

**APPLICATION OF GEOGRAPHICAL INFORMATION
SYSTEM (GIS) IN SELECTED SOIL MAPPING FOR CROP
PRODUCTION IN SELECTED LOCAL GOVERNMENT
AREAS OF ABIA AND IMO STATES, NIGERIA.**

BY

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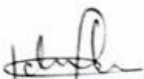
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CERTIFICATION

This is to certify that this work "Application of Geographical Information System (GIS) IN Selected Soil Mapping for Crop Production in Imo and Abia State, Nigeria" was carried out by I Essoribe, Nestor Ugochukwu (20174089708) in partial fulfillment for the award of (M.Sc in Soil Survey and Land use in the Department of Soil Science and Technology) of the Federal University of Technology, Owerri


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DEDICATION

This work is solely dedicated to the Almighty GOD.

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ABSTRACT

This study used Geographic Information System (GIS) as a mapping tool to evaluate the suitability of selected soils of different parent materials for crop production (Tomato, Cabbage, Cucumber and Watermelon) in Southeastern Nigeria. A free survey technique was used in situating soil profile pits. Five (5) Profile pits were dug on each of three (3) dissimilar lithologies, giving a total of fifteen (15) profile Pits. Pits were dug, described and sampled according to FAO (2006). Undisturbed soil samples were collected using core samplers for bulk density and moisture content determination. While soil colour and other morphological properties were determined in-situ. Routine analyses were carried out using standard methods. Ordinary kriging was used to interpolate the values at unsampled location, generating spatial distribution maps for each soil property using geographic information software ArcGIS 10.2. Land suitability evaluation was carried out using FAO(2006) land suitability evaluation method. Soils of Amuro were Sandy Clay, Isiobuzor were Loamy Sand and Umunneochi (Isuochi) were Sandy Loam. The percentage sand content was significantly higher in Umunneochi (856.50g/kg, $P<0.01$) followed by Isiobuzor(845.30g/kg, $P<0.05$). Clay content was significantly higher in Amuro (284.50g/kg, $P<0.01$) and lowest in Isiobuzor (55.910g/kg, $P<0.05$). While Bulk density was significantly higher in Amuro (1.444gcm, $P<0.01$) and low in Isiobuzor (1.33gcm, $P<0.05$). The soils of the areas were acidic irrespective of the parent materials and were ranked thus Isiobuzor>Umunneochi>Amuro. Organic carbon of all the selected soils was generally low and followed thus Umunneochi>Amuro>Isiobuzor. Percentage base saturation was ranked Isiobuzor > Amuro> Umunneochi. Percentage base saturation showed a significant positive correlation with sand ($r=0.774$, $P<0.01$) The soil of Umunneochi was highly suitable (S1) for cucumber and watermelon production. The soil of Isiobuzor was moderately suitable(S2) for cucumber and water melon production. the soil of Amuro was not suitable for cucumber and water melon production as a result of the soil texture (NI). All the soils of the study areas were marginally suitable (S3) for Cabbage and tomato production. The soils of Umunneochi and Isiobuzor were classified as Typic Hapludalf(Soil Taxonomy) while the soil of Amuro was classified as Typic Endoaquoll. The kriging map showed that sand was highest at Umunneochi and decreased down to Amuro and Isiobuzor. Clay content increased from Umunneochi down to Amuro and decreased to Isiobuzor. The moisture content, Bulk density increased from Umunneochi down to Amuro and thereafter decreased to Isiobuzor. Total porosity decreased from Umunneochi down to Amuro thereafter increased at Isiobuzor. Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na), Effective cation exchange capacity (ECEC) and base saturation (Bs) increased from Umunneochi down to Amuro and lowest at Isiobuzor. Aluminium (Al), Bulk density (BD), Total nitrogen were highest at Umunneochi and decreased down to Amuro to Isiobuzor.

KEYWORD: Soil mapping, crop production, geographic information systems, Imo State, Abia State

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Agriculture is one of the world's most important activities supporting human life that is soil-based. Man has used land resources including soils to satisfy his needs while the land resources regeneration is very slow, that of the population growth is very fast, leading to serious imbalance. It has been noted that agriculture has the proven potential of increasing food supplies faster than population growth (Udoh and Akpan., 2015). The study and understanding of soil properties and their distribution over an area have proved useful for the development of soil management plan for efficient utilization of limited soil resources and agrotechnology transfer (Buol et al., 2003).

Geographic information system and other remote sensing application can be used to quickly identify areas suitable for agricultural exploitation and expansion (Sullivan et al., 2005). Geographic information system plays important role in agronomic studies since it is suitable to be used for modeling the variability of nutrient status within a field and assessing specific requirement for external application of fertilization and irrigation or for management practices. Geographic information system has been used to assemble information's layers of chemical and biological properties related to soil fertility, moisture content, and topography to produce a map showing which factors influence crop yield.(Hengl, 2006). It is useful for the storage, retrieval, and analysis of data types for the management of soil resources. (Adamchuk *et al.*, 2011)

Geographic Information System is a high-performance computer-based tool that is playing a critical role in soil resource management and study of pollution. It is a latest tool available to store, retrieve and analyze different types of data for

management of soil resources. (Onweremadu, 2006) It facilitates the systematic handling of data to generate information in a devised format for spatial variability, documentation, accommodation and implication to soil surveys (wilding, 1985). Digital Soil Mapping(DSM) is defined as the creation of geographically referenced soil databases based on quantitative relationships between spatially explicit environmental data and measurements made in the field and laboratory.

It represents the creation and population of spatial soil information systems using field and laboratory observational methods coupled with spatial and non-spatial soil inference systems (Sowton,1991).The availability and accessibility of Geographic Information Systems (GIS), Global Positioning Systems (GPS), remotely sensed spectral data, topographic data derived from digital elevation models (DEMs), predictive or inference models, and software for data analysis have greatly advanced the science and art of soil survey (Abidoeye *et al.*,2019).

Digital soil mapping is a task towards optimizing the usefulness of soils in many places. Several studies (Abidoeye *et al.*, 2019) have shown that such operations are effective ways of ensuring steady availability of soil data. Such operations offer significant supports to solving a myriad of environmental and geographical problems. (Jamagne *et al.*, 1994).

The Geographic Information System (GIS) offers a flexible and powerful tool than conventional data processing systems as it provides a means of taking large volumes of different kinds of data sets and their manipulation and combination into new data sets that can be displayed in form of thematic maps. (Sowton.,1991). The GIS allows the construction of models from which new thematic maps especially for the land suitability map can be produced from a set of thematic maps. (Onweremadu *et al.*, 2007).

The soils should be ameliorated for suitable crop production. The use of GIS should be embraced in soil samples, especially the use of Kriging methods to

improve the decision for field management practices, and that uniform soil management practices should be discouraged, instead soil management should be specific or site specific.

1.2 Problem Statement

The consequences of wrong use of soil fertility classification, suitability evaluation and land capability classification data have several anthropogenic problems that are detrimental on the environment. Such problems include soil erosion, drought, desertification, flooding, solidification, crusting, destruction of biodiversity and watersheds resulting from uncontrolled logging and destruction of agricultural land (Akamigbo.,2001). High rainfall, weathering and leaching contribute to the poor fertility and productivity of the soil, particularly erosion, salinity and alkalinity. Loss of soil fertility seriously reduces the natural potentials of soil to produce food and fibres.

Different parent materials affect the mineralogy, chemistry, and morphology of soils under the same conditions such as topography and vegetation especially in the tropics, (Ahukaemere *et al.*, 2016). According to Couclelis *et al.* (1995) it is therefore important to evaluate the soil using GIS, to evaluate the capability and suitability of the soil to produce these essential crops (tomato, cabbage, cucumber and watermelon). The production of these crops has been in very low pace in this southern part of the country for lack of forensic information on soil evaluation and classification. The rain forest zone of southeastern Nigeria does not have even distribution of rainfall throughout the year, hence the need for land evaluation.

1.3 Objectives of the Study

The major objective of this study was to use Geographic Information System in soil mapping for crop production in Imo and Abia State, Nigeria.

The specific objectives of the include:

- i. Characterize the soil using standard methods.
- ii. Classify the soils using USDA Soil Taxonomy and FAO-UNESCO Legend (WRB).
- iii. Evaluate the land capability and suitability of the sites for selected crop production.
- iv. Map soil using Geographical Information System (GIS) techniques.

1.4 Justification of the Study

The GIS can be used to create more effective and efficient farming techniques, by analyzing soil data and evaluating the best soil and sustainable crop for production on the soil than the convectional system.

It has a great potential in the field of soil study to provide valuable support in handling voluminous data sets. The GIS can prepare and manage large collection of agronomic and land resource data necessary for crop production. Geographic information system as a computer assisted system has the capacity for the acquisition, storage, analysis and display of geographic data according to the user.

Geographic information systems with geostatistics has recently been used as a quick data _generating technology in solving soil degradation problems. It is needed in precision agriculture as it helps farmers to meet the nutrient requirements for their farms. It is also used in pollution monitoring and mapping, especially in areas that are degraded by soil erosion, water logging and salinity. The use of GIS becomes very necessary in providing new procedures which are helpful in soil related environmental problems and suitability classification in soil management practices (Borough, 1986).

GIS is a potential tool rather than analogue product, fast in editing, updating and map production, (professionals of different fields communicate with maps.) The

application of GIS in soil mapping for crop production in Imo and Abia State, Nigeria has not been done in details, therefore. This work is therefore aimed at providing this all important needed information in this regard. Furthermore, it will add to the soil data base of the study areas.

1.5 Scope of the Study

This research on the application of geographic information system in selected soil mapping for crop production in selected local government areas of Abia and Imo state, Nigeria will be limited to some soils formed on selected parent materials in Abia and Imo state, Nigeria.

CHAPTER TWO

LITERATURE REVIEW

2.1 Soils

Soil as a material is a three-dimensional natural body that is varied in time and space Brady and Weil,(2008). It differs from its parent rock due to interactions between the lithosphere, hydrosphere and atmosphere (Chesworth, 2008). Generally, soil development is influenced by five interrelated factors: climate, parent materials, topography, organisms and time (Onweremadu, *et al.*, 2012). Pedologists use the following generic functional relationship for understanding soil formation: $S = f(\text{cl}, \text{o}, \text{r}, \text{p}, \text{t}, \dots)$ (Brady and Weil, 1999). Where s = soil properties, cl = regional climate, o = potential biota, r = relief/topography, p = parent material, t = time and dots indicate additional variables or factors of lesser importance such as mineral accession from the atmosphere or fire which might need to be taken into account. The above equation assumes that there is a casual relationship between soil properties and the soil forming factors. Bockheime *et al.*, (2000) redefined the soil forming factors as 'state' variables and included ecosystem properties, vegetation, land, animal properties as well as soil properties. These variables are the 'static factors' which determine the state of the soil system. Scalenghe *et al.*, (2007) defined soil as those portions of the earth's crust whose properties vary with soil forming factors.

2.2 Pedogenesis

The term pedogenesis refers to the science and study of the processes that lead to the formation of soil (Esu, 2005). Onweremadu, (2012) defined pedogenesis as the process of soil development. Soil is a product of interaction between climate, parent materials, topography and soil organisms. Its formation involves pedogenic processes (Buol *et al.*, 2007) such as addition, transformation, translocation and

losses. While climate and soil organisms actively influence soil formation, topography indirectly affects rate of pedogenesis and distribution of nutrients (Johnson-Maynard *et al*, 2002, Quideau *et al* 2001). Though soils are created by the various horizon development processes of addition, transformation, translocation and losses/removal, it is the soil forming or pedogenic processes that determine the kind of soils that is ultimately formed.

2.3 Soil Characterization

Soil characteristics can be measured, estimated and values obtained used for soil classification. The physical and chemical properties of soils are determined by the forming processes under which they form (Ahukaemere, 2012). Soil properties and characteristics changes with time, but those that change within human life span were referred to as use-dependent properties. Ibia *et al*, (2010) observed that Soil Organic Carbon (SOC), Bulk Density (BD), pH, salinity and aggregate stability; these are referred to as dynamic soil properties. These soil properties either directly influence soil fertility. Nnaji *et al*. (2002) noted that under similar agroecological environment, land use and cultural practices become the dominant factors affecting soil properties and crop production. Soil properties have been found to vary with topographic positions, characteristics of land use and human influence (Ritcher and Markewitz, 2001). Esu (2004) outlined the general soil properties often required in most basic soil survey to include, particle size distribution, organic carbon, total nitrogen, available phosphorus, exchangeable bases (Ca^{2+} , Mg^{+} , Na^{+} and K^{+}), electrical conductivity, soil pH, exchangeable acidity (H^{+} and Al^{3+}), cation exchange capacity (CEC), bulk density, macro porosity, available moisture content and available plant nutrient elements. This is in addition to soil morphological properties such as soil depth, soil colour, soil structure, consistency, root abundance etc. (Akamigbo, 2010).

2.4 Soil Morphological Properties

Soil morphology deals with the form and arrangement of soil features *in-situ* (Onweremadu., 1994). It is the study of soils morphological features in the field through observations, description and interpretation. Soil morphology is best studied in the field (Esu., 2010). A detailed morphological description is of great aid to a pedologist in making adequate inferences about the development of any soil and its possible use and management (Akamigbo., 2010). Soil morphological properties generally, include the physical constitution of the soil profile with respect to the horizons in the profile and many other features such as soil colour, soil consistency, presence or absence of roots, faunal activities, clay coatings, etc Brady and Weil, (2002).

2.4.1 Soil colour

Soil colour is perhaps the first and most obvious physical parameter that is observed about any soil. It reflects an integration of chemical, biological and physical transformations in the soil. Soil colour is an important morphological attribute used in soil classification and interpretation (Esu, 2010).

Colours of epipedons (top soil) reflect a strong imprint of biological processes notably, those influenced by the ecological origin of soil organic matter (SOM). SOM imparts a dark colouration to the soil. A bright light colour can be related to an elluvial horizon where sesquioxides (Fe & Al), carbonates and/or clay minerals have been leached out the subsoil. Colour reflects, more strongly, in most soils the imprint of physical and chemical processes (Neumann *et al*, 2011), in particular, the redox status of Fe and to a lesser extent Mn, strongly influence the variation found in subsoil colour matrix. In a more poorly drained soil (anaerobic condition), Fe compounds are reduced and the neutral gray colours of Fe^{2+} or bluish green colour of Fe phosphate, iron carbonates, or iron phosphate are

visible whereas in a well soil, Fe^{3+} is present which gives soil a yellow or reddish colouration. Light gray or whitish colouration is sometimes inherited from, the parent materials such as marble or quartz, especially in highly weathered soils in the tropical environment. (FAO., 2006) used three attributes of colour namely: hue (major colour; reddish or yellowish), chroma (brightness or intensity) and value (contrast) in describing soil colour.

Soil colour is one of the most important basic properties which help to identify the kinds of soils and recognize the successions of soil horizons or layers in soil profiles. It has long been used for soil identification and qualitative measurements of soil properties and is a helpful field soil property for characterizing soil types. According to (Baldock and skjemstad., 2000), color is a function of pH, redox reaction and organic matter. A change in soil colour from adjacent soil also indicates a difference in the soils mineral origin (parent material) or in soil development (Sharma *et al.*, 2002), geologic origin and degree of weathering of the soil material and leaching or accumulation of chemical compounds such as iron, which may greatly influence soil quality, . (Nuga *et al.*, 2006) reported that the variation in color matrix of soils could be attributed to the sequence of drainage condition and physiographic position. (Hossain *et al.*, 2012) stated that the alternate wetting and drying conditions in the soils resulted in the reduction and subsequent release of iron oxides, which were accumulated in the form of brown, light olive brown, dark brown and dark yellowish-brown mottles in the middle zone of the profiles. (Dengiz *et al.*, 2010) reported that dark color (low chroma) of soils could be related to the strong impregnation of profile by organic matter during pedogenesis or to prolong water logging.

2.4.2 Soil Consistency

Soil consistence refers to the behaviour of soil when pressures are applied, especially at various moisture contents usually when the soil is wet or dry (Agbede, 2010). The cohesion among soil properties and adhesion of soil to other substances or the resistance of soil to deformation is due to consistence. It deals with the strength and nature of the forces between particles. Consistency is described on three moisture levels: wet, moist and dry. Hence in field, it is important to record the moisture status as well. Cementation is also considered when consistency is described (Buol *et al.*, 1997). Lai, (2009) defined soil consistence as the manifestations of the physical forces of cohesion and adhesion adding within the soil at a range of soil moisture contents. It is a term used to describe the action of physical forces of cohesion and adhesion on the attributes of soil material at these moisture contents that determines the resistance of soil material to crushing or rupture and its ability to change the shape or to be molded. Abagyeh *et al.* (2017) stated that friable consistency of soils indicates soils are workable at appropriate moisture content and lack of very sticky and very plastic consistency.

2.4.3 Plants roots

Plant roots give evidence of the plant root activity and the depth of penetration as well as presence of iron pan down the profile (Akamigbo., 2010). Roots presence tends to decrease down the profile, indicating pedoturbation in the soil (Esu *et al.*, 2014). In the field, it is important to record if roots only penetrated through cracks, retarded by waterlogged layers or cemented layers. Other reason for limited root penetration can be soils compaction or the absence of nutrients if there is no obstacle to root growth in the soil.

2.4.4 Soil Structure

(Brady and Weil, 2002) defined soil structure as the arrangement of primary soil particles into secondary particles (aggregates or Peds). It is the product of processes that aggregate, cement, compact or consolidate soil materials. Structure modifies texture in regard to moisture and air relationship, availability of plant nutrients, action of micro-organisms and root growth. A report by (Kosmas *et al.*, 2000b) explained that the structural characteristics of the soil describes the physical constitution particularly the structural properties of the soil profile as exhibited by the kinds of thickness and arrangement of the horizon in the profile. Soil structure can be described as spheroid, plate-like or block-like in shape. It can be classified based on shape and size of pores into coarse, medium, fine and very fine structures. The classification of soil structure in general, can be based on the grade, form, and size of particles. Soil structure are heavily imparted or altered by such activities as over-grazing, tillage, trafficking, drainage, fertilizer application, harvesting etc. Soil structure has a major influence on the ability of soil to support plant growth, cycle Carbon and nutrient, receive and store water and to resist soil erosion, and the dispersal of chemical of anthropogenic origin. (Six *et al.*, 2000) noticed the soil aggregate distribution and stability measurements have been proposed as soil quality indicators. However, pre-treatment of soil, antecedent water content and differences in sand size distribution among soils can confound interpretation of these measurements. Soil structural property variations could be related to organic matter content and textural characteristics. (Six *et al.*, 2000) reported that soil structure is strongly affected by changes in climate, biological activities, soil management practices and physicochemical nature of the soil. The arrangement and placement of soil particles into aggregates determines the response of soil to exogenous stresses such as tillage, traffic, and raindrop impact (Richter *et al.*, 2001). Extensive network of roots, soil micro-organisms and

inorganic materials are among the major responsible factors for the formation of soil structure. Aggregate dynamics is most intensively influenced by soil OM and particle size distribution (Kosmas *et al.*, 2000b).

2.4.5 Soil Profile and Horizons

Soil profile, otherwise known as profile pit, refers to the vertical section of the soil through its horizons, extending to the parent rocks. It is a vertical section excavated in a landscape to expose the internal morphology of the soil (Akamigbo, 2010).

The horizons are more or less parallel to the soil surface and differentiated from other layers above and/or below it by contrasts in properties. The thickness of each horizon or layer is the vertical distance between the upper and lower boundaries. The soil profile is usually characterized by differences in the colour of the various layers and are sometimes, used as mapping units in soil classification. The classification of soil starts with an examination of soil profiles.

A good examination of the spatial variability of soil profile characteristics as it relates to topography and vegetation is essential for good and evaluation which is a pre-requisite for land use planning (Onweremadu., *et al.*, 2015). Three major symbols are generally used in detailed description of a soil profile: or categories on the basis of their characteristics.

2.5 Soil Physical Properties

The physical properties of the soil profoundly influence how soil can be managed (Brady and Weil, 2002). They form the basic architecture of the soil and thus, determines to a great extent, soil productive capability and suitability for agricultural use. (Brady and Weil 2008) stated that soil physical properties profoundly dictate how soil function in an ecosystem, success or failure of both agriculture and engineering projects. Some of the physical properties of the soil include soil

texture, bulk density, electrical conductivity, porosity, infiltration rate, water holding capacity, soil structure, plasticity index.

2.5.1 Soil Texture

Soil texture refers to the size distribution or the relative proportion of the soil separate (sand, silt and clay) in any given soil sample (Agbede, 2010). It deals with the fineness or coarseness of the mineral particles. Texture is regarded as the basic unit of soil, since it is not easily altered by soil management. Soil texture indicates the general nature of soil physical properties which is considered very important in the soil management and characterization (Uzoho *et al.*, 2014).

The distribution of soil particle sizes (texture) can be assessed in the field by feel method or the laboratory by mechanical analysis. A variety of systems are used to classify the size ranges of the soil particles, where the ranges of sand, silt and clay that define a particle class differs among countries. Generally, soil is determined using the textural triangle. For example, a particle size distribution of equal percent ages can be classified as loam soil. Any particle greater than 2mm is removed from textural classification (Jung, 2008).

Soil texture governs the rate of many physical and chemical reaction important to crop growth since it determines the amount of surface on which the reaction can occur and the soils polyphascity (water holding and aeration). Soil texture is an intrinsic attribute of the soil and the one most often used to characterize its physical make-up, having a bearing on such soil behaviors as nutrient and water holding capacity, organic matter (OM) level and decomposition, aeration, infiltration rate, drainage and/or permeability and workability (Forte *et al.*, 2017). (Belay., 1996) reported that Vertisols in the lower toe slopes were much heavier than those on the upper parts and this was mainly attributed to the relatively finer

texture of the fresh alluvium reaching the lower slope positions and its more intense weathering due to higher moisture supply at the site.

Likewise, (Jung., 2008) also reported that the soil textural class varied with positions of soils in the landscape where coarser materials were found in the tipper slope positions and the finer materials in the lower part of the slope position. Most of the physical characteristics of soil depend upon textural class.

2.5.2 Bulk Density

Bulk density is the mass of a unit volume of dry soil (Brady and Wail, 2002). Generally, the density of the soil mineral particles (particles density) usually ranges from 2.6 to 2.7g/cm³. When dry, however, the bulk density of soil is often about half this value, because the voids between the particles are filled with air. Bulk density is usually determined in the field by driving an open-ended cylinder (Core sampler) into the soil, smoothing the ends and then finding the dry mass of the enclosed or trapped soil. Bulk density of soil generally, increase with depth in the profile (Belay, 1996). As a rule, soils with high proportion of pore space to solids have lower bulk densities than those that are more compacted with less pore spaces. Therefore, any factor that affects bulk density of a soil automatically affects the porosity.

2.5.3 Porosity

Porosity is defined as the value percentage of soil bulk occupied by water and air (Brady and Weil., 2002). A close inspection of the soil reveals that it contains solid minerals, water and space between the solid particles called pore space containing air (Isirimah *et al*, 2003). The arrangement of soil particles within the soil to a good extent, determines the soil porosity. It has been reported that the pore size or porosity of soil together with bulk density determine the structure of the soil

(Brady and Weil., 2002). Generally speaking, the finer the soil texture, the greater the surface area and the total pore space. Thus clays have the highest percentage of pore space (50-60%) and sands, the lowest (20-30%) while loams are in between (within 30%) (Donahue *et al.*,1990).

2.5.4 Water Holding Capacity

Water holding capacity of soils is a very important agronomic characteristic. Soil that holds generous amount of water are less subjected to leaching, loss of nutrients and/or soil applied pesticides. This holds because, a soil with a limited water holding capacity. For example, sandy loam reaches its saturation point much sooner than a soil with a higher water holding capacity (Forth, 1984).

A decline in organic matter will adversely affect the infiltration rate, but as the level of organic matter increase in a soil, the water holding capacity also increase due to the affinity of organic matter to water. Soil water content is the, basic parameter required to answer the wetness, quantity of water held in the soil, the amount of Water absorbed before surface runoff started, and the amount of water a particular soil supply to maintain optimum growth. (Abbaspour *et al.*, 2004). Soil water lubricates the soil allowing root penetration, necessary for microbial mobility and action, and it allows nutrient mobility. (FAO , 1994).

Thus, it can be said that water is a regulator of physical, chemical and biological processes in the soil. (Kaushal *et al.*, 1996). These processes, in turn, strongly influence all but every aspect of soil development and behavior ranging from the weathering of minerals to the decomposition of organic matter, from the growth of plants to the pollution of groundwater. (Brady and Weil, 2008). Soil water is, therefore, the most critical limiting resource and will continue to be the most critical crop production factor affecting production and sustainability in the dry

land areas. (Painuli *et al.*, 1996). Available water content refers to the volume of water retained between field capacity (FC) and permanent wilting point (PWP).

However, not all the water held between FC and PWP can be considered as equally available to plants. (Peterson *et al.*, 1991). Soil water contents at FC, PWP and available water content (AWC) increased with depth for the Soils under different management practices. (Wakene, 2001); (Yihenew, 2002) were positively and significantly correlated with the increase of the clay fractions. Variation in topography, land use and soil attribute all affect the distribution of soil moisture (Brady and Weil, 2008).

Water dynamics in soil is governed by many factors that change vertically with depth, laterally across landforms and temporally in response to climate. According to (Wakene.,2001) (Yihenew.,2002), the water-holding capacity of the soil is dependent on a range of soil properties which includes: particle size distribution (with coarse sands holding the least, water and clays the most, but silts and fine sands holding the most water in the available water range), the type of clay (with montmorillonite or swelling clays holding more water than kaolinite type clays), the amount of organic matter in the soil, the bulk density and structure of the soil.

(Abayneh, 2001) reported that AWC of the soils studied had positive correlation with clay and OM content but inversely related with silt content which could be due to the adverse effect of high silt content on the degree of aggregation of soil particles and on structural stability in addition to the proportional decrease in clay content. Three soil moisture states, saturation, FC and PWP are used to describe water content across different water potentials in soil and are related to the energy required to move water (or extract water from soil) (Yihenew, 2002).

The potentially plant available water-increased as the texture of the soils becomes finer and periodic revision of soil classes is important as there will be cumulative effects due to cultural practices, tillage operations and addition of amendments that

can cause changes in chemical, physical, and hydraulic properties of the plantation soils (Brady and Weil., 2008).

2.6 Soil Chemical Properties

2.6.1 Soil pH

This otherwise known as soil reaction, can be defined as an indication of the acidity or alkalinity of the soil. It is a measure of the changes that occur in the soil and is a characteristic of the soil solution. Acidification is a natural process involved in soil formation. It reaches its greatest expression in humid regions where precipitation is high enough to leach thoroughly or an appreciable number of exchangeable bases from the surface down the profile. Consequently, most soil of south eastern Nigeria are very acidic, medium acidic or slightly acidic, with pH ranging from 4.5 to 6.5. Generally, the pH of a soil may be acidic ($\text{pH} < 7$), neutral ($\text{pH} = 7$) or alkaline ($\text{pH} > 7$). Soil pH profoundly influences the soil biological system (microbial activities) and nutrient availability. According to (Onweremadu, 1994), if the soil solution is too acidic, plants cannot utilize N, P, and K and other nutrients they want. Soil reaction (pH) is a measure of the concentration of H^+ ions in the soil solution or in other words a measure of acidity or alkalinity of a soil. It is mostly related to the nature of the parent material, climate, OM and topographic situations. (Tamirat, 1992).

This soil property can be referred to as a "master variable" because it regulates almost all biological and chemical reactions in soils (Brady and Weil, 2008). Soil pH indicates the state of weathering of a given soil and in slightly weathered soil the surface soil pH is neutral to slightly alkaline (Buol *et al.*, 2003). Soil reaction is one of the most outstanding physiological characteristics of the soil solution because availability of nutrients and both soil micro-organisms and higher plants respond so markedly to their chemical environment. (Butterly *et al.* , 2011).

