CHANGES IN LAND USE AND SOIL QUALITY UNDER URBAN LAND USE TYPES IN AKURE AND OKITIPUPA, NIGERIA

BY

AYODELE OLUMIDE ADELANA
Matric. No. 124639

B.Sc. (Geology) (Ife), M.Sc. Agronomy (Soil Science) (Ibadan)

A Thesis in the Department of Soil Resources Management, submitted to the Faculty of Agriculture in partial fulfillment of the requirements for the Degree of

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CERTIFICATION

I certify that this work was carried out by Mr. Ayodele Adelana in the Department of SoilResources Management, University of Ibadan, Nigeria.

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Supervisor
E. A. Aiyelari
B.Sc. (Agric Eng.), M.Sc., Ph.D. (Ibadan)
Professor of Agric. Engineering and Mechanization,
Department of Soil Resources Management, University of Ibadan, Nigeria.

DEDICATION

This work is dedicated to God and to my wife Mrs. Oluwatosin Adedotun Adelana.

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ABSTRACT

Urban soil quality is influenced by anthropogenic activities, which can adversely affect sustainable land use. Soil Quality (SQ) assessment can assist in early detection of adverse effects of urban land use. However, limited information is available on influence of land use and effective methods of assessing SQ for urban areas. Therefore, this study was carried out to determine land use changes over a 32-year (1984-2016) period in Akure and Okitipupa and to assess the SQ of the Urban Land Use Types (ULUTs).

Satellite imageries of Akure and Okitipupa from Landsat Thematic Mapper and Enhanced Thematic Mapper were analysed to investigate land use changes using maximum likelihood classifier. Soil quality associated with ULUTs - commercial, urban agriculture, wetland, residential and institutional were assessed in 2016 using Weighted Additive Quality Index (SQI_{wa}), Statistically Modeled Index (SQI_{sm}) based on principal component analysis and Soil Environmental Quality Index (SEQI). Data were analysed using descriptive statistics and ANOVA at $\alpha_{0.05}$.

In 1984, the area covered by built-up areas, forest, water bodies and farmlands at Akure were 18, 239, 35 and 19 km^2, whereas, in 2016 the corresponding areas changed to 72, 112, 63 and 64 km^2, respectively. At Okitipupa, the respective area covered changed from 60, 298, 10 and 29 km^2 in 1984 to 206, 107, 34 and 50 km^{2}respectively, in 2016 indicating that larger area of forest land was converted to built-up areas at both locations. The SQ indices (SQI_{wa}, SQI_{sm} and SEQI),were significantly different among the ULUTs, and wetlands had the highest ratings at both Akure and Okitipupa. At Akure, the SQI_{wa} ranged from 0.35±0.02 (residential) to 0.59±0.02 (wetland), and from 0.31±0.01 (institution) to 0.63±0.02 (wetland) at Okitipupa. The SQI_{sm} ratings were in the order of residential (0.49±0.02) < commercial (0.56±0.02) < institution (0.64±0.02) < urban agriculture (0.81±0.02) < wetland (0.90±0.03) at Akure. However, at Okitipupa, $SQI_{sm}$was in the order of institution (0.46±0.01) < commercial (0.48±0.01) < residential (0.54±0.01) < urban agriculture (0.59±0.02) < wetland (0.73±0.02). Compared to wetlands, SQI_{sm} was significantly lower by 45.5, 10.0, 37.8 and 28.9% in residential, urban agriculture, commercial and institution, respectively, at Akure. At Okitipupa, the respective decrease in SQI_{sm} were 26.0, 19.2, 34.2 and 40.0% when compared with wetlands. The SEQI ratings at Akure differed significantly among the ULUT and ranged from 0.50±0.01 (commercial) to 0.66±0.02 (wetland). The SEQI were in the order of commercial (0.50±0.01) < residential (0.54±0.01) < institution (0.55±0.01) < urban agriculture (0.64±0.02) < wetland (0.66±0.02). On the other hand, SEQI ranged from 0.47±0.01 (commercial) to 0.63±0.02 (wetland) and was in the order of commercial (0.47±0.01) < institution (0.49±0.01) < residential (0.54±0.01) < urban agriculture (0.56±0.01) < wetland (0.63±0.02) at Okitipupa.

Akure and Okitipupaexperienced steady changes in land use and cover during the 32-year periodresulting to reduction in soil quality.

Keywords: Change detection, Urban soils, Soil quality rating, Environmental quality

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CHAPTER 1

INTRODUCTION

1.1 Background to the Study

Urbanisation resulting from the conversion of other land use types (LUTs) such as agricultural land use to uses related to population and economic growth, is animportant type of land use (Marcotullio *et al.*, 2008). This land use, can impact the environment greatly. As at the year 2011, the population of people living in cities and towns were more than 50% of the entire world population, and it is expected that this trend will increase for the foreseeable future(UNDP, 2011). Accelerated urban growth, coupled with increasingrates of poverty has necessitated the need for sustainable agriculture in sub-Sahara Africa (SSA). Although,a substantial number of people in SSA live and work in rural communities, the 3.5% annual urban growth recorded during the last two decades was highest in the entire world and thusa reason for concern (AfDB, 2012).In Nigeria, there are more cities with over a million people than any other country in Africa, and, as the urban environment continues to sprawl, the country will have to take into cognizance the impact of urbanisation in her development strategic plans (Bins*et al.*, 2003).

Urban soils are soils that can be found in built-up and industrial areas (Rossiter, 2007). According to Bins*et al.* (2003), soils within the confines of a city are usually more prone to human disturbance when compared with soils in the rural areas. Soils in urban areas can be said to be either anthropogenic soils, formed mainly through human activities or natural soils that have not been subjected to human activities but in some cases have been contaminated by dust (Rossiter, 2007). Urban soils are important in maintaining environmental quality as they serve as sink for pollutants that are dangerous to human health (Oluwatosin *et al.*, 2010). Apart from maintaining environmental quality, urban soils are also used for urban agriculture (UA). In the recent past, agricultural activities in urban areas have spread rapidly and it has significantly contributed to people’s livelihoods (Bins*et al.*, 2003). Orsini *et al.* (2013) reported that about a 100-200 million people in the world are involved in one form of commercial or subsistent agricultural production within urban spaces. On the other hand, Akinmoladun and Adejumo (2011), reported that some 800 million city dwellers worldwide are involved in urban agriculture, collectively producing close to 15% of the world's population food. Despite the contrasting number of people reported to have been engaged in urban agriculture, its role in achieving food security is gradually becoming significant. For instance, not less than 25% of vegetables consumed in Oyo and Lagos states were produced from urban agriculture (Akinlade *et al*., 2013). In Nasarawa state, Salau and Attah (2012) reported that urban agriculture contributes about 74% of the total annual income of urban farmers involved in vegetable and fruit cultivation. Bins*et al*. (2003) opined that urban agriculture provides valuable resources for addressing the challenges of nutrition, household food security, and employment in Kano and other sub-Sahara African cities, especially among the low-income urban dwellers.

Due to its critical position in ensuring the long-term sustainability of a soil resource for a particular land use, soil quality assessment is becoming increasingly important. Soil quality assessment entails determining the overall soil ecological functions, by selecting soil properties as indicators, measuring these properties, and calculating an index or ranking for the individual properties as well as the whole soil (Andrews *et al*., 2004). The soil quality index (SQI) is a reflection of soils' properties, functions and the interactions of these properties and functions within the soil (Karlen *et al*., 2001).In order to calculate SQI, using Andrews *et al*. (2004) Soil Management Assessment Framework, a selection of indicators is identified, graded, and then averaged based on subjective expert judgment and literature review.

1.2 Statement of the Problem

With the increasing competition on natural resources, peri-urban areas are being transformed,thusresulting in environmental degradation. Adepoju *et al*. (2006), in their studies in metropolitan Lagos, reported that 35.5% of forest and agricultural lands were lost to urbanisation between 1984 and 2002. Also, Akinbola and Fagbami (2000), Mamman and Liman (2014) and Adewumi *et al*. (2016)reportedthat 14.0, 10.4 and 28.3% of agricultural lands and natural forest have been converted to other land use types associated with urbanisation in Ibadan, Ilorin and Igbokoda, respectively.The need for optimum use of land through adequate and effective planning has never been greater than at present, when rapid population growth and urban expansion are making available agricultural land scarce.

Urban soils are sometimes contaminated with pesticides, domestic and industrial wastes. Construction activities can alsolead to soil structural degradation, compaction, and impeded hydrological functionson urban soils (Beniston*et al.*, 2016),therefore the need to study these soils becomes imperative.Most soils, once degraded as a result of inappropriate use, suffer irreparable damage or are, at best, rejuvenated at very exhorbitant cost. In order to prevent or minimise these adverse developments and protect the remaining urban soils in area of growingpopulation densities, there is need to monitor changes in soil quality. In trying to understand the impact of humans on urban soils, emphasis in most cases is laid on heavy metal contamination (Oluwatosin*et al*., 2010, Nwachukwu *et al*., 2011) and in few cases, some selected physical attributes of the soil (Gbadegesin and Olabode, 2000, Aiyelari and Oshunsanya, 2008). Moreover, information on the set of indicators necessary for monitoring of soil quality changes especially in Akure and Okitipupa, is lacking. However, with the use of multivariate statistical tests such as principal component analysis and multiple correlation, the number of these indicators will be reduced, amounting to reduction in the cost of assessment and elimination of possible bias associated with weight values assigned to each soil function. Therefore, in the face of the increasing role urban soils play in addressing food security, studying them becomes imperative such that asides the health implication on man, environmental quality is also maintained.

1.3 Objectives of the Study

The main objective of this study is to determine the changes in soil quality resulting from urban land use changes in Akure and Okitipupa in order to maintain environmental conservation. The specific objectiveswere to:

1. Identify the different land use/land cover typesand their changes, in Akure and Okitipupaover athirty-two-year period (1984–2016).
2. Assess the characteristics of the soilsassociated with the identified major land use/cover types in the towns.
3. Determine the set of indicators for assessing soil quality ofurban soilsin the study areas.
4. Determine the most appropriate soil quality index for urban soil management.

1.4 Justification of the Study

With the competing need for land on the increase in rapidly developing towns such as Akure and Okitipupa, the need to monitor land use/cover changes is becoming increasingly important. The use of remote sensing has aided in the study of changes in land use/cover such that maps produced from this method if are to be considered accurate representation must be subjected to accuracy evaluation. Previous efforts by Adewumi*et al*. (2016) in Igbokoda and Balogun *et al*. (2011) in Akure did not assess the accuracy of the land use/cover change maps they produced using remote sensing. Therefore, with the evaluation of the Kappa statistics and overall accuracy in this study, the reliability of the land use/cover maps produced for Akure and Okitipupa can be ascertained.

The analysis of urban soils in towns like Akure and Okitipupa is critical for determining the environmental effects of urbanisation.The processes of town establishment and growth, slow as it may seem, can lead to irreversible changes in the properties of urban soils. This is in the face of the continuous dwindling of good agricultural soils due to population explosion and stiff competition from non-agricultural uses. Thus, in towns like Akure and Okitipupa, the usual function of soil as an environment for floral and fauna population including roots can be greatly restricted. Moreover, information on the overall quality of these urban soils are scanty.Olorundare*et al*. (2011) in an attempt to study the urban soils of Akure were only able to identify the heavy metals that impacted soil quality with no information on the physical and biological indicators of soil quality.Similarly, Oluwatosin *et al*. (2010) when studying some urban wetlands did not consider the overall soil quality of these soils but restricted their study to heavy metal contamination.These urban soils play important roles in maintaining environmental quality, human health and achieving food security. Hence, information on urban soil qualities of Akure and Okitipupa are necessary for land use planners and state government to developing sustainable soil management strategies that will not only ensure environmental protection, but also human safety and wellbeing.

1.5 Scope of the Study

With the rapid growth of industrialisation and commercial activities in Akure and Okitipupa of Ondo State, agricultural and forested lands may not be exempted from encroachment. This work is limited to Akure and Okitipupa in Ondo State to carry out studies that will assist land use planners in emerging cities where the impact of urbanisation is not yet pronounced.In addition, information on the overall soil quality of urban soils from different parent materials viz: basement complex (Akure) and sedimentary parent material (Okitipupa) will further help in developing sustainable soil management strategies.

