Government Area of Ondo State to characterise and classify the soil in the area. A soil survey was carried out using Landsat imagery along with field surveys, and 3 soil mapping units were selected and presented in a soil map; Omotosho, Okitipupa and Ode Erinje Fadama series. The findings show that all soils were acidic with nutrient deficiency, and possesses sandy texture on the surface while ranging from sandy loam to sandy clay in the subsoils which show a high vulnerability to erosion. Considering the landforms of the areas, Esu et al. (2014) propose that the Okitipupa soils are relatively suitable for agricultural activity since they are very deep and level, while the Ode Erinje Fadama soils are suitable for dry season vegetable farming and rice production as the area is flooded on annual bases. The Omotosho series, however, is considered marginal due to the undulating landforms associated with it. The study concluded by classifying the soils of Okitipupa, Omotosho, and Ode Erinje Fadama respectively into Typic Paleudults, Typic Plinthohumults, and Humaquentic Endoaquents in the suborder using USDA Soil Taxonomy System (Esu et al., 2014). Despite the fact that the study was carried out in the southern part of Nigeria, which brings us closer to our area of study, empirical conclusions replete with useful insights cannot be drawn from this study with respect to the characteristics and properties of soils in Ovia Northeast Local Government Area of Edo State.

In order to provide reliable information about the characteristics and formation of soils in South-Western Nigeria, a study was carried out by Fasina, Raji, Oluwatosin, Omoju, and Oluwadare (2015), employing both remote sensing and ground soil survey in Ijebu East Local Government in Ogun State, Nigeria. The study designated Kulfo, Ibeshe, Idesan, Iweke, Alagba, and Ondo series, and classified them separately into Typic Paleudalf, Typic Rhodudalf, Fluventic Eutrudept, Typic Udipsamment, and Typic Haphudalf. A significant quantity of iron manganese consolidation, gravels and quartz stones were present in the soils of Ondo and Fagbo. The soils from all the series have been observed to be acidic, with relatively low inherent fertility and low basic cations, organic carbon, cation exchange capacity and nitrogen. However, micro-nutrients were observed to range from being moderate to very high. Alagba, Iweke, Kulfo, Idesan and Ibeshe which are of sedimentary origin were noted to be more fertile than the others that were formed from the basement complex rocks. Fasina et al. (2015) proceeded to specify the predominant soil-forming processes, noting that lessivation, colluvial deposition, erosion, plinthization, braunification, induration, pedoturbation, and leaching were responsible for the development of the various soils. In conclusion, Fasina et al. (2015) suggest that the land within the study area should not be cleared mechanically because it would expose the soil to severe damage, erosion, leaching, and compaction. An extensive recommendation of soil use was proposed in the study. Although the study was well detailed in its presentation of data and delved into all the topics including the soil-forming processes, it does not prove specifically useful in providing an understanding of soils around the Benin sub-region.

The importance of soil characterisation and classification cannot be overstated because this has led researchers to conduct studies in different places within a particular region in a bid to provide local focus concerning soil management and land-use practices. To offer a useful understanding of the nature of soils deposited by surface water in derived savannah in Edo State, Oko-oboh, Oviasogie, Senjobi, and Oriafo (2016) embarked on research employing soil profiles in three mapping units. It was revealed that in all mapping units the surface horizons are mostly sandy loam while the subsoils were primarily sandy clay. The soil ranged from being acidic to neutral, with high exchangeable magnesium while the effective cation exchange capacity fluctuated between 2.5 to 18.36 $cmol\ kg^{-1}$. Oko-oboh et al. (2016) noted three soil types, which were Oxyaquic Haplustalfs (Fluvisols), Typic Paleustalfs (Acrisols) and Typic Kandiustalfs (Acrisols), further proposing that the soil characteristics should be taken into consideration for proper land use planning. Agriculturally, crops that can easily thrive in the water-laden environment were recommended, noting that the soil has the potential to improve crop yield (Oko-oboh et al., 2016).

Soils in some other parts of southern Nigeria has also been characterised. For instance, in a recent study, Aki and Ediene (2018) studied adjacent soils showing profile characteristics due to local topography in Awi, Akamkpa, LGA of Cross River State, Nigeria. Three profiles were dug at different parts of the landscape and their various properties were taken recorded; the depth of the soil was above 100cm with sandy loam surface texture to sandy clay loam subsurface texture. The soils were slightly acidic, with cation exchange capacity (CEC) ranging from 2.0 to 6.0 and bulk density of 1.0 to 1.7 g/cm and a total porosity that fluctuates between 22 to 38%. Other physicochemical characteristics were determined, and the soils were eventually classified as Typic Kandiudults using the USDA Soil Taxonomy. Based on observed soil characteristics, Aki and Ediene (2018) suggested that cover crops should be planted and crop rotation should be practised to reduce leaching of basic cations from the soil.

Employing free survey technique by using geological maps, three soil mapping units were chosen for research carried out by Imadojemu, Osujieke, Obasi, Mbe, and Dibofori (2018) to assess the various chemical, biological and physical properties of some soils in Edo State. The three pedons which correspond with Ekpoma, Benin and Okpella were from clayey sands, sands, and mudstones-shales respectively. The study revealed that the Carbon-Nitrogen ratio was similar to that of total organic carbon, with a considerable decline in Mg and Ca in the pedons corresponding with Ekpoma and Benin, while that of Okpella was moderate. Cation exchange capacity in all pedons was significantly low, available phosphorus gradually decreased down the profiles, total exchangeable acidity was highest in Ekpoma pedon and lowest in Okpella. Soil pH, Carbon-Nitrogen ratio, organic carbon, available phosphorus and total exchangeable bases were observed to correlate positively. Based on the findings, Ekpoma and Benin were classified as Alfisols (Isohypertherimic Psammentic and Arennic Hapludalfs) while the one of Okpella was classified as Typic Kandiustalfs. Since effective cation exchange capacity (ECEC) was found to be low, Imadojemu et al. (2018) proposed that the soil be amended to improve crop yield, further noting that there is a lot of potentials so long as the fertility of the soils is properly managed. This research proves very useful in our study because it was done within Edo State. However, like most of the research reviewed above, it did not take into account the unique characteristics of waterlogged areas and determine the various soil-forming processes at work in such places.

The above studies provide evidence of the growing need for locally-based information on soil in my parts of the world. Soils in different landscapes in Nigeria and around the world have been characterised and classified for various purposes. While some research was carried out solely to assess the quality of land for agricultural productivity in a given place, others were carried out to determine land use suitability. Soils are a finite resource and understanding their characteristics and distribution has helped inform land use and management decisions to ensure that they are used in a sustainable way. Characterising of soil helps in environmental protection as soils play a critical role in ecosystems, serving as habitats for microorganisms and providing vital ecosystem services such as water and nutrient cycling. Understanding the characteristics of a soil can help identify potential risks to the environment and allow for appropriate land use planning and management. Despite the ample amount of literature available, no acceptable conclusions can be reached concerning the properties of soils in every area.

Even the available literature, has not given consideration to low-lying areas around Benin City. Presently, there are a lot of waterlogged areas in Edo State that have not been studied. The soils in such areas of low-lying topography have not been characterised and classified. This research, therefore, aims to assess the characteristics of waterlogged soil in Ovia Northeast LGA and determine its process of formation. This study thus seeks to contribute useful knowledge to address the growing need for soil data. Further research is needed to better understand the characteristics and classification of waterlogged soils in Benin City, as well as the processes that influence its formation and management. This information will be important for identifying and addressing the challenges posed by flooding in the region.

CHAPTER THREE

RESEARCH METHODOLGY

3.0 Introduction

The study of soil characteristics usually involves gathering quantitative data concerning certain parameters of morphological, physical, chemical and biological significance (Burt & National Soil Survey Center (U.S.), 2014). Burns and Grove (1993) sees a quantitative research as a formally objective, systematic procedure of describing variables, testing their relationships and probing to see if there is any cause and effect in the interaction among them. In the study of describing the type of soil in places, there is the need for selecting an appropriate site, depth of sampling, type and the number of samples, details of sample collection, and description of sampling and subsampling procedures (Burt & National Soil Survey Center (U.S.), 2014).

The aim of this chapter, therefore, is to detail the various methods employed in the collection of data in the field, the laboratory analysis of the sample and the statistical techniques used during this research. The types and sources of data, as well as the procedures and methods adopted for data collection is included and important in this section.

3.1 Types and Sources of Data

In this research, both primary and secondary sources of data were used. The primary data were the data got through the direct field measurements and soil samples analysis. The secondary sources of data, on the other hand, include textbooks, academic journals, articles and other source materials that are available online.

3.2 Procedures and Methods of Primary Data Collection

This study adopted the following procedures

a) Reconnaissance survey.

b) Selection of site.

c) Field measurements and soil sampling.

3.2.1 Reconnaissance Survey

Prior to the fieldwork, a reconnaissance field survey was conducted with the aim of:

a) Familiarizing ourselves with the study areas.

b) Identifying the potential challenges that might be encountered.

c) Reviewing existing environmental information on the study area in published and unpublished literature.

d) Planning and programming the fieldwork, and the selection of instruments required.

The instruments used for this research work included; measuring tapes, shovel and digger for digging of the soil profile, hand trowel, polythene bags for sample collection, white masking tape, for labelling of each of the samples, global positioning system (GPS), for accurate coordinate of the location, field notebook and a pen, for recording.

3.2.2 Selection of Site

For the purpose of this study, a place that is usually pooled in and inundated with water in Idunowina, Ovia Northeast LGA kilometre 11 in Benin-Sagamu expressway was chosen. A soil profile of up to 180cm was dug in the area, and six samples were drawn from the each of the horizons in the profile for laboratory analysis.

This site was chosen to determine the soil-forming processes and the various characteristics of a waterlogged soil in surrounding places. The soil colour, structure and consistency were also determined in situ. The soil colour were compared (when it was at a moist state) to the standard set in the Munsell colour chart. The geographical location of the soil sampling points were identified with the use of Global Positioning System (GPS) (etrex 10, GARMIN model).

3.2.3 Field Measurements and Soil Sampling

A soil pit of about 180cm was dug to show the soil profile, and metre stick was placed inside the soil pit beside the soil profile. Soil samples were, then taken after the soil was dug to a depth of 180cm. The six soil samples were taken from the various horizon using a hand trowel into six respective polythene bags labelled accordingly. The width or thickness of each of the horizon were recorded in a field notebook.