Soil pH is influenced by the response of different nitrogenous fertilizer absorption and releases of nutrients at the soil water interface. (Uzoho *et al.*, 2007). Most plants and soil organisms prefer pH range between 6.0 and 7.5. (Uzoho *et al.*, 2007). Soil pH is the first parameter to be considered in soil fertility evaluation (Thomas *et al.*, 1996), reported that the pH of the soil was moderately acidic with values ranging between 6.00 and 6.62 and this value indicates that there is no toxicity of aluminum, manganese and hydrogen the author stated that pH values increased with soil depth because less hydrogen ions are released from decreased OM decomposition, which is caused by decreased OM content with depth.

Soil pH is most useful in soil suitability evaluation and management as it provides information about the solubility and thus potential availability or phyto-toxicity of elements for crops, subsequently the soil suitability for specific crop. Onweremadu *et al.*, (2011). The electrical conductivity (EC) measurement identifies soils, which are saline and/or potentially saline. (Evans *et al.*, 2012). The accumulation of soluble salts in the soil profile curtails crop growth by increasing the osmotic potential of the soil solution and inducing specific ion toxicity or nutrient imbalances. These salts contain the cations Na^+ , Ca^{2+} , and Mg^{2+} and the anions Cl^- , SO_4^{2-} , HCO_3^- , and CO_3^- which can be weathered from minerals and accumulate in the soil solution in areas where the precipitation is too low to provide leaching. (Anderson *et al.*, 2000). Soil CEC correlates with soil properties that affect crop productivity, including soil texture, cation exchange capacity (CEC), drainage conditions, OM level, and subsoil characteristics. (Onweremadu *et al.*, 2011). reported that ECEC values below unity are low below which it can affect the growth of most agricultural crops. Salt affected soils usually occur in arid and semi-arid regions owing to the high evaporation rate. (Shrivstava *et al.*, 2015).

2.6.2 Cation Exchange Capacity (CEC)

This is defined as the ability or capacity of a soil colloid to hold cations. The amount of nutrients that the organic compounds and clay could carry and make available to plant is called the soil's cation exchange capacity. According to (Donahue *et al.* 1990), the CEC of a soil is the quantity of cations that can be needed or exchanged by a given soil. CEC is measured in terms of centimole per kilogram (Cmol/kg) of charge or mill equivalent per 100g soil (meg/100g soil). The term effective cation exchange capacity (ECEC) is often used synonymously with CEC especially in the humid tropics where soils have high content of Al and Fe oxides (sesquioxides) as a result of high rainfall that leaches out basic cations (Ca^{2+} , Mg^{2+} , Na^+ and K^+), leading to soil acidity. The CEC of a soil is an important chemical property that is used for classifying soils in soil taxonomy.

Calcium (Ca) is a macro-nutrient and liming element associated with minerals such as feldspars, calcite, apatite, dolomite, gypsum and amphiboles. Southeastern Nigeria characterized by pronounced soil degradation due to poor aggregation (Onweremadu *et al.*, 2010) which is sometimes influenced by basic cations. Most economic crops yield best in soils where Calcium ion dominates the exchangeable complex (Isirimah *et al.*, 2003), thus exchangeable calcium promotes flocculation of soil colloids (Dontsova and Norton, 2002).

Magnesium (Mg) is an essential nutrient element which must be present in large quantities for the plant to survive. Magnesium is held on the surface of clay and organic matter particles. Its deficiency can occur in sandy and/or well-drained soils which leach it through the soil profile.

Sodium (Na) ions are more associated with semi-arid regions where they cause alkalinity in soils. A soil with high exchangeable sodium can still remain permeable if the percolating solution with which it is in equilibrium is efficiently

nature of the parent material, climate, OM and topographic situations (Tamirat, 1992).

Soil CEC correlates with soil properties that affect crop productivity, including soil texture, cation exchange capacity (CEC), drainage conditions, OM level, and subsoil characteristics. (Onweremadu., *et al.*, 2011). (Shrivastava *et al.*, 2011) reported that CEC values below unity are low below which it can affect the growth of most agricultural crops. Salt affected soils usually occur in arid and semi-arid regions owing to the high evaporation rate.

Concentrated sodic soils are defined as soil having exchangeable sodium percentage (ESP) of more than 15. The chief characteristic of sodic soil from agricultural standpoint is that they contain sufficient exchangeable sodium to adversely affect the growth of most crop plants. Excess exchangeable Na^+ has an consequent reduction in crop growth, significantly or entirely. Hence, sodium has the effect of dispersion on soil properties.

Potassium (K^+) is an essential nutrient element for plant growth. Because large amounts are adsorbed from the root zone in the production of most agronomic crops, it is classified as a macro-nutrient. However, the exact function of K in plant growth has not been clearly defined. (Uzoho *et al.*, 2007) reported that apart from the dynamics of K in the soil, soil usually evaluated by the quantity/intensity (Q/I) ratio of K, the ability of any soil to maintain a reasonable productive K potential under intensive use with minimum external input of organic and inorganic fertilizers depends on the inherent K status of the soil. (White *et al.*, 2006). Available K and K saturation index, defined as the ratio of exchangeable K \ to cation exchange capacity(CEC %) have been widely used for rapid assessment of the soil K status and prediction of crop K requirements (Samadi, 2006).

However, recent research works. (White *et al.*, 2002) showed that exchangeable K. alone couldn't be used as the basis for evaluating K availability under intensive

cropping because there are evidences of K uptake from non-exchangeable form. Exchangeable cations refer to the positively charged ions, which are loosely attached to the edge of clay particles or OM in the soil. The cations that are commonly found in association with the soil exchange site include calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), hydrogen (H) and aluminum (Al). In general, soils; under continuous cultivation, application of inorganic N containing fertilizers, high exchangeable and extractable Al and low pH are characterized by low contents of basic exchangeable cations (Ca, Mg, Na and K) containing minerals and Ca, Mg and K deficiencies due to excessive leaching and low percent base saturation. (Ahukaemere *et al.*,2012). However, soils of virgin and/or grazing lands and areas under long year of fallow practices and Vertisols (Tamirat, 1992) retain more basic cations, which are mainly dominated by exchangeable Ca and Mg.

Exchangeable hydrogen (H) together with exchangeable aluminum (Al^{3+}) are known as soil exchangeable acidity. Soil acidity occurs when acidic H^+ ion occurs in the soil solution to a greater extent and when an acid soluble Al^{3+} reacts with water (hydrolysis) and results in the release of H^+ and hydroxyl Al ions into the soil solution (Uzoho *et al.*;2005), (Brady and Weil, 2008). As soils become strongly acidic, they may accumulate sufficient Al in the root zone and the amount of exchangeable basic cations decrease, solubility and availability of some toxic plant nutrients increase and the activities of many soil microorganisms are reduced, resulting in accumulation of OM, reduced mineralization and lower availability of some macronutrients: like N, S and P and limitation of growth of most crop plants. Cation exchange capacity (CEC) is the ability of the soil solid phase to attract or store and exchange cationic nutrients with the soil solution and render them available to plants through exchange reactions (Muller-Samann and Kotschi, 1994) or is the sum of the negative charges that a soil or other material can absorb cations

at a specific pH (Foth and Ellis, 1997). Cation exchange capacity is the dominant factor in measuring soil fertility which affects exchange of ions on the clay surface (Taye and Yifru, 2010). The non-acid cations (Ca^{2+} , Mg^{2+} , K^{+} and Na^{+}) have been referred to as base cations and their proportion on the CEC is called the percent base saturation (%BS). According to (Brady and Weil 2008), CEC depends on the nature and number of colloidal particles. (Tamirat, 1992) reported that in mineral soils, the clay fraction is largely responsible for cation exchange properties. The possible reason for the highest concentration of the sum of exchangeable bases at the lower elevation soils could be leaching, drainage and run off from the adjacent mountains. (Ihem *et al.*, 2014). (Belay *et al.*, 2003). from their study at the Delbo Wegene Watershed reported that exchangeable cations content of the soils increased with increasing soil depth. The increment was attributed to the leaching of exchangeable cations. The authors also reported that CEC of the soils were generally higher in the surface than in subsurface horizons which could be due to the strong association between organic carbon and CEC.

2.6.3 Percentage base saturation (%BS)

This is a measure of the extent to which the exchange complex is saturated with exchangeable bases (Ca, K, Mg and Na) other than H^{+} and Al^{3+} ions. It is expressed as a percentage of the total CEC. %BS is the proportion of basic cations to the total cations on the exchange complex expressed in percentage. Soils having low %BS show acidic reaction. Sodium (Na^{+}) saturated soils however, have much higher pH values than calcium (Ca^{2+}) and magnesium (Mg^{2+}) saturated soils. Soils of the humid tropics are low in base saturation and tend to be acidic.

2.6.4 Total Nitrogen (TN)

Nitrogen is one of the most important nutrient elements that the plants need. It encourages vegetation growth and gives the leaves a healthy greenish colour. On the other hand, plants which are deficient in N are stunted in growth with yellowish leaves and with a poorly developed root system. Soil nitrogen is a primary nutrient element in soil and varies with depth (Uzoho *et al.*, 2007). High variations in N concentration were recorded at less than one-meter depth while (Ugolini *et al.*, 2017); (Dodd *et al.* (2000) reported significant variation in soil N at depths greater than one meter. Globally, soil contains about 90% of the N in terrestrial biosphere. It is estimated that about 78% of N is contained in atmospheric air. Yet, none is available directly to plants. Plants thus, only absorb soil nitrogen in the form of nitrate (NO_3^-) or ammonium (NH_4^+) ions. Dissolved soil N plays a central role in terrestrial ecology and biogeochemistry as it is an important intermediate in decomposition (Chapin *et al.*, 2002) thereby, influencing pedogenesis. It thus continues to receive a great deal of attention. It took a great deal of research and many publications to delineate the processes of N_2 fixation and N_2 immobilization, mineralization, plant uptake and denitrification (Paul, 2007)., (Graham 2000) have reviewed nitrification, whereas N losses, especially those leading to pollution and global warming have been covered in, (Robertson., 2000) and (Groffman., 2000).

2.6.5 Available Phosphorus

Phosphorus occupies a critical position both in plant growth and in the biology of the soil. It is the second only to nitrogen in terms of the quantity of mineral utilized by plants. Phosphorus occurs in organic and inorganic forms with the organic P constituting more than 80% of the total soil phosphorus (Brady and Weil, 2002). Although. Phosphorus is widely distributed in nature systems like soil and water, P will exist as phosphate (PO_4^{3-}), a chemical form in which each P atom is

surrounded by 5 oxygen atoms. Generally, Phosphate is taken up by plant from soil, utilized by animals that consume plant and return to soil, as organic residues decay in soil; hence, P-cycle (Brady and Weil, 2008). Most tropical soils are inherently low in P due to nutrient mining, among other factors; therefore, there is need for P application. (Sanchez, 2004). In Nigeria, super phosphate is commonly used as P source. (Babalola *et al.*, 2011)

2.6.6 Soil Organic Carbon/Soil Organic Matter: The term "organic" is used to describe materials derived from living organism. All organic substance by definition, contain carbon. Soil organic carbon (SOC) is the carbon associated with soil matter. Organic carbon enters the soil through decomposition of plant and animal residues, root exudates, living and dead organism, and soil biota. The term soil organic matter (SOM) on the other hand, refers to materials derived from plant and animal residues; especially when they are still at various stages of decomposition. A factor of 1.724 commonly referred to as Van Bammelen's factor is used in converting % organic Carbon to organic matter. SOM is a very important component of the soil. The soil receives flushes of organic matter when leaved fall.

Inputs of litter from trees and shrubs and green manure have been noted to increase the size and activity of soil microbial community. (Kantz. *et al.*, 2004 Martinez *et.al.*, 1996., Manici *et al.*, 2004). The beneficial effects of organic materials have been studied by many workers. (Akanbi., 2000). Several studies carried out indicate positive effects of organic matter on soil productivity (Anikwe, 2000). Soil organic matter plays a major role in maintaining (the fertility of the soil by increasing water holding capacity, reducing surface crusting, increasing CEC of soils, thus indicating greater nutrient retention capacity of soil. However, it is important to note that organic wastes differ in their ability to provide nutrient and

enhance soil qualities due to differences in their rates of decomposition. (Mbah et al 2007). In general, organic matter is responsible for most desirable surface soil structure, promotes a greater portion of larger pore sizes, improves water and air relations and reduces erosion by wind and water. It is a source of carbon and energy to soil organisms. Hence, (Babalola., 2000) reported that almost all the life in the soil is dependent on organic matter.

2.7 Characterization and Classification of Soils

Soil classification is the systematic arrangement of soils into groups or categories on the basis of their characteristics. (Brady and Weil 2008). Each soil based on its characteristics has a predictable response to management or any form of manipulation. Soil classification is the grouping of soil into classes (WRB, 2014) and its major purpose is to facilitate the transfer of information about the use and management of soil related technologies from one location to another. It involves the determination of morphological, chemical and mineralogical properties of importance to agriculture and fitting of such soils into widely accepted soil classification systems.

Soil classification is a controversial subject at both national and international levels. According to Akamigbo.(2010), the main purposes of a soil classification is to arrange the ideas of the object in such order that gives us the greatest possible command of our knowledge and leads most directly to the acquisition of more. Other reasons for soil classification are, to foster global communication about soils to simplify processing of soil data, to create a universal language of soils and determine the best possible use and management of the soil. In soil classification, the item to be classified is the soil profile. Thus, soils are classified as natural bodies on the basis of their profile characteristics (Brady and Weil, 2002).

Amusan and Ashaye, (1991) on their study on characterization and classification of soils along the Toposequence in Ajata-Ibeku, Abia State Southeastern Nigeria revealed that percentage sand was high in all the profiles with clay particles increasing with depths. The soils were classified as Typic Hapludult (USDA) or Haplic Acrisol (FAO/UNESCO legend) at the crest, Vertic Rpiaquepl. Vertic Hapludults and Aerie Fpiaquept (USDA) or Gleyic Cambisol, Haplic Acrisol and Gleyic Cambisol (FAO/UNESCO legend) at the middle slope and Vertic Epiaquept (USDA) or Gleyic Cambisol (FAO/UNESCO legend) at the valley bottom. Atoferati *et. al.*, (2012) on their study on wetland of Southeastern Nigeria: Extent and Characteristics revealed that soils were predominantly Typic Dysiropepts. Typic Topopsammens, Imbric kanhaplaquults, and Tropofutrvaquents which dominated the ends. (Tripathi *et al.*, 2009) characterized and classified the soils of Kiar-Nagg H micro Watershed Himalayas as neutral to slightly alkaline (pH 7.2-7.6), mixed in mineralogy, hallow to very deep and have thermatic temperature and udic moisture regime, texture, organic carbon, CEC, base saturation ranged from silt loam to loam, 4.5 to 23.5 g/kg, 9.8 to 14.8 Cmol/kg and 56.6 to 74.8%, respectively. Evidence of clay illuviation in sub-soils were observed in majority of the soils. Soils were classified as Typic Udorthents, Dystric Etitrudepts and Typic Dystrudepts.

(Soil Survey Staff., 2005) characterized the forest soils of Karnataka for their morphological, physical and chemical properties. The texture and colour (hue) of soils varied from sandy loam to clay and 2.5YR to 10YR respectively associated with predominantly sub-angular blocky structure. The soils had high amounts of coarse fragments and sand tractions. The soils were acidic (pH 5.1-5.9), rich in organic carbon and associated with low cation exchange capacity. Based on the characteristics, these forest soils were classified as Dystric Haplustepts, Kanhaplic HaplustalFs, Ustic Haplohumults. (Udoh and Akpan., 2015) on then study

characterization and classification of soils in steep sided hills and sharp-crested ridges in Akwa Ibom State, Nigeria, classified the poorly drained area as Typic Epiaquept (USDA) or Cambisola (FAO/WRB) because of the presence of Ochric epipedon over Gamble B-horizon, minimal soil development and shallow depth. Pedons have ground water at or near the surface at some time during the normal year. While the soils of the well-drained area were classified as Typic Hapludult (USDA) or Haplic Acrisol (FAO/WRB) because of the presence of Ochric A-horizons and argillic B-horizon with low base saturation.

2.7.1 Systems of Soil Classification

Classification systems are essential for us to be able to study and communicate information about soils. While classification systems for plants and other organisms are quite old, a comprehensive soil classification system was only recently developed. The system is much like giving names to people that reflects their heritage or which describe them in a way that makes them different from everyone else. Scientists have developed different systems of soil classification to group soils of similar properties in one class, allowing them to exchange information in soils found in different areas. A number of soil classification systems are in use in different parts of the world. These include the following:

1. A Refined Russian system (with heavy emphasis on factor of soil formation)
2. French classification system (sometimes called Aubert system)
3. Canadian system of soil classification.
4. British system of classification
5. Australian classification system
6. Ghana system of classification
7. China system of classification

8. CCTA (The commission for Technical cooperation in Africa's system)
9. Food and Agricultural organization (FAO) and the United Nations Education, Science, and Cultural Organization (UNESCO), usually called FAO/UNESCO classification system.
10. USDA (United States Department of Agriculture) classification system also known as USDA soil taxonomy.

Although many soil classification systems exist; two systems are widely used: The USDA Soil Taxonomy and the FAO/UNESCO Legend (Esu, 1999). Whereas the FAO/UNESCO system is popular and has resulted to the world Reference Base (WRB) for soil resources as adopted in 1998 by the International Union of Soil Science (IUSS) as the unions system for soil correlation, the USDA classification system (U.S soil taxonomy), is the most popular and basic system for making and interpreting soil surveys. According to FAO/IUSS (2006), the world reference base for soil resources (WRB) has 32 soil groups, some of which occur in west and central Africa.

2.7.1.1 Soil Taxonomy (USDA Soil classification system)

The USDA soil taxonomy also known as U.S. comprehensive soil classification system started in 1951 in a quest to produce a better system that would satisfy the loopholes and weaknesses associated with the previous systems of soil classification used in the United State of America such as the 1938 classification system. An improved conceptual frame of reference also was needed so that research data could be more readily communicated, tested and applied between soils of one area and another where conditions of soil formation or genesis were similar (Onwerermadu et al., 2016). Following a number of approximations, the U.S comprehensive soil classification system was published in 1960. After many revisions and series of amendments to improve the system, a final copy of

classification system was published in 1975 by soil survey staff as "soil Taxonomy". A basic system of soil classification for making and interpreting soil surveys. However, since classification is not static, several amendments and Supplements followed this "comprehensive" publication and another publication was made in 1999. Thus, the latest edition, the eleventh edition of keys to soil taxonomy (2010), incorporates all changes approved since the publication of the second edition in 1991 (Akamigbo, 2010). The soil taxonomy provides hierarchical grouping of soil bodies with major emphasis on soil morphology and less emphasis on soil genesis or soil forming factors (Brady and wail, 2002). Two major features make soil taxonomy unique. Firstly, the system is based on soil properties that can be objectively observed or measured and secondly, the nomenclature employed; which gives a definite connotation of the major characteristics of the soils examined.

Moreover, soil taxonomy is international since it does not base on any one national language. (Esu., 2010) noted that one of the most ingenious devices of U.S soil taxonomy system is the use of observable, quantitative, diagnostic horizons and features which only reflect our present understanding about soil genesis. In essence, the system studies the morphology and properties of a pedon and the classification classifies ply pedons (Akamigbo, 2010). It uses the nature and properties of deep seated mineral horizons (B horizons) as basic criteria, in preference to the superficial horizons. Soil taxonomy has six categories, the order, suborder, great group, subgroup, family, series and twelve main Order(Soil Survey Staff, 1975).

2.8 Geographic Information System (GIS)

Geographic Information System (GIS) is information system that captures, stores, manipulates, analyzes and displays, geospatial data (Onweremadu., 2006). It is

an information system which supports people in decision making by providing them consistent results. (Borrough., 1986), facilitates the integration of spatially referenced data in a problem-solving environment (Densham, 1991). According to (Onweremadu., 2006), GIS is Computer-Based information system that is used to capture, model, store, retrieve, share, manipulate, analyze and present geographically referenced data.

Geographic Information System can be defined as an art which visualizes the geographic data in the form of maps, hence GIS is mostly associated with maps. Couclelis and Manmonier (1995) defined it as an information system which supports spatial decision-making process, provides geographical information, analyzes capabilities such as graphic overlay- to produce a variety of maps; topological overlay which integrates two or more files to generate site suitability models and other forms of locational analysis, addressing geo-coding to assign automatically a coordinate point or district to an address.

2.8.1 Application of GIS in Soil as a Mapping Tool.

Geographic Information System is widely used for studying Earth's resources at various levels, such as the establishment of procedure in soil environment management in developing countries. GIS-based model enables accurate prediction of nutrient and sediment loads in soil. GIS offers integration of spatial and non-spatial data to understand and analyze the soil-forming processes and helps in drawing a plan for integrated soil development and management. (Sowton., 1991).

Appleton., (2003) observed that with the use of GIS scientists can identify landscape risk and the use the information to help make decisions to implement conservation practices. GIS can be applied in carbon and Nitrogen management, the development of erosion probability maps, soil conservation, managing nitrate

leaching and spatial variability within soil. (Appleton., 2003) used satellite data and GIS to produce Ramsar sites database to map wetland areas, quantify the condition of wetlands along Sri Lanka where changes in population and land use are contributing changes in population and land use are contributing to wetland loss and degradation.

2.8.2 Application of GIS in Soil Suitability.

Geographic Information Systems (GIS) can be applied in crop and soil management (Onweremadu *et al.*, 2012) for suitability evaluation. Inventory and mapping of agricultural land parcel, mapping of soil characteristics, measuring of crop hectare, agricultural evaluation and classification provide avenue for adequate suitability evaluation. Suitability is a function of crop requirements and land characteristics. It is a measure of how well the qualities of land unit match the requirements of a particular form of land use (FAO, 1976).

The process of land suitability classification is the appraisal and groping of specific area of land in terms of their suitability for defined uses (FAO, 2000). GIS has become an effective tool for decision support that provide interactive information support to help complex decision making and problem solving in soil suitability classification (Oliver *et al.*, 1990).

2.8.3 Application of GIS in Crop Production.

Here, great emphasis will be made on the application of GIS in Cucumber, Onion, Cabbage and Watermelon production. (Iqbal *et al.*, 2005) developed soil fertility map and determined crop suitability in Philippines using GIS by overlaying agro climatic map with land suitable maps for farming and soil fertility map. Matching crops biological requirements for growth to the crops applicable in certain part of the province.

The GIS can be used for visualizing farming conditions, as well as measuring and monitoring the effects of farm management including regulatory compliance, permit distribution subsidy tracking and pest management by improving the way producers collect, store and access information related to these activities, GIS enables a more complete command of their business (Onweremadu et al., 2007). GIS can be used in fertilizer application for precision farming of Cucumber and Watermelon, Onion and cabbage. GIS can be used in management and mapping of agricultural biodiversity, monitoring of crop health and growth conditions, estimating crop yield and mapping of crop patterns.

Therefore, it is very essential to make wise assessment of the land suitability evaluation for the southeastern soils for the cultivation of cucumber, watermelon cabbage and onion so that land capacity and crop need would be matched. This helps to prevent land degradation and further generate maximum possible production with minimum input cost. It is further lead towards sound and sustainable cultivation practices.

2.8.4 Component of GIS

A GIS operation seen as a software system similar to other information technologies, the components being the various tools used to manipulate, store, query, analyze and output data. The component of GIS includes: the hardware which include the computer such as PC sand works stations, and operating system such as window, Linux, UNIX, monitor, scanner for digitization of spatial data. Software, the people and infrastructure which refers to the necessary physical organizational, administrative and cultural environment that support GIS operation (Borrough,1986).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area:

The study was conducted at three sites of dissimilar lithological origin. These include: Upper Coal Measure for Umunneochi (Isuochi) in (Abia State) (Nsukka formation), Coastal Plain Sand (Benin formation) for IsiObuzor in Ukwa West L.G.A (Abia State) and Imo Clay Shale for Amauro in (Imo State).

In Abia State, Umunneochi is situated between latitudes ($6^{\circ}00'027''\text{N}$ and $7^{\circ}24.271''\text{E}$) and in Isi Obuzor is between longitudes ($4^{\circ}54'447''\text{N}$ and $7^{\circ}12'810''\text{E}$) with the elevation not greater than 52 meters above sea level. (Orajaka, 1975) while in Imo, samples were collected from Amauro in Okigwe (between lat $5^{\circ}47.091'\text{N}$ and Long. $7^{\circ}17.365'$) with an altitude not exceeding 116m above sea level.

The relief of the areas are characterized by plains and gentle slope to undulating slopes. The major relief structures are termite castle that spread sporadically with the landscape.

As a result of the high acidic nature of these soils, they are low in nutrient status and have poorly developed profiles which predispose them to soil erosion and other forms of soil degradations prevalent in the area which is characterized by high rainfall. The rainy season begins in April and ends in October with a short period of draught, commonly known as "August Break", while dry season starts from November and lasts till March. The rainy season is characterized by low evapotranspiration due to high relative humidity and frequent cloud covers. The area has a typical rainforest with vegetation at Isuochi and densely vegetated rainforest at Amuro while Isiobuzo is dominated by primary forest which intercepts precipitation, thereby reducing rain drop impact on soil. Typical characteristics of the tropical forest are exhibited in Isiobuzor as there are varieties

of trees, sometimes exceeding 170 different species per hectare and it is this great diversity which makes the rainforest the greatest in terms of biomass productivity of all terrestrial ecosystems. The natural vegetation of the Isiobuzor consists mainly of primary forest except where human interference through annual uncontrolled bush burning and small-scale farming method have reduced the original forest to secondary ones, bush re-growth and thicket.

3.2. 1 Geology and Geomorphology

The lithology of Imo State and Abia are similar and composed predominantly of Benin formation, Imo State, Nsukka Formation, Bende, Ogwashi formation and Alluvium, Igali Sandstone (Onweremadu, 2007). The Soils are basically Ultisols formed on 6 lithological materials namely Alluvium, Coastal Plain sands (Benin formation), Lower coal measures (Mamu formation), upper coal measures (Nsukka formation), shale (Bende-Ameke formation) and false bedded sandstone (Orajaka, 1975).