CHAPTER 2

LITERATURE REVIEW

2.1 Land Use and Land Cover

The use of land like any other inventoried land characteristics, is a function of frequency and distribution. It entails the modification and management of natural ecosystem into built ecosystem such as urban infrastructure and natural habitats such as pastures, arable fields, and forestlands. Land use, according to Campbell (1983), is any form of permanent or cyclic human intervention on land, especially when the focus is on the economic returns obtained from land.Watson *et al.* (2000)defined land use as the entire organization, activities, and inputs occurring in a given land cover type i.e. physical or biological cover types. Also, land use can be said to concern the outputs or benefits resulting from human activities such as the land management deployed that will produce those benefits and outputs (Marcotullio *et al.*, 2008).

Anderson *et al.* (1976) categorized land use in their broadest categoryinto the following:

a. Urban which includes residential, industrial, institutional, commercial, transportation, recreational and mixed urban uses such as urban agriculture;
b. Agricultural land use i.e. cropland, pastures, orchards and plantation;
c. Rangeland;
d. Forests and woodland;
e. Water bodies such as rivers, lakes, streams, ponds and dams;
f. Wetland;
g. Barren land e.g. rock outcrop;
h. Tundra; and
i. Perennial snow or ice.

As at the early 90s, approximately 13% of the earth's land mass was used for arablecultivation, with about 26% put into pastoral use, 32% forests and woodland, while 1.5% was put to built-up or urban use (Grubler, 1994).The World Factbook (2011), reported that 44.7% of the total land area in Nigeria is used for arable and permanent crops cultivation, 33.3% for pastures, 9.5% is used for forest, while others (among which is built-up) account for 12.5%.Land use dynamics in a developing country like Nigeria can be said to be a product of a number of interactive forces dictated by economic considerations, societal values, and cross-cultural differences (Akinbola and Fagbami, 2000). In trying to overcome the issues related to uncontrolled and haphazard physical development, loss of prime agricultural lands and the ever-deteriorating environmental quality in Nigeria, information on the right use of land has become important.

According to Meyer and Turner (1992), land cover can be said to be the assemblage of abiotic and biotic observation on the surface of the earth. These observations may include grasslands,shrublands, croplands, forests, waterbodies and built-up areas. It can be said that land cover is the visible representation of land use (Giri, 2012). In a nutshell, land cover is the physical cover observed, whileland use is the purpose to which a land is being used.

2.2 Urban Land Use

Land use in urban areas are very dynamic and prone to changes at an alarming rate. According to Marcotullio *et al.* (2008), urban land use, which includes the built-up environment, accounts for about 3% of the earth's land surface.The expansion of cities, is usually accompanied by two features. These are the outward spread of the city with its impact on agricultural activities and the environment, and the intensification of the land use within the city with the resultant modifications of soils and urban land use structures (Akinbola and Fagbami, 2000). Recently, attention has been drawn to the environmental impacts of human activities in the cities on the distruption of geochemical cycles and the biosphere. An area of great concern has to be the impact of urban land use on the environment viz: water, air, and soil. Of these, soils have received increased attention (Marcotullio *et al.*, 2008). With the increasing growth in population, coupled with advancement in urbanization, the demand for land for various uses especially in the urban centres has increased. This increasing demand has exacerbated the pressure on conflicting demands for land. According to Grubler (1994), urbanization outbids all other uses for land adjacent to the city, including prime agricultural lands in less developed countries such as Nigeria. This has led to the conversion of these lands to others uses associated with urbanization, with its resultant effects on environment not being addressed.

Nigeria has several urban centres, the majority of which are poorly planned or unplanned at all, causing severe environmental and human damage. There is a lack of evidence on the effect of anthropogenic activities on the properties of urban soils and the processes that occur in them (Beniston and Lal, 2012; Hagan *et al.*, 2012). But soil management techniques commonly used on agricultural soils are now being used on urban soils (Lorenz and Lal, 2009; Oluwatosin *et al.*, 2010). For example, Oluwatosin *et al.* (2010), observed that continuous contaminant monitoring of urban valley bottom soils in cities is necessary in ascertaining the health status of consumers of vegetables grown within urban spaces, and domestic grazers. Similarly, Bins*et al.* (2003) using empirical evidence from Kano in northern Nigeria suggested that collaborative research involving key stakeholders such as agricultural scientists, urban planners, and health specialist would help in developing sustainable management practices within urban environments. Vrscaj *et al.* (2008), reported that the principles of soil evaluation based on soil quality indicators from agricultural soils, can be applied to soil quality evaluation in all soil relatedenvironments, including the urban environment. As a consequence, information on environmental quality is necessary when evaluating the sustainability of urban environments (Grimm and Redman, 2004).

2.3 Concept of Urban Soil

According to Hazelton and Murphy(2011), the study of urban soils has increased over the years, although the number of studies and the volume of information on urban soils is still low when compared with agricultural soils.Since urbanization has resulted in the creation of urban soils, their occurrence can be said to be exclusive to the urban area.Soils in the urban environment are characterized by Hollis (1991) as an organic material or unconsolidated mineral contained on the earth's surface that can support plant growth. Urban soil, according to Craul (1992), is any soil substance with a non-agriculture, man-made surface layer greater than 50 cm thick, created by mixing, filling, or pollution of ground surfaces in urban and peri-urban areas.

Evans *et al.* (2000) was able to expand the scope of the definition of urban soils to include all soils that had undergone one form of human alteration irrespective of the location thereby removing the geographical restriction of earlier definitions. This broad view of urban soils was also held by other authors that included undisturbed soils that had been altered by climatic elements such as moisture and temperature (Pouyat and Effland, 1999; Lehmann and Stahr, 2007). From these definitions, it is evident that some amount of anthro-pedoturbation is involved in the formation of urban soils. But according to Effland and Pouyat (1997), a more restrictive formation process of urbanthro-pedoturbation can be associated with urban soils. This process is describedas any non-agronomic activity initiated by humans that affects the composition and genesis of soil.

Non-agronomic human activities have a number of impacts on soil genesis and related soil characteristics, depending on the degree and rate of disruption. Surface extraction, urban waste collection, and road building may all have a significant impact on soil pedogenesis. The rate and degree of soil formation can be influenced by the addition of cut and fill earth materials or anthropogenic objects such as broken mortar and glass, ashes, and crushed stone. In addition, indirect effects such as soil hydrophobicity (Craul, 1992), deposition of pollutants from the atmosphere such as heavy metals (Murray *et al*., 2004), and organic chemicals (Wong *et al*., 2004) play important roles in soil formation in the urban environment.

2.4 Categories of Urban Soil

According to Lehmann and Stahr (2007), anthropogenic soils are categorized into three based on the degree of disturbance in their formation process. The categories are:

"Man-influenced soils" These soils lack artefacts or contain a few and are essentially disturbed soils that are characterized by mingling of soil horizons. Man-influenced soils are formed by mixture of materials by man through processes such as excavation, transportation and deposition. The properties of these soils are mainly inherited from the fill materials and they show weak profile development. *"Man-changed soils"* Man-changed soils usually exhibit high alkalinity and high soil organic matter content coupled with high coarse fragments (Lehmann and Stahr, 2007). In these soils, there is an increase in age with increase in depth. *"Man-made soils"* These soils are formed solely from artefacts or materials resulting from human activities such as rubbles, ash, wastes and spoil. They are usually transported soils with soil properties mainly inherited from the anthropogenic parent materials.

2.5 Classification of Urban Soil

Mapping of soils has usually been carried out on agricultural soils, and when studying soil formation and behaviour (Rossiter, 2007). But recently, mapping of urban soils has increased with the advancement in the role urban environment play in human wellbeing and the increasing importance of the ecological services offered by these soils.

Due to the high functionality of soils in the urban environment, a practicable taxonomy for urban soils is necessary for the identification and management of urban soils. One of the earliest classifications of urban soils is that of Avery (1980), who categorized the soils into disturbed and humic anthropogenic soils.

According to FAO (1998), urban soil classification correlates with the World Reference Base for Soil Resources (WRB) as Anthrosols and Regosols Reference Soil Group (RSG). Anthrosols are soils that have undergone major modifications due to anthropogenic processes or burying of the initial soil horizons, as a result of anthropogenic organic material inputs. Anthropedogenesis, which involves extensive fertilization, deep, persistent mechanical activities, and addition of extrinsic material or sediment ladenwater through irrigation, is the most common soil forming process for Anthrosols (FAO, 1998). Regosols on the other hand are recently exposed, earthy materials. They are weakly developed and therefore lack soil characteristics arising from typical pedogenic processes (Effland and Pouyat, 1997).

In 2006, the International Union of Soil Sciences working group WRB proposed the Technosols RSG to represent urban soils that are strongly influenced by human activities (FAO *et al.*, 2006). The Technosols are characterized by high content of artefacts, presence of a constructed impermeable layer such as a pavement. In a modification to the FAO (1998) classification of urban soils, Rossiter (2007), also proposed that soils with substantial anthropogenic influence are to be classified as Technosols.

It should be noted that urban environment contains other soil types (i.e. asides Anthrosols, Regosols and Technosols). These soils are usually found in unbuilt areas and parks where they show significant effects from their urban environment (Rossiter, 2007). In such situations, there are qualifiers that explains the anthropogenic effects in these soils. For example, Densic for strong compaction, Toxic for contaminated soils, Garbic for soils with municipal organic waste and artefacts and, Urbic for soils with rubble and refuse from human settlements (FAO *et al.*, 2006).

2.6 Characteristics of Urban Soils

According to Martellozzo *et al.*(2014), urban soils exhibit high spatial variability because of the different influences on its formation resulting from human activities. Theseactivitiesinclude but not restricted to addition of organic waste, source point pollution, rapid land use changes, and landscaping (Jim 1998). Urban soil characteristics vary widely and can exhibit properties close to those of natural soils or differ significantly in their properties. Marcotullio *et al.* (2008) summarized the properties of urban soils as given in Table 2.1.

2.6.1 Vertical and spatial variability

In contrast to what is observed on natural soils, horizonation in urban soils is usually not parallel to the surface of the soil. A typical profile of an urban soil is characterized by broken horizons leading to marked vertical variability.The degree of non-agricultural human disruption and the processes that affect it can be seen in the heterogeneity of urban soils (Effland and Pouyat, 1997). When discussing the vertical and spatial variability observed in urban soils, Craul (1992) pointed out that due to anthropogenic activities, urban soils exhibit short ranged soil horizonation or lithologic discontinuity. Craul and Klein (1980) reported this short-range vertical change to be between 6 and 35 cm on some urban soils in New York City. Also, Gbadegesin and Olabode (2000) reported a man-made surface layer produced by mixing, covering and contamination of the original natural soil by non-soil materials in the urban area of Ibadan to be about 30 cm thicker than what is obtained in the rural zone.

Asides vertical variability, urban soils also exhibit complex lateral/spatial variability that has great impact on the rooting zone of plants. There is greater and less predictable spatial variability in urban soils due to intensive human activities. For instance, there are significant spatial variabilities in the values reported for soil bulk density in urban soils. These values range from a very low bulk density of less than 0.8 g cm^{-3} to very high values that are greater than 1.85 g cm^{-3} (Pouyat *et al.*, 2007). Also, urbanization has led to increased spatial diversity in urban soils. The diversity can be seen in locations where freshly altered soils are found in close association with older natural soils (Craul, 1992). This situation was observed by Jim (1998)when studying profiles of urban soils from Hong Kong where regolith of weathered granite occurred closely with construction rubbles.

In urban soil profiles, it has been observed that large heterogeneity can also occur within a soil horizon. Gbadegesin and Olabode, (2000) reported that the depth at which heterogeneity occurs in horizons located in metropolitan region of Ibadan, Nigeria, was almost 15 times more than that of rural soils.To therefore understand the formation of soils within the urban landscape, prior knowledge about the past building history and information on land use pattern are necessary.