The samples were taken to the laboratory where they were air-dried at room temperature. The samples were crumpled and sieved through 2mm wire mesh for the determination of selected morphological, physical, chemical and biological properties. During the collection of soil samples, some buried dirt and other waste products were removed and each sample was properly mixed. This is important in order to minimize any differences and errors. The result were subjected to statistically analysis using the IBM Statistical Package for the Social Science (SPSS) version 23.0.

Plate 3.1: Study Site.
Source: Author's Fieldwork, 2021.

Plate 3.2: Soil Profile
Source: Author's Fieldwork, 2021.

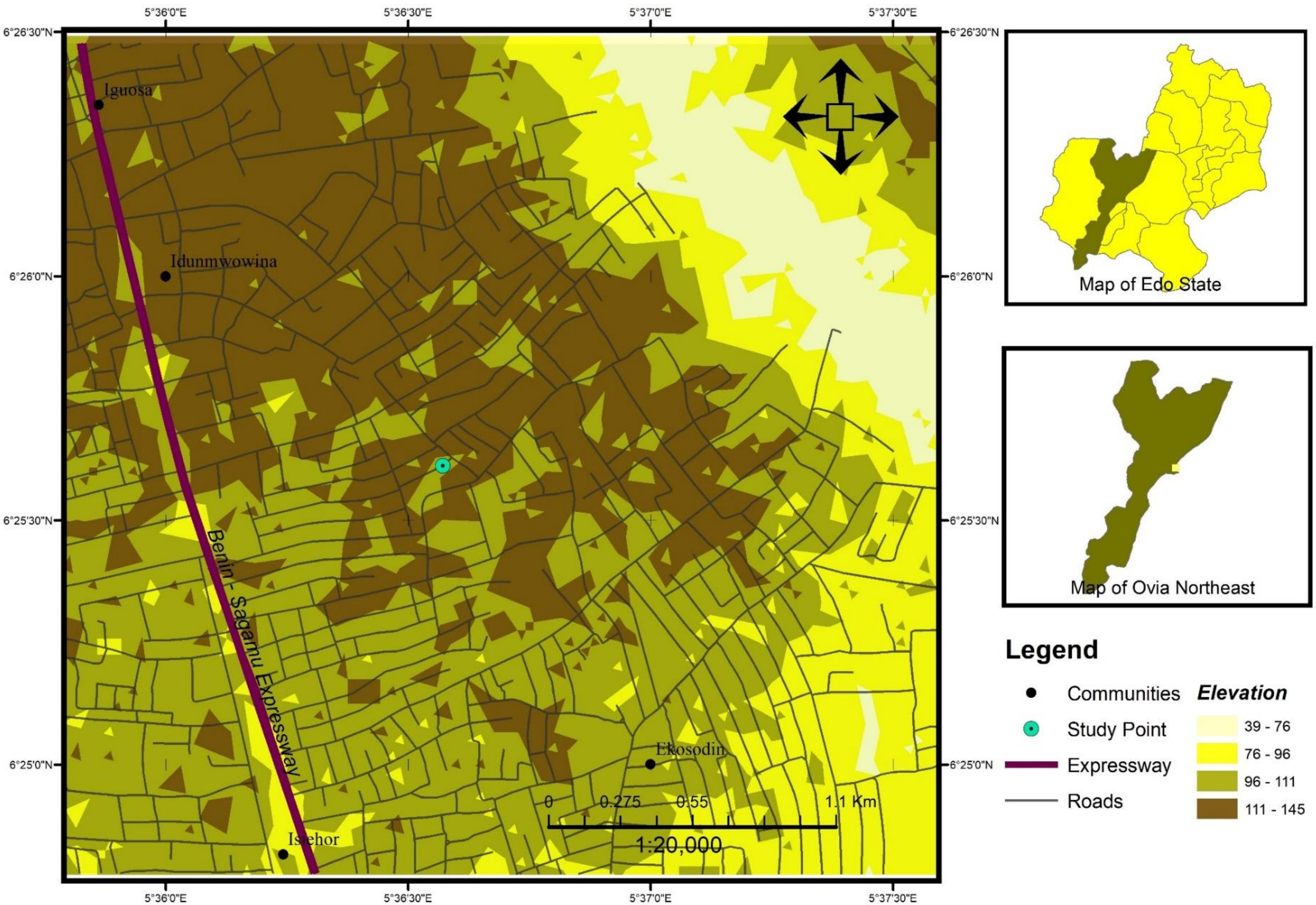


Figure 3.6: Location of the Study Area in Benin City (Inset Edo State).
Source: Drawn by Author using ArcMap 10.7 using from data Open Street Map.

3.3 Laboratory Soil Sample Analysis

3.3.1 Physical Characteristics

Bulk Density: 10g of dry soil sample was weighed and placed into a measuring cylinder containing known volume of water. The difference in volume after the dry soil sample was added in the cylinder was noted. Bulk Density was calculated as follows:

Dry Weight of Soil/Total Volume

$$\% \text{ Porosity} = \frac{\text{Pore Volume (VP)}}{\text{Total Volume (Vt)}} \times 100$$

Vp = Pore Volume

Vt = Total Volume

Particle size Distribution: The particle size distribution was determined by hydrometer method as described by Gee and Bauder (1986). Samples Textural Class were determined with soil Textural Triangle.

3.3.2 Chemical Characteristics

Titratable Acidity: It was determined by titrating 0.5m NaOH against 5ml of the sample using phenolphthalein indicator as described by AOAC (1990).

pH: The samples pH was determined in the ratio of 1:1 of sample(soil) to distilled water with a pHmeter with glass electrode (U.S. Department of Agriculture & Agriculture, 2019)

Total Nitrogen (T-N): Total-Nitrogen was determined by Micro Kjeldahl digestion method as described (Bremner and Mulvaney, 2015)

Calcium, Magnesium Determination, Potassium and Sodium Determination: Ca and Mg were determined by EDTA Titration, While K and Na were determined by flame photometer.

Macro Nutrients: The soil samples were air dried and sieved. 1g of the sieved sample was weighed into a digestion flask. Thereafter, 20ml of concentrated nitric acid was added and the mixture was digested with hot plate. The solution was allowed to cool and 30ml of distilled water was added and filtered with Whatman filter paper. The digested solution was made up to 50ml with distilled water and was read with atomic absorption spectrometer Unican 939 model.

3.4 Bacteria Count

Preparation of culture media: All media were prepared according to the manufacturer's instructions. The media used in this study are Nutrient agar and Potato dextrose agar.

Nutrient Agar: This was used to culture non-fastidious organisms and for bacteria heterotrophic plate count. This medium was prepared from commercially available dehydrated powder available from most suppliers of culture media. In the preparation, 28g of nutrient agar powder was dissolved in 1litre of distilled water in a conical flask covered with cotton wool and aluminum foil paper. It was mixed thoroughly and sterilized by autoclaving at 121^{o}C for 15 mins. The medium was cooled to 45-50^{o}C and then dispensed aseptically into sterile petri dishes.

Isolation of Microorganisms: 1g of the samples were weighed into sterile beaker and 9ml of sterile distilled water was added. This was 10-1 dilution. The 10-1 suspension of the sample was subsequently serially diluted using ten- fold serial dilution up to 10-4. Aliquot of 1m of the appropriate dilution from each samples were plated in nutrient agar for isolation of bacteria. The nutrient agar plate was incubated at 370C for 24 – 48hrs. After incubation, the number of discrete colonies were counted in terms of colony forming units. The viable count was obtained from this value by reference to dilution factor used.

Potato Dextrose Agar: This was used for the cultivation of fungi. The medium was prepared from commercially available dehydrated powder. 39 grams of Potato Dextrose agar powder was dissolved in 1 litre of distilled water in a sterile conical flask covered with cotton wool and aluminum foil paper. It was mixed thoroughly and autoclaved at 1210 C for 15 mins. Themedium was cooled after autoclaving to 45-500 C and then dispensed aseptically into sterile Petri dishes.

Isolation of Fungi: 1g of the samples were measured into sterile test tube and 9ml of sterilized distilled water was added. The 10-1 suspension was subsequently serially diluted using tenfold serial dilution up to 10-3. 1ml of the appropriate dilution from each samples were plated in a petri dish for isolation of fungi. The potato dextrose agar plates were incubated at room temperature (280C) for 72 hours. After incubation, the number of discrete colonies were counted in terms of colony forming units. The viable count was obtained from this value by reference to the serial dilution or dilution factor used.

Enumeration of Bacteria and Fungi: The method described by Holt et al. (2000) for estimating bacterial and fungal counts was used to enumerate the total viable counts of the isolates. The discrete colonies on the Nutrient agar and Potato dextrose agar plates were selected and counted. The mean colony counts on the Nutrient agar and potato dextrose agar plates of each given dilution was used to estimate the total viable count for the samples in colony forming units per gram (Cfu/g).

3.4 Statistical Analysis

The research work employed both descriptive and inductive statistical methods. Data collected from the field were subjected to statistically analysis using the IBM Statistical Package for the Social Science (SPSS) version 23.0. The various morphological, physical, chemical and biological properties were used as indicator in the characterization and classification process as well as in determining the various soil-forming processes at work in the area. Statistical methods such as correlation and regression were used to determine any multicollinearity among soil factors, and to explore the relationship among them. Principal component analysis equally proved useful in determining causal relationship among the different soil characteristics.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Introduction

In this chapter, focus is on data presentation, analysis, interpretation and discussion of findings.

Tables 4.1, 4.2, 4.3 and 4.4 show the morphological, physical, chemical and biological properties respectively.

4.1 Morphological Properties

The morphological properties are shown in Table 4.1. The topsoil was moderate, medium, sub-angular blocky to moderate, very fine, sub-angular blocky over the rest of the pedon which is moderate, fine, sub-angular blocky. This indicates that the aggregates have irregular blocks and the edges are sub-rounding. The implication is that water penetration is less than in the topsoil. Figure 4.11 depicts, therefore how the colours varies across the profile. The colours ranged from dark reddish brown (2.5 YR 2.5/4 moist, and 5YR 3/2, moist) to red (2.5YR 4/6, moist) with the pedon having a YR (yellow-red) hue with values ranging from 10YR and 5YR to 2.5YR. The various soil colours may be used to explain certain properties of the soil. For example, yellow, brown or red pigmentation can be due to the coating of iron oxides (Soil Survey Staff, 2014). There were coarse, few medium distinct mottles at the endopedon, and some charcoals appearing at a depth of 51 – 90 cm, which might be due to anthropogenic activities. The mottles are possibly due to anaerobic or perhaps, alternating aerobic processes. Where mottling occurred in the well-drained B horizon, the mottles were brownish in colour. According to Brady (2002) the mottled condition implicates a zone of alternate good and poor aeration. There were roots at the top and subsoil from a depth of about 10 cm to about 40 cm where there were also cassava tubers.