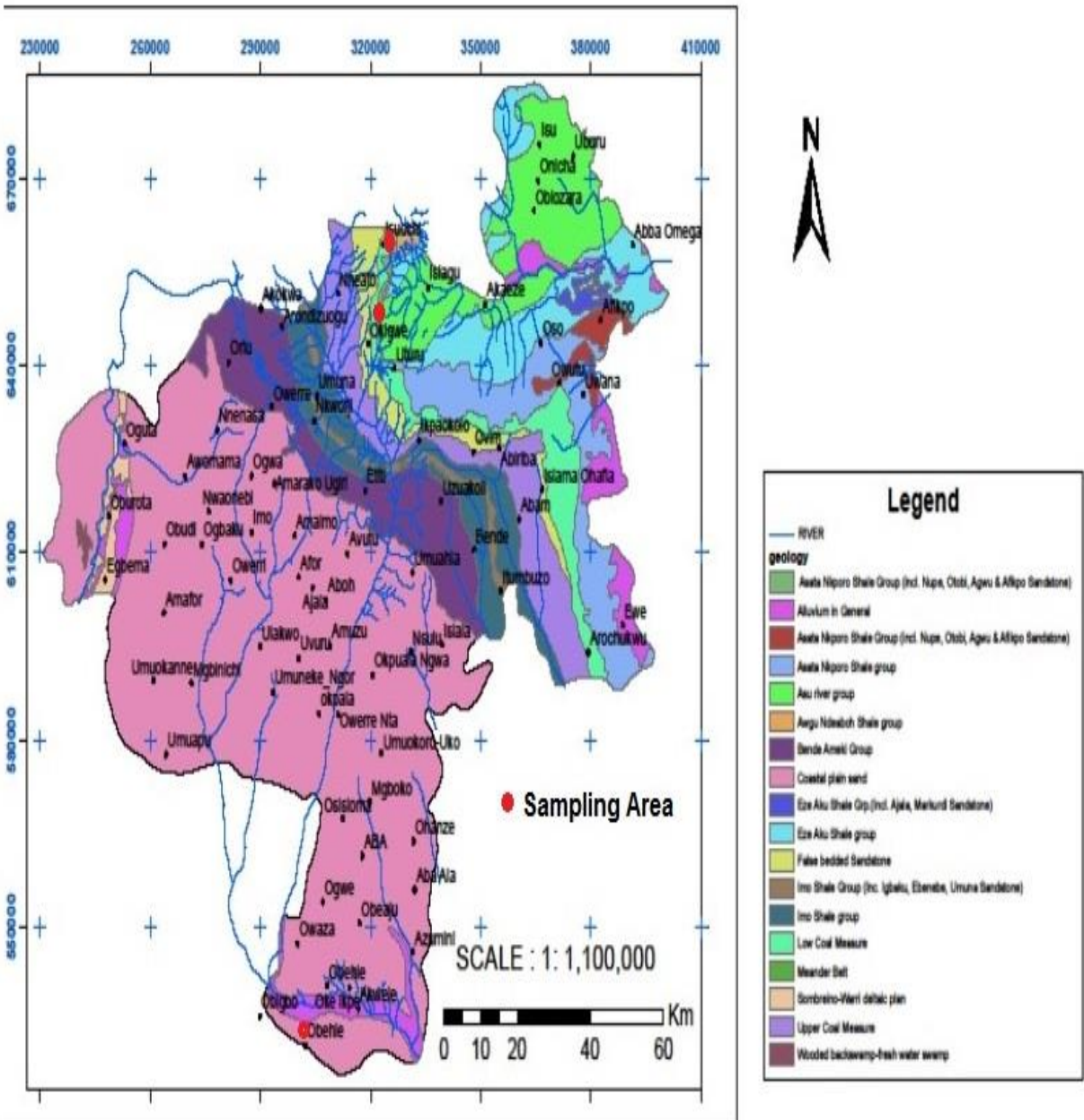


Fig. 3.2: Geology Map of the Study Area

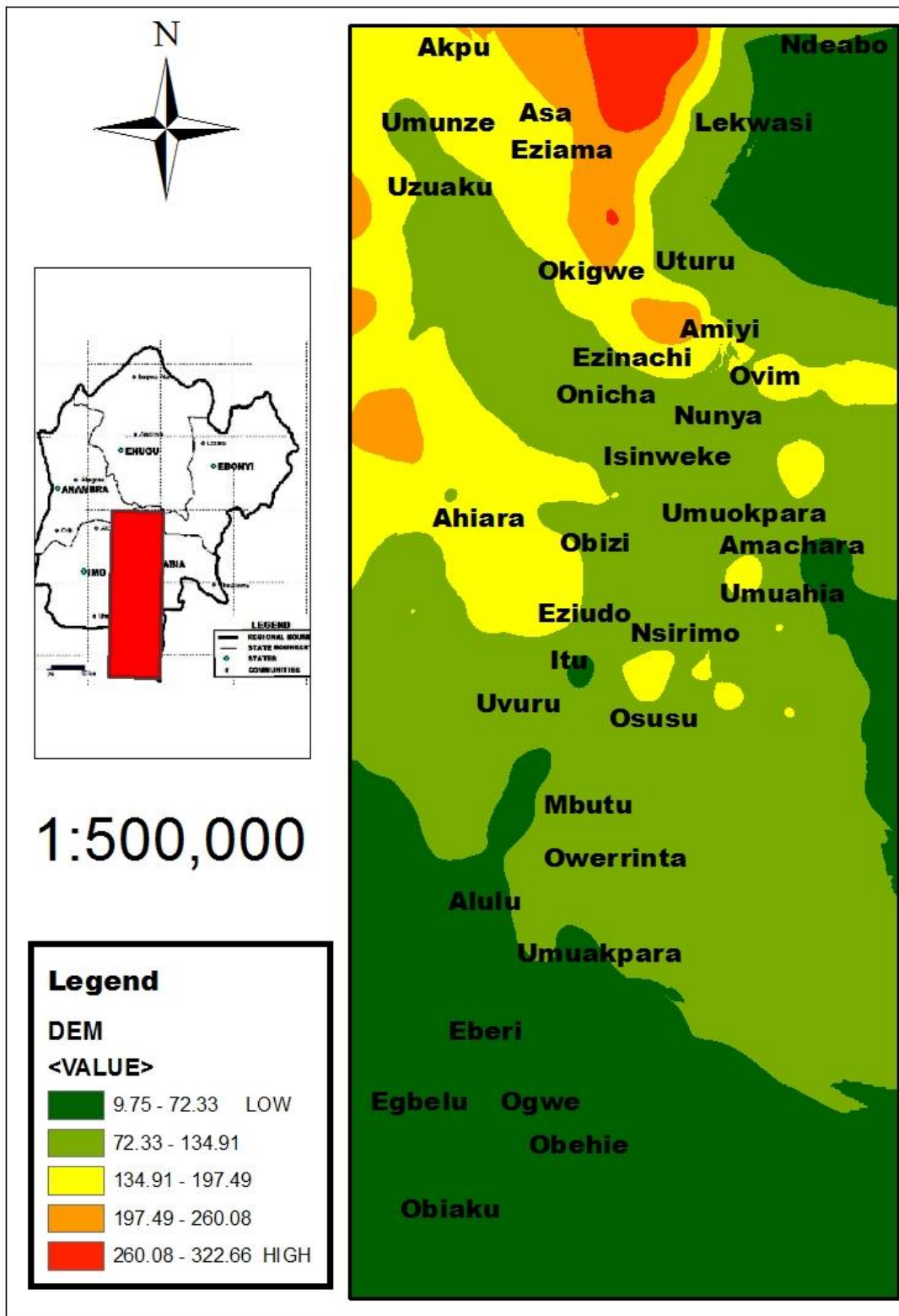


Figure 3.3: Digital Elevation model of the studied areas

Agriculture is the major socio-economic activity in the area. Farming activities in the area involve men and women that engages in the production of cassava (*Manihot Spp*), oil palm (*Elacsis guinensis*), fluted pumpkin (*Telferia occidentalis*), maize (*Zea mays*), at subsistence level. The major cash crops are mango and citrus, while mix-cropping is the commonest cropping pattern this area, maize + cassava and yam + maize + melons. Slash and burn technique is a common land clearing method. Soil fertility regeneration is mainly by bush fallowing and occasional crop rotation practices.

3.2 Field Studies;

Pre-field survey was carried out in the study areas using the existing geological, location and topographical maps.

With the aid of location and geological maps of the study area, reconnaissance visit was done to identify the sampling sites and parent materials from which the soils of the sampling sites were derived. Three (3) different parent materials were selected for the study. Five (5) profile pits were dug in each of the three (3) lithological materials(Upper coal measure for Umunneochi(Isuochi), Coastal plain sand for IsiObuzor in Abia State and Imo clay shale for Amauro in Okigwe Imo State) giving a total of fifteen (15) profile pits. A total of 72 samples were collected from the profile pits. The spatial position of all the profile pits were determined using a hand held Global position system (GPS) receiver. Soil sampling was done based on horizon differentiation (FAO., 2006). The profiles pits were described and samples for routine and special laboratory analysis. Undisturbed soil samples were collected using core samplers for bulk density. Soil samples collected were transported, air-dried and sieved using a 2-mm sieve preparatory for laboratory analyses.

3.3 Laboratory Analysis

Soil samples brought from the field were air-dried, crushed and sieved through a 2mm sieve before used for laboratory analysis. Selected physical and chemical properties of the sampled soils for the application of geographic information system in selected soil mapping for crop production were determined as follows: Particle size distribution was determined by using Bouyoucous Hydrometer method according to the produce of (Gee and Or., 2002), where sodium hexametaphosphate (Calgon) solution was used as a dispersing agent.

Moisture content was determined by Gravimetric method as described by Tara (2005). It was calculated as:

$$\% M_c = \frac{W_2 - W_3}{W_3 - W_1} \times \frac{100}{1}$$

Where % M_c = Percentage Moisture Content

W_1 = Weight of moisture can

W_2 = Weight of air-dried soil plus moisture can

W_3 = Weight of oven-dry soil plus moisture can

Bulk density was determined by the core sampler method according to the procedure of (Grossman & Reinsch., 2002). It was calculated as:

$$\text{Bulk Density} = \frac{\text{Mass of Oven dried soil}}{\text{Volume of core sampler}}$$

It is expressed in g/cm^3 (Brady and Weil, 2010).

Total porosity was calculated from the result of bulk densities and particle density.

$$\text{Total Porosity, } f = \left(1 - \frac{P_b}{P_s}\right) \times \frac{100}{1} \text{ (Brady and Weil, 2002)}$$

Where f = porosity

P_b = Bulk density (g/cm^3)

P_s = Particle density (assumed to be 2.65 g/cm^3)

Soil pH both in 1:2:5 soil to liquid suspension of water and KCL using the glass electrode pH. (Hendershot, *et al.*, 1993).

Organic carbon was done titrimetrically using the Walkley and Black wet oxidation method by (Udom *et al.*, 2015).

The percentage organic matter was calculated by multiplying the percentage organic carbon by 1.724 (Van Bemelen factor) on the assumption that organic matter content contains approximately 58% carbon.

Total nitrogen was determined using the modified micro kjeldhal method according to the procedure of (Bremner & Mulvaney, 1982).

Available phosphorus calorimetrically using Bray and Kurtz No1 method as described by (Udom *et al.*, 2009)

Exchangeable acidity ($Al^{3+} + H^{+}$) was determined by leaching the soil with INKCL and titrate with 0.05N NaOH as described by (Udom, *et al.*, 2009).

Exchangeable bases were determined by using extracting Ammonium Acetate (INN H_4 OAc) pH7 leachate of the soil. Exchangeable calcium and magnesium were determined by the EDTA versenate titration method while exchangeable sodium and potassium were determined by flame photometer method as described by (Udom, *et al.*, 2009).

Effective Cation Exchange Capacity (ECEC) was derived by the summation of the total exchangeable bases and exchangeable acidity as described by (Brady and Weil., 2010).

Percentage Base Saturation was calculated as the sum of exchangeable bases divided by the effective cation exchange capacity and multiplied by 100 (Esu., 2000).

3.4 Characterization and Classification of Soils

Based on the morphological, physical and chemical properties of soils, the soils of the study sites were classified using the USDA (Soil Taxonomy) classification system (Soil Survey Staff., 2010). The result obtained were correlated using the FAO/UNESCO WRB classification system . Land suitability evaluation was carried out using FAO (2006) land suitability evaluation method where the land requirement of each crop was matched with the land and soil characteristics of the study site. Land capability classification was done using the USDA (Soil Survey Staff 2010) land capability classification system.

Table 3.1: Land requirement for Tomatoes

Land quality/soil-site characteristic		Unit	Suitability rating			N 1
			S1	S2	S3	
Climate(C)	Mean temperature In growing season	°C	25 – 28	29 – 32 20-24	33 – 36 15-19	< 15 > 36
	Total rainfall	°C	600 -750	500-600 750-1000	450-500 >1000	
	Rainfall in growing Season	Mm	>150	120-150	90-120	
	Length of growing season	Days	>150	120-150	90-120	
Topograph (t)	Slope	%	1-3	3-5	5-10	> 10
Wetness (w)	Soil drainage	Class	Well drained	Moderate	Imperfect	Po or ls, s
Soil physical Properties (s)	Texture	Class	si,l,cl,scl	Sicl,sic,sc,c(c(ss)	
	Coarse fragments Effective soil depth	vol (%) cm	<15 >75	m/k) 15-35 50-75	>35 25-50	< 25
Fertility (f)	pH	1 - 2.5	6.0-7.0	5.0-5.9;	<5	
	CEC	Coml.(p+)	>15	7.1-8.5	>8.5	
Soil toxicity (n)	CaCO ₃ in root zone	/kg %	Non-calcareous	10-15	<10	
	Salinity (EC Saturation extract)	dS m ⁻¹	Non-saline	Slightly calcareous	Strongly calcareous	
	Sodicity (ESP)	%	Non-sodic	Slightly saline	Strongly saline	
	Alst %			Slightly sodic	Strongly sodic	

SI = Highly suitable,S2 = Moderately suitable,S3 = Marginally suitable, N1= Not suitable.

Source: Modified from NBSS&LUP, 1994

Table 3.2: Land requirement for Cabbage

Land quality/soil-site characteristics		Unit				
		Unit	S1	S2	S3	N1
Climate(C)	Mean temperature In growing season	⁰ C	25 – 28	29 – 32 20-24	33 – 36 15-19	<15 >36
	Total rainfall	Mm	600 -750	500-600 750-1000	450-500 >1000	
	Rainfall in growing Season	Mm	>150	120-150	90-120	
	Length of growing season	Days	>150	120-150	90-120	
Topograph (t)	Slope	%	1-3	3-5	5-10	>10
Wetness (w)	Soil drainage	Class	Well drained	Moderate	Imperfect	Poor
Soil physical Properties (s)	Texture	Class	sl, l, cl, sil	ls,sicl,sic,sc,c(m/ k)	c(ss)	S
	Coarse fragments	Vol (%)	<15	15-35	>35	
	Effective soil depth	Cm	>75	50-75	25-50	<25
Fertility (f)	pH	1-2.5	6.0-7.0	5.0-5.9; 7.6-8.5	<5 >8.5	
	ECEC	Coml.(p+)/	>15	10-15	<10	
	CaCO ₃ in root zone	kg %	Non- calcareous	Slightly calcareous	Strongly calcareous	Strongly saline
Soil toxicity (n)	Salinity (EC Saturation extract	Ds m ⁻¹	Non-saline	Slightly saline	Strongly saline	
	Sodicity (ESP)	%	Non-sodic	Slightly sodic	Strongly sodic	

SI = Highly suitable, S2 = Moderately suitable, S3 = Marginally suitable, N1= Not suitable.

Source: Modified from NBSS&LUP, (1994)

Table 3.3: Land requirement for cucumber and water melon.

Land qualities/characteristics	S1	S2	S3	N1
Rainfall (mm)	1700-2000+	1250-1700	850-1250	< 850
No of dry months	>3	3-4	4-5	>5
Absolute temperature (Oc)	25-30	22-25	15-22	<15
Relative humidity during dev stage (%)	75-85	60-70	60-70	<60 8-16
Topography (t)				
Slop (%)	0-4	4-8	8-16	>16
Wetness (w)	Well drained	Moderately drained not	Poorly drained	Poor drained
Drained	Drained	imperfect	drainable	Aerie
Flooding potentials	F0	F1	F2	F3
Soil physical characteristics				
Texture	CL,SL,CL,SI	SL,LFS,LS	LCS,FS,S,C,CS,C	SIC,SC,L,SCL
Depth (cm)	L	50-75	20-50	<20
Soil fertility (f)	>75			
Base saturation (%)		20-35	<20	<0.4
PH	>35 >1.2 5.5-6.5	0.8-1.2 6.5-5.5	0.4-0.8 4.5-5.5	<4.0>7.5

SI = Highly suitable, S2 = Moderately suitable, S3 = Marginally suitable, N1= Not suitable.

Source: Modified from NBSS&LUP, (1994)

3.5 GIS Data Model

All sites were geo-referenced using hand held Global Positioning System (GPS). Geological map of the area serves as the base map. A base map was scanned into a folder and brought into Arc GIS Arc map environment using Arc GIS 10.2 software. The essence is to make it register with its real world location. In the Arc map, each data layer was digitized using on screen mode with the scanned map as a back drop using the editor tool box. Ordinary kriging was used to estimate or predict each soil variable at unsampled location. For the kriging, sample points containing all the attributes were added to the map interface and kriging was performed on the sample layers to generate the prediction/distribution maps. The basic equation for interpolation by kriging at unsampled location is given by

$$Z(x_o) = \sum_{i=1}^N \lambda Z(x_i)$$

Where Z = value of soil parameter of interest; X_i = sample location; λ = weighting factors associated with each $Z(x_i)$; N = number of the closet neighbouring sampla data points used for the summation and $Z(x_o)$ = estimate of Z at unsampled location X_o (Heuvelink and Webster, 2001).

3.6 Data Analysis

Data were subjected to GIS Data Model. Linear Correlation was used to estimate degree of relationship among soil properties of three different parent materials in mapping tools of selected soils for crop production.

TABLE 3.4: Coordinates of the Study Area

Pit Number	Latitude	Longitude	Elevation(m)
Amuro			
OBA p1	5°47.560 ¹ N	7°17.431 ¹ E	104
ARO p2	5°47.383 ¹ N	7°17.668 ¹ E	94
NDA p3	5°46.795 ¹ N	7°17.642 ¹ E	85
UMA p4	5°47.091 ¹ N	7°17.365 ¹ E	116
OKP p5	5°47.842 ¹ N	7°17.396 ¹ E	108
Isiobuzor			
1PI p1	4°54.279 ¹ N	7°13.337 ¹ E	23
1P2 p2	4°54.447 ¹ N	7°12.810 ¹ E	27
1P3 p3	4°54.349 ¹ N	7°12.396 ¹ E	21
IP4 p4	4°53.642 ¹ N	7°12.454 ¹ E	15
IP5 p5	4°53.825 ¹ N	7°12.329 ¹ E	20
Umunneochi			
IAI p1	5°59.797 ¹ N	7°24.302 ¹ E	48
IA2 p2	5°59.797 ¹ N	7°24.047 ¹ E	41
IA3 p3	6°00.027 ¹ N	7°23.928 ¹ E	32
IA4 p4	6°00.027 ¹ N	7°24.271 ¹ E	52
IA5 p5	5°59.992 ¹ N	7°24.223 ¹ E	43

OBA p1 = Amuro pit 1, ARO p2 = Amuro pit 2, NDA p3 = Amuro pit 3. UMA p4 = Amuro pit 4, OKP p5 = Amuro pit 5; 1PI p1 = Isiobuzor pit 1, 1P2 p2 = Isiobuzor pit 2, 1P3 p3 = Isiobuzor pit 3, 1P4 p4 = Isiobuzor pit 4, 1P5 p5 = Isiobuzor pit 5; IAI p1 = Umunneochi pit 1, IA2 p2 = Umunneochi pit 2, IA3 p3 = Umunneochi pit 3, IA4 p4 = Umunneochi pit 4, IA5 p5 = Umunneochi pit 5.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Morphological properties of the soils

The details of the morphological properties of the soils of Isibuzo, Amuro and Umunneochi were shown in Table 4.1, 4.2 and 4.3 respectively. The basic differences between pedons were in colour, texture, structure and consistency. The soils of Isibuzo were characterized by black to light olive brown (5Y2.5/1 – 2.5Y5/3) topsoil over light yellowish brown to reddish gray (2.5Y6/4 - 2.5Y5/1). The soils are deep and well drained. The structure was single-grained at the top to sub-angular blocky and massive at the sub-horizons. The soils of Amuro were characterized by very dark grayish brown to olive brown (10YR3/2 – 2.5YR4/6) topsoil over light olive brown to gray (2.5Y5/3 - 2.5Y5/1). The soils were not deep and poorly drained. The structure is crumb to sub-angular blocky at the top and angular blocky and massive at the sub-horizons. The soils of Isuochi were characterized by dark brown to light brown (7.5YR3/2 – 7.5YR6/3) topsoil over reddish brown to red (5YR4/3 - 2.5YR4/4). The soils were deep and well drained. The structure was moderately granular to fine sub-angular blocky at the top and sub-angular blocky at the sub-horizons. The results showed that top soils were loose and friable at Isibuzo and Umunneochi while in Amuro, the top soils were firm. Changes in consistency of soils were as a result of differences in parent materials. The soils of Amuro were poorly drained due to increase in clay content, which led to decrease in infiltration rate. Gushing gutters, water stain in the basement and mold showed the poor drainage of Amuro.

The consistence of the soil were very friable in the upper part of the soil horizon at Isibuzo, to friable in the sub-surface horizon, while at Umunneochi the entire soil horizons were friable and, the soils of Amuro were friable at upper part of the soil horizon and very friable in the sub-surface horizons.

The soil structure generally ranged from very weak, fine, angular, moderately medium to sub-angular blocky.

There were commonly many fine, and medium roots in the pedons of the studied soils.

The boundary ranged from clear wavy to clear smooth for Umunneochi, wavy smooth to clear wavy for Amuro, while Isiobuzor was diffused clear to clear smooth and loosed smooth.

TABLE 4.1: Morphological Properties of Amuro

Horizon	Dept.(cm)	Colour (moist)	Structure	Consistence (moist)	Roots abundance	Drainage	Faunal activity	Boundary distinctness
PROFILE PIT 1								
AP	0-17	Dark brown (10YR3/3)	1,m,cr	Fi	Many fine & common	Drained	Minimal	Ws
AB	17-34	Dark yellowish brown (10Y4/4)	1,s,cr	Fi	Common fine & medium	Poorly drained	—	Ws
Bg ₁	34-58	Light olive brown (2.5Y5/4)	1,c,sbk	Vfi	—	“	—	Wg
Bg ₂	58-107	Yellowish brown (7.5YR5/4)	2,c,sbk	Vfi	—	“	—	wg
Bg ₃	107-126	Grey (2.5Y6/1)	2,c,abk	Vfi	—	“	—	—
PROFILE PIT 2								
Ap	0-22	Yellow brown (10 YR 5/4)	l, m, cr	Fi	Many fine & medium	Poorly drained	Minimal	Cw
AB	22-65	Olive Brown (2.5 YR 4/6)	l, s, cr	Fi	Few fine	Poorly drained	Minimal	Cs
Bg ₁	65-96	Light Olive brown (2,5 Y 5/3)	l, c, sbk	Vfi	—	“	—	Gw
Bg ₂	96-133	Olive Yellow (2.5 Y 2/6)	l, c, sbk	Vfi	—	“	—	Gs
Bg ₃	133-170	Light Grey (2.5 Y 6/1)	1, c, abk	Vfi	—	“	—	—
PROFILE PIT 3								
A	0-33	Dark Yellowish (10 YR3/4)	1, m, gr	Fi	Fine and medium	Drained	Minimal	Cw
AB	33-52	Dark Brown (10 YR 3/3)	1, s, gr	Fi	Few	Poorly drained	“	Cw
Bg ₁	52-105	Grey (5 Y 6/1)	1, c, sbk	Vfi	—	“	—	Gs
Bg ₂	105-140	Light Yellowish brown (2.5Y 6/6)	1, c, sbk	Vfi	—	“	—	gs
Bg ₃	140-180	Grey (2.5 Y 6/1)	1, c abk	Vfi	—	“	—	—
PROFILE PIT 4								
AP	0-29	Very dark greyish brown (10YR 3/2)	1, s, gr	Fi	Fine and medium	Drained	Minimal	Gw
AB	29-66	Yellowish Red (5 YR 5/6)	1, c, sbk	Fi	Few	Poorly drained	Minimal	Cw
Bt ₁	66-79	Strong Brown (7.5 YR 4/6)	1, c, abk	Vfi	—	“	—	gs
Bt ₂	79-128	Yellowish Brown (10 YR 5/4)	2, c, abk	Vfi	—	“	—	—
PROFILE PIT 5								
Ap	0-25	Dark Yellow Brown (10 YR 4/4)	1, m, cr	Fi	Fine and medium	Poorly drained	Minimal	Cw
AB	25-48	Dark Brown (10YR 4/3)	1, c, sbk	Fi	Few	“	—	Gw
Bg ₁	48-97	Light Olive Brown (2.5 Y 4/3)	2, c, sbk	Vfi	—	“	—	Gs
Bg ₂	97-136	Olive Grey (2.5 Y 3/6)	2, c, abk	Vfi	—	“	—	Gs
Bg ₃	136-159	Grey (2.5 Y 5/1)	2, s, abk	Vfi	—	“	—	—

Structureless = o, Fine = f, Weak =1, Moderate =2, Strong = 3, vf = Very fine, c = Coarse, m = medium, vc = Very coarse, pl = Platy, pr = Prismatic, col = Columnar, gr = Granular, abk = Angular blocky, sbk = Sub-angular blocky, Few = f, Loose = l, Abbroat = a, Smooth = s, Many = m, Friable = fr, Gradual = g, Irregular = i, Abundant = abt, Very friable = vfr, Clear = c, Broken = b, Very few = vf, Firm = fi, Diffuse = d, Wavy = w, Very firm = vfi, Few = f, Loose = l, Abbroat = a, Smooth = s, Many = m, Friable = fr, Irregular = I, Abundant = abt, Very friable = vfr, Clear = c, Broken = b, Firm = fi, Diffuse = d, Wavy = w, Very firm = vfi, Clay S = Sand, Sil = Silk loam, SiCL = Silty clay loam, LS = Loamy Sand, Si = Silk, SC = Sandy clay, SL = Sandy foam, SCL = Sandy clay loam, C = clay, L = Loam, CL = Clay loam, SiC = Silty clay

TABLE 4.2: Morphological Properties of Isiobuzor

HORIZON	DEPTH (cm)	COLOUR (moist)	STRUCTURE	CONSISTENCE (moist)	ROOTS ABUNDANCE	DRAINAGE	FAUNAL ACTIVITY	BOUNDARY DISTINCTNESS
PROFILE PIT 1								
A	0-10	Very Dark Brown (10 YR 2/2)	O, f, gr	Vfr	Many fine & medium	Excessively drained	Moderate	dc
AB	10-31	Brown (10 YR 3/4)	1, m, sbk	Fi	Common fine & medium	Well drained	Moderate	cs
BA	31-47	Brown (7.5 YR 5/4)	1, m, sbk	Fi	Many fine	”	minimal	cs
Bt ₁	47-160	Yellowish Red (5 YR 5/6)	1, co, sbk	Vfi	Few fine	Drained	—	cs
Bt ₂	106-125	Reddish Yellow (5 YR 6/6)	1, co, sbk	Vfi	Very few fine	“	—	cs
Bt ₃	125-190	Reddish Grey (2.5 YR 5/1)	1, co, sbk	Vfi		“	—	—
PROFILE PIT 2								
A	0-9	Dark Grayish Brown (10 YR 4/2)	O, f, gr	Vfr	Many fine & medium	Excessively drained	Moderate	cw
AB	9-29	Grayish Brown (10YR 5/2)	1, m, gr	Vfr	Common fine	Well drained	—	cs
Bt ₁	29-61	Brownish Yellow (10 YR 6/6)	1, m, sbk	Fr	Few fine	“	minimal	cs
Bt ₂	61-142	Yellowish Brown (10 YR 5/8)	1, co, sbk	Fr	Rare	“	—	—
PROFILE PIT 3								
A	0-20	Very Dark Gray (10 YR 3/1)	O, f, gr	Vfr	Many fine & medium	Well drained	Moderate	cs
AB	20-36	Dark Yellowish Brown (10YR 4/4)	1, m, gr	Fr	Few fine	“	Minimal	cg
Bt ₁	36-107	Yellowish Brown (10 YR 5/6)	1, m, sbk	Fi	Rare	Drained	—	cg
Bt ₂	107-180	Light Yellow (7.5 YR 6/4)	1, co, sbk	Vfi				—
PROFILE PIT 4								
A	0-13	Very Dark Gray (5Y 3/1)	O, f, gr	Vfr	Many fine medium	Well drained	Moderate	dc
AB	13-31	Dark Grayish Brown (2.5 Y 4/2)	1, m, gr	Fr	Common fine			cs
Bg ₁	31-40	Light Olive Brown (2.5 Y 5/4)	1, m, sbk	Fi	Few fine	“	Minimal	cs
Bg ₂	40-80	Olive Brown (2.5 Y 4/4)	1, co, sbk	Fi	Very few fine	Drained	—	cg
Bg ₃	80-118	Light Yellowish Brown (2.5Y6/4)	1, co, sbk	Vfi				—
PROFILE PIT 5								
A	0-16	Black (5Y2.5/1)	1, m, gr	Fr	fine & medium	Well drained	minimal	ds
AB	16-33	Light Olive Brown (2.5 Y 5/3)	1, m, sbk	Fi	Common fine	“	—	cw
Bg ₁	33-49	Light Olive Brown (2.5 Y 5/4)	1, m, sbk	Fi	Few fine	Drained	—	cs
Bg ₂	49-119	Light Yellowish Brown (2.5 Y6/4)	1, Co, Sbk	Vfi	Very few fine	“	—	cs
Bg ₃	119-160	Olive Yellow (2.5Y 6/6)	1, Co, Sbk	Vfi				—