Table 2.1: General characteristics of urban soils

General characteristics of urban soils	Causes	Problems
Vertical variability	Anthropogenic sources result in layers of different materials.	Discontinuity in layers for burrowing soil organisms and rooting plants.
Compaction	Human traffic and pressure from vehicles.	Reduction in volume of water and air pores. Plants produce shallow roots.
Impeded water drainage	Loss of soil structure thereby interrupting natural movement of water through the soil.	Reduction in plant available water and increased runoff leading to flooding.
Crusting and water repellency	Chemical dispersion and compaction.	Creation of impermeable barriers to water and gas exchange.
High soil temperature	Higher ambient air temperature and little buffering effect from vegetal cover.	Reduced plant available moisture at the soil surface.
Contaminants	Indiscriminate disposal of municipal waste, effluents from industries and vehicle emissions.	Contamination of food chain and ground water with heavy metals.
High pH	Resulting from calcareous building materials.	If soil is too alkaline, phosphorus immobilization may occur thus nutrient deficiency for plant growth.

Source: Marcotullio *et al*. (2008)

2.6.2 Structure modification and compaction

The formation of the soil structure is a result of soil pedogenesis. The aggregation of individual soil particles will lead to increase soil volume thereby reducing soil bulk density. This aggregation will favourably influence soil aeration, root penetrability and water permeability. Contrary to this, prevailing conditions in most urban soils are predisposed to the destroying and prevention of good soil structure formation. These conditions include low concentration of soil organic matter that will lead to little or poor aggregate formation, and drastic reduction in aggregate formation by soil microbial activities (Pouyat *et al*., 2002).

Another characteristic of urban soils is compaction. Compaction occurs when the volume of pores in a soil are reduced. Thereduction in pores leads to inhibition in drainage, aeration, and root volume. Urban soils are subjected to compressive forces that contribute to this compaction (Scharenbroch *et al*., 2005). According to Craul (1992), conditions that could result in compaction are:

(i) In urban soils, there is collapse of soil structure resulting in compaction which could be exacerbated by the lack of tillage.

(ii) In urban soils, the low organic matter content limits aggregation.

(iii) Due to the low soil organic matter content, activities of both macro and micro-organisms that promotes aggregation and increased porosity are limited.

(iv) Destruction of vegetal cover due to human activities has exposed urban soil surfaces to compression, while also limiting the cohesive forces of plant roots on soil particles.

The bulk density of a soil is an indicator of how compacted it is. Scharenbroch *et al*. (2005) measured bulk density from the surface horizon of certain metropolitan soils in Idaho and Washington, USA, with values ranging from 1.39 to 1.74 g cm^{-3}. Pouyat *et al*. (2007), found bulk density values of 1.74 g cm^{-3}for surface soils in metropolitan district of Baltimore, USA. These are significantly large values when compared with agricultural soils. Beniston *et al*. (2016),also measured bulk density with high values of 1.37-1.99g cm^{-3}with anaverage of 1.79 g cm^{-3}from degraded urban soils used for urban agriculture in Ohio, USA.Jim (1998) found similar levels of 1.6 to 1.8 g cm^{-3} in tropical urban soils in Hong Kong.Gbadegesin and Olabode (2000) from Ibadan, Nigeria, recorded urban soil bulk density of 1.05-2.18 g cm^{-3}. Despite the fact that some of the bulk densities reported from Nigeria were smaller than those seen in developed countries, they were nevertheless higher than those found in rural agricultural fields and peri-urban regions.

2.6.3 Restricted water drainage and aeration

The decrease in total porosity due to loss of macropores resulting from compaction is a problem encountered on urban soils. These macropores serve as channels through which movement of water and gases occur after gravitational water flow. According to Pitt *et al*. (2008), compaction has a significant impact on the rate of water infiltration into the soil and, as a result, runoff water produced in urban areas. This is so because the total porosity of a soil is inversely proportional to the level of compaction. Asides the reduction in plant available water content, urban environments generally have lower water tables when compared with other less disturbed environment (Scalenghe and Marsan, 2009). Restricted water drainage and aeration in urban soils has obvious serious repercussions on neighbouring areas. Due to the speed and amount of stormwater generated from compacted and sealed urban areas, neighbouring natural soils are therefore prone to erosion.

Furthermore, flooding has been an environmental issue during the rainy season within the urban landscape especially in areas with poor drainage facilities. This is due largely to the large amount of compacted and sealed soil surfaces in urban areas. When comparing the rate of infiltration on urban and arable soils in their study, Dornauf and Burghardt (2000) reported that the infiltration rate on the urban soil was significantly lower than what obtained on the arable soil due to compaction of the surface soils in the urban area. Hasse and Nuissl (2007), conducted a study in Leipzig, Germany and reported that between 1940 and 2003, surface runoff water increased by more than 100% because of the increase in sealed areas thereby resulting in restricted water drainage. Yang and Zhang (2011) working on soils in Nanjing city, China observed a decrease in infiltration rate due to increase in bulk density resulting in an increase in storm water runoff. Similar results have also been reported from USA (Choi and Deal, 2008), UK (Perry and Nawaz, 2008) and Ibadan, Nigeria (Akinbola and Fagbemi, 2000). As a result, soil infiltration is critical to water movement and therefore a critical indicator of a soil's ability to manage water.

2.6.4 Modified soil organism activity and interrupted nutrient cycling

When compared with natural soils, nutrients, and soil organic matter cycling are generally lacking in urban soils. Urban soil organic matter (SOM) contents are highly variable, and in most cases compacted urban soils are low in soil organic matter content (Scharenbroch *et al*., 2005). Some studies reported lower soil organic matter content from urban soils when compared with soils of other systems (Jo, 2002; Scharenbroch *et al*., 2005). Scharenbroch *et al*. (2005) reported that urban soil organic matter contents from Idaho and Washington, USA was < 1.0 g kg^{-1} soil when compared with forest soils that had 4–5g kg^{-1} soil, and some agricultural soils that were > 10g kg^{-1} soil. Similarly, some urban soils from South Korea had lower percentage of soil organic matter content when compared with forest and natural soils (Jo, 2002). These has been attributed to the fact that nutrient containing materials such as plant biomass and faecal remains are usually produced in little quantity or in some instances are completely removed by human. Contrary to authors that reported low SOM content from urban soils, some studies have reported significantly higher organic matter content from urban areas in comparison to non-urban soils (Pouyat *et al*., 2002; Zhu *et al*., 2004; Lorenz and Lal, 2009; Raciti *et al*., 2011). Pouyat *et al*. (2002) measured significantly higher soil organic carbon in urban soils of New York and Baltimore, USA, at 97 g kg^{-1} soil, as compared to peri-urban and rural areas, which had 83 and 73 g kg^{-1} soil, respectively. Lorenz and Lal (2009) found that organic matter in the form of humus in the top 100 cm of urban soils was higher than in adjacent farmland and forested soils in Stuttgart, Germany. Similarly, the concentration of soil organic matter recorded from Phoenix, Arizona, was significantly higher than natural soil values (Zhu *et al*., 2004).

Pouyat and Turechek (2001) looked at how urbanization affected nitrogen mineralization and nitrification rates in both rural and urban soils in the New York metropolis. Their findings revealed that urban soils nitrified at a rate of 6.3 times that of rural soils. In addition, by comparing urban and rural soils, gross inorganic nitrogen concentration was 87 percent higher in urban soils. Raciti *et al*. (2011) reported that mean soil nitrogen density was slightly higher in residential (552 g m^{-2}) than forestedsoils(403 g m^{-2}) in Baltimore, USA.This nitrogen accumulation in urban soils is linked to nitrogen inputs such as fertilizer and nitrogen deposition, all of which are common in urban soils (Groffman and Pouyat, 2009).

Organic matter is a nutrient supply for the bulk of soil biota (i.e. soil macro and microorganisms). The soil biota is restricted in low-organic-matter soils, and their activities are reduced as a result. Due to limited moisture and aeration in urban soils, the activities of nitrogen fixing bacteria is limited. With the lack of adequate input of organic matter as seen in agricultural and forested soil, macro-organisms such as earthworms are absent. This absence in earthworms has contributed to the reduction in the rate of nutrient cycling (Kaye *et al*., 2006). In contrast, nonnative earthworm populations were found to be more abundant (25.1 individuals m^{-2} vs. 2.1 individuals m^{-2}) and had higher biomass (2.16 g m^{-2} vs. 0.05 g m^{-2}) in urban vs. rural oak stands planted in New York, according to Steinberg *et al*. (1997).

2.6.5 Presence of anthropogenic materials and contaminants

Urban soils formed during urbanization sometimes contain a large percentage of anthropogenic materials such as wood, plastic, nylon, metal, glass and organic waste (Lorenz and Lal, 2009) and in some cases, natural materials such as transported soil (Lehmann and Stahr, 2007). These materials influence urban soil properties in a variety of ways (Scharenbroch *et al*., 2005). For instance, these materials may create physical impedance to root development and thereby reduce root volume of plants. Asides these physical alterations, decomposition by-products and gasses from these materials could negatively alter the chemical composition of the urban soils and render them detrimental to plants, animals and in some cases humans.

In urban soils, heavy metal accumulation is an additional cause of contamination (Murray *et al*., 2004). Arsenic and lead (Calderon *et al*., 2001), and mercury (Debes *et al*., 2006) all have binding sites in urban soils. Heavy metals are released into the atmosphere by both anthropogenic and natural activities. The presence of heavy metals in urban soils has been established in different cities. Abdu *et al*. (2011a) reported elevated concentrations of total zinc and cadmium in Kano city's urban soils. They observed that there is a potential risk for these heavy metals to enter the food chain and aquifer in the urban environments. Cadmium, nickel, and lead levels in urban topsoil from various sites in Akure, southwestern Nigeria, revealed a substantial accumulation of these metals above background levels (Olorundare *et al*., 2011). The authors concluded that indiscriminate dumping of waste lubricant oil in the mechanic sites studied was the primary source of the metals.

Soils in developed cities also show high levels of HM contamination. For instance, in Copenhagen metropolis, Denmark, Li *et al*. (2014) reported elevated total cadmium, copper and lead concentration from urban soils when compared with agricultural soils.They reported that thesecontaminants were from emissions from industries and vehicular traffic, fossil fuel combustion and wastes generated from residential and industrial activities. Imperato *et al*., (2003) found large concentrations of copper, chromium, lead, and zinc in the eastern part of Naples, which coincided with the city's heavy industrial areas. From their results, close to 14% of the total number of soils analysed had levels of copper, lead and zinc above the acceptable regulatory limit. The order of contamination was lead>zinc>copper>chromium.Wong *et al*. (2004) reported that residues from pesticides and herbicides could also contaminate urban soils when applied to urban vegetation for agricultural purposes.

In general, the distribution of heavy metals in urban soils will vary by depth and location of the soil within the city, and mainly depend on the land use and intensity of human activities. In some cases, the parent material could also be a source of heavy metals in urban soils.Table 2.2 outlines the different origins of certain heavy metals, according to Marcotullio *et al*. (2008).

2.7 Significance of Urban Soils

Soils in the urban landscape significantly contribute to the quality of life of urban dwellers. The intensity of use of urban soils with regards to number of users per area is greatest with these soils hence are objects of interest (Lehmann, 2007). Furthermore, these soils perform various important functions which are similar to those of natural soils. The important roles urban soils play can be grouped into four major groups i.e. (1) prevents hazards; (2) provides sources of food; (3) contributes to environmental quality; and (4) contributes to urban infrastructure.

The role of urban soils when properly managed in hazard prevention can be seen in its ability to protect against stormwater damage and flooding events by facilitating water infiltration, breakdown of organic contaminants by micro-organisms and ability to retain and fix contaminants. As regards provision of sources of food, urban soils are used for crop production for food supply through urban agriculture (UA) and provision of groundwater for water supply (Bins*et al*., 2003). In terms of environmental quality, urban soils help in dust entrapment (Biasioli *et al*., 2006); sequestration of carbon (Lorenz and Lal, 2009); and buffering of climate, mainly through cooling by evaporation. Another important use to which urban soils are engaged in is through contributing to urban infrastructure by providing site for recreation and sporting activities. Apart from the advantages that urban soils can have, it is important to remember that they still have certain drawbacks. They include groundwater contamination, health risks from eating polluted vegetables or inhaling contaminated dust, greenhouse gas emissions that contribute to climate change, and floods exacerbated by limited infiltration.