The characteristics of the horizon boundaries were clear and irregular at the top horizon while being gradual, irregular to diffuse in the AB (Fig. 4.11). Field observation showed evidence of fine root and ant holes at the pedon, faunal pedoturbation seemed to be actively taking place.

The soil texture revealed that the aggregates were mainly sandy clay loam at depth of 0 - 51 cm while the rest of the pedon was mainly clay from a depth of 51- 180 cm. This is probably why the consistence of materials in all of the horizon were friable when under moist conditions as a result of coherent of the soil particles. Soil consistence is the resistance of soil at various moisture content to stress.

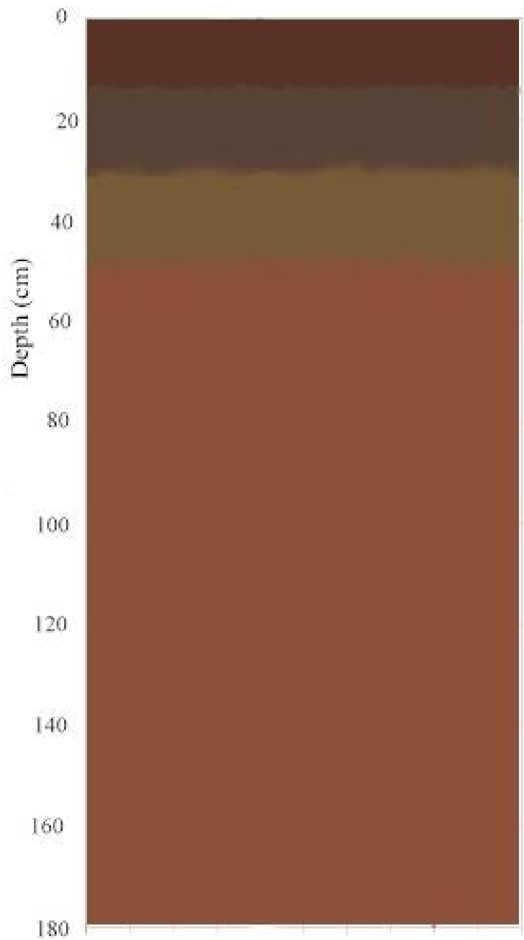


Figure 4.11: Graphical Representation of the soil profile

Table 4.1: Morphological Properties of the soil

Horizon	Depth (cm)	Colour *Moist*	Texture	Mottling	Structure	Consistency *(moist)*	Root	Horizon Boundary
Ap	0 – 14	2.5 YR 2.5/4	SCL	-	2,m,sbk	fr	vf,m	c, ir
AB	14 – 30	5YR 3/2	SCL	c	2, vf, sbk	fr	vf,m	g,ir
Bt1	30 – 51	10YR 4/4	SCL	f,m,d	2, f,sbk	fr	vfc	d,ir
Bt2	51 – 90	2.5YR 4/6	C	ch	2, f, sbk	fr		d,ir
Bt3	90 – 127	2.5YR 4/6	C	-	2, f, sbk	fr		d,ir
Bt4	127 - 180	2.5YR 4/6	C	-	2, f, sbk	fr		-

Key:
Structure *– 1=weak, 2=moderate, m=medium, f=fine, vf=very fine, sbk=sub-angular blocky*
Consistency: *f=firm, fr=friable*
Texture: *SCL=Sandy Clay Loam, C=Clay*
Boundary: *c=clear, g=gradual, ir=irregular, d=diffuse*
Roots*: f=fine, vfc=very few, vf=very fine, m=many, co=common*
Mottles: *c=coarse, f=few, m=medium, d=distinct, ch=charcoal*

4.2 Physical Properties

The physical properties of the soil are shown in Table 4.2. The clay content is relatively low at the surface horizon (0 - 30 cm), but gradually accumulates down the pedon resulting in clayey soil horizons (Bt). This, according to Adamu et al (2015), is likely due to illuviation and eluviation. The movement of clay particles is probably brought about by leaching with percolating waters, or precipitated as clay mineral in the B horizon. This may be brought about, according to Young (1976), by high temperature and moisture. The highest amount of clay fraction is recorded in the subsoil, while the least proportion of clay was noted in AB Horizon. Clay fraction has a mean value of 330 gkg^{-1} across the profile. However, the proportion of sand fraction fluctuates between 600 gkg^{-1} at the topsoil and 400 gkg^{-1} at the subsurface horizon. The mean value for sand is 490 gkg^{-1}. The highest value of sand was observed in the surface horizons while the least value was observed at Bt_2 horizon. Generally, the sand contents of the soil seem to decline with increase in soil depth. This is in contrast with the clay fraction which seems to increase down the profile. The high content of sand fraction in the pedon is presumably due to the fact that the soils are derived from sandstone parent materials.

In variance, the proportion of silt tends to fluctuate down the profile. However, it remained slightly constant fluctuating between 50 to 200 gkg^{-1} from a depth of 30 cm to 180 cm (Figure 4.12). The highest value of silt was recorded in AB horizon with a value of 300 gkg^{-1} and sharply declined to its lowest value of 50 gkg^{-1} in Bt_1 horizon. This abrupt decline of silt fraction may be due to transformation of silt content to clay which resulted in the sharp increase in the clay content from as low as 100 gkg^{-1} in the AB to as high as 400 gkg^{-1} in Bt_1. This is in line with the findings of Ugwa et al. (2016), who deduced that for silt fraction to have decreased down the profile, it must have transformed into clay. Furthermore, Figure 4.12 shows a relationship between sand and silt, because as sand content declines, silt content gradually increased at a depth of 40 to 90cm, and fluctuate inversely against one another down the profile. The mean value of silt is 170.5 gkg^{-1}. Compared to the mean value of sand and clay, it is obvious that silt fraction is the lowest throughout the profile. According to Ugwa et al. (2016), this low value is indicative of advanced weathering. In the study area, the sandy fraction is predominant which has a negative effect on the soil. Therefore, the addition of organic matter is of considerable importance to soil fertility especially in the area of water retention and soil nutrient.

The bulk density value is highest at the topsoil with a value of 1.38 Mgm^{-3}, and sharply declined to its lowest at 1.31 Mgm^{-3}, and gradually increased to 1.35 Mgm^{-3} at a depth of 51cm and remained constant throughout the profile. The bulk density is highest at the Ap horizon which may be due to the high sand fraction and also lesser pores as noted by Akinsanya et al (2015). A look at Table 4.2, showed that the subsoil (51 to 180 cm) has a consistent bulk density value of 1.35 Mgm^{-3}. The mean bulk density is 1.34 Mgm^{-3}. The high bulk density at the topsoil seems to indicate a comparatively low organic matter in the top soil (Ugwa et al, 2016). However, the bulk density of the soil is within the acceptable range that promote plant growth and root penetration; <1.60 Mgm^{-3} for sandy soil; and <1.40

Mgm^{-3} for clayey soil (NRCS (National Resources Conservation Service), 2008). The total porosity is lowest at the topsoil with a value of 47.9% and rapidly increased to 50.6% at AB and Bt_1 horizons and slowly rose 49.1% (51 cm) and remained constant throughout the profile. This trend revealed a perfect relationship between bulk density and total porosity, such that when bulk density is high, total porosity is observed to be low. Figure 4.13a and b indicate that the total porosity values decreases with increase in soil depth showing an inverse relationship with bulk density. The mean total porosity is 49.4%. The highest total porosity value of 50.6% is found between a depth of 14 to 51 cm, while from 51 to 180 cm has a similar value of 49%. This relatively high value of total porosity may be due to the high clay fraction that characterized the rest of the profile (Jones and Wild, 1975). All the horizons have a total porosity of >45% which, according to Adamu et al (2015), is an indication of good soil. This is in alliance with the observation of Essoka and Esu (2001) who reported that as bulk density increases, the total porosity decreases. Soil porosity is adequate suggesting enhanced microbial activities and free flow of gases and fluids in the soil complex as well as good root penetration.

Table 4.2: Physical Properties of the soil

Horizon	Depth (cm)	Clay	Silt (gkg^{-1})	Sand	Silt/Clay ratio	Silt/Silt+ Clay	Erodability Index	Evidence of Argillic (Bt) Horizon	Clay activity	Hydraulic Conductivity (mls)	WHC (%)	Bulk density (mgm^{-3})	Total Porosity (%)
Ap	0 – 14	200	200	600	1.00	0.5	4.00	1.00	48.7	$7.2x10^{-3}$	46	1.38	47.9
AB	14 – 30	100	300	600	3.00	0.75	9.00	0.5	143.2	$7.2x10^{-3}$	44	1.31	50.6
Bt_1	30 – 51	400	50	550	0.13	0.11	1.50	2.00	30.9	$7.0x10^{-3}$	56	1.31	50.6
Bt_2	51 – 90	450	200	350	0.44	0.31	1.22	2.25	20.8	$1x10^{-8}$	64	1.35	49.1
Bt_3	90 – 127	450	100	450	0.22	0.18	1.22	2.25	19.7	$1x10^{-8}$	56	1.35	49.1
Bt_4	127 - 180	400	200	400	0.50	0.33	1.50	2.00	30.3	$1x10^{-8}$	52	1.35	49.1