Loose smooth = ls, Structureless = o, Fine = f, Weak =1, Moderate =2, Strong = 3, vf = Very fine, c = Coarse, m = medium, vc = Very coarse, pl = Platy, pr = Prismatic, col = Columnar, gr = Granular, abk = Angular blocky, sbk = Sub-angular blocky, Few = f, Loose = l, Abbroat = a, Smooth = s, Many = m, Friable = fr, Gradual = g, Irregular = i, Abundant = abt, Very friable = vfr, Clear = c, Broken = b, Very few = vf, Firm = fi, Diffuse = d, Wavy = w, Very firm = vfi, Few = f, Loose = l, Abbroat = a, Smooth = s, Many = m, Friable = fr, Irregular = I, Abundant = abt, Very friable = vfr, Clear = c, Broken = b, Firm = fi, Diffuse = d, Wavy = w, Very firm = vfi, Clay S = Sand, Sil = Silk loam, SiCL = Silty clay loam, LS = Loamy Sand, Si = Silk, SC = Sandy clay, SL = Sandy foam, SCL = Sandy clay loam, C = clay, L = Loam, CL = Clay loam, SiC = Silty clay

TABLE 4.3: Morphological Properties of Umunneochi

HORIZON	DEPTH (cm)	COLOUR (moist)	Structure	Consistence (moist)	Roots abundance	Drainage	faunal Activity	Boundary Distinctness
PROFILE PIT 1								
A	0-11	Brown (10 YR 4/3)	1, f gr	Fr	Many fine & medium	Excessive drained	minimal	Clear, wavy
AB	11-26	Light brown 7.5 YR 6/3	1, m gr	Fr	Common fine & medium	Well drained	"	Clear, smooth
Bt ₁	26-58	Reddish brown 5 YB 4/3	1, Co-sbk	Fr	Few fine	Well drained	"	Gradual, smooth
Bt ₂	58-130	Red 2-5 YR 4/6	1, Co-sbk	Fr	Very few fine	Well drained	"	Gradual, smooth
Bt ₃	130-198	Red 2-5 YR 5/6	1, Co-sbk	Fr	—	Well drained	"	Gradual, smooth
PROFILE PIT 2								
A	0-18	Dark brown (7.5 YR 3/2)	1, f, gr	Fr	Many fine & medium	Well drained	minimal	Clear, wavy
AB	18-29	Brown (7.5 YR 4/2)	1, f, sbk	Fr	Common fine	Well drained	minimal	Clear, wavy
Bt ₁	29-77	Reddish brown (5 YR 4/3)	1, c, sbk	Fr	Few fine	Well drained	"	Clear, smooth
Bt ₂	77-130	Red (2.5 YR 4/3)	1, c, sbk	Fr	Rare	Well drained	"	Gradual, smooth
Bt ₃	130-180	Red (2.5 YR 4/4)	1, c, sbk	Fr	—	—	"	—
PROFILE PIT 3								
Ap	0-21	Dark brown (10 YR 3/3)	1, f, gr	Fr	Abundant fin & medium	Excessive drained	prominent	Clear, wavy
AB	21-48	Brown (10 YR 4/3)	1, f, sbk	Fr	Many fine	Well drained	minimal	Clear, smooth
Bt ₁	48-96	Reddish brown (5 YR 4/3)	1, c, sbk	Fr	Rare	Well drained	"	Gradual, smooth
Bt ₂	96-160	Red (2.5 YR 4/3)	1, c, sbk	Fr	—	Well drained	"	—
PROFILE PIT 4								
A	0-10	Dark brown (7.5 YR 3/2)	1, f, gr	Fr	Abundant fine & medium	Excessive drained	"	Clear, wavy
AB	10-33	Dark brown (7.5 YR 3/3)	2, f, sbk	Fr	Common fine & medium	Well drained	"	Clear, wavy
Bt ₁	33-66	Brown (7.5 YR 4/2)	2, c, sbk	Fr	Few fine	Well drained	"	Gradual, smooth
Bt ₂	66-110	Reddish brown (5 YR 4/3)	1, c, sbk	Fr	Very few fine	Well drained	"	Gradual, smooth
Bt ₃	110-200	Red (2.5 YR 4/4)	1, c, sbk	Fr	Rare	Excessive drained	"	—
PROFILE PIT 5								
A	0-5	Dark brown (7.5 YR 3/2)	1, f, gr	Fr	Many fine & medium	Well drained	"	Clear, wavy
AB	5-35	Brown (7.5 YR 4/2)	2, f, sbk	Fr	Common fine	Well drained	"	Clear, wavy
Bt ₁	35-72	Reddish brown (5 YR 4/2)	1, c, sbk	Fr	Few fine	Well drained	"	Clear, smooth
Bt ₂	72 -120	Red (2.5 YR 5/5)	1, c, sbk	Fr	—	Well drained	"	Gradual, mooth
Bt ₃	120 -205	Red (2.5 YR 4/5)	1, c, sbk	Fr	—	Well drained	"	—

Loose smooth = ls, Structureless = o, Fine = f, Weak =1, Moderate =2, Strong = 3, vf = Very fine, c = Coarse, m = medium, vc = Very coarse, pl = Platy, pr = Prismatic, col = Columnar, gr = Granular, abk = Angular blocky, sbk = Sub-angular blocky, Few = f, Loose = l, Abbroat = a, Smooth = s, Many = m, Friable = fr, Gradual = g, Irregular = i, Abundant = abt, Very friable = vfr, Clear = c, Broken = b, Very few = vf, Firm = fi, Diffuse = d, Wavy = w, Very firm = vfi, Few = f, Loose = l, Abbroat = a, Smooth = s, Many = m, Friable = fr, Irregular = I, Abundant = abt, Very friable = vfr, Clear = c, Broken = b, Firm = fi, Diffuse = d, Wavy = w, Very firm = vfi, Clay S = Sand, Sil = Silk loam, SiCL = Silty clay loam, LS = Loamy Sand, Si = Silk, SC = Sandy clay, SL = Sandy foam, SCL = Sandy clay loam, C = clay, L = Loam, CL = Clay loam, SiC = Silty clay

4.2 PHYSICAL PROPERTIES OF THE SOILS

4.2.1 Bulk density and Total Porosity

In Isiobuzor, the mean bulk density and mean total porosity ranged from 1.26 – 1.36 g/cm³ and 48.75 – 52.45%, and in Amuro, they ranged between 1.40 – 1.48g/cm³ and 44.08 – 47.09% while in Umunneochi, they ranged from 1.40 – 1.43 g/cm³ and 46.06 – 47.20%, respectively.

In all the profiles, bulk density increased with increased profile depth, while total porosity was in inverse direction. The results also showed that increase in bulk density and total porosity of the area was low. The low variations may be as a result of the land use pattern of the areas. There was a higher bulk density in Amuro than Isiobuzor and Umunneochi (Isuochi) this was as a result of the parent material of the area. All the profiles pits had a direct relation to the clay content, soil pH, but inversely proportional to the total nitrogen, organic carbon, percentage moisture content and percentage base saturation (Onweremadu ., Akamigbo., and Igwe., 2007) . From all the lithologies, the soils of Isiobuzor had the higher total porosity, which signifies that the soil of Isiobuzor had the lowest bulk density, which favours infiltration rate, microbial activities and root abundance.

4.2.2 Percentage Moisture Content

In Isiobuzor, the mean percentage moisture content ranged from 1.40 -1.80% and in Amuro, it ranged from 152.86 – 159.90% while in Umunneochi, it ranged between 21.48 – 23.58%. There was increase in moisture content in Amuro compared to that of Umunneochi and Isiobuzor, and this may be as a result of the clay deposits and parent material. The results showed that moisture content decreased with soil depth in all the parent materials. The results also showed that increased moisture content in all the profiles increases the level of organic matter, root abundance, microbial activities and nutrients. These results agree with the findings of many researchers who concluded that soil moisture is a regulator of physical, chemical and biological processes in the soil (Gupta, 2002). The results showed that the coefficient of variation (CV) of all the soil under different parent materials was moderately varied. This variation suggested that moisture content strongly influenced every aspect of soil development and behavior, ranging from the weathering of minerals to the decomposition of organic matter (Brady and Weil, 2008).

Table 4.4: Soil physical properties of Amuro

Horizon	Depth (cm)	Sand gkg ⁻¹	Silt g kg ⁻¹	Clay gkg ⁻¹	Textural Class	BD gcm ⁻³	TP (%)	MC(gkg)
Ap	0 -17	600.70	122.20	277.10	SCL	1.36	48.68	171.50
AB	17-34	590.70	122.20	287.10	SCL	1.37	48.3	138.10
Bg ₁	34-58	570.70	122.20	307.10	SCL	1.39	47.55	135.70
Bg ₂	58-107	570.70	122.20	307.10	SCL	1.44	45.66	122.90
Bg ₃	107-126	550.70	122.20	307.10	SCL	1.65	37.74	120.20
	Mean	576.70	122.20	297.10	SCL	1.442	45.586	137.68
Ap	0-22	630.70	102.20	267.10	SCL	1.31	50.57	201.50
AB	22-65	620.70	92.20	287.10	SCL	1.34	49.43	182.10
Bg ₁	65-96	590.70	112.20	297.10	SCL	1.37	48.3	142.90
Bg ₂	96-133	580.70	102.20	317.10	SCL	1.42	46.42	139.30
Bg ₃	133-170	580.70	122.20	297.10	SCL	1.57	40.75	133.70
	Mean	600.70	106.20	293.10	SCL	1.402	47.094	159.90
A	0-33	650.70	82.20	267.10	SCL	1.34	49.43	198.30
AB	33-52	630.70	112.20	257.10	SCL	1.39	47.55	172.50
Bg ₁	52-105	600.70	122.20	277.10	SCL	1.44	45.66	135.50
Bg ₂	105-40	600.70	122.20	277.10	SCL	1.52	42.64	130.60
Bg ₃	140-180	590.70	122.20	287.10	SCL	1.61	39.25	124.20
	Mean	614.70	112.20	273.10		1.46	44.906	152.22
Ap	0-21	630.70	102.20	267.10	SCL	1.34	49.43	187.0
AB	29-66	620.70	112.20	267.10	SCL	1.37	48.3	142.30
Bt ₁	66-79	600.70	112.20	287.10	SCL	1.44	45.66	134.80
Bt ₂	79-128	570.70	122.20	307.10	SCL	1.59	40	129.10
	Mean	605.70	112.20	282.10		1.435	45.8475	148.30
Ap	0-25	640.70	92.20	267.10	SCL	1.36	48.68	208.50
AB	25-48	620.70	112.20	267.10	SCL	1.39	47.55	172.70
Bg ₁	48-97	600.70	122.20	277.10	SCL	1.44	45.66	140.30
Bg ₂	97-136	590.70	122.20	287.10	SCL	1.61	39.25	125.60
Bg ₃	136-159	580.70	132.20	287.10	SCL	1.61	39.25	117.20
	Mean	606.70	116.20	277.10		1.48	44.08	152.86
	CV	4.20	5.80	10.90		7.30	8.80	18.80

CV = coefficient of variation, cv < 15 = low, 15 – 35 – moderate, > 35 = high variation

Table 4.5: Soil physical properties of Isiobuzor

Horizon	Depth	Sand g/kg ⁻¹	Silt g/kg ⁻¹	Clay g/kg ⁻¹	Textural Class	BD gcm ⁻³	TP (%)	MC(g/kg)
A	0-10	900.00	20.00	80.00	LS	1.55	41.49	1.50
AB	10 – 31	870.00	20.00	110.00	LS	1.27	52.08	1.70
BA	31-47	850.00	20.00	120.00	LS	1.29	51.32	1.40
Bt ₁	47-106	830.00	20.00	150.00	LS	1.32	50.19	1.30
Bt ₂	106-125	820.00	20.00	160.00	LS	1.34	49.43	1.30
Bt ₃	125-190	854.00	20.00	124.00	LS	1.37	48.30	1.30
	Mean	850.00	20.00	100.00	LS	1.36	48.80	1.40
A	0-9	820.00	20.00	160.00	LS	1.21	54.34	2.10
AB	9 – 29	800.00	20.00	180.00	LS	1.22	53.96	1.90
Bt ₁	29-61	780.00	20.00	200.00	LS	1.27	52.08	1.80
Bt ₂	61-142	840.00	60.00	100.00	LS	1.34	49.43	1.40
	Mean	818.00	28.00	148.00	LS	1.26	52.45	1.80
A	0-20	870.00	20.00	110.00	LS	1.23	53.58	1.80
AB	20-36	830.00	20.00	150.00	LS	1.27	52.08	1.60
Bt ₁	36-107	780.00	10.00	210.00	LS	1.29	51.32	1.60
Bt ₂	107-180	850.00	20.00	130.00	LS	1.35	49.06	1.50
	Mean	832.50	17.50	150.00		1.29	51.51	1.60
A	0-13	880.00	20.00	100.00	LS	1.22	53.96	2.00
AB	13-31	860.00	10.00	130.00	LS	1.29	51.32	1.90
Bg ₁	31-40	860.00	10.00	130.00	LS	1.33	49.81	1.70
Bg ₂	40-80	870.00	10.00	120.00	LS	1.37	48.3	1.30
Bg ₃	80-118	900.00	10.00	90.00	LS	1.42	46.42	1.30
	Mean	874.00	12.00	114.00		1.33	49.96	1.60
A	0-16	840.00	20.00	130.00	LS	1.29	51.32	1.70
AB	16-33	830.00	20.00	150.00	LS	1.34	49.43	1.50
Bg ₁	33-49	810.00	30.00	160.00	LS	1.35	49.06	1.40
Bg ₂	49-119	870.00	20.00	110.00	LS	1.37	48.3	1.40
Bg ₃	119-160	890.00	10.00	100.00	LS	1.44	45.66	1.20
	Mean	848.00	20.00	130.00		1.36	48.75	1.40
	CV	4.00	51.00	25.70		5.9	5.9	16.6

CV = coefficient of variation, cv< 15 = low, 15 – 35 – moderate, > 35 = high variation

Table 4.6: Soil Physical properties of Umunneochi

Horizon	Depth	Sand gkg ⁻¹	Silt gkg ⁻¹	Clay g/kg	Textural Class	BD Gcm	TP (%)	MC(gkg)
A	0-11	901.84	49.04	49.12	S	1.32	49.80	17.10
AB	11-26	957.84	21.04	21.04	LS	1.35	49.00	19.50
Bt ₁	26-58	922.90	40.18	36.82	LS	1.41	46.70	20.10
Bt ₂	58-130	982.84	40.12	37.04	SL	1.50	43.30	26.10
Bt ₃	130-198	964.84	17.12	18.04	SL	1.52	41.50	26.80
Mean		866.84	66.12	67.04	LS	1.42	46.06	21.92
A	0-18	769.04	38.94	38.20	LS	1.26	52.40	18.80
AB	18-29	873.90	64.18	61.82	SL	1.36	51.30	22.40
Bt ₁	29-79	873.84	63.12	63.04	SL	1.45	45.20	26.90
Bt ₂	79-130	936.84	33.12	30.04	SL	1.50	43.30	28.30
Bt ₃	130-180	880.87	56.35	62.79	LS	1.56	41.10	19.20
Mean		891.40	54.20	54.42		1.43	46.66	23.12
A	0-21	922.90	39.18	37.82	LS	1.27	52.00	18.70
AB	21-48	880.90	55.18	63.82	SL	1.37	48.30	25.80
Bt ₁	48-98	894.84	53.12	52.04	SCL	1.48	44.10	29.40
Bt ₂	98-160	971.90	12.18	15.82	SL	1.51	43.00	20.40
Mean		917.64	39.92	42.38		1.41	46.85	23.58
A	0-10	943.84	26.14	27.04	LS	1.23	53.50	18.60
AB	10 – 33	818.03	88.31	93.65	SL	1.33	49.80	19.30
Bt ₁	33-66	817.74	15.28	89.23	SL	1.39	47.50	19.70
Bt ₂	66-110	860.03	75.31	64.67	LS	1.45	45.20	18.80
Bt ₃	110-200	811.03	91.31	97.67	S	1.56	41.10	15.20
Mean		850.13	59.27	74.45		1.39	47.42	18.32
A	0-5	817.84	89.12	93.04	SL	1.21	54.30	20.10
AB	5 -35	845.84	82.12	72.04	SL	1.31	50.50	25.90
Bt ₁	35-72	887.93	60.21	51.85	SL	1.39	47.50	26.80
Bt ₂	72-120	824.93	86.85	86.85	LS	1.48	44.10	20.00
Bt ₃	120-205	894.93	56.21	48.85	S	1.60	39.60	14.60
Mean		854.29	74.90	70.53		1.40	47.20	21.48
CV		8.3		57.4		7.80	7.80	19.70

CV = coefficient of variation, cv< 15 = low, 15 – 35 – moderate, > 35 = high variation

4.2.3 Soil Texture

The result of Isiobuzor showed that the mean soil texture of all the profiles was loamy sand and Amuro, sand clay loam, while that of Umunneochi was sandy loam. The differences in soil texture of the three different locations may be as a result of their parent materials. Higher clay content in Amuro influenced its soil texture .

4.3 Chemical Properties of the Soils

4.3.1 Soil pH

In Isiobuzor, the mean soil pH ranged from 5.40 – 5.86 while in Amuro and Umunneochi it ranged from 5.42 – 5.46 and 5.58 - 5.62 respectively. The results showed that the soil pH of all the profiles was acidic and these agree with the findings of many researchers that soils of Southeastern Nigeria are acidic in nature Onweremadu *et al* (2006) . The results also showed that the soil pH was low at the surface horizons in all the profiles of the three different parent materials, signifying that some of the basic cations had been replaced by the acid cations as a result of leaching, as well as the uptake of basic cations by plants. (Landon, 1991).

4.3.2 Soil Organic Carbon

In Isiobuzor and Amuro carbon ranged between 0.80 – 0.57% and 10.00 – 10.84%, while in Umunneochi, it ranged between 14.06 - 18.78%. The results showed that the soils of Umunneochi had the higher soil organic carbon, followed by Amuro and Isiobuzor. The results also showed that there was higher organic carbon at the surface horizons of all the profiles and that soil organic decreased with increase in soil depth. Increased soil organic carbon on the surface horizons of all the profiles was as a result of organic matter accumulation through the decay of debris and remains of crop materials left after crop harvest. There was a higher variation of organic carbon in Umunneochi and Isiobuzor while in Amuro, the soil organic

carbon varied moderately and this may be attributed to clay content of the soils that help in binding the soil particles together. According to soil nutrient rating by Landon (1991), that when the soil organic carbon is >3.5 the Soil organic carbon became moderate.

4.3.3 Total Nitrogen

In Isiobuzor, the mean total nitrogen ranged from 0.12 – 0.08 % and 0.91 – 0.96 % in Amuro while in Umunneochi, it ranged between 0.97 and 1.96%. Low variations were observed in the soils of Isiobuzor and Umunneochi, while in Amuro, the total nitrogen varied moderately, and this may be as a result of high percentage clay content in Amuro while weathering and leaching may be the cause for the higher variations. The results showed that total nitrogen decreased with decrease in soil depth in all the profiles. The low content of total nitrogen in Isiobuzor may be as a result of nitrate losses and excessively drained nature of the soil. (Landon,1991)

Table 4.7: Soil chemical properties of Amuro

Location	Horizon	Depth (cm)	pH water	OC g/kg	TN	Avail P g/kg	Ca	Mg	K	Na Al ³⁺		H ⁺	TEB	TEA	ECEC	BS%
										Cmol/kg						
OBA	Ap	0-17	5.21	15.10	1.30	3.21	1.6	0.28	0.13	0.03	0.58	1.19	2.04	1.77	3.81	53.4
	AB	17-34	5.23	14.70	1.22	3.85	1.51	0.28	0.12	0.06	0.62	0.11	1.97	0.73	2.7	73
	Bg ₁	34-58	5.33	10.10	0.90	1.89	1.31	0.22	0.12	0.07	0.07	0.97	1.72	1.67	3.39	50.7
	Bg ₂	58-107	5.39	6.90	0.77	1.44	1.28	0.19	0.09	0.09	0.81	0.77	1.65	1.58	3.23	51.1
	Bg ₃	107-126	5.34	6.30	0.59	1.37	1.22	0.18	0.08	0.1	0.89	0.75	1.58	1.64	3.22	49.1
			5.30	10.62	0.95	2.35	1.38	0.23	0.108	0.07	0.59	0.758	1.792	1.47	3.27	55.46
ARO	Ap	0-22	5.40	15.20	1.26	4.02	1.62	0.31	0.12	0.04	0.67	1.2	2.09	1.87	3.96	52.8
	AB	22-65	5.37	14.50	1.14	4.32	1.55	0.27	0.13	0.04	0.69	1.15	1.99	1.84	3.83	52.0
	Bg ₁	65-96	5.51	11.30	0.92	2.05	1.38	0.24	0.09	0.06	0.75	0.81	1.77	1.64	3.41	51.9
	Bg ₂	96-133	5.55	6.70	0.74	1.80	1.3	0.19	0.09	0.07	0.75	0.83	1.75	1.58	3.33	52.6
	Bg ₃	133-170	5.48	6.50	0.61	1.47	1.27	0.17	0.08	0.07	0.79	0.82	1.59	1.61	3.2	49.7
			5.46	10.84	0.92	2.72	1.42	0.236	0.102	0.05	0.73	0.962	1.838	1.70	3.546	51.8
UMA	A	0-33	5.32	17.10	1.32	4.15	1.59	0.34	0.14	0.04	0.55	1.21	2.11	1.76	3.87	54.5
	AB	33-52	5.36	14.80	1.17	3.93	1.52	0.3	0.12	0.5	0.62	0.99	1.99	1.61	3.6	55.3
	Bg ₁	52-105	5.42	11.50	0.89	2.17	1.32	0.24	0.11	0.08	0.68	0.9	1.75	1.65	3.4	51.5
	Bg ₂	105-40	5.50	7.00	0.73	1.55	1.29	0.22	0.09	0.08	0.7	0.89	1.68	1.59	3.27	51.4
	Bg ₃	140-180	5.47	6.10	0.65	1.52	1.22	0.2	0.08	0.08	0.73	0.71	0.58	1.44	3.02	52.3
			5.41	11.30	0.95	2.66	1.38	0.26	0.108	0.15	0.66	0.94	1.622	1.61	3.432	53.0
OKP	Ap	0-21	5.28	16.30	1.22	3.97	1.62	0.34	0.13	0.03	0.67	1.18	2.12	1.85	3.97	53.4
	AB	29-66	5.57	12.70	1.22	3.99	1.53	0.33	0.13	0.04	0.68	1.12	2.05	1.80	3.85	53.2
	Bt ₁	66-79	5.43	9.60	0.81	1.81	1.3	0.33	0.13	0.04	0.68	1.12	0.05	1.80	3.85	53.2
	Bt ₂	79-128	5.44	6.90	0.78	1.66	1.25	0.287	0.09	0.07	0.75	1.03	1.74	1.78	3.52	49.4
			5.43	11.30	0.97	2.85	1.42	0.32	0.12	0.05	0.70	1.11	1.49	1.81	3.80	52.3
UKA	Ap	0-25	5.31	15.40	1.27	3.72	1.57	0.29	0.12	0.04	0.67	1.2	2.02	1.87	3.89	51.9
	AB	25-48	5.49	12.30	1.13	4.03	1.44	0.28	0.11	0.06	0.72	1.07	1.89	1.79	3.68	51.4
	Bg ₁	48-97	5.47	90.00	0.86	2.14	1.37	0.22	0.11	0.08	0.72	0.88	1.78	1.6	3.38	52.7
	Bg ₂	97-136	5.43	6.70	0.66	1.68	1.3	0.21	0.09	0.08	0.77	0.88	1.68	1.65	3.33	50.5
	Bg ₃	136-159	5.42	6.60	0.63	1.54	1.29	0.21	0.09	0.07	0.72	0.84	1.66	1.56	3.22	48.7
		Mean	5.42	10.00	0.91	2.62	1.39	0.24	0.10	0.07	0.72	0.97	1.81	1.69	3.50	51.04
		CV	1.80	35.70	26.90	43.20	10.1	21.20	18.10	114.8	22.0	13.60	27.50	13.80	9.50	8.80

CV= Coefficient of variation, cv< 15 = low, 15 – 35 – moderate, > 35 = high variation