Table 2.2: Potential origins of some heavy metals

Heavy metal	Origin
Cadmium	Phosphate fertilizer, farmyard manure, fossil fuel burning, pigment from plastic and paint residue, battery, incineration, parent rock.
Lead	Fossil fuel burning, pesticide, paint pigment, mining, farmyard manure, sewage sludge, battery.
Manganese	Fertilizer, parent rock.
Copper	Sewage sludge, incineration ash, fertilizer, fungicide, farmyard manure, parent rock.
Chromium	Fertilizer, cement, pigment, incineration ash, sewage sludge, parent rock.
Zinc	Fertilizer, pesticide, rubber manufacturing, sewage sludge, coal and fossil burning, galvanized iron and steel manufacturing, battery, parent rock.

Source: Marcotullio *et al*. (2008)

2.7.1 Urban soils and crop production

The role of urban soils in crop production through urban agriculture (UA) has become increasingly important. In Nigeria, Zezza and Tasciotti (2010) using data from 2004 estimated that about 32% of the urban population are involved in UA contributing more than 10% to the income of the urban dwellers. Information from Dakar, revealed that 60% of vegetables consumed were produced through UA (Mbaye and Moustier, 2000).Evidence presented from Kano city, Nigeria suggested that UA providedfood and employment to farmers (Bins*et al*., 2003).

Urban agriculture, according to Zezza and Tasciotti (2010), is the cultivation of crops and livestock within the confines of a city or town. The key goal of UA is to grow crops or raise livestock on empty plots in urban environments. It entails the cultivation of vegetables, food, and fruits for consumption and sale to the local population within urban areas. According to a United Nations Development Programme study on UA, it has the ability to enhance nutrition, boost food security, and build employment opportunities (Beniston and Lal, 2012). Evidence has also shown that the most susceptible group to food insecurity are the poor urban dwellers. While urban agriculture is not a total solution to this problem, it could offer the poor urban dwellers a reliable source of food and increased access to nutrient rich food (Zezza and Tasciotti, 2010).

As the practice of using vacant urban plots for agriculture increases worldwide, the constraints to production may include availability of nutrient and water, soil pollution, and soil degradation. While numerous studies on the social and economic benefits of urban agriculture exist, the practice however faces a peculiar set of production constraints, and research is necessary to improve agronomic management practices, and increase productivity. For instance, Beniston *et al*. (2016) evaluated soil management and agronomic properties for crop production on a degraded urban soil in Ohio, USA. Their results showed that soil degradation occurred after demolition activities which led to compaction of the soils with bulk densities ranging between 1.5 and 1.8 g cm^{-3}, and reduced soil microbial biomass carbon. But with the application of yard waste organic manure amendments on these soils', significant improvements to soil properties, quality and ultimately vegetable crop yield were observed. Similar results were obtained from the addition of compost to urban soils used for ornamental landscaping and tree planting in some cities in USA (Cogger, 2005).

When considering soil pollution constraints, various studies (Yusuf *et al*., 2003; Agbenin *et al*., 2009; Oluwatosin *et al*., 2010) have shown problems of soil pollution associated with urban agriculture in Nigeria. As compared to soils from residential areas of Lagos, Yusuf *et al.* (2003) found considerably higher levels of cadmium, copper, and nickel in five different vegetables cultivated on soils from industrial areas.Similarly, Agbenin *et al.* (2009) examined the amounts of eight metals in soil and vegetables cultivated in 15 urban gardens in Kaduna. Concentrations of arsenic, chromium, cobaltand cadmium were similar to background values, but zinc, nickel, lead and copper had double the concentration recorded on rural arable soils. Oluwatosin *et al.* (2010) studied the uptake and accumulation of cadmium, lead and zinc in vegetables grown on some urban soils of south western Nigeria. Their results showed that there was accumulation of these metals due to anthropogenic inputs and, concentration ranged from 0.4-2.0 mg kg^{-1}for lead, 0.38-1.20 mg kg^{-1} for cadmium and 8.2-30.4 mg kg^{-1} for zinc. Urban soils can be used as a source of sustainable alternative in achieving food security by evaluating and improving their quality.

2.7.2 Urban soils and hazard prevention

In any ecosystem, of importance is the hydrologic processes that account for water infiltration and runoff after any rainfall event. Within the urban environment, the ability of the soils to filter and store water is limited therefore resulting in more runoff and pollution load into water bodies (Recanatesi *et al.*, 2017). Stormwater runoff in an urban ecosystem can be said to be associated with flooding, channel erosion, and poor water quality (Yang and Zhang, 2011). When vegetal cover is removed impervious layers are created, and when floodplains are occupied due to urbanization in a watershed, flooding incidence tend to occur more frequently (Recanatesi *et al.*, 2017). Several studies have shown the importance of urban soils in stormwater management especially in developed countries (Gregory *et al.*, 2006; Yang and Zhang, 2011; Shuster *et al.*, 2014; Jia *et al.*, 2015).

Gregory *et al.* (2006), observed that compaction in urban soils of central Florida resulted in significantly lower infiltration especially when heavy construction equipment is used. They reported that infiltration rates on compacted soils of natural forest, planted forest and pasture ranged from 8-175 mm hr^{-1}, 160-188 mm hr^{-1}, and 23 mm hr^{-1} respectively, and that construction activities reduced infiltration by 70-99%. These resulted in an increase in potential runoff, and therefore a need for large stormwater conveyance in the area in order to prevent flooding. Similarly, low infiltration rates were reported by Shuster *et al.* (2014) from urban soils in vacant plots in Cleveland. They attributed these values to high concentration of remnant buried debris in the soils. They recommended development of infiltration prone green areas within the vacant plots to guard against flooding. Asides runoff quantity, urban soils also impact greatly on runoff water quality. Yang and Zhang (2011), studied different urban soils in Nanjing, China and reported lower rates of water infiltration with higher runoff coefficients from compacted urban soils resulting in the prevalence of flooding. Their study also reported poor quality in surface runoff water during flooding events from these compacted urban soils. Concentrations of chemical contaminants and suspended materials in the urban soils were significantly higher than those in agriculture and forested soils. In trying to improve runoff water quality in China, Jia *et al*. (2015) studied the importance of innovative low-impact development (LID) approach to urban stormwater runoff management. They reported that LID such as bioretention cells, grassed swales, buffer strip, and infiltration pits did not only control runoff quantity but also water quality. It is evident from the various studies that urban soil plays an important role in hazard prevention. Nigeria, like other developing nations, needs to collect evidence on the functions and significance of urban soils in preserving environmental sustainability.

2.8 Urban Soil Properties and Land Uses

The urban land use type (ULUT) implies thedifferent and contrasting uses a land is being put to use. These uses can be for agricultural and recreational purposes, infrastructural construction or environmental preservation. In the urban landscape, these contrasting land use types are very evident therefore their properties exhibit a high variability. Pouyat *et al*. (2007), related significant variations observed in soil pH, phosphorus, potassium and bulk density to different ULUTs. They concluded that higher soil nutrients and pH values in urban soils could be attributed to fertilizer application and irrigation of residential lawns, urban vegetable and flower gardens (Gbadegesin and Olabode, 2000; Lorenz and Lal, 2009). Residential soils, urban and peri-urban agricultural soils are usually higher in organic matter and in some cases in nitrogen due to the addition of plant biomass, grass cuttings and other organic waste. In addition, soil contamination could be an issue in urban soils, especially on soils presently or previously associated with industrial and commercial (mechanic workshops) land use types.

Human factors cannot be the entire cause for differences in soil properties in the urban environment.Since soil in a given urban area may be produced from materials with a variety of physiographic sources, variation in soil parent material becomes important.Pouyat *et al.* (2007),analysed the impact of parent material on urban soils in Baltimore, USA, and discovered that texture and heavy metal concentrations were closely linked to the parent material. Time is another significant element in the measured variations in the properties of urban soils. After a period of time has passed since an urbanization operation took place, the effects of that activity may become less noticeable.According to Scharenbroch *et al.* (2005), soil bulk density, organic matter and biological activity in some urban soils in USA were comparable to levels measured on rural soils years after the urban development.

2.9 Land Use Classification

The distribution of land use/cover in space can be gotten from classification of remotely sensed satellite imageries. This classification involves the assignment of individual pixels or clusters of pixels of the imageriesinto thematic classes. Image classification involvesthe process during which pixels in an imagery are categorized into various classes of land cover which is based on either the application of logical decision or statistical decision rules in the spatial or multispectral domain respectively (Gao, 2009). The decision rules for imagery classification in the spatial domain make use of geometric size, texture, shape, and object or pixel patterns obtained over a recommended neighbourhood. While, imagery classification in the spectral domain could be said to be pattern recognition where the spectral values of the remotely sensed data are the basis for the classification (Gao, 2009).

According to Lillesand and Kiefer (2000), there are two types of classification methods.These are (1) the supervised methodthat requires previous information about the area of interest, and (2) the unsupervised method that does not require any previous information.Imagery classification has been utilized in a variety of ways and for different purposes when monitoring changes on the earth surface (Muttitanon and Tripathi 2005; Kiage *et al.*, 2007).In determining the choice of a classification method, major factors such as the objectives of the study, the nature of the area to be studied, the type of remotely sensed data available, and the needs of the user are to be considered (Lu *et al.*, 2010).

2.9.1 Unsupervised classification method

Thismethod is a computer driven processthatinvolves essentially clustering analysis in which pixels are grouped into certain categories in terms of the similarity in their spectral values (Gao, 2009). Its application is based on the ability of the imagery spectral data to cluster pixels with the same spectral characteristics into similar cluster or category of spectral. In this approach, the different classes of spectral are firstly determined by the user, and subsequently the appropriatenessof these classes are defined. Unsupervised classification techniques include:

2.9.1.1 Interactive self-organizingdata analysis (ISODATA)

This is one of the most commonly used pixel-based unsupervised classification. In the execution of the ISODATA algorithm, three sets of information are to be provided by the user. These are (1) the number of classes to be allowed, (2) the number of iterations to be allowed, and (3) the convergence threshold, which explains the maximum percentage of pixels with unchanged class values between iterations (Al-Ahmadi and Hames, 2009).

Several authors have reported the use of ISODATA algorithm to classify remotely sensed imageries (Kiage *et al.*, 2007; Babamaaji and Lee, 2014 and Mariwah *et al.*, 2017).For instance, Babamaaji and Lee (2014) working with imageries from Lake Chad area in Nigeria, reported a high reliability of the overall accuracy of the classification obtained from ISODATA algorithm. Similarly, Kiage *et al.* (2007) in their study in Lake Baringo, Kenya used ISODATA algorithm to map land use/cover changescaused by land degradation.

2.9.1.2 Moving cluster analysis

This method is also called*K*-means clustering technique. In this method, moving clustering starts with the specification of the total number of spectral classes to be grouped from the input data.Information on the convergence threshold are then supplied into the algorithm.Afterwards, the classification algorithm choses this number of clusterscentres as the candidates (Gao, 2009).Since it is easier to merge several clusters into one than splitting one into a few, it is recommended that more clusters than is necessary be specified initially. In this classifier, not all cluster corresponds to a specificland cover irrespective of the number of clusters that are generated in a classification. This problem is solved using the ISODATA method (Gao, 2009).

2.9.1.3 Agglomerative hierarchical clustering

Unlike the moving clustering and ISODATA method, the algorithm of this method does not require the user to specify the number of clusters before the classification. Rather, all the pixels in the imagery are considered to be potential clusters

(Gao, 2009).In this method, the clustering is such that pixels with short spectral distance betweeneach other are grouped to form a cluster provided the distance is below a specific threshold value.This technique is rarely used to classify remotely sensed imagery because of the tremendous number of pixels involved and thus a high intensity of computation (Gao, 2009).