Source: Authors Field Work, 2022

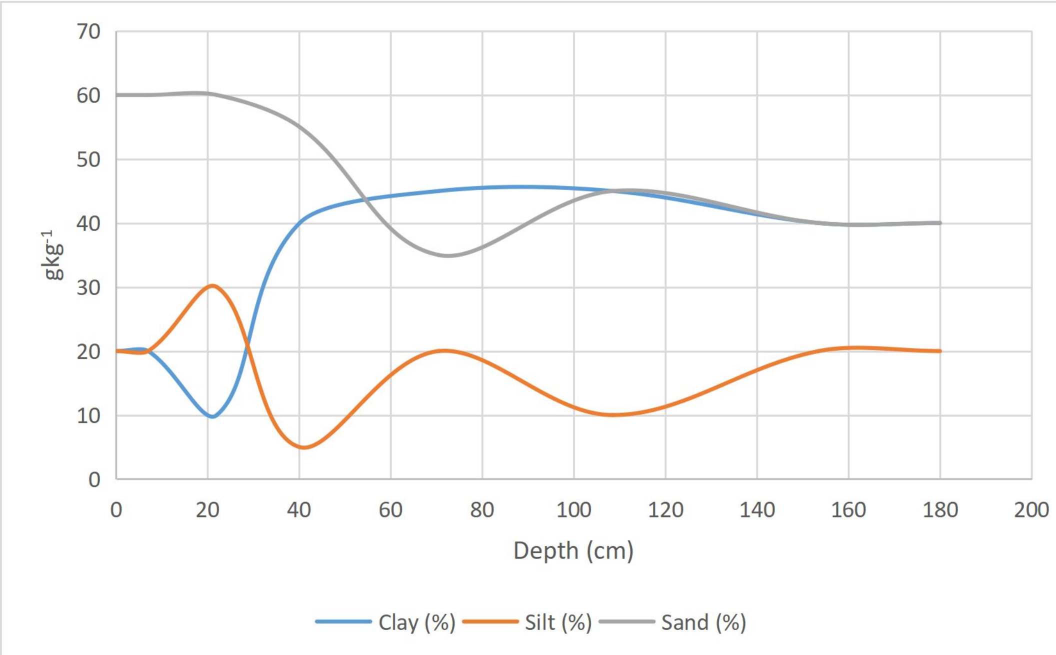
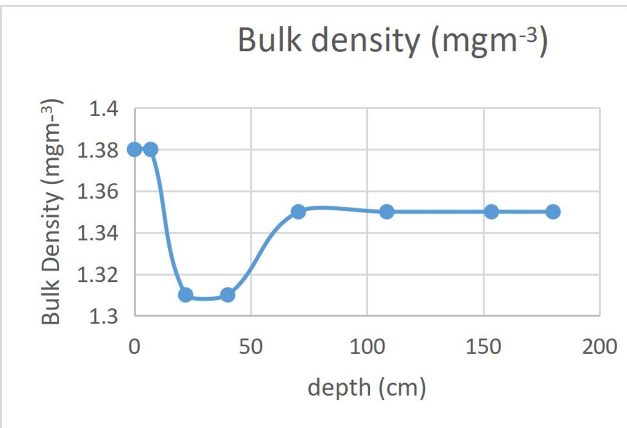


Figure 4.12: A multiple line graph showing the proportion of clay, silt and sand fraction of the soil.



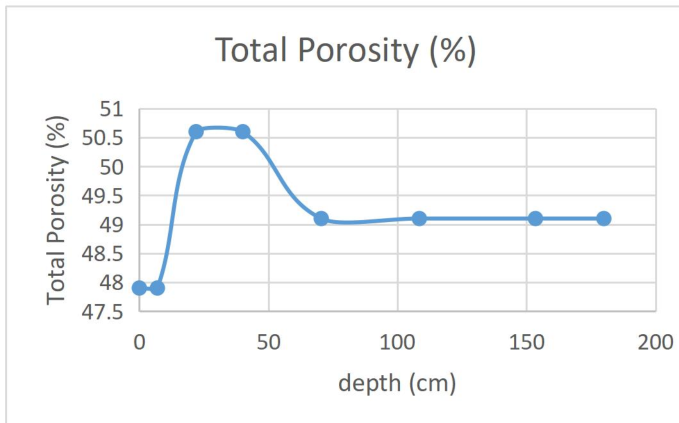


Fig. 4.13a; b: Line graph showing the trend of bulk density (Mgm^{-3}) and total porosity (percent)

Water Holding Capacity (WHC) of the soil ranges from 46 and 44% in the surface horizons to 64 and 52% in the subsurface horizon. The mean WHC is 53% across the pedon. The highest value of WHC is found at Bt_2 horizon (51-90 cm), while the least value of 44% was recorded at AB horizon (14-30 cm). This lowest values are associated with the surface horizons, which may be due to their high proportion of sand. The relatively high value of WHC associated with the subsurface horizons is probably due to its high clay fraction (Curell, 2022). Generally, WHC increased gradually from 46% to 52% with a budge in the 51 to 127 cm soil depth. The improvement in WHC of the soil may be attributed to the moderate value of soil organic matter which is hydroscopic thereby contributing to its values in the soil.

The clay activity in the topsoil was 48.7 and rapidly spiked to 143.2 at a depth of 14-30 cm and declined to low as 30.9 at a depth 30-51cm, and remained between 20.8 and 30.3 down the rest of the profile. Clay activity is an index of weathering, and with a value >50 indicating severe weathering (Westin and de Brito, 1969). The sudden spike in clay activity to 143.2 at the AB horizon from 48.7 at Ap horizon shows that AB horizon is severely weathered. The subsequent decline of clay activity from 143.2 at the AB horizon to as low as 30.9 creates a budge in the clay activity (Figure 4.14) providing a proof that eluviation takes place in the Bt_1 horizon while illuviation occurs in the subsoil horizons below. There is no doubt that AB horizon (14-30 cm) is highly vulnerable considering its high value of erodibility index, silt/silt+clay ratio, and the other indices (Table 4.2). The evidence provided by all the indices reveal a similar trend, implying that the top soil (Ap horizon) is a recent deposit while the layer below (AB horizon) is old and severely weathered resulting in increased clay content in subsurface horizons (Fig. 4.14).

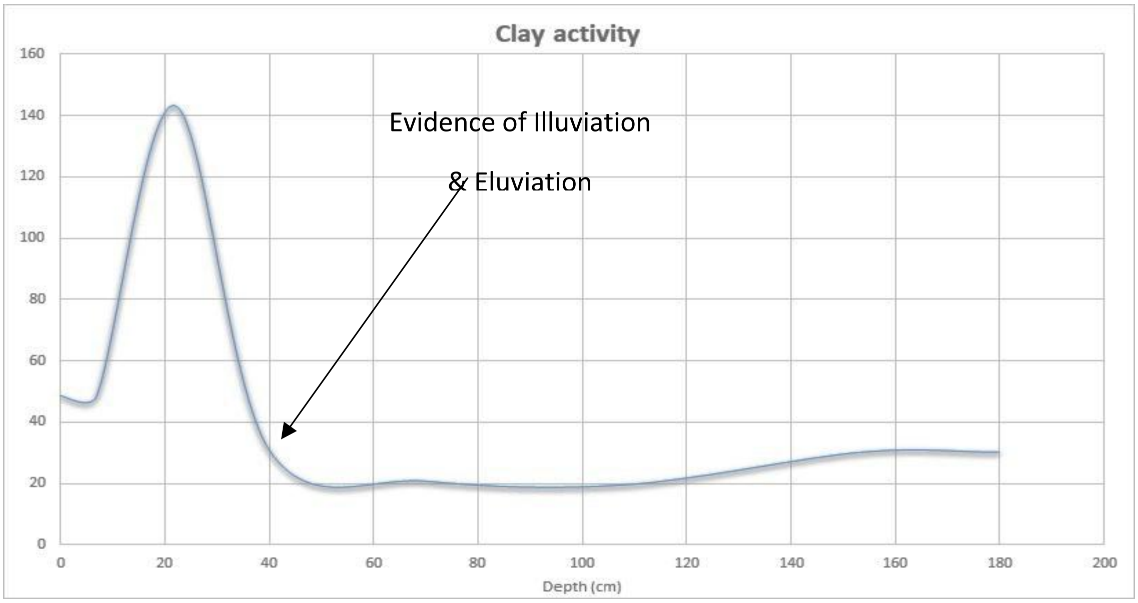


Figure 4.14: A depiction of clay activity in the soil profile

The values for erodibility index range from 4.00 and 9.00 at the topsoils to as low as 1.22 and 1.50 in the subsoil. The high value of erodibility index of AB horizon (14-30 cm) affirms its susceptibility to sheet and rill erosion (Kinell, 1981). This seems reasonable judging from its silt/silt+clay ratio of 0.75 which is higher than the critical value of >0.7. According to report by Ajiboye et al. (2015); silt/silt+clay ratio of 0.7 indicates moderate weather, <0.7 for severe weathering and >0.7 for incipient weathering. This is an evidence of severe weathering activity. The highest value may be due to sandy content of the top soils (0-30 cm) soil. The different values of soil erodibility of the horizon could be attributed to their different soil properties. The highest values may be due to land use and the lowest may be due to the higher clay content (Table 4.2).

The values for silt/silt+clay ratio were all below the critical value of 0.7 except in horizon AB which has 0.75 (Table 4.2). The value of 0.5 associated with the topsoil revealed that there is incipient weathering, implying a recent soil deposit which may be due to erosional deposition. However, the sudden increase to the value of 0.75 at the underlying horizon (AB) shows that the soil at AB horizon has undergone severe weathering resulting in the reduction of clay content and the transforming of silt to clay in the Bt_1 horizon. This, therefore, has resulted in the increase in clay content down the rest of the profile.

Furthermore, silt/clay ratio values range from 1.00 and 3.00 at the topsoil and 0.13 to 0.50 at the subsoil. The highest values of 1.00 and 3.00 were recorded at 0-30cm while the lowest value was 0.13 recorded at a depth of 30-51cm. The implication of this is that the first two horizons are young with low weathering intensity, while the third horizon (Bt_1) is old with high weathering intensity. According to Ikemefuna (2010) if the silt-clay ratio is 5 (none), 3 (moderate), 2 (high) and 1 (very low), then the soil can be valued for vulnerability potential. Thus, the horizon with the silt-clay ratio of 1.0 has a high degradation rate and vulnerability potential. This result does not seem to be consistent with the other indices. The critical values for silt/silt+clay ratio and that of silt/clay ratio are different, thus it may likely lead to opposing conclusions at times. However, when the graph for the two indices are compared (Figure 4.15), they apparently reveal similar trends. Therefore, since the two indices reveal the same trend, it is reasonable to presume they point to the same conclusion. Consequently, the silt/silt+clay ratio values were lower than those of silt/clay ratio. This low value according to Ajibola et al (2011) is an indication that some of the silt had weathered more to clay. It seems, therefore, that silt/silt+clay ratio of the soil presented a better picture and evaluation of the stage of development and age of the soils studied than the silt/clay ratio.

The values associated with evidence of argillic (Bt) horizon fluctuate between 2.00 to 2.25 from a depth of 30-180 cm. Values for evidence of argillic (Bt) horizon at the subsoil (30-180cm) is above 1.5 (Table 4.2). Nsor and Adesemuyi (2016) reported that if the value is >1.5, there is evidence of translocation of clays in B horizon and thus, evidence of argillic (Bt) horizon. This is further confirmed when silt/silt+clay ratio is examined.