Table 4.8: Soil chemical properties of Isibuzo

Horizon	Depth	pH (H ₂ O)	% OC	% TN	Avail. P g/kg	Ca	Mg	K ⁺	Na ⁺ Cmol/kg	Al ³⁺	H ⁺	TEB	TEA	ECEC	%BS
A	0-10	5.94	0.06	0.02	5.88	1.10	0.76	0.13	1.54	0.74	0.07	3.53	0.81	4.34	81.34
AB	10 – 31	5.45	1.49	0.16	5.81	1.60	0.84	1.36	1.96	0.89	0.20	5.76	1.09	6.85	84.09
BA	31-47	5.91	0.33	0.07	4.55	1.50	0.90	0.22	2.08	0.67	0.35	4.70	1.02	5.72	82.17
Bt ₁	47-106	5.25	0.25	0.05	6.93	1.10	1.00	0.24	3.57	0.60	0.40	5.91	1.00	6.91	85.53
Bt ₂	106-125	5.00	0.97	0.12	5.74	1.50	0.70	0.24	3.54	0.90	0.22	5.98	1.12	7.10	84.23
Bt ₃	125-190	5.73	0.31	0.04	6.30	1.60	0.96	0.59	2.11	1.15	0.10	5.26	1.25	6.51	80.80
	Mean	5.55	0.57	0.08	5.87	1.40	0.86	0.46	2.47	0.83	0.22	5.19	1.05	6.24	83.02
A	0-9	5.86	0.07	0.03	3.99	0.87	0.40	0.70	0.47	0.92	0.10	2.44	1.02	3.46	70.52
AB	9 – 29	5.86	0.09	0.02	5.11	0.80	0.29	0.81	1.00	0.43	0.37	2.90	0.80	3.70	78.38
Bt ₁	29-61	6.02	0.39	0.05	5.18	2.10	1.68	0.60	1.06	0.94	0.10	5.44	1.04	6.48	83.95
Bt ₂	61-142	5.70	0.15	0.03	6.72	0.90	0.63	0.11	1.41	0.95	0.10	3.05	1.05	4.10	74.39
	Mean	5.86	0.18	0.03	5.25	1.17	0.75	0.56	0.99	0.81	0.17	3.46	0.98	4.44	76.81
A	0-20	5.50	0.49	0.09	8.12	1.70	1.00	0.63	1.40	0.64	0.35	4.73	0.99	5.72	82.69
AB	20-36	6.05	0.11	0.02	6.23	1.11	0.60	0.85	2.94	0.82	0.13	5.50	0.95	6.45	85.27
Bt ₁	36-107	6.25	0.21	0.04	7.35	1.75	0.40	0.33	0.95	0.90	0.23	3.43	1.13	4.56	75.22
Bt ₂	107-180	5.62	0.69	0.12	4.35	1.80	1.69	1.56	3.11	0.95	0.40	8.16	1.35	9.51	85.80
	Mean	5.86	0.38	0.07	6.51	1.59	0.92	0.84	2.10	0.83	0.28	5.46	1.11	6.56	82.25
A	0-13	5.90	1.23	0.14	5.88	1.70	0.50	2.00	1.77	0.15	0.48	5.97	0.63	6.60	90.45
AB	13-31	6.06	0.49	0.10	4.76	1.20	0.60	0.29	0.63	1.19	0.20	2.72	1.39	4.11	66.18
Bg ₁	31-40	5.00	0.21	0.03	5.01	1.19	0.89	0.56	0.26	1.29	0.22	2.90	1.51	4.41	65.82
Bg ₂	40-80	5.76	0.35	0.08	3.99	0.80	0.54	0.74	2.11	1.17	0.08	4.19	1.25	5.44	77.04
Bg ₃	80-118	5.70	0.19	0.04	3.15	0.92	0.61	0.43	0.47	1.42	0.13	2.43	1.55	3.98	61.06
	Mean	5.68	0.49	0.08	4.56	1.16	0.63	0.80	1.05	1.04	0.22	3.64	1.27	4.91	72.11
A	0-16	5.45	0.29	0.07	5.60	0.83	0.37	0.64	0.61	1.40	0.27	2.45	1.67	4.12	59.47
AB	16-33	5.68	0.47	0.11	6.65	0.98	0.80	0.10	0.72	1.36	0.31	2.60	1.67	4.27	60.89
Bg ₁	33-49	5.44	0.99	0.13	6.44	0.99	0.70	0.06	0.18	1.43	0.06	1.93	1.49	3.42	56.43
Bg ₂	49-119	5.42	0.49	0.09	4.34	2.10	1.40	0.12	0.20	1.32	0.19	3.82	1.51	5.33	71.67
Bg ₃	119-160	5.00	1.77	0.18	5.60	1.18	0.70	1.09	4.96	1.48	0.17	7.93	1.65	9.58	82.78
	Mean	5.40	0.80	0.12	5.73	1.22	0.79	0.40	1.33	1.40	0.20	3.75	1.60	5.34	66.25
	CV	6.2	91.8	61.5	21.3	31.4	46.8	82.8	77	35	56.2	40.6	24.6	31.1	12.9

CV = coefficient of variation, cv < 15 = low, 15 – 35 – moderate, > 35 = high variation

Table 4.9: Soil chemical properties of Isuochi

Horizon	Depth (cm)	pH water	OC %	TN %	Avail P g/kg	Ca	Mg	K	Na →Cmol /kg	Al	H	TEB	TEA	ECEC	BS%
A	0-11	5.90	33.20	1.71	26.40	0.81	0.24	0.11	0.02	1.18	0.26	1.16	1.42	2.608	45.30
AB	11 – 26	5.40	22.40	1.13	16.20	0.61	0.18	0.10	0.02	0.91	0.28	1.22	1.50	2.41	37.70
Bt ₁	26-58	5.60	12.30	0.97	14.20	0.70	0.26	0.26	0.03	1.11	0.21	1.12	1.33	2.44	45.40
Bt ₂	58-130	5.70	8.40	0.88	6.60	0.81	0.30	0.13	0.03	1.27	0.17	1.11	1.28	2.55	49.50
Bt ₃	130-198	5.50	7.60	0.80	5.20	0.62	0.21	0.14	0.03	1.00	0.14	1.10	1.24	2.24	44.60
Mean		5.62	16.78	1.10	13.72	0.71	0.24	0.15	0.03	1.09	0.21	1.14	1.35	2.41	44.50
A	0-18	5.80	31.30	1.62	24.80	0.92	0.22	0.10	0.03	1.27	0.18	1.14	1.32	2.59	49.00
AB	18-29	5.50	22.80	1.24	16.70	0.50	0.16	0.08	0.04	0.78	0.26	1.38	1.64	2.42	32.20
Bt ₁	29-79	5.60	11.80	0.93	14.30	0.81	0.31	0.11	0.08	1.31	0.22	1.11	1.33	2.64	49.60
Bt ₂	79-130	5.50	7.30	0.76	7.90	0.82	0.28	0.14	0.08	1.32	0.16	1.09	1.25	2.57	51.30
Bt ₃	130-180	5.50	4.60	0.67	6.10	0.71	0.26	0.15	0.09	1.21	0.14	1.02	1.16	2.37	51.00
Mean		5.58	15.56	1.04	13.96	0.75	0.25	0.12	0.06	1.18	0.19	1.15	1.34	2.52	46.62
A	0-21	6.40	38.60	2.14	31.60	1.43	0.32	0.12	0.01	1.88	0.16	1.10	1.26	3.14	59.80
AB	21-48	6.00	19.50	1.08	15.70	0.64	0.20	0.06	0.01	1.45	0.30	1.36	1.66	3.11	46.60
Bt ₁	48-98	6.50	10.20	0.89	8.60	0.80	0.27	0.18	0.06	1.31	0.22	1.16	1.38	2.69	48.60
Bt ₂	98-160	6.30	6.80	0.73	6.70	0.90	0.30	0.20	0.07	1.49	0.11	1.11	1.22	2.71	54.90
Mean		6.30	18.78	1.21	15.65	0.94	0.27	0.14	0.04	1.53	0.20	1.18	1.29	2.91	52.48
A	0-10	5.60	26.80	1.52	23.10	0.81	0.22	0.14	0.02	1.19	0.18	1.06	1.24	2.43	48.90
AB	10 – 33	5.30	13.40	1.01	14.20	0.51	0.16	0.10	0.01	0.78	0.32	1.32	1.64	2.42	32.20
Bt ₁	33-66	5.70	10.20	0.90	9.80	1.12	0.20	0.13	0.04	1.49	0.22	1.21	1.43	2.92	51.00
Bt ₂	66-110	5.60	8.30	0.86	7.30	0.91	0.28	0.14	0.06	1.39	0.12	1.14	1.26	2.65	52.40
Bt ₃	110-200	5.50	4.20	0.49	3.60	0.90	0.30	0.15	0.06	1.11	0.11	1.10	1.21	2.32	47.80
Mean		5.54	12.58	0.96	11.60	0.85	0.23	0.13	0.04	1.19	0.19	1.17	1.36	2.55	46.46
A	0-5	5.70	27.50	1.58	23.40	0.92	0.23	0.10	0.02	1.27	0.16	1.08	1.24	2.51	50.50
AB	12905.00	5.40	19.50	1.07	15.90	0.41	0.17	0.06	0.02	0.66	0.33	1.19	1.52	2.18	30.20
Bt ₁	35-72	5.60	11.80	0.94	13.20	0.61	0.26	0.11	0.04	1.02	0.15	1.06	1.21	2.23	45.70
Bt ₂	72-120	5.80	7.30	0.76	4.90	0.80	0.21	0.12	0.04	1.17	0.03	1.03	1.16	2.33	50.20
Bt ₃	120-205	5.40	4.20	0.48	3.20	0.71	0.20	0.14	0.06	1.11	0.92	0.92	1.03	2.14	57.80
Mean		5.58	14.06	0.97	12.12	0.69	0.21	0.11	0.04	1.05	0.32	1.06	1.23	2.28	46.88
CV		5.50	65.50	38.60	59.50	27.10	20.70	33.70	59.50	22.10	74.20	9.30	12.30	10.30	15.90

CV = coefficient of variation, cv < 15 = low, 15 – 35 – moderate, > 35 = high variation

4.3.4 Available Phosphorus

In Isiobuzor, the mean available phosphorus ranged from 5.73 – 5.87 mg/kg, in Amuro it ranged from 2.62 – 2.35 mg/kg while in Umunneochi, mean available phosphorus ranged between 12.12 and 13.72 mg/kg. The results showed that the surface horizons had low available phosphorus in all the profiles, while available phosphorus decreased variably in soil depth and these results agree with the findings of Steven (2010). The results also showed that Umunneochi had the highest available phosphorus, followed by Isiobuzor while Amuro had the lowest available phosphorus and this may be as a result of the parent material of Amuro which had higher clay content, as phosphorus availability depends on the amount and clay shale content of the soil (Brady and Weil, 2010). The results also showed that in Amuro, the available phosphorus were moderately(0.5-0.8) while in Amuro and Isuobuzor, were low moderate respectively. Landon., (1991). Generally, the soils had moderate available phosphorous.

4.3.5 Percentage Base Saturation

The mean percentage base saturation of the soils varied between 66.25 – 83.02, 51.04 -55.46 and 46.88 – 44.50 in Isiobuzor, Amuro and Umunneochi, respectively. The results showed that the soils of Isiobuzor had the higher percentage base saturation, than Amuro and Umunneochi. The results also showed that percentage base saturation decreased with increase in soil depth and varied from one location to the other across the profiles.

This could be as a result of the parent material and the altitude of the study site.

4.4 Relationship among Soil Properties

Tables 4.10, 4.11 and 4.12 showed the relationship between physical and chemical properties of Isiobuzor, Amuro and Umunneochi, respectively. In Isiobuzor, the percentage base saturation correlated negatively with silt content and clay content at 5% (-0.702) and 1% (-0.552) but positively correlated with sand content at 1% (0.774). This result signifies that increase in percentage sand content led to increase base saturation but decrease in silt and clay content led to the decrease to base saturation. The results also showed that percentage organic carbon correlated negatively with clay content at 5% (-0.519) probability level, while percentage moisture content was negatively correlated with the bulk density at 1% (-0.691), thereby signifying that increase in bulk density led to decrease in moisture content and vice versa.

In Amuro, total nitrogen was correlated negatively with bulk density at 1% and clay content at 5% probability level but correlated positively with sand content, total porosity and moisture content at 1% probability level. The results also showed that available phosphorus correlated positively with sand content, total porosity and moisture content at 1% but correlated negatively with clay content and bulk density at 1% probability level. In Umunneochi, the results showed that available phosphorus, organic carbon and total nitrogen were correlated positively with total porosity at 1% probability level. This result showed that increase in total porosity led to increase in available phosphorus, organic carbon and total nitrogen.

Table 4.10: Relationship between physical and chemical properties of Amuro

Soil properties	Sand	Silt	Clay	MC	BD	TP
AP	0.835**	-0.672*	-0.720**	0.843**	-0.782**	0.782**
BS	0.182	-0.067	-0.188	0.127	-0.393	0.392
ECEC	0.71**	-0.672*	-0.537*	0.754**	-0.579*	0.579*
PH (H ₂ O)	-0.163	0.141	0.181	-0.402	0.292	-0.292
TEA	0.366	-0.428	-0.239	0.444	-0.179	0.179
TEB	0.358	-0.305	-0.306	0.503*	-0.458	0.458
TN	0.80**	-0.629*	-0.687*	0.843**	-0.878**	0.878**

*and ** = significant at 0.05 and 0.01 probability level respectively

AP= Available Phosphorous, BS= Base Saturation, ECEC= Effective cation exchange capacity, TEA= Total exchangeable acidity, TEB= Total exchangeable base, TN= Total nitrogen, MC= Moisture content, BD= Bulk density, TP= Total porosity

Table 4.11: Relationship between physical and chemical properties of Isibuzor

Soil property	Sand	Silt	Clay	MC	BD	TP
%BS	0.774**	-0.702**	-0.552*	0.004	-0.129	0.129
%OC	0.443	-0.185	-0.519*	-0.116	0.041	-0.041
%TN	0.358	-0.090	-0.476	-0.124	0.024	-0.023
Avail. P	0.287	-0.197	-0.265	-0.031	-0.144	0.143
ECEC	0.633*	-0.511*	-0.511*	-0.324	0.114	-0.113
TEA	-0.563*	0.580*	0.337	-0.401	0.358	-0.357
TEB	0.716**	-0.599*	-0.558*	-0.250	0.051	-0.051
pH_H2O	-0.033	-0.131	0.175	0.403	-0.240	0.240
MC	-0.002	-0.093	0.091	1.000**	-0.691**	0.691*

*and ** = significant at 0.05 and 0.01 probability level respectively

Table 4.12: Relationship between physical and chemical properties of Izuochi

Soil property	SAND	SILT	CLAY	MC	TP
Bsat	0.145	0.041	-0.167	-0.214	-0.342
Avail. P	0.160	0.023	-0.238	-0.155	0.893**
ACEC	0.162	-0.243	-0.106	-0.195	0.064
ECEC	-0.068	-0.151	0.107	0.085	0.262
OC	0.216	-0.021	-0.278	-0.187	0.877**
pH(water)	-0.122	-0.096	0.141	0.150	0.079
TEA	-0.169	-0.204	0.236	0.239	0.498
TEB	0.037	-0.022	-0.041	-0.065	-0.050
TN	0.168	0.004	-0.236	-0.148	0.856**

*and ** = significant at 0.05 and 0.01 probability level respectively

Bsat= base saturation, Avail p= Available phosphorous, ECEC= Exchangeable cation exchange capacity, OC= Organic carbon, TEA= Total exchangeable acidity, TEB= Total exchangeable base, TN= Total nitrogen, MC= Moisture content, TP= Total porosity.

4.5 Distribution of Soil Properties using GIS

The parameters obtained from GIS were used to produce an interpolation map of the soil physical and chemical properties of the study areas as shown in figures 4.1. From the distribution map of the soil properties, (Fig 4.2) the percentage of sand was higher at Umunneochi and decreases down to Amuro and low at Isiobuzor. The increase in sand content of the study areas was in line with the associates of their parent materials, land use and climate. Clay content increase in Amuro and the communities within Amuro and decrease in Isiobuzor and Umunneochi and this was as a result of their parent material (Isiobuzor; coastal plain sand, Umunneochi; Upper coal measure and Amuro; Imo clay shale). Higher clay content in Amuro was due to its lithology, implying that this area had the capacity to retain moisture and nutrient, protect the enzyme and microbial biomass which plays an important role in turnover of organic substrate.

The soils of Isiobuzor and Umunneochi had higher total porosity which could be due to higher sand content, land use which reduces organic matter content in the area, lowering bulk density and increasing the amount of potassium content, which allow easy movement of water downward and may cause ground water pollution in the area. The increase in bulk density in Amuro may be due to deposition of sediments which cause hard pan or compaction on the soil surface. This reduces water infiltration and root penetration down the deeper soil layers. The low bulk density in Isiobuzor and Umunneochi allows penetration of roots, movement of water and materials down the deeper layer of the soils, thereby encourages root growth and higher crop yield in the area.

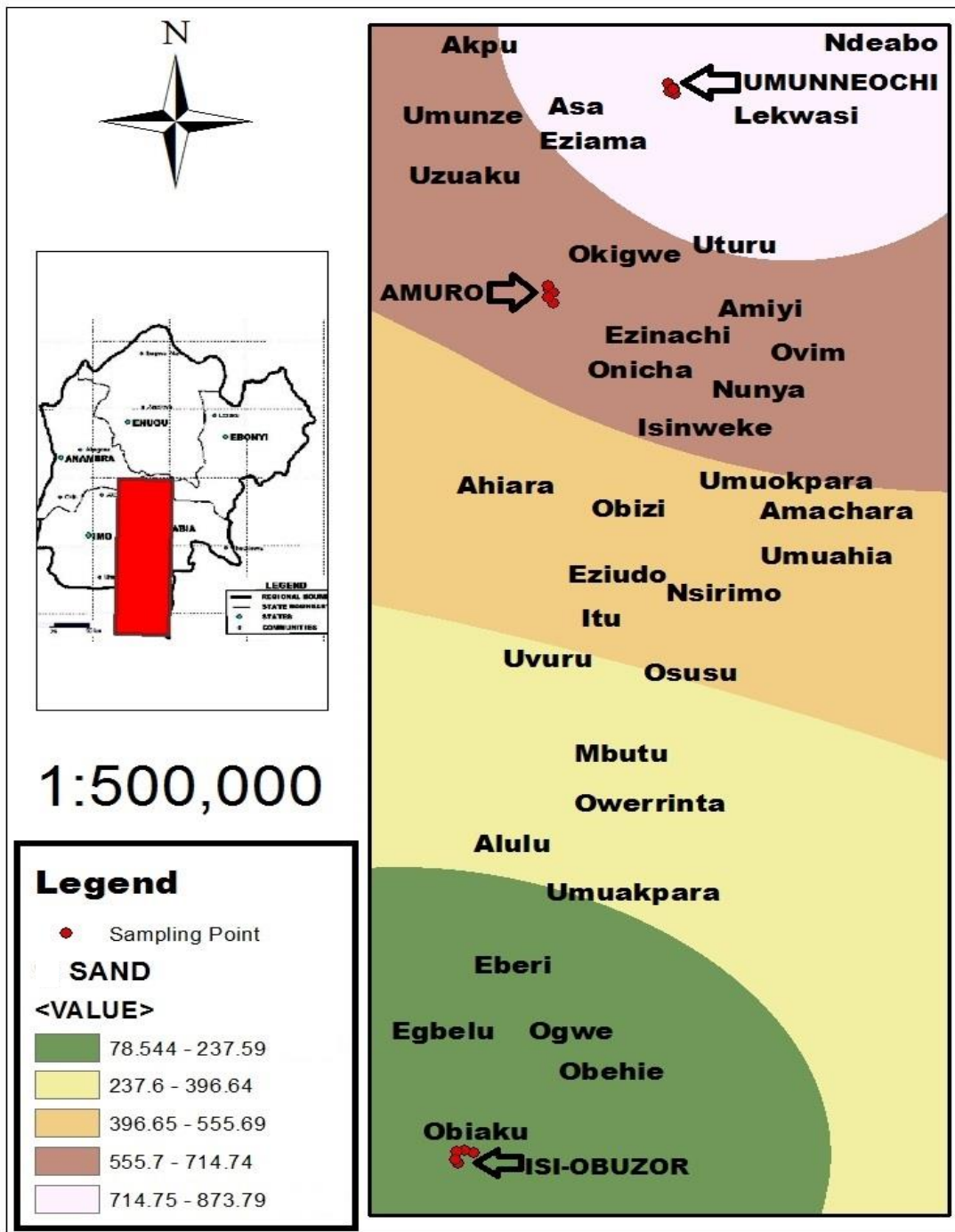


Figure 4.1: Kriged map of the sand in the studied soils

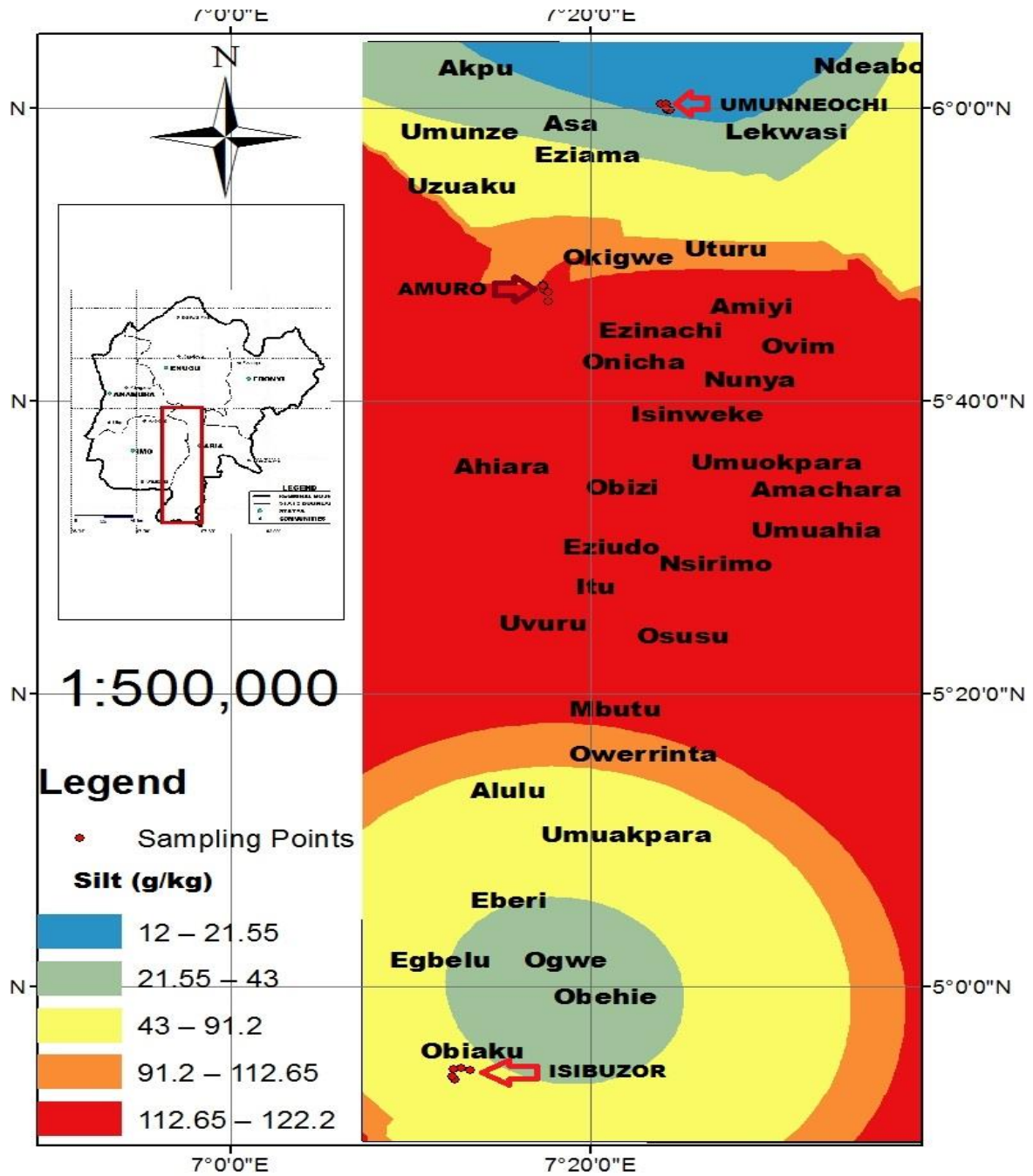


Figure 4.2: Kriged map of silts content g/kg of the study soils

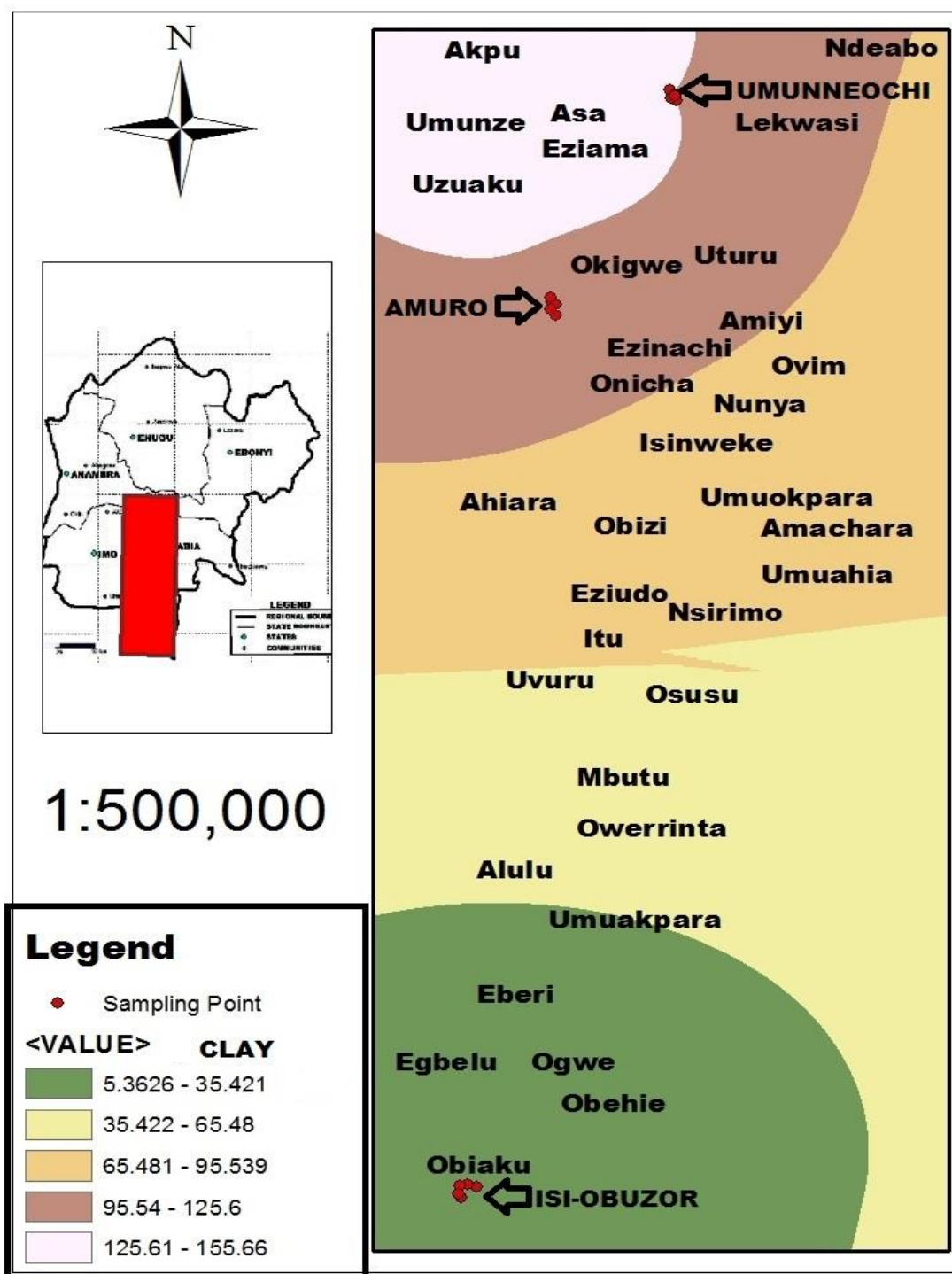


Figure 4.3: Kriged map of the clay of the studied soils

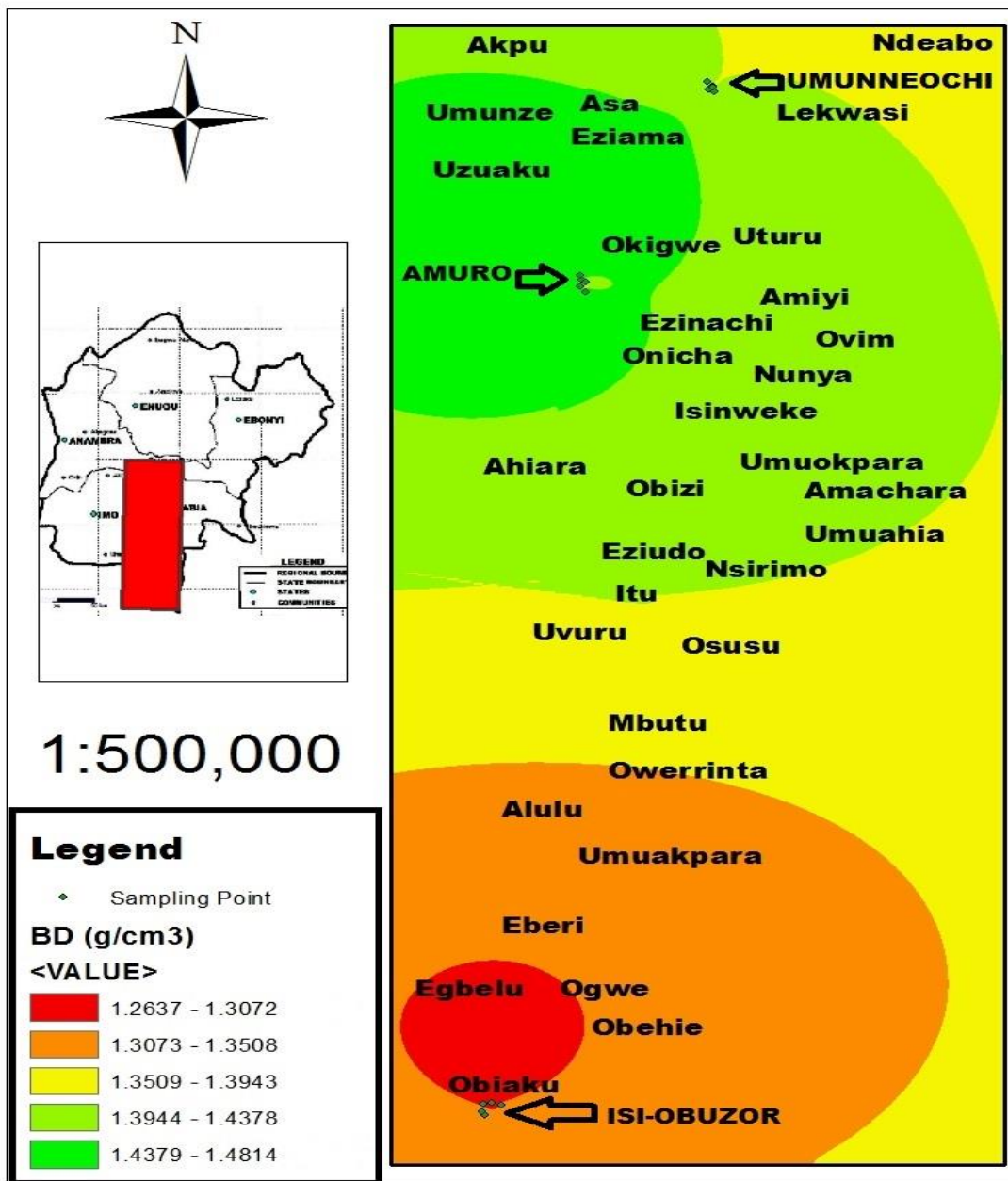


Figure 4.4: Kriged map of the Bulk Density of the studied soils

From the map of soil property, sand increased from the upper part of the studied soils (Umunneochi) down to the middle part (Amuro) and thereafter decreased down the lower part of the studied soils. The highest % sand was found at the upper part of the studied soils (Umunneochi) decreased to the middle part (Amuro) and the lowest was in the lower part of the studied area (Isiobuzor). The highest sand content at the upper part was due to the parent material found in the area (upper coal measure, Nsukka formation), land use and climate. Deficiency in organic matter shows poor water and nutrient in the soil as macropores inherent in the soil allow rapid horizontal and vertical trend within the area (Turgut *et al.*, 2008).