2.9.2 Supervised classification method

As mentioned earlier, this method requires previous information(ground-truths) about the area of study. The classification algorithm is trained by the analyst when using this method. This training is carried out by selecting samples of spectral data fordifferent land use/cover classes that will enable the algorithm to identify spectrally similar pixels to the trained land use/cover classes. Results from supervised classification are influenced by different factors. These factors are 1)ancillary and ground truth data acquired, 2) the complex nature or otherwise of the area of interest and the analyst's familiarity with the area of study, 3) imagery band selected and processed, and 4) choice ofclassifier and proficiency of the researcher with the classifier chosen (Lu and Weng, 2007).The different types of supervised classification techniques are:

2.9.2.1 Maximum likelihood algorithm/classifier

The maximum likelihood supervised classification method is based on the probability that a given pixel is correlated with a given class, and the algorithm relies on the second-order statistics of the Gaussian probability density function model for each particular class (Gao, 2009).The basic theory presumes that the imagery bands have normal distributions and thatthese probabilities are similar for all classes. However, because this classification method depends largely on a normal distribution,it has the disadvantage of over-classifyingimages (Al-Ahmadi and Hames, 2009).

In a recent study, Ganasri and Dwarakish (2015) compared maximum likelihood algorithm with two other classification techniques whenmappingchanges in land use/cover in Karnataka, India. Results showed that maximum likelihood classifier produced the most accurate classification when compared with parallelepiped classifier and minimum distance to mean classifier. Abd El-Kawy *et al*. (2011) working in Egypt were able to achieve a mapping accuracy of approximately 96% by integrating image enhancement and visual interpretation with supervised maximum likelihood algorithm. Similar acceptable classification results using maximum likelihood algorithm were obtained by Adewumi *et al*. (2016) from remotely sensed data of Igokoda, Ondo State and Toboreet *al*. (2021) from the assessment of some wetlands of Ibadan, Oyo State.

2.9.2.2 Minimum distance to mean algorithm/classifier

This method calculates the spectral distance between acandidate pixel's measured vector and the individual signature'saverage vector. The classifier, according to Al-Ahmadi and Hames (2009), is based on the Euclidean distanceequation which explains the relativity among the spectral distances betweenthe centre of all information classes that have been derived from the training samples and the pixel in question.According to Babamaaji and Lee (2014) this method requires the least time of computation when compared with other supervised methods, and its simple to compute.However, the disadvantage is that the method does not consider variability in the classes and thus the pixels that ought to be unclassified then become classified.

2.9.2.3 Mahalanobis distance algorithm/classifier

This classification method is similar to theearlier defined minimum distance to mean algorithm technique. Unlike minimum distance, this technique puts into consideration the class variability. It has an advantage in its application over the minimum distance to mean algorithm in situations where statistical criteria must be considered. Also, the weighting factor that isused with the maximum likelihood algorithmis not necessary (Al-Ahmadi and Hames, 2009). However, the speed of computation when compared with that of minimum distance to mean classifieris slower, and it depends largely on a normal distribution of the imagery data.

2.9.2.4 Parallelepiped algorithm/classifier

Also known as the "box" method, this classifier allocates a pixel into any of the previously determined information classes in terms of its value in relation to the digital number range of each class in the same band.In this technique, the statistical parameters used are the minimum and maximum values, obtainable from the training samples, of an information class (Gao, 2009). The minimum and maximum pixel values are defined in two ways. First, they are literally the smallest and the largest values. Use of these actual values poses a high vulnerability to the influence of a few outlier pixels. In order to prevent this from taking place, the minimum and maximum values should be defined more reliably from such statistical parameters as mean and standard deviation.This method is efficient in its computation when classifying remotely sensed data, and it is characterized by its simplicity. The decision-making process does not require sophisticated computation. This method is limited by the fact that not every pixel can be reliably classified in the output result, causing it to sometimes have a considerable gap(Ganasri and Dwarakish, 2015).

2.9.2.5 Decision trees classifier

Decision trees are hierarchical, non-parametricclassifierthatis an alternative technique over maximum likelihood classifier in that it has the advantage of improving the accuracy of the classification results. This technique also has the advantage of faster time of computation and easier interpretation. According to Versluis and Rogan (2010), this techniquepossesses the ability to make use of imagery data from varying scale of measurement and the independency of theclassifier to make use of previous assumptions. Decision trees focus on training sites and user-defined input data imagery to create rules for deciding land use/cover category based on the data imagery's ability to allocate each pixel to a class (Pradhan, 2013).

2.9.2.6 Support vector machine classifier (SVM)

Theyare non-parametric, supervised classification technique that are similar to the decision trees algorithm but differ in that they do not make use of previous assumptions. Mountrakis *et al*. (2011) in their review of support vector machines classification techniqueshowed that the efficiency of these technique is related to its quick learning pace,ability to self adapt and limited need for training data. Setting the training samples is the first step in the SVM process. The aim of the training is to figure out a function that depicts the interaction between input and output. Support vector machines have the advantage of soft classification, which helps them to create more detailed maps of urban environments with mixed pixel scenarios (Vaudour *et al*., 2010).

2.10 Land Use Classification Accuracy Assessment

In the studies of land use classification, the assessment of the accuracy of the maps produced is of great importance. A classification output can onlybe said to be reliable if certain accuracy conditions are met. A land use map produced from remotely sensed imagerycould have certain errors resulting from different factors such as the classification technique used or the methods of acquiring the satellite data (Babamaaji and Lee, 2014).Accuracy assessment is a quality control step in which classification outcomes are compared to what is available at the time of imaging or something that may be considered a suitable alternative, often known as the ground reference. Uncertainty in data is a major factor in any land use classification product, and there are techniques for dealing with inconsistencies in remote sensing and GIS representation and analysis. The techniques include: (i) number of evaluation pixels, (ii)collection of reference data and (iii) error matrix.

2.10.1 Number of evaluation pixels

It is very important to have the right number of evaluation pixels. A very small number leads to low reliability in the accuracy indicators generated because the evaluation results are subject heavily to a little abnormality. Conversely, a large number is not desirable either, because it prolongs the evaluation process and increases the cost of results validation (Gao, 2009).One method of determining the necessary minimal sampling size N is given below:

$$N = \frac{Z^2pq}{E^2} \qquad (1)$$

where N= minimum number of pixels evaluated,

Z= 2 based on a bimodal distribution,

p= percentage of accuracy expected,

q= $100 - p$,

E= error allowed.

Equation 1 gives an approximation of the total number of pixels for the mapped land use/cover classes. This accuracy technique does not specify the manner of allocation of the pixels into the different land use/covers types. The number of pixels that should be selected for a given land use/cover class N is determined with the use of the following equation:

$$N = (p + q)^x \qquad (2)$$

where p and q are the same as in Eq. (1) and x is the sample size.

2.10.2 Collection of reference data

Reference data collection plays an indispensable and often neglected role in accuracy assessment. Any misinformation in the reference data will lead to unrealistic classification results thereby degrading the confidence in the quality assurance generated from the accuracy assessment (Gao, 2009). According to Congalton and Green (1999), there are a number of ways to collect reference data through which the genuine identity of reference pixels is established, such as, study of existing maps, visual examination of the raw colour composite image and large-scale aerial photographs, and field visits guided with a Global Positioning System (GPS) receiver.

2.10.3 Error matrix

The error matrix is one of the most commonly used tools for presenting classification accuracy results. This matrix is also known as a covariance matrix, a correlation matrix, or a confusion matrix (Turker and Asik, 2002, Kiage *et al*., 2007 and Babamaaji and Lee, 2014). Statistical parameters (overall accuracy, omission and commission error percentage and kappa coefficient (*K*)) that quantify classification accuracy can be determined from the error matrix (Congalton and Green, 1999).

According to Congalton and Green (1999), the commission error indicates the user's accuracy. This error shows the likelihood that a feature on the classified map is actually a ground representationof that particular land use/cover type. Commission errors cause a land use/cover to be overestimated in the classification results. The omission error on the other hand indicates the producer's accuracy, which is the likelihood a ground truthing reference feature is being classified correctly.Omission error can lead to underestimation of a concerned land use/cover in the classification result.

The overall classification accuracyis defined as ratio of the sum of diagonal cells in aconfusion matrix to the sum of all evaluation pixels in the matrix or the grand total of all row sums or column sums (Gao, 2009). Mathematically it is calculated as:

$$Overall\ accuracy = \frac{A1+B2+C3+D4}{\sum_{i=1}^{4}(Ai+Bi+Ci+Di)} \tag{3}$$

It measures the overall disagreement or agreement between the ground truthing reference data of a particular land use and the classified output (Jensen, 1996).Equation (3) can be rewritten using the following relationship:

$$Overall\ accuracy = \frac{total\ \ sum\ \ of\ \ all\ pixels\ \ classified\ \ correctly}{total\ \ number\ \ of\ \ pixels\ \ in\ the\ confusion\ \ matrix} \tag{4}$$

Because accuracy assessment using confusion matrix is dependent on the sampling points (ground truthing reference data), the efficiency of using overall accuracy is therefore limited. For instance, in situations where few ground truthing reference data is available, misclassification may occur. The overall accuracy is prone to overestimation of the classification accuracy because it does not take into cognizance the agreement due to chance in the datasets (Congalton and Green 1999). This shortcoming is however corrected by calculating *K* which puts into consideration agreement due to chance.

Bishop *et al*. (1975) stated that kappa analysis can be used to statistically determine significant differences between one confusion matrix which is a discrete multivariate tablefrom another. It gives a more accurate measure when comparing the accuracy of different classification algorithm. The estimate of *K*, is a measure of the difference between the observed matchingin the classification result with the ground truthing information as shown in an error matrix, and the agreement of chance matching with the same reference data that is shown in another matrix similar to the error matrix. It is calculated mathematically by removing the contribution due to chance agreement from the observed agreement, i.e.

$$K = \frac{(overall\ \ classification\ \ accuracy\ \ - expected\ \ classification\ \ accuracy\ )}{(1 - expected\ \ classification\ \ accuracy\ )} \qquad (5)$$

where *K* is kappa coefficient, overall classification accuracy is derived from Eq. (4) and expected classification accuracy is$\check{K}$.

When there is total agreement the kappa coefficient is 1.00, but when agreement is completely due to chance, the coefficient is 0.00.

2.11 Land Use Change Detection

This is the act of establishingvariations in the condition of a phenomenon or object when observed at different times (Facchinelli *et al*., 2001). It is the spatial comparison of different land use/cover maps of similar geographical position and area obtained from remote sensing data that were recorded at different times. Changes on the earth's land use/cover has being occurring for a very long time and it will continue to occurfor theforeseeable future. Both natural and anthropogenic forces are responsible for this change. But in recent times, the changes due to human activities has being occurring at a much faster rate than the natural changes (Giri, 2012).From recent evidences, these human induced land use changes have resulted in the release of a huge (approximately 20%) amount of anthropogenic emission particularly in tropical areas (Giri, 2012).

Information on changes in land use/cover and their consequencesareparamount in the management of natural resources and monitoring of environmental quality.The use of remotely sensedimagery and GIS based approach has eased the monitoring of land use changes. These techniques are relatively cheap and can be a quick way of acquiringreal time information over a large geographical area. Also, information can be acquired from remote and largely inaccessible areas and the information provided are a true reflection of land use. In monitoring changes in land use/cover, different methods have been utilized and this include image differencing,post-classification comparison (PCC), principle components analysis and vegetation index differencing (Lu and Weng, 2007).

2.11.1 Post classification comparison technique (PCC)

The PCC technique detects changes in land use/cover through the comparison of independently produced maps from imageriesacquired on different dates. This method minimizes the issues that occurs when multi-temporal imageries acquired under varying environmental and atmospheric conditions are to be used.Post classification comparison also possess the advantage of showing if the change is positive or negative (Yuan*et al*., 2005).Studies on the assessment and monitoring of changes in land use/cover in Nigeria has employed the use of PCC in change detection. For example, in a study conducted in Zaria, Nigeria, Abbas and Arigbede (2011) with the objective to provide data for future planning, investigated the land use/land cover changes between the years 1985 and 2005. They observed an increase in residential LUT towards the east–west route in the city resulting in the reduction of agricultural lands and water body in the 20-year span of the study. Mamman and Liman (2014) in their study in Ilorin observed changes in land use pattern resulting from urbanization over a period of 10 years from 1994 to 2004 using remotely sensed data. Similarly, Babamaaji and Lee (2014) using NigeriaSat-1 and Landsat data of Lake Chad area were able to investigate changes in land cover from 1970 to 2006.