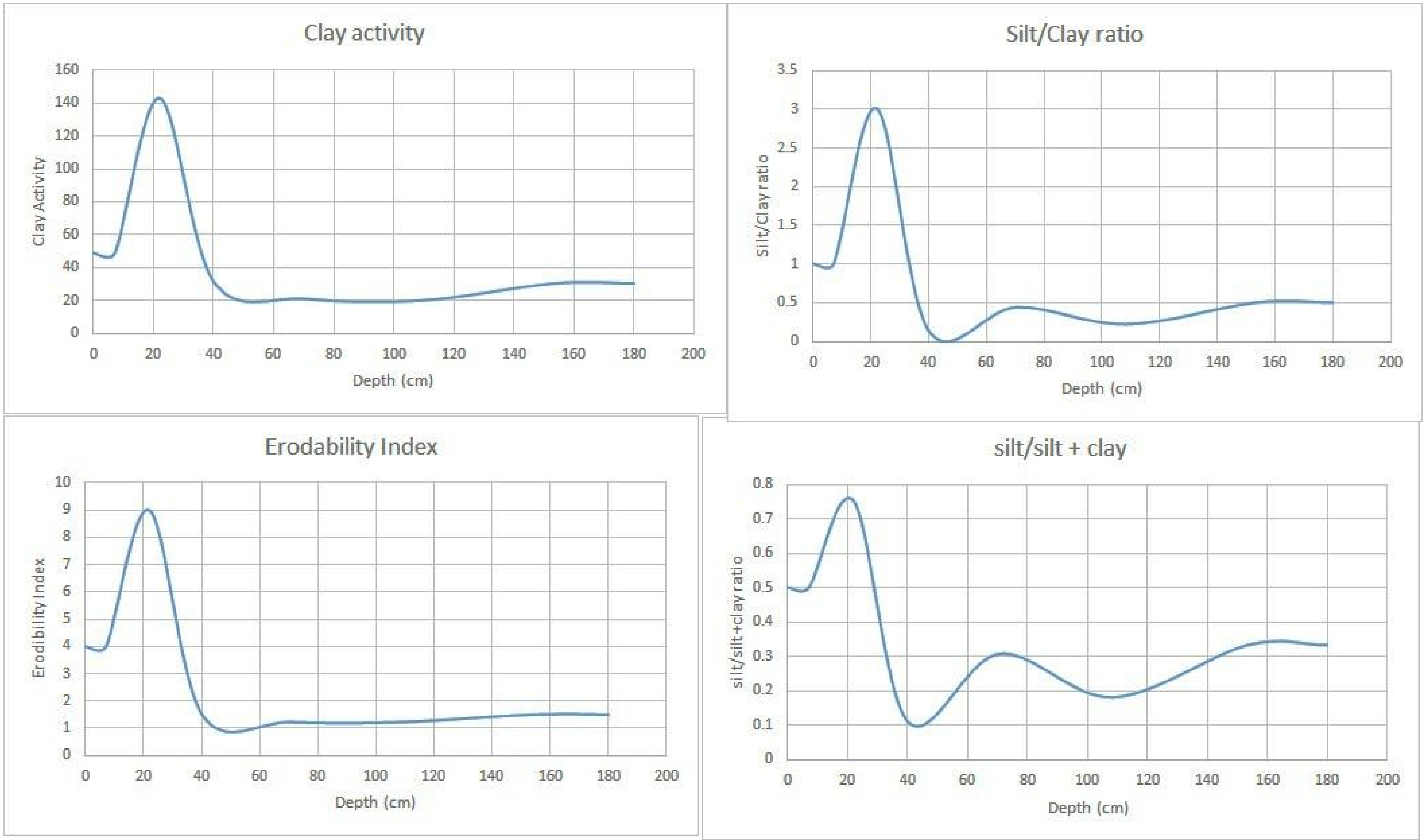


Figure 4.15 *a, b, c, d: line graphs shows the trend patterns of different indices.*

4.3 Chemical Properties

Detailed chemical properties of the pedon is presented in Table 4.3.

The pH of the soil varies from 6.4 to 6.8. The highest soil pH value was recorded at a depth of 51 - 90 cm, while the lowest value was noted at Bt_4 horizon (127-180 cm). The mean soil pH value is 6.6. There seems to be no clear pattern in the soil pH level throughout the soil profile. Compared to the critical values as presented by FDALR (1990), the pedon seems to have very high pH. Overall, the profile is uniformly neutral in soil reaction. Such a soil reaction does not pose problem to tree crop cultivation (Ugwa et al, 2016).

Organic Carbon ranges from 3.95 and 4.65 gkg^{-1} at the topsoil, to 2.79 and 3.41 gkg^{-1} at the subsoil. The highest value was observed at AB horizon (14-30 cm), while the lowest value was recorded at Bt_4 horizon (127-180 cm). Generally, the range of OC in the soil is less than 4 gkg^{-1} which according to Chude et al. (2011) is considered very low. This implies that total organic matter may equally be affected leading to overall reduction in soil fertility. Total Nitrogen ranges from 2.7 and 3.8 gkg^{-1} at the topsoils, to 1.32 and 1.8 gkg^{-1} at the subsoil. The mean value of total nitrogen is 2.72 gkg^{-1}. The highest value was noted at AB horizon (14-30 cm), while the lowest value was noted at Bt_4 horizon (127-180 cm). Generally, it is within the range reported by Chude et al. (2011), therefore can be considered moderately high.

The trend is similar to that of organic Carbon and Phosphorus. With exception of the top two horizons, there is a decrease in total Nitrogen (TN) with increase in soil depth. This is possibly due to intense weathering and leaching of organic matter from the surface horizons. Although the values of Ap horizon (0-14) slightly deviates from the rest, it only attests to the possibility of depositional erosional activity occurring in the area. This is clearly revealed in the erodibility index and the other ratios. Although, total nitrogen levels are lower compared to that of organic Carbon (C), they seem to be consistently related (see Fig.4.21). There is a direct relationship between organic carbon and nitrogen (Figure 4.21). Where there is high organic carbon, the total nitrogen is also high. This supports the findings of Ugwa et al. (2016), who reported that Total Nitrogen is directly related to organic matter.

Table 4:3: Chemical Properties of the soil.

Horizon	Depth (cm)	*pH*	Org. C	TN	Avail. P	H^+	Al^{3+}	EA	Ca	Mg	K	Na	ECEC	BS	Mn	Fe	Cu	Zn
			(gkg^{-1})		*(mg/ kg^{-1})*				*(C mol Kg^{-1})*					*(%)*		*(mg/kg^{-1})*		
Ap	0 – 14	6.6	3.95	2.7	1.38	0.63	1.2	1.83	4.8	1.2	1.1	0.8	9.73	81.2	52.0	421	2.0	10.4
AB	14 – 30	6.5	4.65	3.8	1.61	0.63	1.29	1.92	8.0	1.8	1.4	1.2	14.32	86.6	72.1	411	4.2	29.6
Bt_1	30 – 51	6.7	4.30	3.5	1.42	0.63	1.72	2.35	6.4	1.5	1.2	0.9	12.35	81.0	50.5	432	3.2	11.3
Bt_2	51 – 90	6.8	3.76	2.4	1.27	0.56	0.91	1.47	4.8	1.2	0.9	1.0	9.37	84.3	64.0	435	4.1	9.8
Bt_3	90 – 127	6.6	3.41	2.1	1.32	0.56	0.8	1.36	4.8	1.2	0.8	0.7	8.86	84.7	56.4	431	3.5	9.1
Bt_4	127 - 180	6.4	2.79	1.8	0.86	0.51	0.8	1.31	6.8	1.6	1.3	1.1	12.11	89.2	48.2	431	1.9	6.7

Source: Author's Field Work 2022

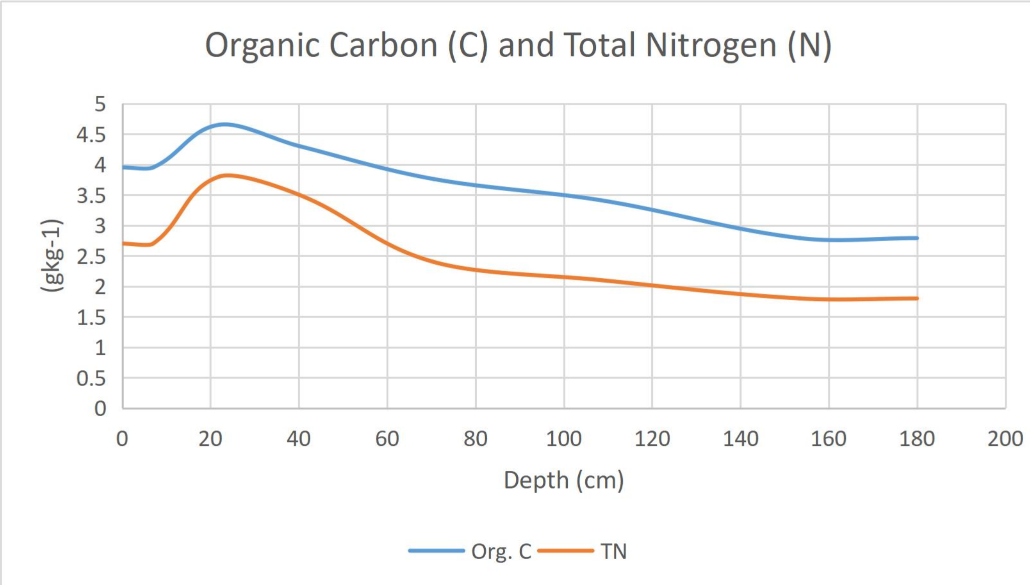


Figure 4.16: Multiple line graph showing the organic carbon (C) and total Nitrogen (N)

Available Phosphorus (P)

Phosphorus (P) which is one of the macronutrients required in greater amount for crop husbandry, varies from 1.38 and 1.61 $mgkg^{-1}$ at the topsoils to 1.32 and 0.86 $mgkg^{-1}$ at the subsoils. The mean value of Phosphorus (P) across the profile is 1.31 $mgkg^{-1}$. The highest value, 1.61$mgkg^{-1}$ was observed at AB horizon (14-30 cm), while the lowest value, 0.86 mg/kg^{-1} was at Bt_4 (127-180 cm). The trend in available P seems to have no definite pattern. When compared to critical limit presented by Chude et al. (2011), the amount of available Phosphorus (P) which is <1.3 $mgkg^{-1}$ is very low. The trend occurring here is similar to that of organic carbon and total nitrogen.

Exchangeable Acidity (EA)

The amounts of hydrogen (H^+) and aluminium (Al^{3+}) which is exchangeable acidity do not reveal any clear trend. Hydrogen cations (H^+) remains constant throughout the profile, while Aluminum (Al^{3+}) changes slightly. From the figure 4.20, Al^{3+} contributes more to the acidity than H^+. Their values tend to fluctuate slightly through the profile. EA values, as derived from the summation of acidic cations (H^+ and Al^{3+}), also do not reveal any definite pattern. The values of EA range from 0.8 to 1.72, with a mean value of 1.11 which is about 10% of the mean value of ECEC. This explains why there is a relatively low level of acidity in the soil as reflected in the soil pH levels.