From the spatial map Silt (Fig 4.2) indicates that silt increased from Umunneochi down to Amuro and showed a total similarity Isiobuzor. The similarity of the soils of the study areas could be as a result of the relationship parent (Imo clay shale, coastal plain sand and upper coal measure) material and the factors of soil formation.

Spatial map % clay (fig. 4.3) indicated that at Akpu, Umunze and Eziama in Umunneochi, the upper part of the study area increased down to the middle (Amuro) thereafter to the lower part of the study area (Isiobuzor) probably due to the relief where the movement of materials and clay were deposited. The high/clay content at the upper part (Umunneochi) and Amuro may be due to the parent material (upper coal measure, and Imo clay shale) which composed of coarse, sands, shale and carbounaceous shale risk (Orajaka, 1975) indicating that this area has the capability to retain moisture and nutrient, protect the enzyme and microbial biomass which plays an important function in organic substrate (Mclauchipan, 2006).

The kriged maps for bulk density (BD) decreases within communities Isuochi, Ndeabo, Lekwasi, and increased to middle part (Amuro) and decreases down the lower part of the area (Isiobuzor) as explained by the spatial values and colours in the map (fig. 4.5). The increase in BD in Amuro may be due to the deposition of sediments, flooding from the main river which causes hard plant compaction on the soil surface (Igbal *et al.*, 2005) this reduces water infiltration and root penetration down the deeper soil layers, loses of nutrient and poor yield in the lower parts.

The Kriged maps for bulk density (Fig4.5) and total porosity are shown in and (Fig4.6) Bulk density increased with increase in soil depth while the total porosity increased with decrease in soil depth in all the profiles of three lithologies.

Distribution map of moisture content(Fig 4.12) shown that the moisture content was patterned with high values. The higher soil moisture variations were due to soil management practices. Differences in the moisture content could be due to land use which is likely due to deferring evapo-transpiration rates from different vegetation types and soil surface physical properties that are related to the vegetation types.

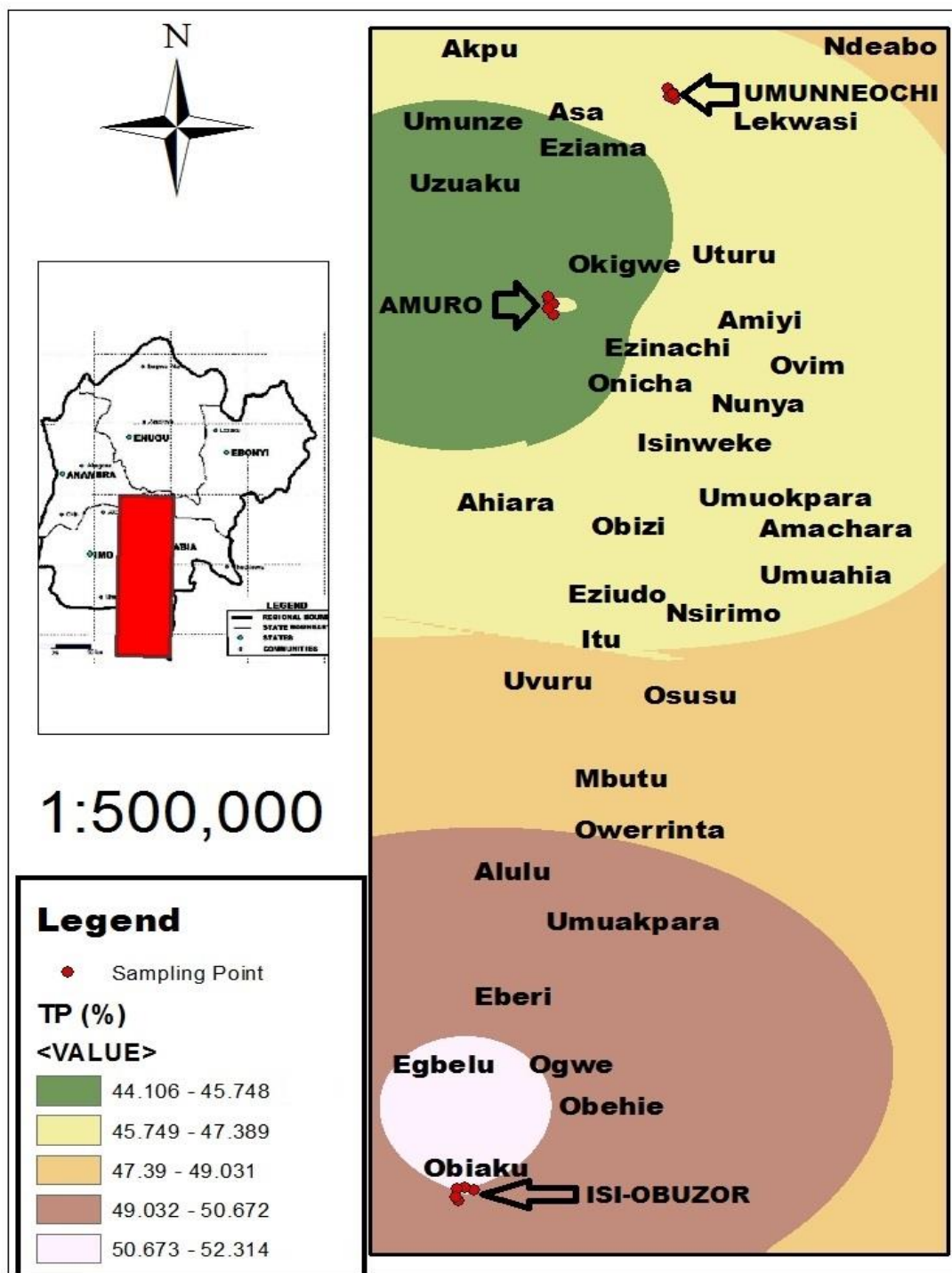


Figure 4.5: Kriged map of Total Porosity of the studied soils

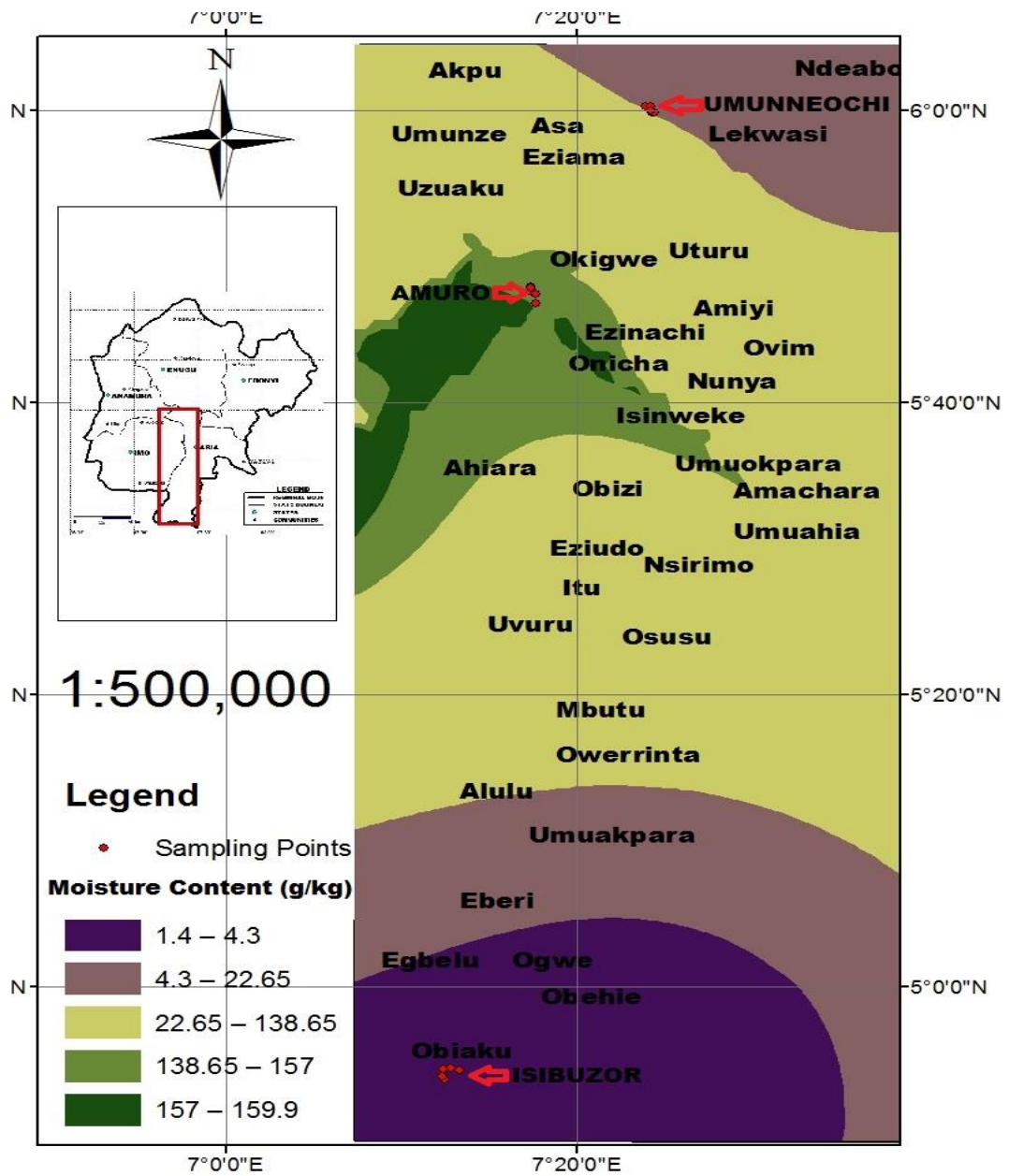


Figure 4.6: Kriged map of moisture content g/kg of the study soils

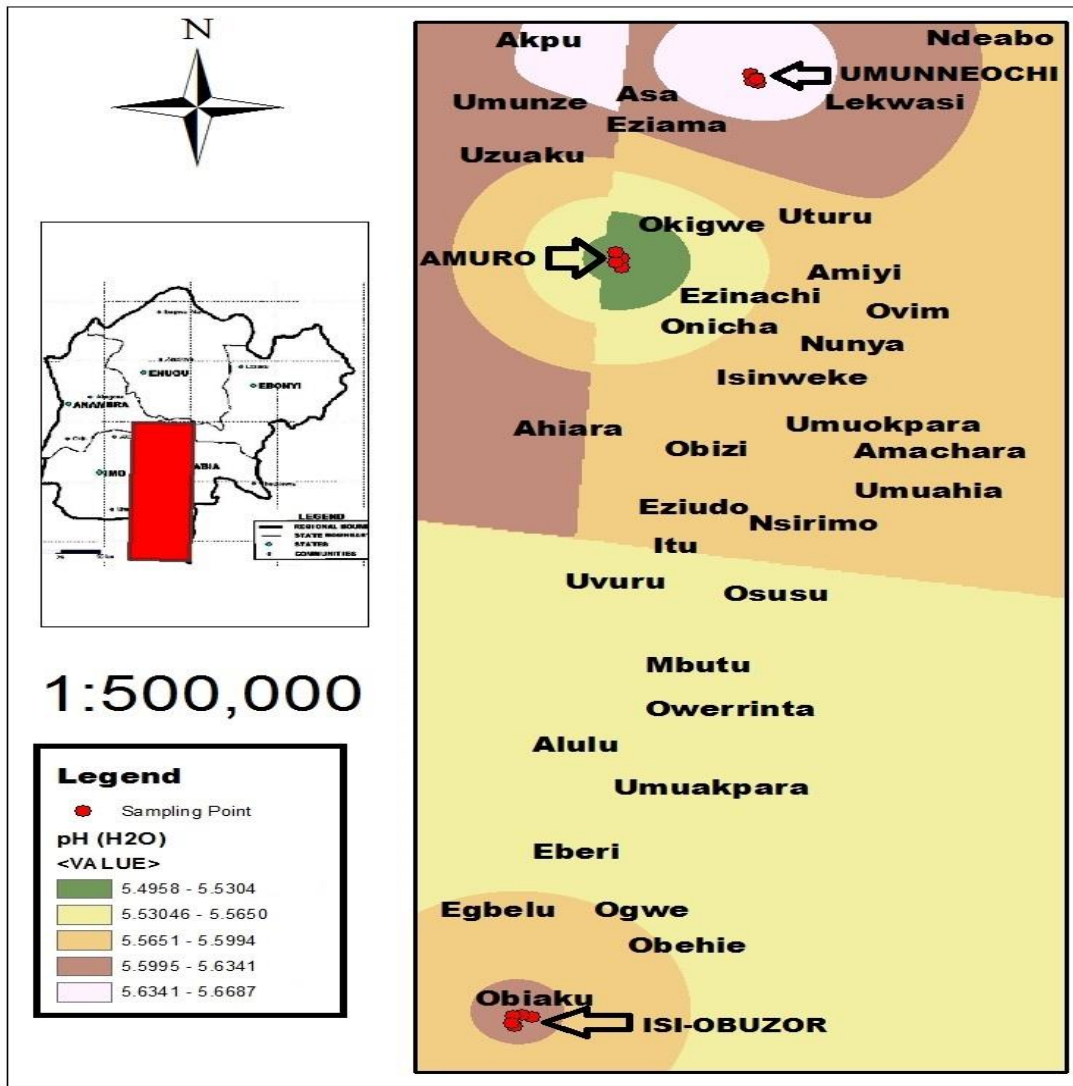


Figure 4.7: Kriged map of the pH of the studied soils

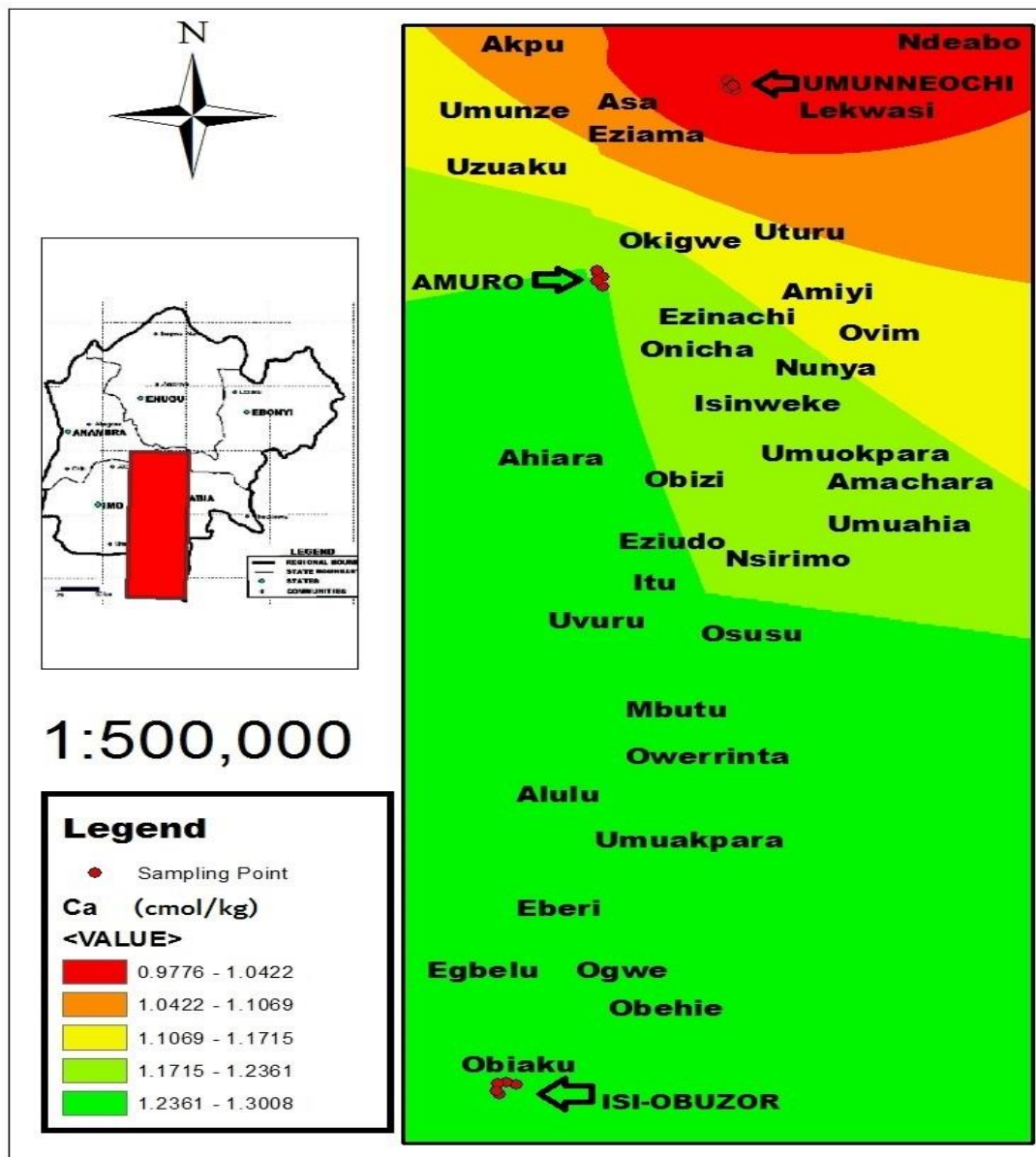


Figure 4.8: Kriged map of the Calcium of the studied soils

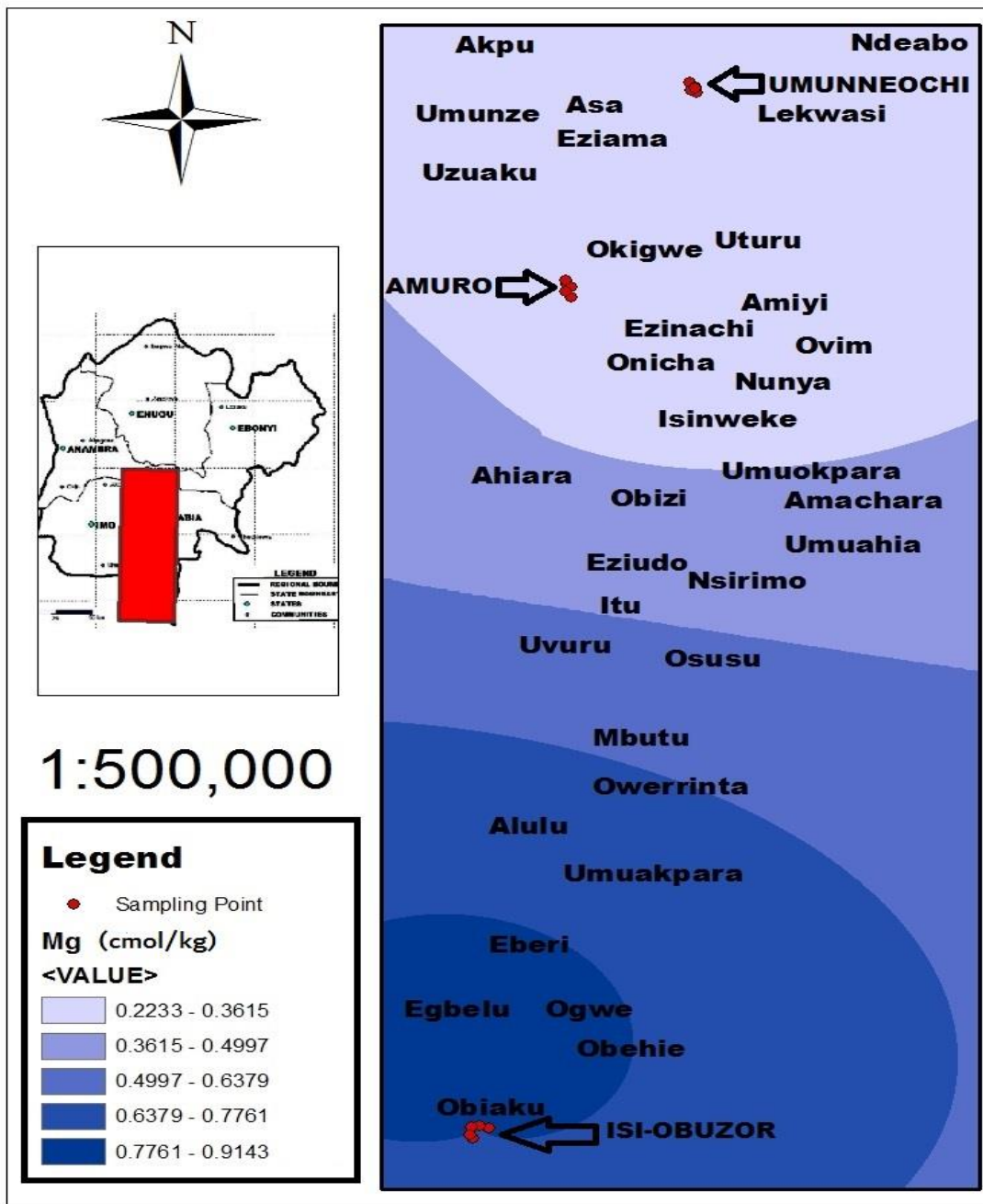


Figure 4.9: Kriged map of the Magnesium of the studied soils

Spatial map of pH (fig. 4.7) showed that pH increased from the upper part of the studied area (Umunneochi) with little variation to the middle (Amuro) and decreased to lower part of the area (Isiobuzor) as shown by the colour value of the map legend. This showed that the soils of the study areas are acidic and could be attributed to the landscape of the locations as most of the profile were on level plain ground which encourages washing and distrugration of soil particles and soil nutrient.

Fig. 4.8: Showed that the soils of the lower part (Isiobuzor course) had the higher concentration of exchangeable Ca, the Concentration decreased down from Umunneochi to the middle part (Amuro) . The higher concentration of the lower part of the studied areas may be due to the parent material (coastal plain sand) and landscape position leading to the movement of nutrients alongside with water and deposited at the lower part of the rivers. The low concentration of exchangeable calcium at the middle and upper part of the study areas could be due to effect of landslide (water erosion and tillage practices),

Fig. 4.9: indicated that the lower part of the study soils (Isiobuzor) had higher concentration of exchangeable magnesium (Mg) and decreased from Umunneochi to the middle part (Amuro) with similar colour as shown in the kriging map. The higher concentration of Mg at the lower part of the studied soil (Isiobuzor) maybe due to the parent material composition. Generally, from the map Mg level in the soils of the locations within the map were low (FAO., 2004), in Umunneochi the crop grown in this area may suffer Mg deficiency.