2.11.2 Normalized difference vegetation index (NDVI) differencing

The NDVI differencing technique is a change detection method that utilizes the ability to differentiate green vegetation from any other surface.According to Wilson and Sader (2002), the principle behind NDVI differencing is based on the fact that during photosynthesis, plant chlorophyll absorbsred waveband light while it reflects near-infrared (NIR) waveband. The output image from NDVI differencing show thick vegetation strongly while it also identifies clearly areas with sparse vegetation. The NDVI can be calculated using equation (6):

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \qquad (6)$$

where RED denotes reflectance wavelength at 630-690 nm (visible red) and NIR denotes reflectance wavelength at 760-900 nm (near-infrared).

The advantages of usingNDVI in change detection are, the ability of the technique to differentiate vegetation from different satellite imageries, the simple manner with which NDVI detects lack or presence of vegetation, and the ease in interpreting the change detected (Wilson and Sader 2002, Muttitanon and Tripathi 2005).The use of NDVI differencing is effective in monitoring land use/cover changes and land degradation. For example, Kiage *et al.* (2007) using this technique observed within a 14-year period, a reduction of over 40% in forest cover in Lake Baringo catchment, Kenya.

2.11.3 Tasseled cap transformationtechnique

This technique basically uses principal component analysis (PCA) to transform Landsat bands into different parts/components of known properties or orthogonal planes. Tasseled Cap component one measures the albedo or brightness(i.e. brightness index (BI)), Tasseled Cap component two measures greenness (i.e. greenness index (GI)), while Tasseled Cap component three measures the amount of moistureheld in the soil or by the vegetation(i.e. wetness index(WI))(Kiage*et al.*, 2007). According to Jensen (1996), Tasseled cap BI, GI and WI can be calculated from the underlisted equations:

$$BI = 0.2909(TM1) + 0.2493(TM2) + 0.4806(TM3) + 0.5568(TM4) + 0.4438(TM5) + 0.1706(TM7) \tag{7}$$

$$GI = -0.2728(TM1) - 0.2174(TM2) - 0.5508(TM3) + 0.7221(TM4) + 0.0733(TM5) - 0.1648(TM7) \tag{8}$$

$$WI = 0.1446(TM1) + 0.1761(TM2) + 0.3322(TM3) + 0.3396(TM4) - 0.6210(TM5) - 0.4186(TM7) \tag{9}$$

where, *TM1….TM7* are Landsat ETM/TM bands.

The above-mentioned change detection techniques have been successfully used in different studies. The Tasseled cap transformation technique was found to be useful when monitoring changes in albedo, while both the NDVI technique and thepost-classification comparison technique have been found to be useful in detecting changes in vegetation (Muttitanon and Tripathi 2005).

2.12 Role of Geographical Information System (GIS) in Urban Soil Assessment

Information on the properties of the soil, as well as its spatial distribution, are crucial in the implementation of any land use strategy.Traditionally much of this information is presented in tables and paper maps, but with the advent of GIS, this information can be organized, analysed and presented in a better and more efficient way. Geographical information system is a high-performancecomputer-based tool,now playing animportant role in land resources management and pollution studies (Weng, 2002).

In urban soil management, change detection in time and space is critical. For example, Jin *et al*. (2011), investigated the spatial variability of soil fertility in Daxing district, China using GIS. They were able to measure spatial changes in soil fertility and the causative anthropogenic influences. Their study delineated the district into 3 classes in a map reflecting the land use and soil management practices within the district.In another study showing the role of GIS in urban soil management, Weng (2001) integrated remote sensing and GIS methods in investigating urban growth and its effect on surface soil temperature in Zhujiang, China. This study was found to be effective in monitoring and analysing urban growth patterns, and in the evaluation of impacts of urbanizationon surface temperature.In their estimation and mapping of spatial variability of soil physical quality, Amirinejad *et al*. (2011), used geostatistical extensions in ArcGIS software to develop maps showing the variability of selected soil physical indicators in a farm. The overall soil physical quality of the farm had a high correlation with landuse.

Another critical application of GIS in urban soil assessment is in the area of geochemical mapping. GIS enhances the provision of the geostatistical information obtained during mapping through visualization and provisionof a reliable medium of environmental monitoring and identification of problematic areas.The use of GIS can also be applied to the identification of soil contaminant hotspot and in the assessment of potential sources of pollution in urban soils. In their study to identify natural and human sources of metals in urban and rural soils of Colombia, Davis *et al*. (2009), using GIS, principal component analysis and interpolation techniques determined the concentration and potential sources of nine metals in rural and urbansoils. Similar studyshowing the importance of GIS in geochemical mapping of urban soils have been conducted in Italy (Facchinelli *et al*., 2001).

2.13 Importance of Soil Quality

Soilsplay a variety of roles which can be broadly grouped into social, financial and environmental. In the performance of these roles, soils which are non-renewable within human time-scale experience gradual change with time. According to Vrscaj *et al*. (2008), due to the increasing pressure soils are being subjected to, their qualitytendsto diminish with time. A soil's quality can be defined as its ability to play a role in sustaining plant and animal health, preserving or improving air and water quality, and promoting human wellbeing and habitation within a natural or man-made environmental boundary (Karlen *et al*., 2001). Soil quality, as described by Pierce and Larson (1993), is fit for use. Soil quality assessment is needed to ensure the proper and long-term usage of land in terms of the soil's ability to perform its environmental functions.

When interpreting soil quality, the functionsa soil performs are of great importance. According to the National Soil Resource Institute (NSRI, 2001) these functions include: (1) interacting with the environment; (2) providing food and fibre; (3) providing a platform for anthropogenic activities; (4) supporting biodiversity and ecological habitat; (5) providing raw materials; and (6) protecting natural and cultural heritage.The function of a soil in meeting its environmental roles represented by the interplay of the physical, chemical and biological properties of the soil, largely defines its quality (Vrscaj *et al*., 2008). The methods used in evaluating agricultural soils and the indicator set used in monitoring soil quality on these soils can be useful when evaluating soil quality on any soilassociated ecosystem not exempting the urban ecosystem (NSRI, 2001).

2.13.1 Soil quality indicators

The quality of a soil, or its ability to function, is reflectedin its dynamic and inherent properties (Doran and Parkin, 1996). Inherent, or use-invariant soil properties hardly change with management. On the other hand, dynamic or management dependent soil properties experience changes resulting from human use and natural disturbances.In soil quality assessment, direct measurements ofthese dynamic soil properties are carried out. These properties act as indicators for the different soil functions since measuring soil functions directly may be difficult and, in most cases,subjective.Therefore,a quality indicator is said to bea soil process or property that is sensitive to change in soil functions.Doran and Parkin (1996), suggested that an ideal indicator should exhibit some characteristics which include ability to integrate soil properties and processes, good correlation with ecosystem processes, be relatively easy to use and assemble, and be sensitive to management and climate changes.Furthermore, according to Oliver *et al*. (2007), good indicators must be adaptive to changes, simple to quantify and analyse, methodology must be repeatable, and reversibility such that both increase and decrease can be detected.

For various evaluations, diverse sets of soil quality indicators have been proposed. For example, the National Soil Research Institute (NSRI) developed a minimal dataset (MDS) of physical, chemical, and biological indicators for evaluating soil quality based primarily on crop production (NSRI, 2001).Are *et al*. (2012) while using 16 physical, chemical and biological indicators concluded that soil organic matter content and associated nutrients played a major part in variation in soil quality of an eroded sloping land under different vetiver system management. Adelana *et al*. (2013) used indicator set of soil organic carbon, bulk density, penetration resistance, water stable aggregates and meanweight diameterto determine the structural quality of an agricultural soil as influenced by residue management in a derived savanna of southwest Nigeria. Similarly, Adeyolanu *et al*. (2013), used physical and chemical indicators to assess the sustainability of slash-and-burn agriculture in crop production in a tropical rainforest ecology of Nigeria. With regards to urban soils, very little informationexists on the assessment of soil quality especially from Nigeria. Hartley *et al*. (2008), working on some remediated anthropogenic urban soils in England assessed the effectiveness of 11 biological indicators (plant assay, invertebrate assay, microbial assay and functional processes) in monitoring soil quality. They concluded that the identification of a universally acceptable benchmark suite of biological indicators is very unlikely without considerable further studies.Taylor *et al*. (2010), monitored urban soil quality in New Zealand's Waikato region using a suite of physical (macroporosity, aggregate stability and bulk density) and chemical (total carbon, nitrogen, available phosphorus, heavy metals) minimum dataset (MDS). They were able to identify five key issues that causespoor soil quality within the urban area. These issues are compaction, depletion of soil organic matter, excessively high fertility, predisposition to erosion, and soil pollution.When selecting appropriate indicators for a soil function, attention must be given to indicators that are sensitive to a particular management goal (Andrews *et al*., 2002).

2.13.2 Soil quality indices

In the development of integrated soil quality indices, different methodical approaches have been used. Imaz *et al*. (2010),used factor analysis when determining soil quality. Pierce and Larson (1993), in their own study proposed the use of statistical quality control methods to measure changes in soil quality over time. Halvorson *et al*. (1996) developed a multi-variate indicator transformationmethodthat combines values or ranges of values into the best estimation of soil quality. This approach uses specificconditions to convert recorded data values into a unitary value. They combined their method with kriging when developing maps on a landscape scalewhich indicated thelikelihoods of satisfying soil quality criteria. On the other hand, Doran and Parkin (1996) recommended the use of a simple multiplicative function for the assessment of soil quality.Theirframework considered geographical, climatic and socio-economic factors in the computation of soil quality. Karlen *et al*. (2001) used normalized scoring curves obtained through a systematic engineering methodin the evaluation ofthe effects of a production system on soil quality.

Neill (1979) carried out one of the earliest studies on soil quality assessment. He coined the term "Productivity Index," which is a measure of productivity loss caused by soil erosion. The model uses properties like bulk density, plant available water content, aeration, electrical conductivity, and soil pH to rate the soil's ability to sustain plant roots. Scores ranging from 0 to 1 were allocated based on the significance of soil properties to root growth, and the quantities of these scores were used to rank the soils. Another index is the Physical Rating Index (PRI) developed by Gupta and Abrol (1993). This index rates the potential productivity of the soil based on some soil physical constraints. In order to rate the constraints, soil properties measured were bulk density, water infiltration capacity, depth to water table, plant available water content and soil organic matter. Subsequently, the potential productivity of the soil was predicted under optimum level of water and nutrient input.

Vrscaj *et al*. (2008), presented a scheme for evaluating urban soil quality for various land use types. They proposed 3 measures of urban soil quality. Firstly, index of soil quality (ISQ) which measures the quality or suitability of a soil put to a particular use. Secondly, is thesoil environmental quality index (SEQI) which is a measure of the environmental value of a soil through its ability to carry out important ecological functions. Thirdly is the land use change index (I) that measures the impacts of land use on the soils.Their method of assessmenthas the potential for better utilization of soil data in urban planning and management of soil quality especially in the urban environment.

2.14 Soil Physical Quality

Indicators of a soil's physical quality provides series of information about the condition of the soil. One of this information relates to soil aeration and hydrological condition of the soil which gives an idea about theinfiltration of water into the soil and the capacity of the soil to store water. In addition, since the physical properties of a soil affect the root volume and depth, they will in turn also influence nutrient uptake and plant growth. Another area where the physical properties of a soil provides information about the soil is in the structural stability of the soil. This is a measure of the soil's capability to withstand break down of aggregates, soil dispersion and erosionresulting from the destructive forces of rainfall splashes or rapid entering of water into the soil (Dexter, 2002). According to Cass *et al.* (2002) the structural stability of a soil can be surrogates to some properties of that soil, namely rate of water infiltration, plant water holding capacity, macro-porosity, penetration resistance at similar moisture condition, aggregate stability, and the balance of salinity and sodicity.Water stable aggregates, soil bulk density,water holding capacity, water infiltration capacity, crust formation, and macroporosity are some physical measures that may be used to quantify soil function and quality, according to Kuykendall (2008).