Macronutrients (Ca, Mg, K, Na)

All the macronutrients in the soil seem to have similar trends; they are slightly low at the Ap horizon (0-14 cm), and increased rapidly at AB horizon (14-30 cm), then reduced significantly where it began fluctuating gradually down the pedon. The soil macronutrients, generally reduced with increase in soil depth (See Fig. 4.23 and Fig. 4.24). The values of the macronutrient in the topsoil is as follows: Ca>Mg>K>Na. A high Ca soil will have more oxygen, drain more freely and support more aerobic breakdown of organic matter and this is the opposite of Mg (Hardy, 1971). Therefore, a balance of Ca and Mg is necessary for optimum plant growth in a flooded area.

Calcium (Ca) has values ranging from 4.8 to 8.0 $cmolkg^{-1}$ in the profile. The mean value of Ca content in the soil is 5.9 $cmolkg^{-1}$. The highest value of calcium Ca, 8.0 $cmolkg^{-1}$ was noted at AB horizon (14-30 cm). The high value of Ca at the subsoil is due to the leaching effects. According to Chude et al. (2011), the values of calcium, greater than the critical level of 1.0 $cmolkg^{-1}$, can be considered to be high. Therefore, the soil is typically very high in calcium. The upshot of this is that excessive calcium levels can obstruct the uptake of other crucial elements, such iron, zinc, and manganese, leading to nutritional shortages that can harm plant growth and development (Ekong and Uduak, 2015). Furthermore, soil that has a lot of calcium becomes more alkaline which can affect the availability of certain nutrients to plants. However, Ca is useful to all plants, but it is important to note that all plants have different nutrient requirements and some may be more sensitive to calcium deficiency than others (Horst et al., 2014).

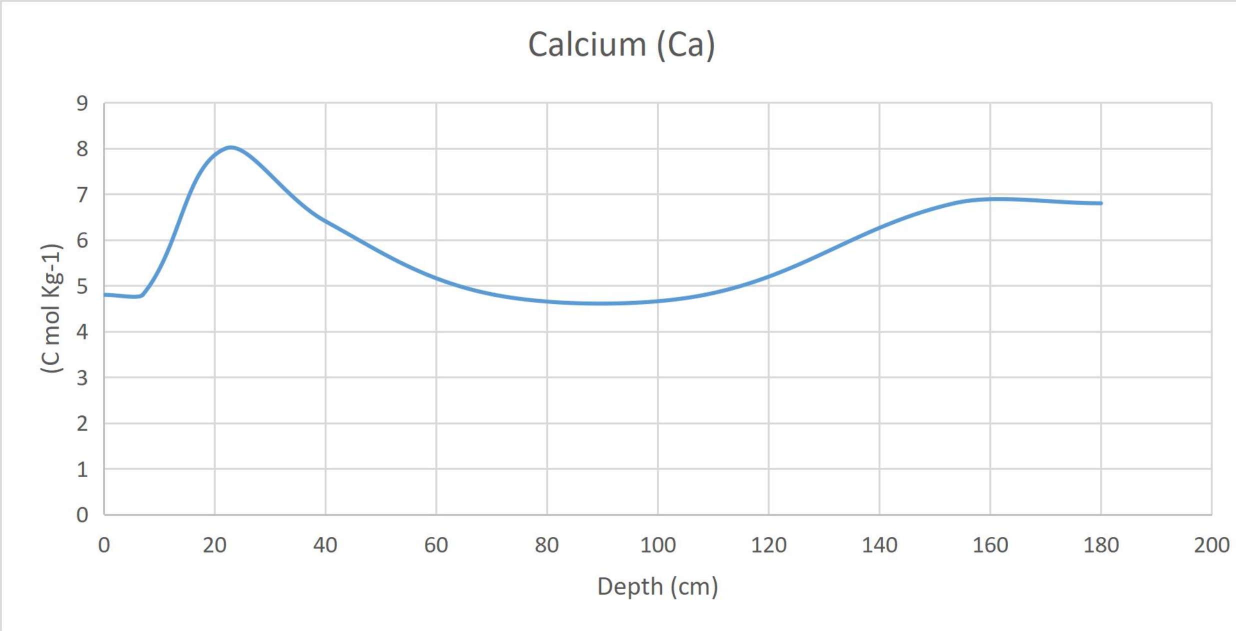


Figure 4.17: line showing the amount of calcium in the soil profile

The values for magnesium (Mg) range from 1.2 and 1.8 cmolkg^{-1} at the topsoils, to 1.2 and 1.6 cmolkg^{-1} at the subsoils. The mean value of Mg is 1.4 cmolkg^{-1}. The highest value of 1.8 cmolkg^{-1} was recorded at AB horizon (14-30 cm), while the lowest value of 1.2 cmolkg^{-1} was noted at three different horizons (Ap, Bt_2 and Bt_3). This pattern seems to correlate directly with that of Ca. Generally, the amount of Mg in the soil seemed to be low (1-10 cmolkg^{-1}). According to Chude et al. (2011), the concentration of magnesium (Mg) in a soil is typically low if it ranges between 1 -10 cmolkg^{-1}. This means that there is a relatively small amount of magnesium present in the soil. Mg is an essential element for plant growth and development, and it is involved in various physiological processes. Magnesium deficiency may lead to reduction in soil fertility. It is therefore necessary to apply organic matter to the soil in order to increase the nutrient level of the area. The source of the organic matter could be from concentrated organic manure.

Potassium (K) in the soil has values ranging from 1.1 and 1.4 $cmolkg^{-1}$ at the surface horizons, to 0.8 and 1.3 $cmolkg^{-1}$ at the sub-surface horizons. The mean value of K across the pedon is 1.1 $cmolkg^{-1}$. Similar to other bases, potassium (K) is highest at AB horizon (14-30 cm), while being at its lowest at Bt_3 horizon (90-127 cm) (Fig. 4.18). Overall, the value of potassium (K) can be considered to be very high which is above the range (0.61 - 0.73 $cmolkg^{-1}$) as reported by Chude et al. (2011). Potassium (K), like other bases, is beneficial to all plants, but excessive amounts can raise soil alkalinity, which can immobilize other crucial nutrients for plants necessary for plants in the soil.

Similarly, sodium (Na) ranges from 0.8 and 1.2 $cmolkg^{-1}$ at the topsoils, to 0.7 and 1.1 $cmolkg^{-1}$ at the sub-surface horizons, with the highest value recorded at AB horizon (14-30 cm), while the lowest was noted at Bt_3 horizon (90-127 cm). The mean value of sodium (Na) is 0.9 $cmolkg^{-1}$ (See Fig. 4.24). The amount of sodium (Na) across the pedon can be considered to be adequate for plant growth which is >15 $cmolkg^{-1}$.

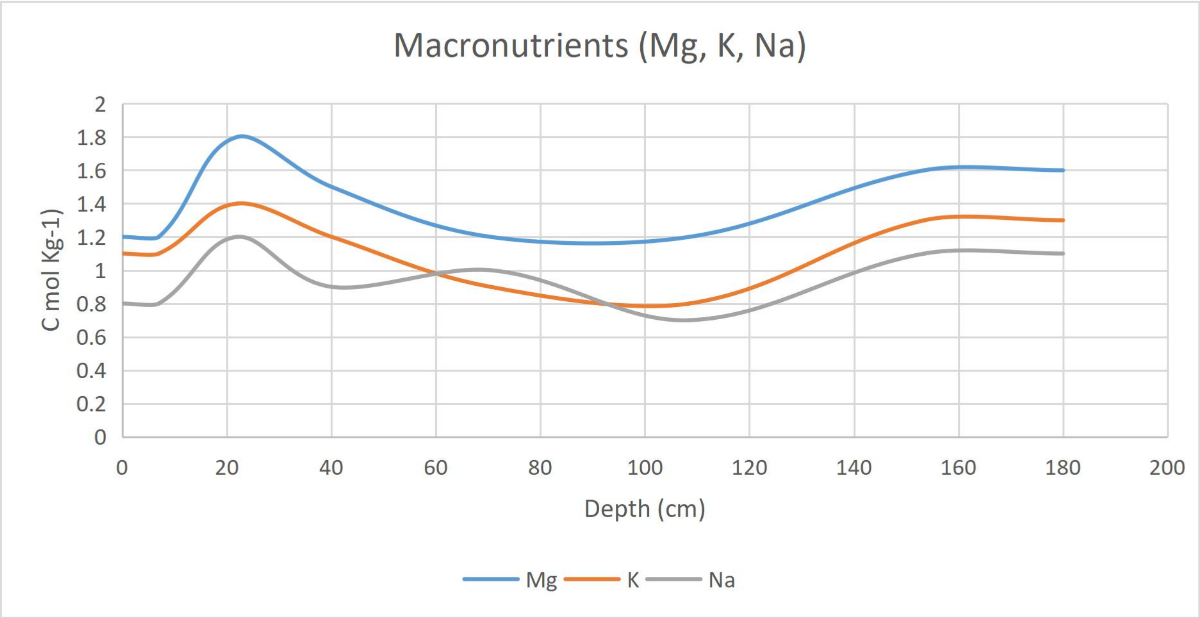


Figure 4.18: multiple line graph showing trend of magnesium, potassium and sodium in the profile.

Effective Cation Exchange Capacity (ECEC)

ECEC ranges from 9.73 and 14.32 $cmolkg^{-1}$ at Ap horizon and AB (14-30) horizons respectively, to 8.86 and 12.11 $cmolkg^{-1}$ at the sub-surface horizons. The values of ECEC at each horizon was derived by the summation of all acidic cations (Al^{3+} and H^{+}) and basic cations (Ca, Mg, K, Na) that are attracted to and retained on the soil colloids in each horizon. The highest ECEC value was recorded at AB horizon (14-30 cm), while the lowest was at Bt_3 (90-127 cm). The mean ECEC value obtained is 11.2 $cmolkg^{-1}$. (Figure 4.19) The ECEC is often used as an indicator of soil fertility, as it reflects the soil's ability to supply essential plant nutrients. The ideal range of Effective Soil Cation Exchange Capacity (ECEC) values for plant productivity might differ depending on the particular requirements of the plants being cultivated and the kind of soil being used. Although some plants may need higher or lower ECEC values based on their nutritional requirements and tolerance for soil pH, the results were below the threshold of 20 $cmolkg^{-1}$ considered appropriate for crop productivity (FAO, 1976). The ECEC values can be said to be high which according to Ojo-Atere et al (2012) is attributed to Kaolinitic nature of the Southern part of Nigeria.