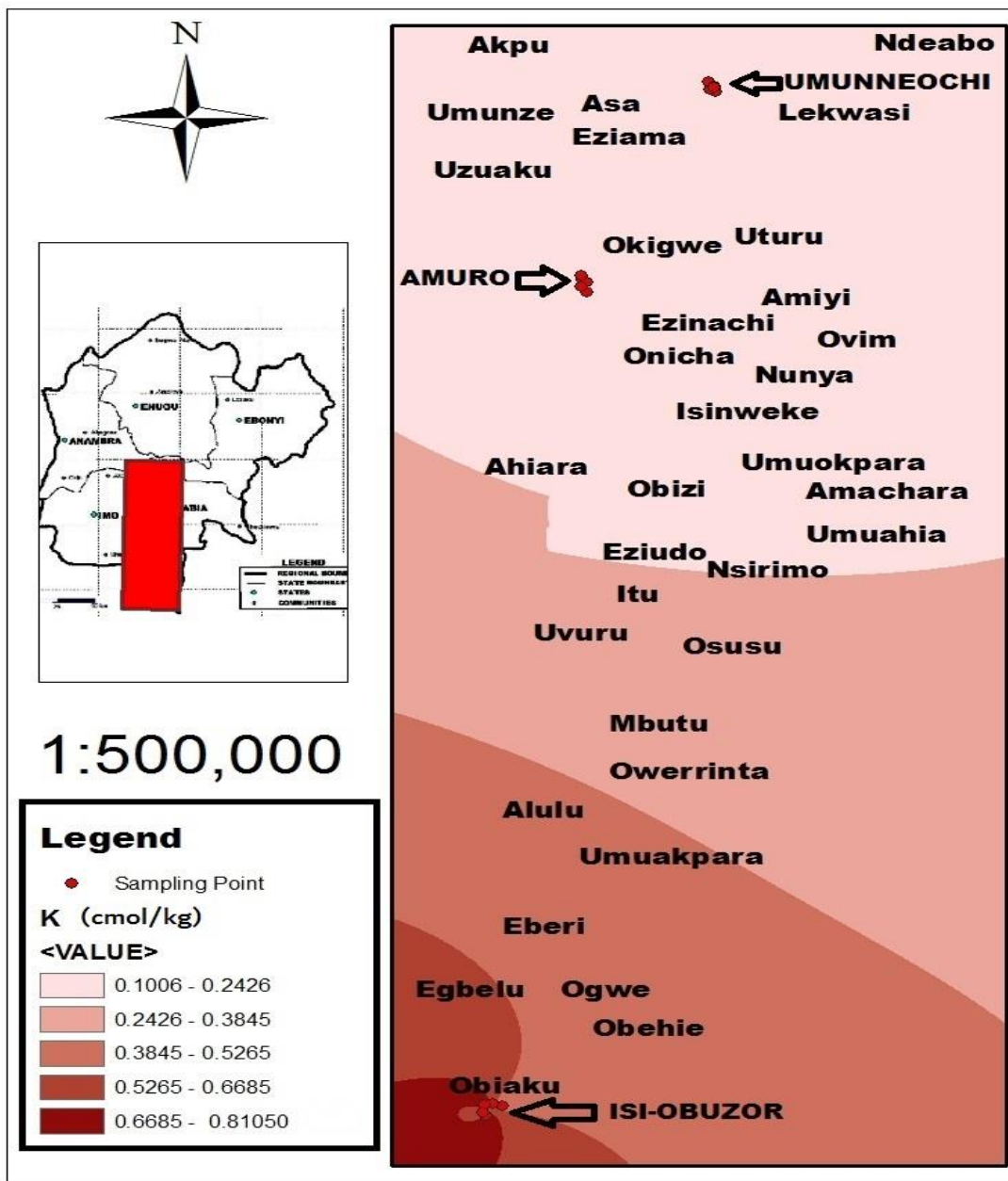


Figure 4.10: Kriged map of the Potassium of the studied soils

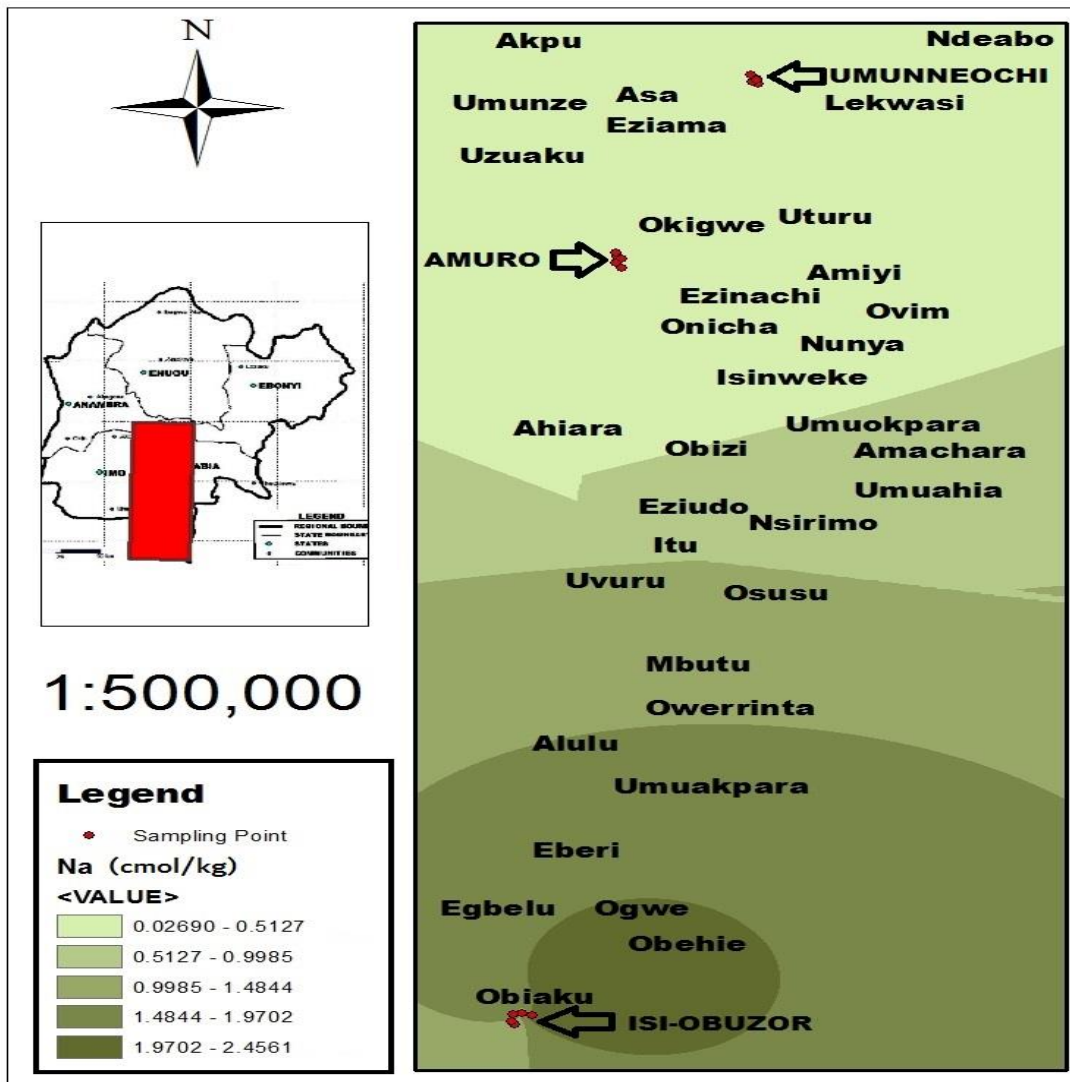


Figure 4.11: Kriged map of Sodium of the studied soils

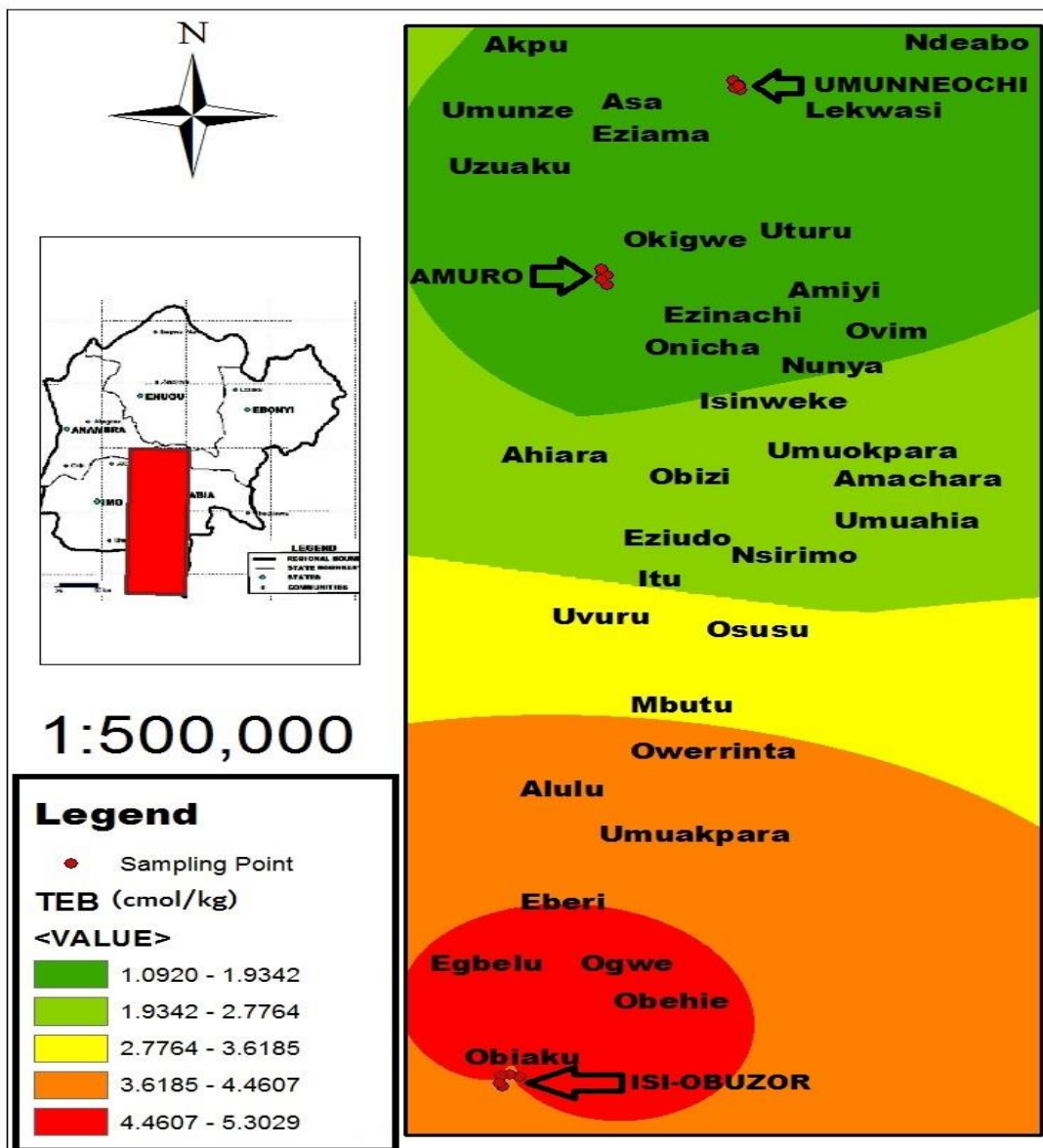


Figure 4.12: Kriged map of the Total Exchangeable Bases of the studied soils

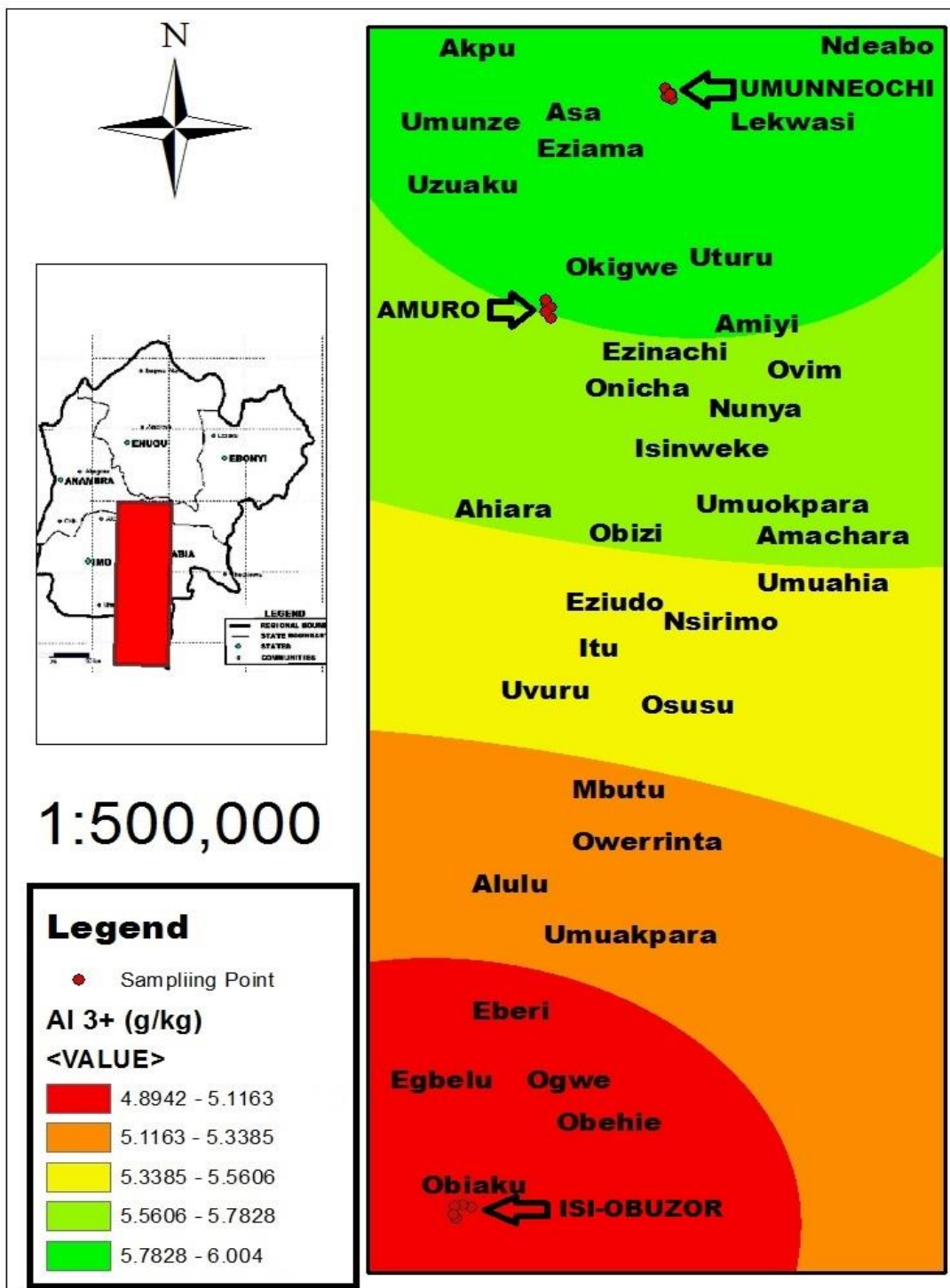


Figure 4.13: Kriged map of Aluminum of the studied soils

Substantially, the spatial map of exchange potassium (K^+ in $mg\ kg^{-1}$) fig. 4.9 Showed that the concentration of exchangeable K^+ at the lower part (Isiobuzor) was the highest. It decreases from Umunneochi to Amuro as indicated by spatial map legend. This could be related to stable intrinsic factors as soil formation.

The spatial distribution map for exchangeable Na^+ (Fig. 4.11) the kriging for Na^+ showed a higher amount of Na^+ at the lower part (Isiobuzor) and the surrounding Egbela, Uvuru and Mbutu as it decreased down from Umunneochi to the middle part Amuro. However, the higher concentration of Na^+ at the lower part of the studied area was due to the movement of material (exchangeable bases) down the lower part (Isiobuzor) due to topography and landscape position and marine influences.

The spatial distribution map for total exchangeable base (TEB) showed a higher variation from the value legend in lower part (Isiobuzor) and as decreased from Umunneochi to the middle Amuro course with little variation.

The map of Aluminum (Fig. 4.13) showed the Al was higher at the upper course of the kriging map and implying aluminum toxicity in the site (Onweremadu, 2007). this showed that the area had suffered high intensity of soil erosion and leaching of basic cations. Further, Al decreased down to the middle part (Amuro course) suggesting low toxicity of aluminum as shown by low concentration of Al^{2+} in the kriging map fig. 4.13. and thereafter decreases to the lower part (Isiobuzor course). The variation of Al_{sa+} may be due to the interaction influence of soils formation process and land use.

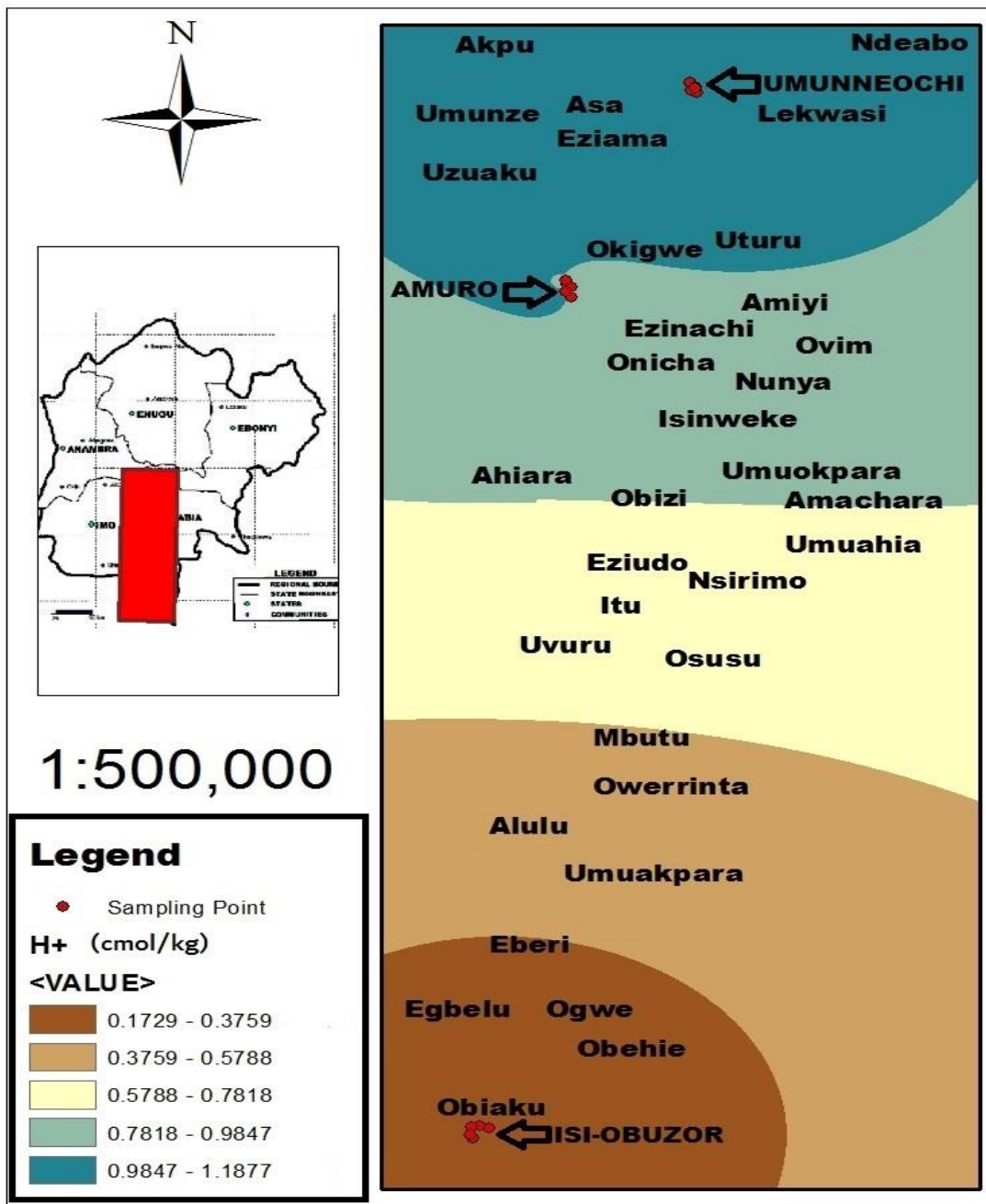


Figure 4.14: Kriged map of Hydrogen ion of the studied soils

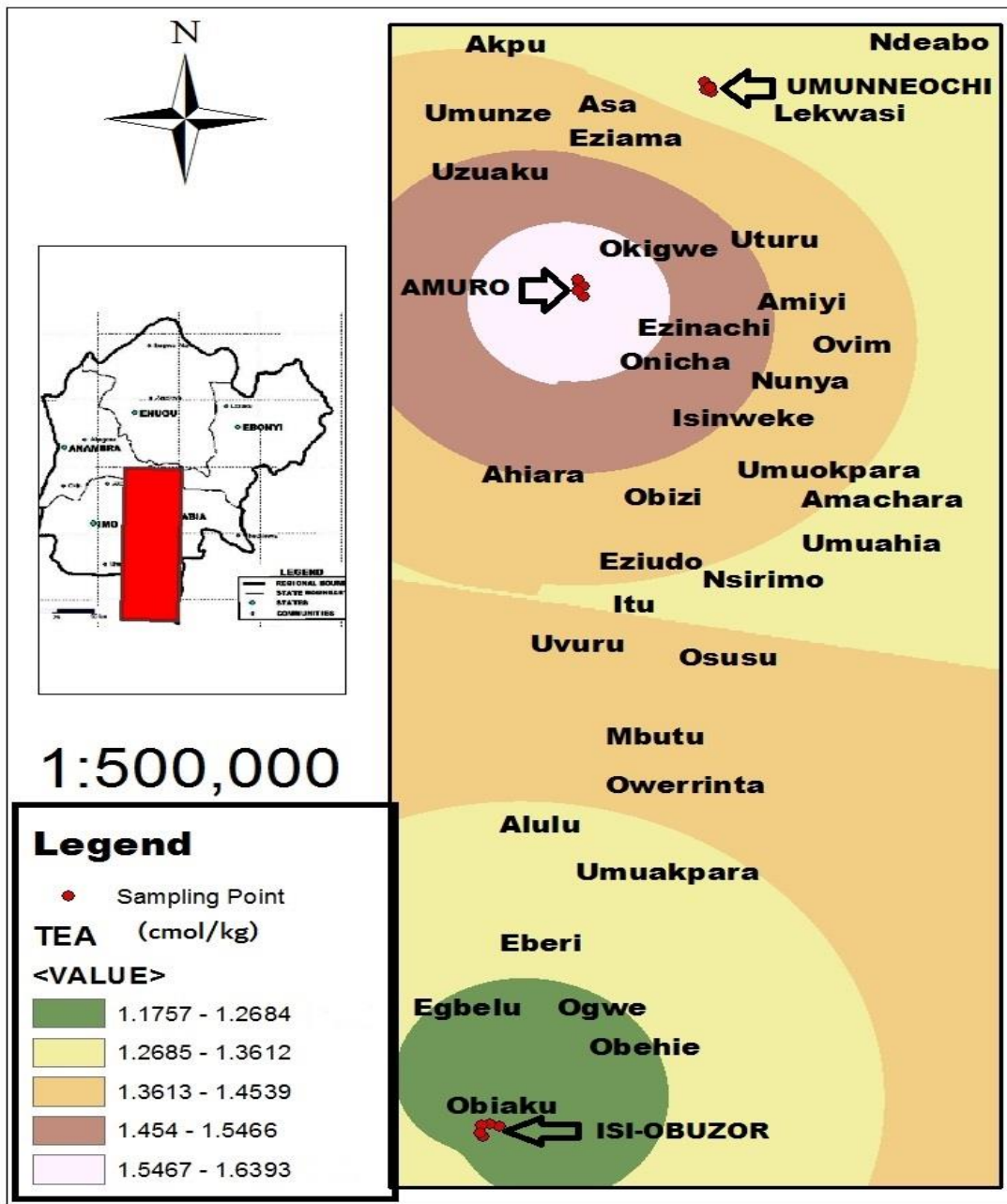


Figure 4.15: Kriged map of Total Exchangeable Acidity of the studied soils

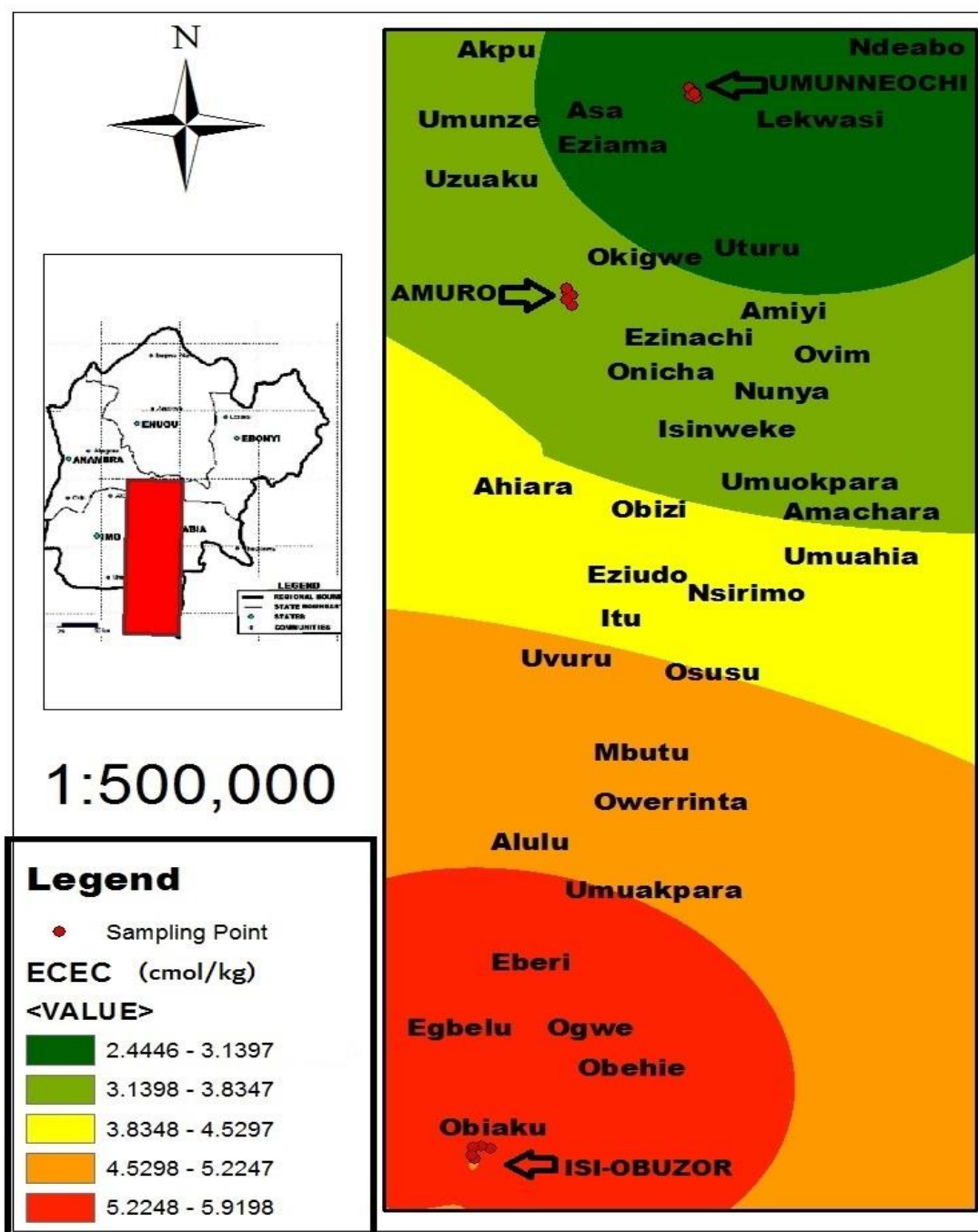


Figure 4.16: Kriged map of Effective Cation Exchange Capacity of the studied soils

Map obtained with kriging (Fig 4.14) for concentration of H^+ showed that the upper part of the studied area had the higher concentration of hydrogen (H^+) with little variation, decreased to the middle part (Amuro) and thereafter decreased to the lower part (Isiobuzor) as shown by the kriging map. It can be due to the parent material and factors of soil formations

The kriged map for total exchangeable acidity (TEA) Fig. 4.15 indicated that the soils of (Amuro area) and surroundings had higher concentration of total exchange acidity which decreased towards the upper part (Umunneochi course) the Isiobuzor soils had the lowest total exchangeable acidity.

The kriging map of Effective Cation Exchange Capacity (ECEC) (Fig. 4.16) showed that Isiobuzor had the highest ECEC value, while the values decreased through Amuro to Umunneochi. The higher ECEC at lower part of the study area and the low clay could be due to parent material and topography. Guided by Esu (1991), rating of ECEC of tropical soil, from the map it is evident that the study areas had low ECEC.