2.14.1 Soil physical quality indicators

2.14.1.1 Soil texture

Different studies have proposed the use of soil textureas an indicator of soil quality (Pattison *et al*., 2008; Nakajima *et al*., 2015). Soil texture is an inherent property of the soil and is not likely to change with management practices. Due to the inherent nature of the soil texture, its use in monitoring changes in soil quality is not suitable but can be useful in characterizing the soils to be assessed (Oliver *et al*., 2013).

2.14.1.2 Aggregate stability

The aggregate stability of a soil is an important dynamic indicator of a soil's physical quality which is sensitive to changes in soil management. Aggregation occurs when individual soil particles combine to form larger particlesthat can vary in size from microns to millimetres. The arrangement of these aggregates in the soil determines the soil structure. An aggregate is said to be stable when the binding forces between the particles are stronger than the disruptive forces resulting from the impact of rainfall, swelling of clay or movement of farm machines. According to Oliver *et al.* (2013), when the aggregates of a soil are stable, the soil structure can be said to be stable and this stability is necessary for different functions and processes in the soil. The soil functions and processes affected by aggregate stability include water infiltration and storage, aeration, ability to resist erosion, microbial activity and plant growth. Thus, good water stable aggregates (WSA)arenecessary fordifferent physical and bio-chemical processes in any ecosystem.

Another indicator of the soil's physical quality that is related to the aggregate stability is the mean weight diameter (MWD). The mean weight diameter of a soil is the average size of the aggregates that are in that soil. According to Sparling *et al*. (2008), before a soil can be said to function in a productively and environmentally sustainable manner, the mean weight diameter must be larger than 2 mm.Within the urban ecosystem, both WSA and MWD are good indicators of ecological function of the soil that relates to foundation for plant growth and stormwater infiltration.

2.14.1.3 Bulk density

The soil bulk density is one of the most important indicators that has been used by several authors in the assessment and monitoring ofsoil physical quality (Are *et al*., 2012; Adeyolanu *et al*., 2013; Adelana *et al*., 2013; Beniston *et al*., 2016). The bulk density measures how compacted or loose a soil is, and consequently, the total porosity of the soil.For any soil to function sustainably, the soil must have an appreciable volume of pores. These pores do not only store both water and air that are necessary for plant growth, but also serve as channels for the movement of water and air.When a soil is compacted, there is a reduction in the air-filled pores (i.e. macropores) and the water holding capacity (WHC) of the soil. Also, poor drainage in compacted soil will lead to poor aeration resulting in poor root development, and the impeded water infiltration can result in increased water runoff and subsequently increased erosion (Lal and Shukla, 2004; Gregory *et al*., 2006). On the other hand, when a soil with low bulk density is too loose and porous, the soil is prone to erosion, poor WHC and loss of soil organic carbon through rapid oxidation (Sparling *et al.*, 2008).

2.14.1.4 Penetration resistance

Closely related to soil bulk density is soil penetration resistance (PR). The shear strength of a soil as measured through the penetration resistance can give an indication about the physical quality of the soil. Soil strength is a measure of the capability of a soil to prevent structural loss by compaction and rainfall induced slaking. The soil strength is also a measure of the resistance offered by the soil to growing plant roots and burrowing soil macro-organism. High penetration resistance can result from detachment of soil particles in soils with unstable soil structure. According to Lal and Shukla (2004), there must be a balance between how strong and how weak the strength of a soil with good physical quality. The soil must be strong enough to offer good foundation for plants while also weak enough to allow plants and macro-organisms to penetrate.

2.14.1.5 Macroporosity

The macroporosity of a soil is the volume of air-filled pores in the soil i.e. pores with >50 microns diameter. Although, in an ideal situation, the total porosity (macro and micro porosity) is usually half the total soil volume. However, it is the macroporosity that is most important for sustainable use of that soil. Macropores serve as the main channels for water and air movement into and within the soil column. Asides this role, they are also useful in providing a conducive environment for solute transportation, microbial activity and plant root proliferation. According to Lal and Shukla (2004), the macropores in the soil serve as pore channels through which water drainage by gravity occur, therefore they play important roles in soil hydrology.The loss of macropores due to compaction or structural breakdown can lead to a number of conditions in the soil. These include reduction in aeration and plant available water content, suppression of root growth, restriction in drainage and infiltration, accelerated erosion and loss of vegetal cover, biomass,and plant yield (Sparling *et al.*, 2008).

2.14.1.6 Water holding capacity

The ability of a soil to absorb and retain water which is the WHCof that soil determines largely soil function of storm water infiltration and foundation for plant growththrough root distribution (Beniston and Lal, 2016). According to Oliver *et al.* (2013), the WHC of a soil is a measure of the volume of water readily available for plant uptake in a unit depth of that soil. The WHCof a soil is positively influenced by organic matter content while it is negatively influenced by bulk density, soil fraction greater than 100 microns and loss of topsoil.Furthermore, Lal and Shukla (2004) stated that the WHC of a soil is related to the soil texture, structure, organic matter content, porosity and type of clay mineral in the soil.

2.14.1.7 Saturated hydraulic conductivity

The saturated hydraulic conductivity of a soil is the ability of a soil to transmitwater when all the pores are completely filled with water. It determines the rate of excess water drainage from the plant root zone. The hydraulic conductivity of a soil is influenced by the soil texture and structure. A soil with high porosity, fractures, or aggregation will exhibit greater conductivity when compared with a densely packed and highly compacted soil. Hydraulic conductivity is not only influenced by the volume of the total pores, but also by the sizes of the pores, tortuosity, connectivity, and soil surface roughness (Lal and Shukla, 2004).The saturated hydraulic conductivity value has been used as an indicator of soil structural quality when monitoring changes in soil management practices (Adelana *et al*., 2013; Beniston *et al*., 2016).Littlechanges in pore sizes and shape resulting from soil management practices can lead to substantial changes in hydraulic conductivity. These changes will result in significant change in the rate at which water transmission occurs in the soil thereby impacting on stormwater infiltration.

2.15 Soil Chemical Quality

The main function of any soil when considering its chemical quality for environmental protection as a management goal in an urban environment is to regulate chemical and biological reactions and also to serve as sink for contaminants (Beniston *et al*., 2016). Under crop production management goal, the function considers the ability of the soil to provide nutrient (Are *et al*., 2012). Since urban soils are put to crop production especially within the valley bottom and undeveloped vacant plots, soil chemical quality becomes important in an urban environment. The soil's chemical quality affects some soil processes which include; the soil buffering capacity, soil-plant relation, nutrient and water availability, soil water quality, fixation of contaminants, and physical processes such as crust formation.The main chemical indicators used are pH, electrical conductivity, exchangeable cations, total nitrogen, available phosphorus, and heavy metal contamination especially lead and cadmium (Andrews *et al*., 2004, Oliver *et al*., 2013).

2.15.1 Soil chemical quality indicators

2.15.1.1 Soil pH

The pHof the soil determines the availability of nutrients and heavy metals through its role in metal ion solubility. It also affectstherelease of nutrient anions and cations by soil, and it influences microbial activity in the soil (Oliver *et al*., 2013).The cation exchange capacity of any soil is a function of the soil pH. For example, acidic soils with low pH are usually nutrient deficient in the basic calcium, magnesium and potassium cations, and phosphorus. On the other hand,alkaline soils with high pH are usually deficient in trace elements such as iron, zinc, andalso phosphorus(Hou*et al*., 2014).Due to its influence on both soil chemical and biological processes, the use of soil pH as indicator of soil quality has been recommended by different authors (Oliver *et al*., 2013; Beniston *et al*., 2016).

2.15.1.2 Electrical conductivity

The electrical conductivity of a soil solution, which is a representation of the total amount of soluble salt in the solution, can be a good indicator of soil quality. Because of the significant reduction in the crop's ability to retain water, high salinity in soils will limit crop productivity (Rhoades, 1996). In the natural environment, soils with high soluble salt content are usually associated with areas of low rainfall and poor drainage. Also, salinity problems can occur as a result of the use of poor-qualitysalt laden irrigation water.

2.15.1.3 Exchangeable cations

The four most abundant cations in soils are Na^+, Ca^{2+}, Mg^{2+} and K^+. In assessing soil quality, the exchangeable cations and Al^{3+} (especially in acid soils) becomes a useful component. This is because they are used in the calculation of effective cation exchange capacity (ECEC).The ECEC of a soil influences the soil structural stability, nutrient availability, as well as the heavy metal availability. While assessing soil quality in a tropical rainforest of Nigeria, Adeyolanu *et al*. (2013) recommended ECEC as a soil quality indicator with crop production function as goal.

2.15.1.4 Heavy metal concentration

In considering soil quality in the urban environment, heavy metal contamination especially lead (Pb) and cadmium (Cd) are of primary concern and they can serve as good indicators of soil quality. Soils in many urban environments are susceptible to heavy metal contamination resulting from exhaust fumes from vehicles, municipal waste and in some cases, from industrial effluents (Oluwatosin *et al*., 2010, Adelana *et al*., 2016). Leachates from mechanic workshops in urban cities can also exacerbate the contamination of urban soils. The risk of this contamination to human health is seen where these urban soils are used for urban agriculture especially for vegetable cultivation. For example, Oluwatosin *et al*. (2010) observed elevated levels of heavy metal in some wetlandsoils used for edible vegetable cultivation in south west Nigeria.

2.15.1.5 Macronutrients

Several authors have proposed the use of soil macronutrients as indicator of soil quality especially for crop production goal (Adeyolanu *et al*., 2013, Oliver *et al*., 2013). Phosphorus and nitrogen contents are important macronutrients for both crops and organisms in the soil. However, elevated levels of these nutrients can lead to eutrophication of water bodies. Soil phosphorus and nitrogen can be leached into water bodies in or around built up areas, and this leachate would ultimatelyaffect urban water quality (Yang and Zhang, 2011). Furthermore, phosphorus and nitrogen are major plant nutrients, therefore, levels of nitrogen and plant available phosphorus would affect crop growth especially in locations where urban agriculture is being practiced.

2.16 Soil Biological Quality

Different studies have documented the importance of chemical and physical indicators while monitoring soil quality. According to Ritz *et al*. (2009), many of these indicatorsare influenced by the soil biota. It can be complicated and complex when studying the interaction between soil organisms and soil processes.Nevertheless, when some of these soil organisms are directly measured, inferences could be made on the soil processes that are taking place in the soil.For example, when changes in soil microbial activity is observed, this could be an indication of changes in soil physical and chemical quality and therefore can serve as an early indicator of soil disturbance. Some commonly used biological indicators when assessing soil quality are soil organic matter, microbial biomass, respiration, enzyme activities and potentially mineralizable nitrogen.

2.16.1 Soil biological quality indicators

2.16.1.1 Soil organic matter

The soil organic matter is both the dead and living biological materials that are found in the soil which can be used in assessing soil quality (Riches *et al*., 2013). It is an important soil quality indicator because it influences the physical, chemical, and biological characteristics of the soil, and the processes occurring in the soil.According to Lal (2007), soil organic matter can influence soil physical properties and processes such as formation and stability of aggregates, soil water holding capacity, improvement of water quality through filtration of pollutants, and ability to resist compaction. The majorchemical properties and processes affected by soil organic matter are soil cation exchange capacity, nature of charge on soil binding sites, soil buffering capacity, interaction with pesticides and heavy metals, and formation of soluble and insoluble metal complexes (Lorenz and Lal, 2015). The biological properties of soil organic matter, according to Riches *et al*. (2013), are its function as a source of energy for soil organisms and its importance as a reservoir of crop nutrients through mineralization.The amount and quality of organic matter in a soil are regarded as important factors when evaluating land use or management practice sustainability (Riches*et al.*, 2013).