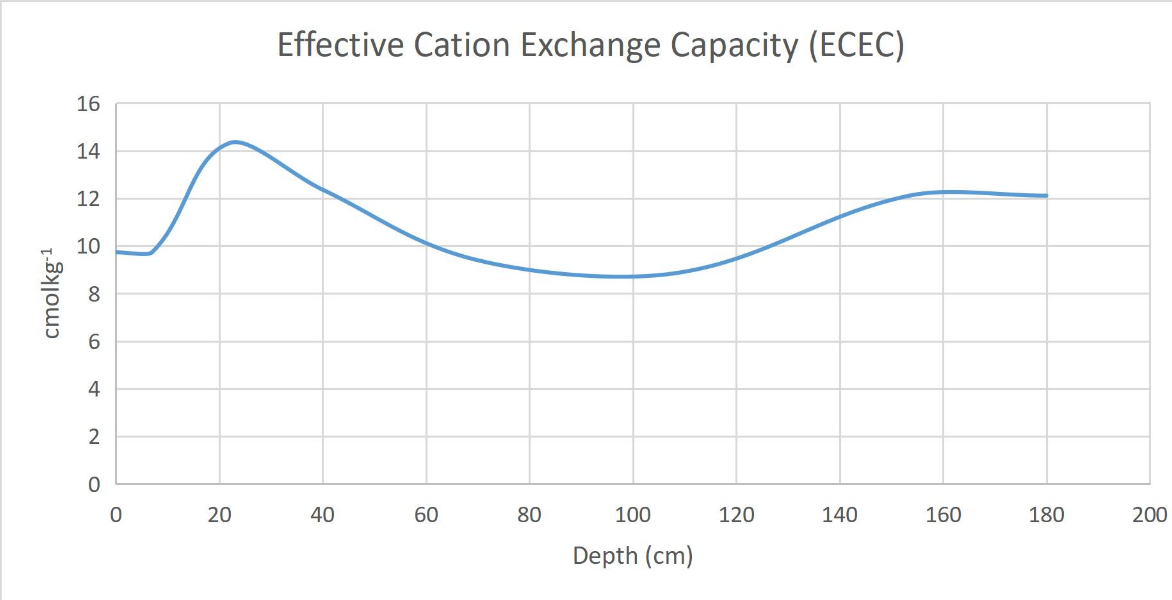


Figure 4.19: Line graph showing trend of Effective Cation Exchange Capacity (ECEC) in soil profile

Base Saturation (BS)

The BS values across all the horizons range from 81.0 to 89.2%. The mean value of BS is 84.5%. This implies that about 85% of the cations that are attracted to soil colloids in the pedon are alkaline, causing a reduction in the acidity of the soil, thus contributing to the soil pH levels. The base Saturation (BS) levels of the soil promote plant productivity, because the amount of acid cations (H^+ and Al^{3+}) are considerably low. This lends credence to the relatively high amount of Calcium, potassium and sodium the similar trends they exhibit (Figure 4.18).

Micronutrients (Mn, Fe, Cu, Zn)

The micronutrients do not exhibit a clear trend when viewed together. However, when examined independently, each micronutrient seems to have a relationship with another. For example, there seems to be a strong negative correlation between iron (Fe) and Zinc (Zn). That is to say, when one increases, the other decreases. Manganese (Mn) also exhibits a strong negative correlation with copper (Cu). The micronutrients occur in the order Fe>Mn>Zn>Cu. According to Esu (2010), the higher value of Fe compared to Cu, Mn and Zn can be attributed to the presence of sesquioxides in humid tropical soils.

The iron content of the profile seems to be relatively low at AB horizon (14-30 cm) where macronutrients and basic cations are high, and increases gradually with soil depth. This may be a reflection of the clay fraction of the soil profile, because the trend revealed is similar to that of clay (See Figure 4.20 and Figure 4.15).

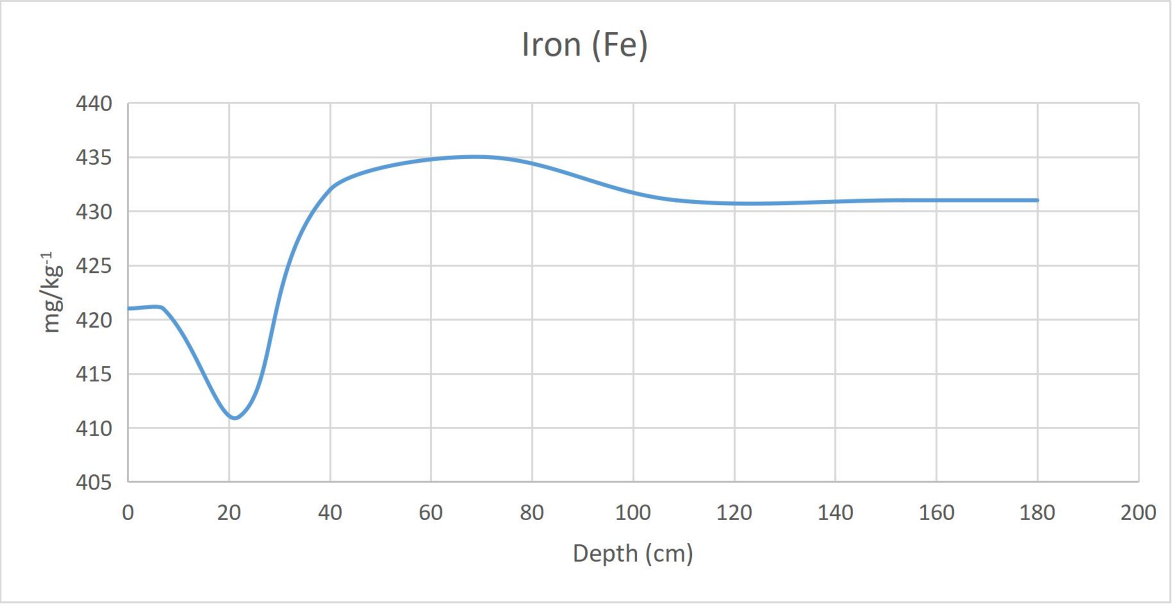


Figure 4.20: Line graph showing the trend of Iron (fe) content in the soil profile

Zinc, on the other hand, shows a trend similar to those of the macronutrients where there seems to be a notable spike in the value at AB horizon (14-30 cm). Zinc content tends to decrease with increase in soil depth (See Fig. 4.30).

The copper (Cu) content of the soil ranges from 1.9 to 4.2 mg/kg^{-1}, with a mean value of 3.1 mg/kg^{-1}. Unlike the other micronutrients it does not exhibit any notable trend. The content of manganese (Mn), however, ranges from 52.0 and 72.1 mg/kg^{-1} at the surface horizons, to 56.4 and 48.2 mg/kg^{-1} at the sub-surface horizons. After spiking to 72.1 mg/kg^{-1} at AB horizon (14-30 cm), the manganese (Mn) content drops and fluctuates downward through the profile. This trend is the same as the pattern observed in the macronutrients (See Fig. 4.30)

The content of iron (Fe) has been observed to be the highest among the micronutrients, followed by manganese (Mn), then Zinc (Zn), while copper (Cu) is the least value across all the horizons.

In general, micronutrient levels were higher than the necessary values for Mn (1.0 mg/kg^{-1}), Cu (0.2 mg/kg^{-1}), Zn (0.5 mg/kg^{-1}), and Fe (4.5 mg/kg^{-1}) (Ibia, 2012). Given that all of the values recorded were above 1.00 mg/kg, the soils had high Mn concentrations. According to Black (1968), Mn levels in soil between 1 mg/kg^{-1} and 15 mg/kg^{-1} and above would be detrimental to crop plant growth. According to Ibia (1995), crop plants would not develop well if the available Zn content in soil was between 4.5 mg/kg^{-1} and 10 mg/kg^{-1}. The high levels of micronutrients in the soils may be related to their acidity and waterlogging. If sufficient calcium and other bases were not present in the soil, there might be risk of micronutrient toxicity (particularly Mn and Fe). The metallic micronutrients such as Mn and Fe, often form complexes with other elements in the soil to improve their availability to crops. This means that they are more easily taken up and utilized by plants for growth and development. This is supported by the findings of Udoh et al. (2005).

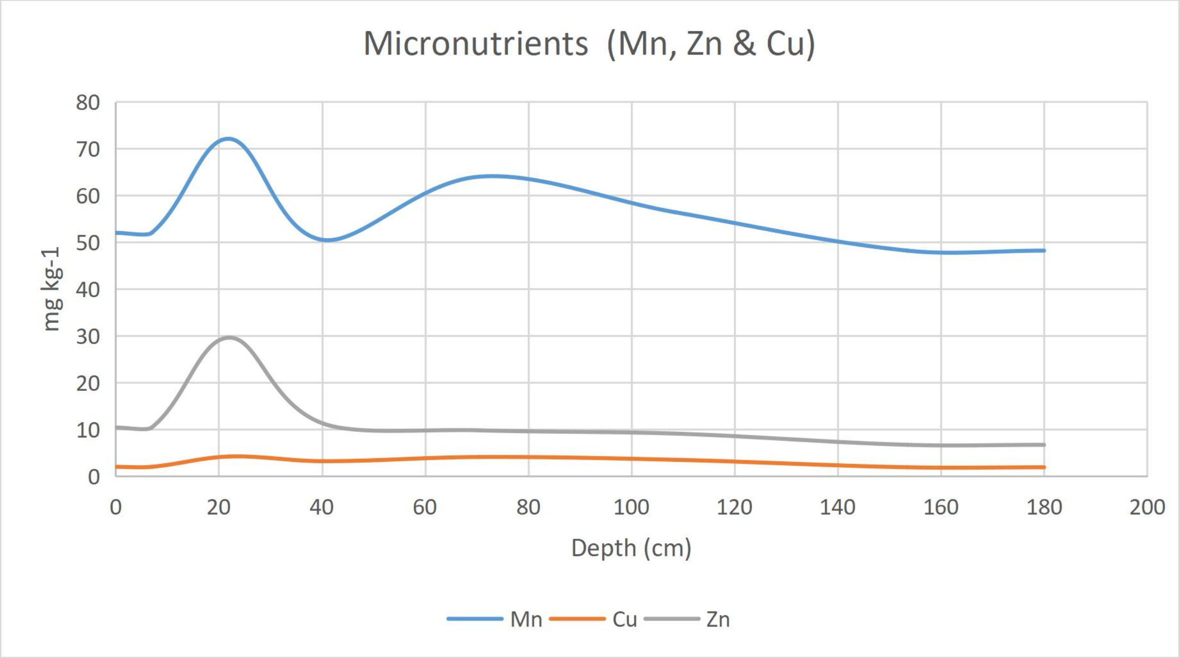


Figure 4.21: Multiple line graph showing the respective trend of manganese (Mn), zinc (Zn), and Copper (Cu) in the soil profile.