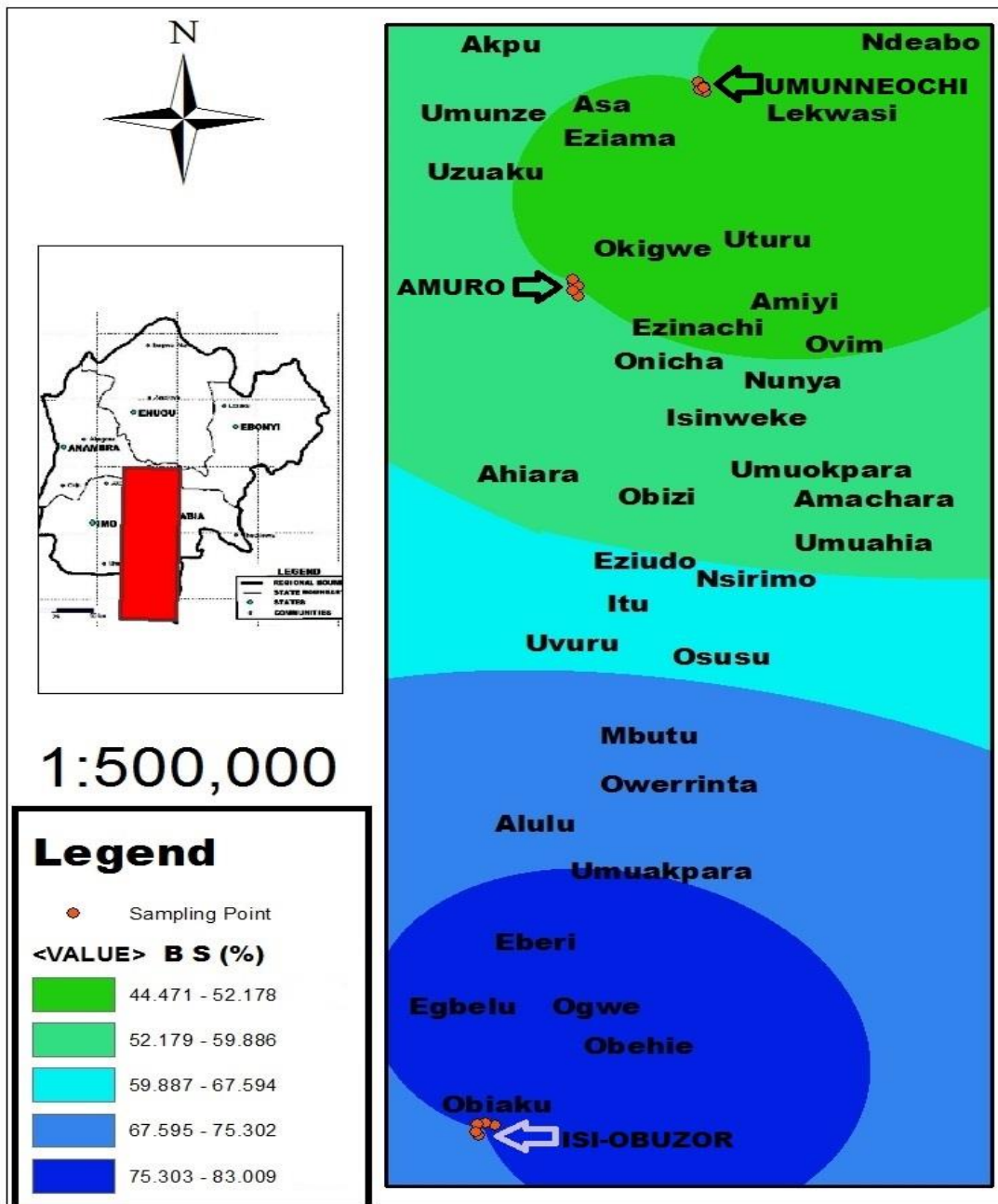


Figure 4.17: Kriged map of percentage (%) Base Saturation of the studied soils

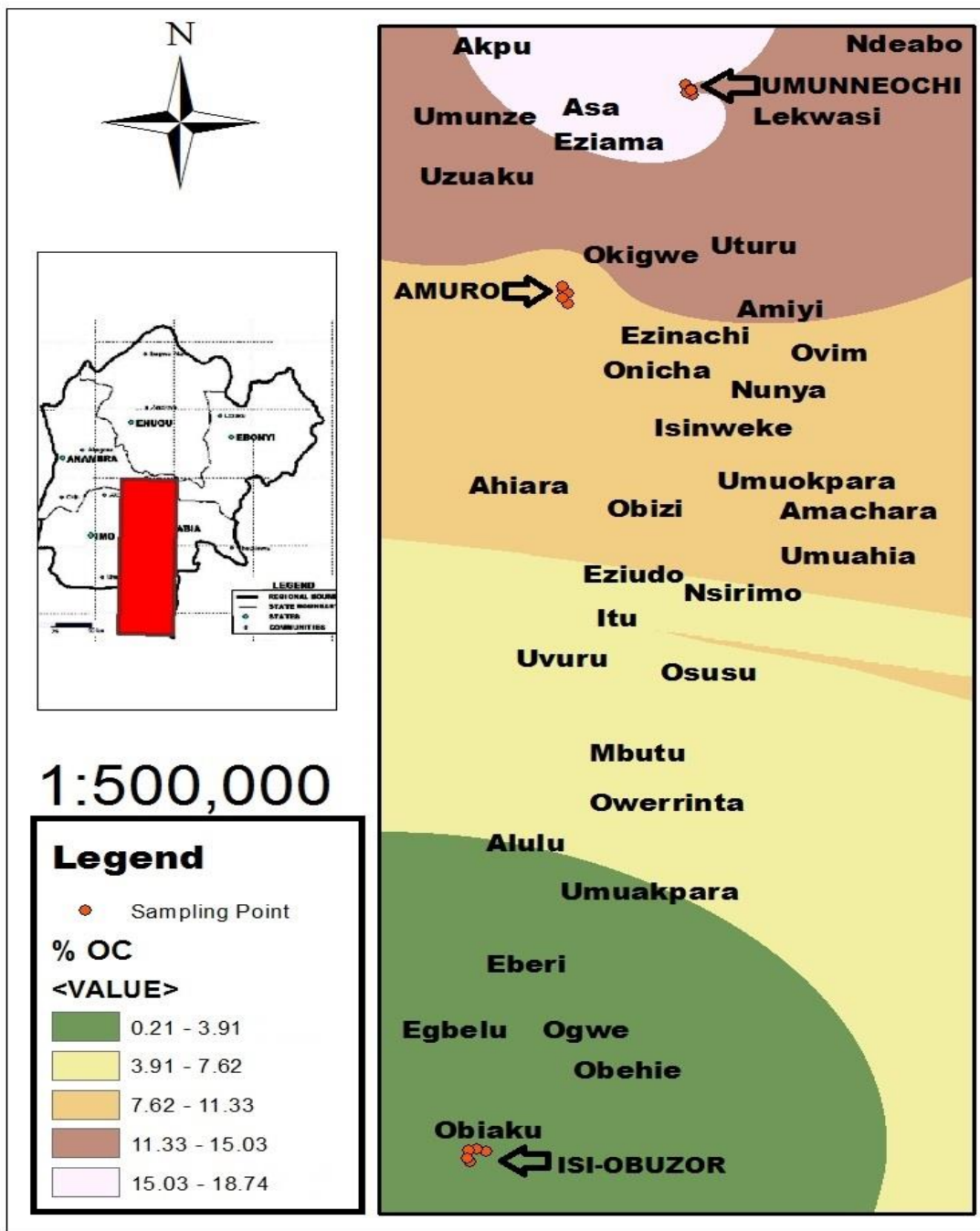


Figure 4.18: Kriged map of percentage (%) of Organic Carbon of the studied soils

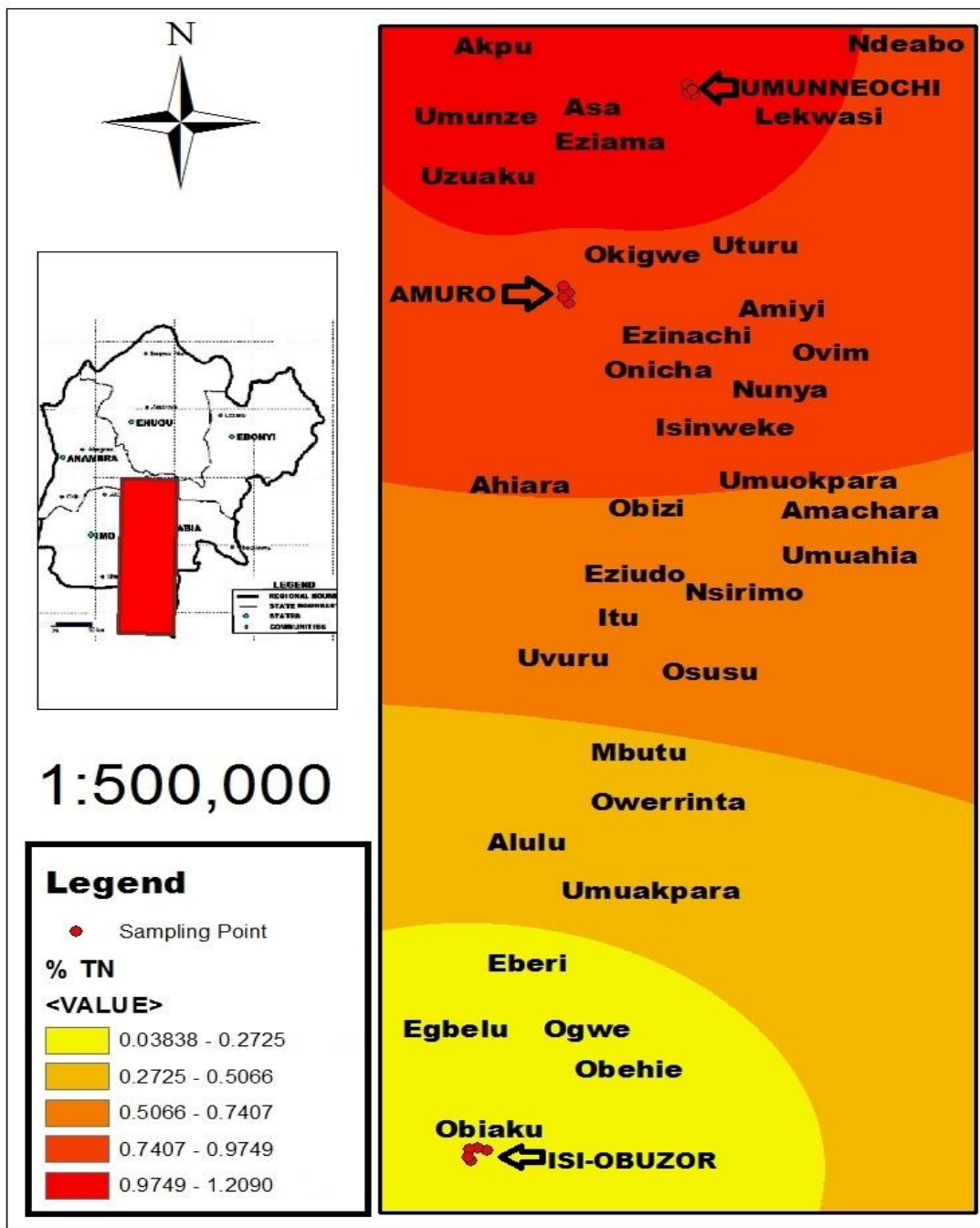


Figure 4.19: Kriged map of percentage (%) Total Nitrogen of the studied soils

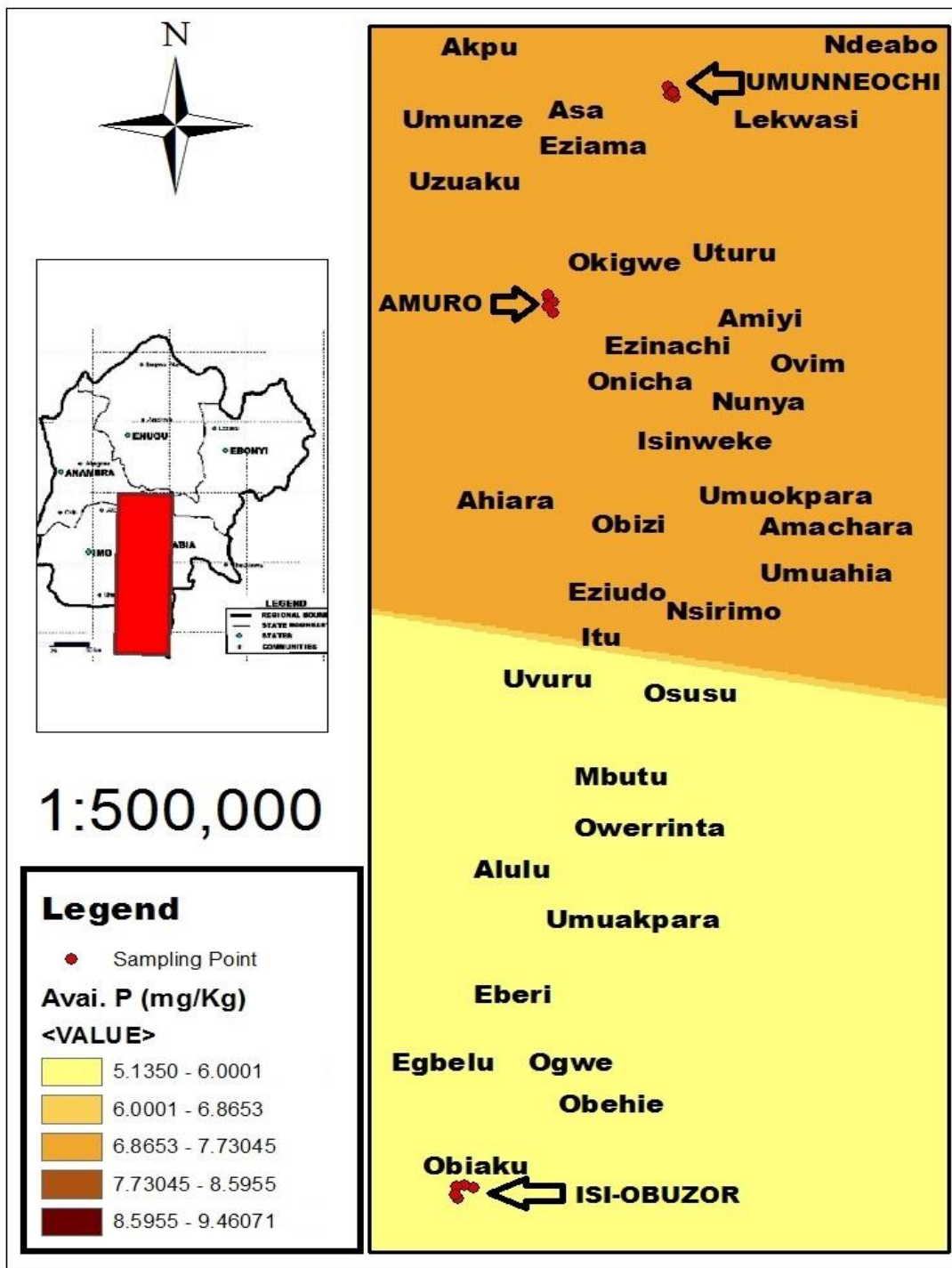


Figure 4.20: Kriged map of Available Phosphorous of the studied soils

Spatial distribution of BS showed (Fig 4.17) that BS was higher at the lower part (Isiobuzor course) and within the surrounding, Obehie, Ogwe, Eberi and Owerrinta compared to Amuro and Umunneochi . This is due to the altitude and parent material of the study areas.

Fig. 4.18 showed the map of soil organic carbon (OC) at the study area by interpolation via kriging. As indicated by the legend, organic carbon was higher at the upper part (Umunneochi) and decreased at the middle part (Amuro) down to the lower part (Isiobuzor). The soils of the lower part showed low concentration of OC indicating loss of organic matter which might be due to land use, and soil erosion in the area (Sun *et al.*, 2003). This implies that the agricultural production in this area would be significantly affected.

Fig. 4.19 kriging map indicated that concentration of TN was higher at the upper part (Umunneochi) and decreased down to the middle part (Amuro) and to Isiobuzor. The increase in Total Nitrogen at the upper part is an indication that soil quality improved in this area more than the other areas (Ogunwole *et al.*, 2010).

Kriging map of available phosphorous (Avail P) showed that the concentration of avail P at the upper part(Umunneochi) and middle part (Amuro) were higher and similar and thereafter decreased at (Isiobuzor). The homogeneity (similarity) of the colour at the upper part and middle part of the studied area could be related to the availability phosphorous in the studied area. The availability of phosphorous in the study area may be due to the presence of farm organic materials, green manure and animal manures which contains phosphorous increased by soil organisms making it easier for plant to use. The lower concentration of phosphorous at Isiobuzor may be due to fixation of phosphorous making it unavailable for plant to use.

4.6 Suitability classification

Showed that the temperature and pH of the studied areas Amuro, Umunneochi and Isiobuzor were moderately suitable. The rainfall, ECEC, salinity, Al³⁺ saturation and solidity of the studied areas were marginally suitable then the topography of the studied areas were highly suitable while the texture of Amuro and Umunneochi were highly suitable but for Isiobuzor that were marginally suitable. Then drainage of the studied sites of Isiobuzor was moderately suitable while Amuro was marginally but for Umunneochi were highly suitable. This could be as a result of the parent material and land use pattern.

TABLE 4.13: SUITABILITY CLASSIFICATION FOR TOMATO

CHARACTERISTICS	ISIOBUZOR	AMURO	UMUNNEOCHI
Temperature (°C)	S2	S2	S2
Rainfall (mm)	S3	S3	S3
Topography (Slope)	S1	S1	S1
Drainage	S2	S3	S1
Texture	N1	S1	S1
Ph	S2	S2	S2
ECEC	S3	S3	S3
Salinity	S3	S1	S2
Al st Saturation	S3	S2	S2
Sodicity	S3	S1	S1
Overall Suitability	N1	S3	S3

SI= Highly suitable, S2= moderately suitable, S3=Marginally, N1= Not suitable

TABLE 4.14: LAND CHARACTERISTICS OF THE STUDIED SITES

LAND/SOIL CHARACTERISTICS	IsiObuzor	Amauro	Umunneochi
Climate	-	-	-
Rainfall (mm)	2500	2300	1700
Temperature	29 ⁰ C	31 ⁰ C	26 ⁰ C
Relative Humidity	-	-	-
Drainage	Moderate	Moderate	Well drained
Topography (Slope)	1%	1%	1.5%
Soil depth	> 150	150-100	100-50
Texture	Loamy sand	Sandy clay	Sandy loam
pH	Moderate	Moderate	Moderate
OC (g/kg)	Moderate	Marginal	Moderate
AVP	Moderate	Moderate	Moderate

TABLE 4.15: SUITABILITY CLASSIFICATION OF CABBAGE

CHARACTERISTICS	ISIOBUZOR	AMURO	UMUNNEOCHI
Temperature (°C)	S2	S2	S2
Rainfall (mm)	S3	S3	S3
Topography (Slope)	S1	S2	S1
Texture	S2	S1	S2
Drainage	S2	N1	S1
pH	S2	S2	S2
ECEC	S3	S3	S3
Al st Saturation	S3	S2	S2
Sodicity	S3	S2	S2
Overall Suitability	S3 (c,f)	N1 (s)	S3 (c,f)

S1= Highly Suitable, S2= Moderately Suitable, S3= Marginally suitable, N1= Not Suitable.

TABLE 4.16: SUITABILITY CLASSIFICATION OF CUCUMBER AND WATERMELON

CHARACTERISTICS	ISIOBUZOR	AMURO	UMUNNEOCHI
Temperature (°C)	S1	S1	S1
Rainfall (mm)	S1	S1	S1
Relative Humidity	S1	S1	S1
Topography (Slope)	S1	S1	S1
Drainage	S2	S3	S1
Texture	S2	N1	S2
Depth	S1	S1	S1
Ph	S1	S3	S1
%BS	S1	S1	S1
Organic carbon	S2	S1	S1
Overall Suitability	S2 (c,f)	N1 (s)	S2 (c,f)

4.7 Land Suitability of the study area

4.7.1 Cabbage

The land suitability assessment of the study area revealed that the entire study area was marginally suitable for cabbage production. However, slight to moderate limitations ranging from climate and some soil chemical properties that affect the fertility of the soil. Texture was highly to moderately suitable soil characteristics in the study area while total rainfall, mean temperature, soil pH, ECEC, Al^{3+} Saturation and sodicity were areas of moderate limitations.

4.7.2 Tomato

The assessment of the study area also revealed that the soil-site suitability was moderately suitable for tomato production in Isiobuzor and Isuochi, but marginally suitable for tomato production in Amuro. Then, moderate limitations ranging from climate to soil properties that affect the fertility of the soil. Topography was highly suitable land characteristics in the study area, while other parameters were of moderate limitations, except texture of Isiobuzor that was not suitable for tomato production, and in Amuro and Isuochi where sodicity and texture were highly suitable.

4.7.3 Cucumber and Watermelon

The soil-site suitability assessment shown that the study area of Isiobuzor and Isuochi was slightly suitable for Cucumber and Watermelon while Amuro is moderately suitable for cucumber and watermelon production. However, texture was not suitable for soil characteristic, and drainage and soil pH were marginally suitable while in Isiobuzor, drainage, texture and organic carbon were moderately suitable for cucumber and watermelon.

4.7.4 LAND CAPABILITY CLASSIFICATION RESULT

CHARACTERISTICS	CLASS I	CLASS II	CLASS III	CLASS IV
Slope(%)	0-1		3-8	8-5
Erosion	Nil		Moderate	Moderate
Depth	>150		100–50	50-25
Texture	Loam		S1	SC1
Soil Reaction	6.2		5.5	N3
Permeability	Moderate		Rapid slow	Very Rapid Slow

CLASS I: Isiobuzor= Soils have slight limitations that restrict their use.

CLASS II: Umunneochi= Soils have severe limitations that restrict the choice of plants or that requires special conservation practices or both.

CLASS IV: Amuro= Soils have very severe limitation that restrict the choice of plants or that require very careful management or both.

4.8 Soil Classifications

The data obtained from the field study and laboratory analyses were used to classify the soils according to the USDA Soil Taxonomy System (Soil Survey Saff, 2010) and then correlated with World Reference Base(WRB).

Pedons were placed in a particular order, suborder, great group and sub-groups based on the presence of diagnostic horizons, properties associated with moisture regime, horizon features and their arrangement.

Order: Results showed that the soils of Amuro and Umunneochi had higher content of organic matter, while Isiobuzor had moderate content of organic matter and these decrease down the profile pits. The five (5) pedons of Isiobuzor and the five (5) pedons of Umunneochi in Abia State showed evidence of Argilic (Bt) horizons and Amuro in Imo State showed Cambic (Bg) horizons which classified them in the Alfisols order(soil survey

staff, 2010) with Base saturation greater than 35 percent (BS > 35%). Salchow et al., 1996., Bruand et al., (2003) explained that soils of Umunneochi and Isiobuzor as having “low content of clay” although all the pedons possess Udic soil moisture regime and were consequently placed in the suborder

Suborder: Udalfs because the soils had argilic and kandic horizons (low CEC of the clay <17cmol/kg) that did not have a densic, lithic paralithic contact within 150cm of the mineral soil surface therefore the soil were classified as at great group level as Hapludalf.

Sub-Group: All soil of the study areas had slight sand particle size class between 0.17cm deep. The soils were therefore at Sub-Group level as Oxyaquic Hapludalfs (FAO/ WRB).

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary.

A Geographic Information System (GIS) was employed as a technology mapping tool of selected soils of different parent materials for crop production (Tomato, cabbage, cucumber and water melon) in selected local government areas of Imo and Abia State, Nigeria, comprising Isiobuzor, and Isuochi of Abia State and Amuro of Imo State. A free survey technique guided by geological and location map of the areas was used in situating soil profile pits. All the profiles were geo-referenced by hand held Global Position System (GPS) receiver. Five (5) profile pits were dug in each of the three (3) dissimilar lithologies, giving a total of fifteen (15) profile pits. Pits were dug, described and sampled. Sampling was done base on the horizon differentiation (FAO, 2006). Detailed description of each horizon was carried out and attributes described included soil structure, consistence, colour, root development, faunal activities, boundary distinctiveness, etc. and these were written against each horizon in the proforma for the pits. Undisturbed soil samples were collected using core samplers for bulk density and moisture content determination. Soil colour of genetic horizon was determined in-situ using Munsell colour chat. A total of seventy-two (72) samples were collected from the fifteen (15) profile pits. The samples were stored in sampling bags, properly labeled, transported to the laboratory and air-dried for laboratory analyses. Routine laboratory analyses were carried out and ordinary Kriging was used to predict each soil properties while some selected soil properties were used for suitability classification. Results were presented in Tables and chats. Results were also subjected to coefficient of variation and correlation was used to determine the relationship among soil physio-chemical properties.

Results showed that soil textures of Isiobuzor were loamy sand, Amuro were sandy clay and Isuochi were sandy loam. Results also showed that Amuro and Isiobuzor had high percentage clay content. In Amuro, the percentage of sand content, total porosity and moisture content were significantly high with available phosphorus, ECEC and total nitrogen at $p = 0.01$. In Isuochi, total porosity was highly significant with available phosphorus, organic carbon and total nitrogen at $p = 0.01$. The results also showed that in Isiobuzor, the bulk density was negatively significant with percentage moisture content at $p = 0.01$ while sand content was positively correlated with percentage base saturation and total exchangeable bases at $p = 0.01$.

Results also showed that the soils were acidic with low variability through the profiles. The results also showed that Isuochi was highly suitable for cucumber and water melon production while Isiobuzor was moderate and Amuro was marginally suitable for cucumber and water melon production. The study showed that GIS can successfully be used to predict results and this can help to reduce work. GIS can help to determine variation between and within parent materials.

Conclusion:

- i. The soils were generally low in most parameters and are therefore rated low in fertility.
- ii. Soils of the study areas are classified as Typic Endoaquoll for Amuro and Typic Hapludalf for Isuochi and Isiobuzor respectively.
- iii. Cucumber and watermelon can be gainfully produced in Isiobuzor and Isuochi.

5.2 Recommendations

Based on the findings of this study, amendment of the soils adopting a balance use of inorganic and organic nutrient sources would be necessary for sustainable use of the soils especially the soil of Isiobuzor to enhance the fertility status while the soils of Isuochi is suitable for CUCUMBRE and WATERMELON production.

(2) I recommend that because of the critical nature of the soil texture of Amuro which made it not suitable for any of these essential crops, that conservative practices which encourage adequate cover of the soil surface such as mulching, cover cropping, planting terraces and shifting cultivation should be encouraged in the area.

(3) In Soil studies geographic information system(GIS) technique should be embraced especially the use of kriging methods to improve the decision for field management practices.

(4) Uniform soil management practices should be discouraged in Isiobuzor, instead soil management should be location specific or site specific.

(5) Cucumber and water melon should be cultivated in the study areas, especially in Isuochi where soil and land suitability is higher while some soil parameter should be adjusted to favour the option of yield of cucumber and water melon in Isiobuzor.

(6) Further studies should be carried out to ascertain the rate of soil and land suitability especially through the use of GIS as this will help the local farmers to make better and precise decisions for their farm produce.

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APPENDIX 1

STRUCTURE GRADE	CLASS	TYPE
Structureless = (1)	Very fine = vf	Platy =pl
Weak =1	Fine =f	Prismatic = pr
Moderate = 2	Course = c	Columnar = col
Strong = 3	Medium = m	Granular =gr
	Very course = vc	Angular blocky = abk
		Sub-angular blocky = sbk

ROOTS AND FAUNA ACTIVITY CONSISTENCE (MOIST)

BOUNDARY	TOPOGRAPHY		
Few = f	Loose = l	Abbroat = a	Smooth = s
Many = m	Friable = fr	Gradual = g	Irregular = i
Abundant = abt	Very friable = vfr	Clear = c	Broken = b
Very few = vf	Firm = fi	Diffuse = d	Wavy = w
	Very firm = vfi		

TEXTURE

Clay S = Sand	Sil = Silk loam	SiCL = Silty clay loam
LS = Loamy Sand	Si = Silk	SC = Sandy clay
SL = Sandy foam	SCL = Sandy clay loam	C = clay
L = Loam	CL = Clay loam	SiC = Silty clay

Soil nutrient interpretation according J. Landon (1991)

Nutrient	Low	Moderate	High
Nitrogen (%)	<0.2	0.2-0.4	>0.5
Phosphorus (ppm)	<10	10-25	>35
Potassium cmol/kg	<0.5	0.5-0.8	>2.0
Calcium cmol/kg	<1	1-3.0	>5.0
Magnesium cmol/kg	0.5	0.5-1.5	<1.5
Organic carbon (%)		>3,5	
pH		5.5-7.5 suitable for most crops	

APPENDIX II