Judging from the weathering indices derived from the physical properties of the soil, we can reasonably conclude that this recurrent trend in the micronutrients and some of the other minerals is due to intense weathering and leaching of the surface horizons.

4.4 Biological Properties

Table 4.4 shows the biological properties. Total Heterogenous Bacteria Counts (THBC) and total Heterogenous Fungi Count show that the soil teems with high microbial activities. Brady and Weil (2002) are of the opinion that fungi and bacteria inhabit the pore spaces of soil. There are relatively high bacterial and fungal activities at the first two horizons (Ap and AB). However, as soil depth increases, microbial activities tend to reduce. This trend is expected because porosity influence the amount of oxygen (O_2) available for soil microbes (Bardgett, 2005). It may be influenced by the sandy clay loam texture at surface horizons. The amount of microbial activities is high at a depth of 14cm to 30 cm (AB horizon). This cannot be by mere coincidence, because the AB horizon (14-30 cm) holds more basic cations as shown in values of Base Saturation and ECEC. This considerably impacts on the soil pH which seem to be slightly neutral, promoting high microbial activities in the horizon (Paul and Clark, 1996).

The same can be said of the other horizons, because the soil pH across the profile, seem favourable for high microbial activities. However, the reduction in both bacterial and fungal count with soil depth, can be related to the availability of total Nitrogen (N), Carbon (C) and other basic cations that are fixed to colloid in the soil (Nelson and Sommer, 1982).

Table 4.4: Biological Properties of the Soil.

Soil Depth (cm)	THBC($x10^4$ cfu/g)	THFC($x10^3$ cfu/g)
0 – 14	$1.38x10^6$	$1.4x10^4$
14 – 30	$1.81x10^6$	$1.9x10^4$
30 – 51	$1.45x10^6$	$1.6x10^4$
51 – 90	$1.32x10^6$	$1.4x10^4$
90 – 127	$1.41x10^6$	$1.5x10^4$
127 - 180	$1.29x10^6$	$1.2x10^4$

Source: Author's Field Work 2022

4.5 Soil Classification

Soil classification were done using USDA Soil Taxonomy (Soil Survey Staff, 2020) At the order level the soil is classified as Alfisols due to the presence of an argillic and kandic horizon and without a plaggen epipedon and it has clay films in I mm or more thick in some part of the horizons. The suborder should be Udalfs due to the udic moisture regime in the area.

It does not have a densic, lithic or paralithic, contact within 150 cm of the mineral soil surface; and it has a kandic horizon within 150 cm of the mineral soil surface, it has a clay increase with increasing depth of 20 percent or more from the maximum clay content. It has a clay increase of 3 percent or more in the fine-earth fraction hence it is classified as Kandiudalts (Great group). At this level, it is Typic Kandiudalts as it does not fit into any other group. In the family level the soil can be classified as Kaolinic. The classification is therefore Typic Kandiudalts (Kaolinic).

CHAPTER FIVE

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

There is a lack of research on the physical, chemical, and biological properties of soils in specific areas, such as waterlogged environments, in the Benin region. Even within the same soil classification group, there can be significant differences in soil characteristics. There are many flooded and waterlogged areas in Edo State that have not been adequately documented or studied, despite the fact that they cover a significant portion of the land and are home to unique hydrophilic plants and animals. Flooding and waterlogging are among the major soil-related problems facing this region, and understanding the characteristics and processes of soil formation in waterlogged areas is crucial in addressing these issues.

The findings of this research have the potential to inform the responsible utilization of soil resources by considering the physical, chemical, and biological processes that influence soil behaviour.

This chapter, therefore, provides a summary of the research findings that were derived from the analysis and discussion of the results. Subsequent sections present the conclusions and recommendations that were formulated based on these findings, highlighting potential avenues for further research.

5.1 Summary of Findings

1. The soil in this study has a moderate, medium, sub-angular blocky structure in the topsoil, while the rest of the soil profile (30-180 cm) is moderate, fine, and sub-angular blocky. The soil colours range from dark reddish brown to red.

2. The bulk density is within the permissible limit and therefore may not pose any problem in crop production. In the study, bulk density is highest at the topsoil and decreases downward before gradually increasing.

3. The water holding capacity (WHC) of the soil in this study is highest in the subsurface horizon and lowest in the surface horizons. The highest value of WHC is found at the Bt2 horizon, while the lowest value is recorded at the AB horizon. The surface horizons have lower values of WHC due to their high proportion of sand, while the subsurface horizons have higher values due to their high clay fraction and organic matter. The WHC gradually increases throughout the soil profile, with a peak at the 51-127 cm depth. The soil organic matter may contribute to the high values of WHC in the soil.

4. The clay activity in the topsoil rapidly increases to a high value at a depth of 14-30 cm, before declining and remaining relatively constant down the rest of the profile. The sudden increase in clay activity from the topsoil to the AB horizon (14-30 cm) suggests that this horizon is severely weathered.

5. The erodibility index values range from 4.00 to 9.00 at the topsoils and decrease to values as low as 1.22 to 1.50 in the subsoil. The high value of erodibility index for the AB horizon (14-30 cm) suggests that it is susceptible to sheet and rill erosion. This is supported by the silt/silt+clay ratio value of 0.75, which is above the critical value of 0.7, indicating severe weathering.

6. The pH of the soil in this study varies from 6.4 to 6.8 and has a mean value of 6.6. The pH is slightly acid to neutral. The soil pH does not follow a clear pattern throughout the soil profile, but is generally neutral and not problematic for tree crop cultivation.

7. The amount of available phosphorus in the soil, which is less than 3 $mgkg^{-1}$, is very low compared to critical limits. P is readily not available in the soil. The trend of phosphorus in the soil is similar to that of organic carbon and nitrogen, and it is likely that similar underlying chemical processes are responsible for this pattern.

8. The Effective cation exchange capacity (ECEC) of the soil ranges from 9.73 to 14.32 $cmolkg^{-1}$ at the surface horizons and from 8.86 to 12.11 mg/kg^{-1} at the sub-surface horizons. The mean ECEC value is 11.2 mg/kg^{-1}.

9. The levels of micronutrients in the soil, including manganese (Mn), copper (Cu), zinc (Zn), and iron (Fe), were higher than the necessary values for crop plant

growth. Crop sensitive to these micronutrients should not be planted. For instance, Cocoa is sensitive to high levels of Zn.

10. Total heterogeneous bacteria count and total heterogeneous fungi count in the soil indicate high levels of microbial activity. There are relatively high levels of bacterial and fungal activity at the first two horizons (Ap and AB), but as soil depth increases, microbial activity tends to decrease. This trend may be due to the influence of porosity on the amount of oxygen available for soil microbes, as well as the sandy clay loam texture at surface horizons.

11. The amount of microbial activity is particularly high at the topsoil, which may be related to the high levels of basic cations and slightly neutral soil pH in this horizon. The reduction in both bacterial and fungal counts with soil depth may be related to the availability of total nitrogen, carbon, and other basic cations that are fixed to colloids in the soil.

5.2 Conclusion

Based on the data and analysis conducted in the study, the following conclusions have been drawn.

1. The soil in this study is classified as a Typic Kandiudalts based on its characteristics, including the presence of an argillic and kandic horizon, the udic moisture regime in the area.

2. The sandy fraction is predominant in the soil, which has a negative effect on soil fertility.

3. The study shows soils in the flooded area to vary in morphology, mainly in terms of texture, structure, consistency and colour which have helped significantly to guide in the soil classification and recommendation.

4. From the findings, it can be concluded that the soil at the top of the profile (Ap horizon) is a relatively recent deposit, while the soil at the AB horizon (14-30 cm) is older and has undergone severe weathering, resulting in a high clay content in the subsurface horizons. The sudden decline in clay activity creates a bulge (Bt_1 and subsoil), indicating that eluviation (the removal of fine particles from the soil) occurs in the Bt_1 horizon and illuviation (the accumulation of fine particles in the soil) occurs in the subsoil horizons below.

5. Based on the erodibility index, it can be concluded that the soil in the topsoils has high erodibility and severe weathering, while the soil in the subsoil has lower erodibility and weathering intensity. There is also evidence of clay translocation and the presence of an argillic horizon in the soil at a depth of 30-180 cm. These processes likely contribute to the formation of the soil in the study area.

6. From the above findings, the soil analyzed in this study exhibits suitable levels of sodium and pH for plant growth. However, the high calcium carbonate content

and overall bulk density of the soil may affect its structure over time. Additionally, the soil is deficient in key macro nutrients including potassium, magnesium, available phosphorus, and organic carbon, while exhibiting a high effective cation exchange capacity which may be beneficial for crop productivity. Conversely, micronutrient levels including iron, zinc, copper, and manganese are higher than necessary and may potentially have negative impacts on plant growth

7. The high levels of micronutrients may be related to the acidity and waterlogging of the soil. If sufficient calcium and other bases are not present, there may be a risk of micronutrient toxicity. This is supported by the findings of previous research.

5.3 Recommendation

Understanding the properties of waterlogged soil can provide insights into local ecosystems and inform decisions about vegetation and land use. Soil characteristics can also be used to explain trends in soil moisture and temperature. This research helps to understand the nature and functions of ecosystems in a flooded and eroded location. In light of above therefore, the following recommendations are made.

1. The soils in the study area are very distinct in their properties, with a major limitation being wetness. Implementing a good drainage system and water control

facilities will improve the productivity of the soils for swamp rice and cocoyam husbandry.

2. The nutrient levels in the soil are moderate, but good organic matter management, including the use of farmyard manure, is necessary to enhance nutrient availability, particularly in phosphorus.
3. Periodic liming of the area will help to improve the high levels of micronutrients.
4. Sand agronomic erosion control measures, such as planting vetiver grass hedges, grasses, and establishing cashew plantations, will help to control erosion in the area.
5. Planting mango and other trees that absorb carbon dioxide is recommended to reduce the warming of the area and mitigate the effects of climate change.
6. Adding organic matter to the soil is important for water and nutrient retention.

While some progress has been made in understanding some particular aspect of soils in Southern Nigeria, there is still more work to be done in order to fully understand the nature and soil-forming processes of waterlogged soil which will prove useful in addressing any outstanding questions or challenges in agriculture, forestry, environmental science, civil engineering, and geology.

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