2.16.1.2 Soil microbial biomass

The soil microbial biomass, which includes bacteria, fungi, archaea, protozoa, and actinomycetes, is the living component of soil organic matter, excluding plant roots and macro fauna (Riches *et al.*, 2013). It's a measure for number of soil microbes in a given area, and it's a sensitive indicator for changes in soil quality caused by land use.The soil microbial biomass plays different roles in the soil and they include controlling the transformation of soil organic matter, influencingcarbon accumulation, and also serving as reservoir and source of crop nutrients. The different metabolic activities of the living constituents of soil organic matter, regulates the energy in the soil and soil nutrient cycle(Riches *et al.*, 2013).Given that soil microbial biomass responds faster to changes in soil management than soil organic carbon (Sparling*el al.*, 2008), different authors have proposed the use of microbial quotient given as microbial biomass carbon divided by soil organic carbon as an indicator of differences in biological activity (Sparling *et al.*, 2008).

2.16.1.3 Soil respiration

This is a highly variable indicator that changes with moisture and temperature of the soil. The use of soil respiration as biological indicators when assessing soil quality should be done with caution. This is because soil respiration measurements are subject to spatial and temporal variability in both soil and environmental conditions, which makesbaseline values establishment difficult(Andrews *et al.*, 2004). Nevertheless, soil respiration is used in carbon sequestration to measure the amount of greenhouse gases being emitted to the atmosphere.

2.16.1.4 Potentially mineralizable nitrogen

The potentially mineralizable nitrogen is the fraction of organic nitrogen that is convertible to plant available form under specifiedenvironmental conditions and time.Since the two indicators have a strong positive correlation, measuring potentially mineralizable nitrogen has been proposed as an alternative to measuring microbial biomass (Sparling*et al.*, 2008).Soil properties and management practices that affects thesoil organic matter and organic nitrogen dynamics will ultimately affect potentially mineralizable nitrogen levels. According to USDA (2014), soils with stable aggregates will protect soil organic matter and associated available nitrogen from microbial degradation when compared to soils with unstable aggregates.

The various works reviewed has helped provide an understanding to land use classification, detection of land use changes resulting from urbanization, urban land use types, importance of urban soils, and assessment of urban soil quality. It is evident that urban soils play an important role in achieving food security through UA, and in maintaining environmental quality. However, information and research on the quality of these soils especially in developing nations such as Nigeria are lacking or scanty.

CHAPTER 3

MATERIALS AND METHODS

3.1 Study Locations

The researchwas conducted in Akure and Okitipupa,Ondo State, Nigeria (Figure 3.1).

3.2 Akure Location (Akure South LGA)

Akure with a population of 690,533 (UN, 2021) islocated within latitudes7° 9'N and 7° 25'Nand longitudes 5° 6'E and 5° 21'E, about 210km east of Ibadan. The town sits at anelevation of 396 meters above sea level. The climate in Akure is warm humid tropical, with a distinct seasonal change in wind patterns. The city is under the influence of rain-bearing south-west monsoon winds from March to October, with rainfall peaks between July and September. During the dry season, which lasts from November to February, the region is influenced by dust-laden winds blowing in from Northern Africa. The average annual rainfall in Akure is about 1500 millimetres (NIMET, 2017).

The average temperature in Akure is high. The average yearly temperature is 27°C, with a low of 21°C and a high of 31°C (NIMET, 2017). Akure has a high annual relative humidity, with a value of about 77 percent (NIMET, 2017). For the months of August and February, the percentage of sunshine varies between 16 and 59 percent, with a mean of 44 percent. Tropical rainforest vegetation dominates the landscape.

The area is underlain by Precambrian basement complex rocks (Smyth and Montgomery, 1962). It is characterized by low lying outcrops with small conical hills (inselbergs) in several places within the metropolis. Generally, Akure is well drained with a dendritic drainage pattern, with three major rivers:River Ala, River Ogburugburu andRiver Owena.

The soil types in Akure are formed from medium to coarse grained granite and gneisses, and pegmatite. The soils are well-drained, medium to fine-textured soils overlying brown mottled clay and belong to the Ondo association. The Ondo, Apomu, Iregun, Owo, Fagbo, and Oba soil series are the most popular in the area (Smyth and Montgomery, 1962). Figure 3.2 depicts the general soil map of Akure South LGA.

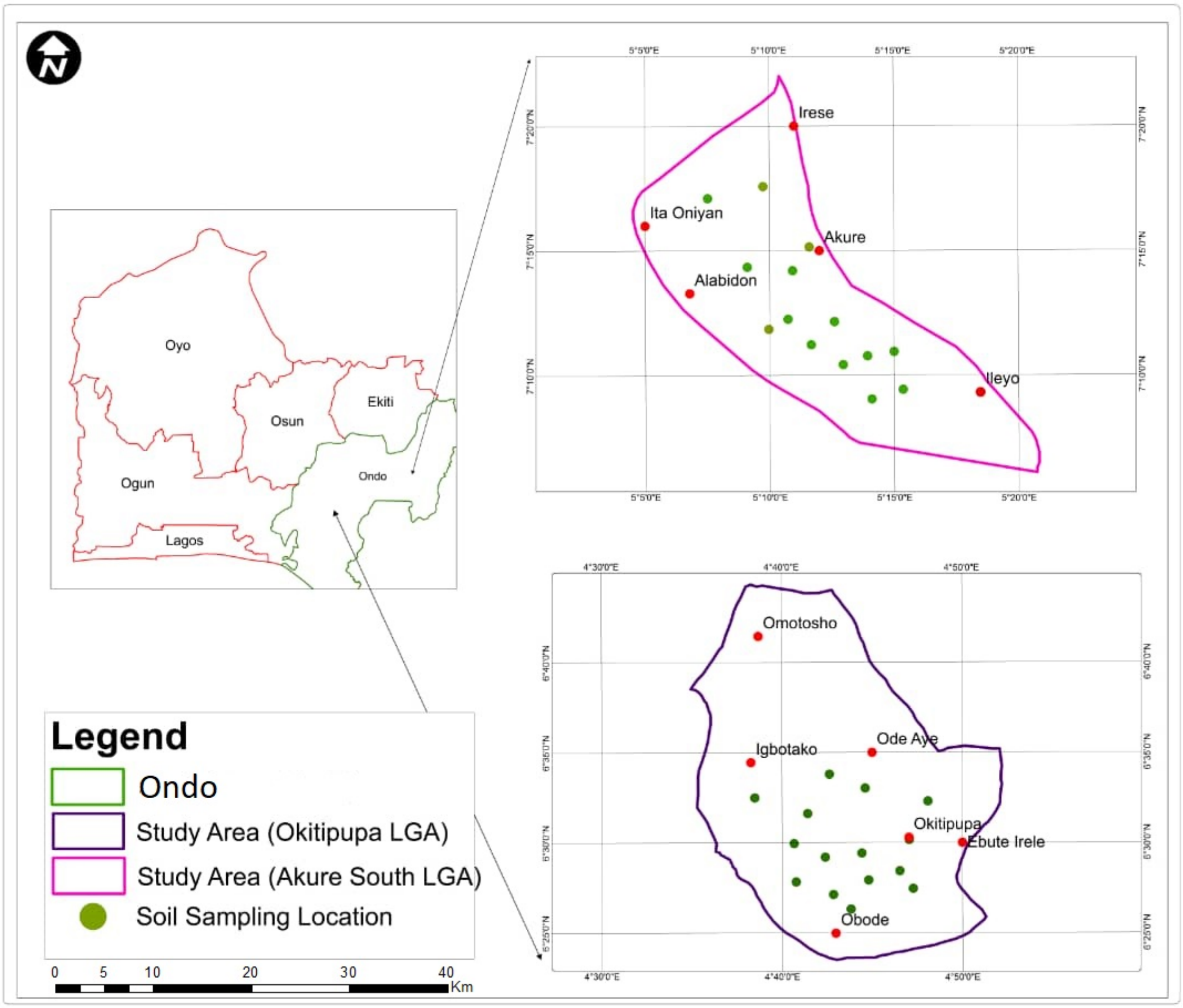
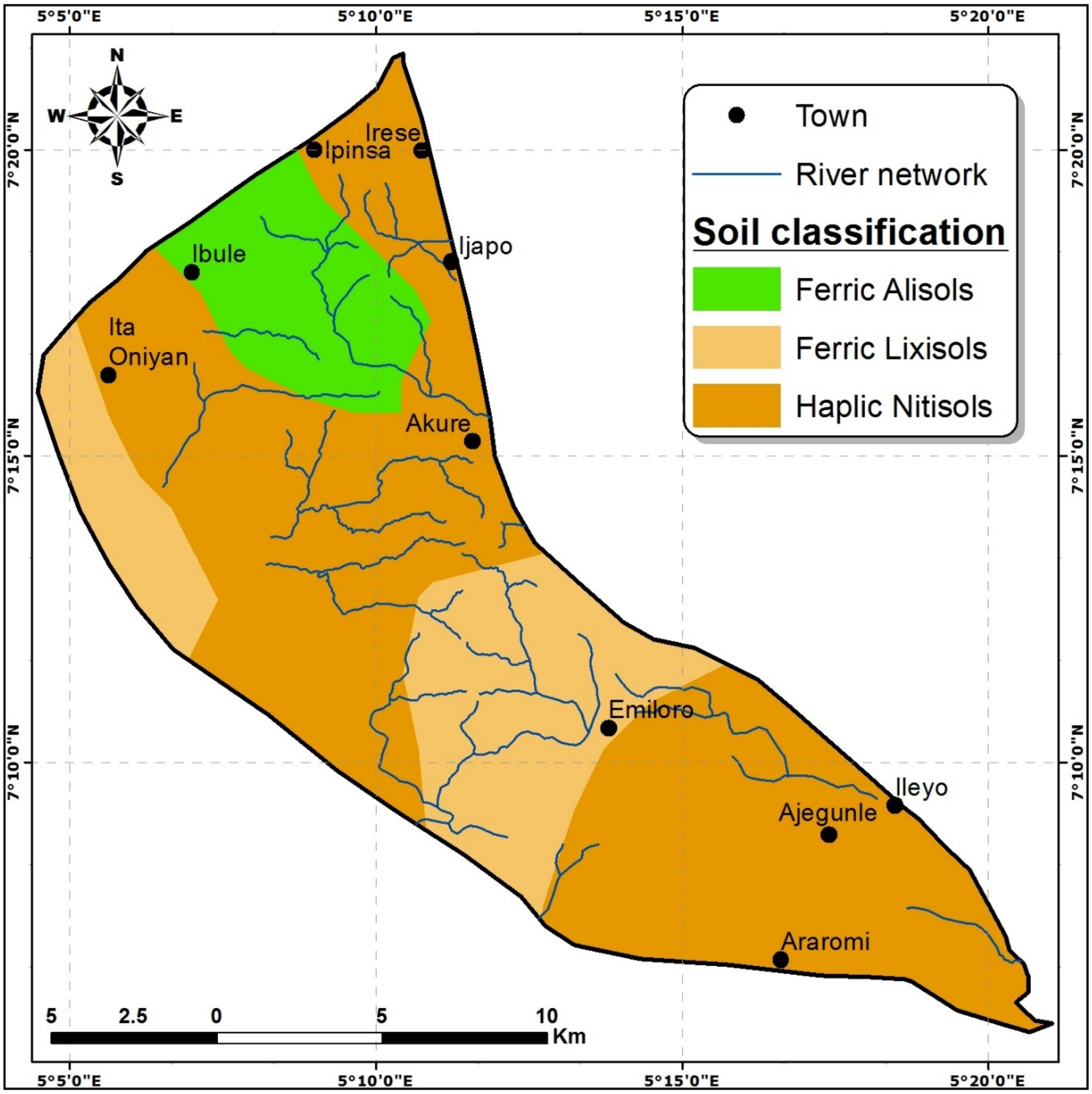


Fig. 3.1: Study locations at Akure South and Okitipupa Local Government Area in Ondo State, Nigeria



Source: Sonneveld (2005)

Fig. 3.2: Soil map of Akure South Local Government Area

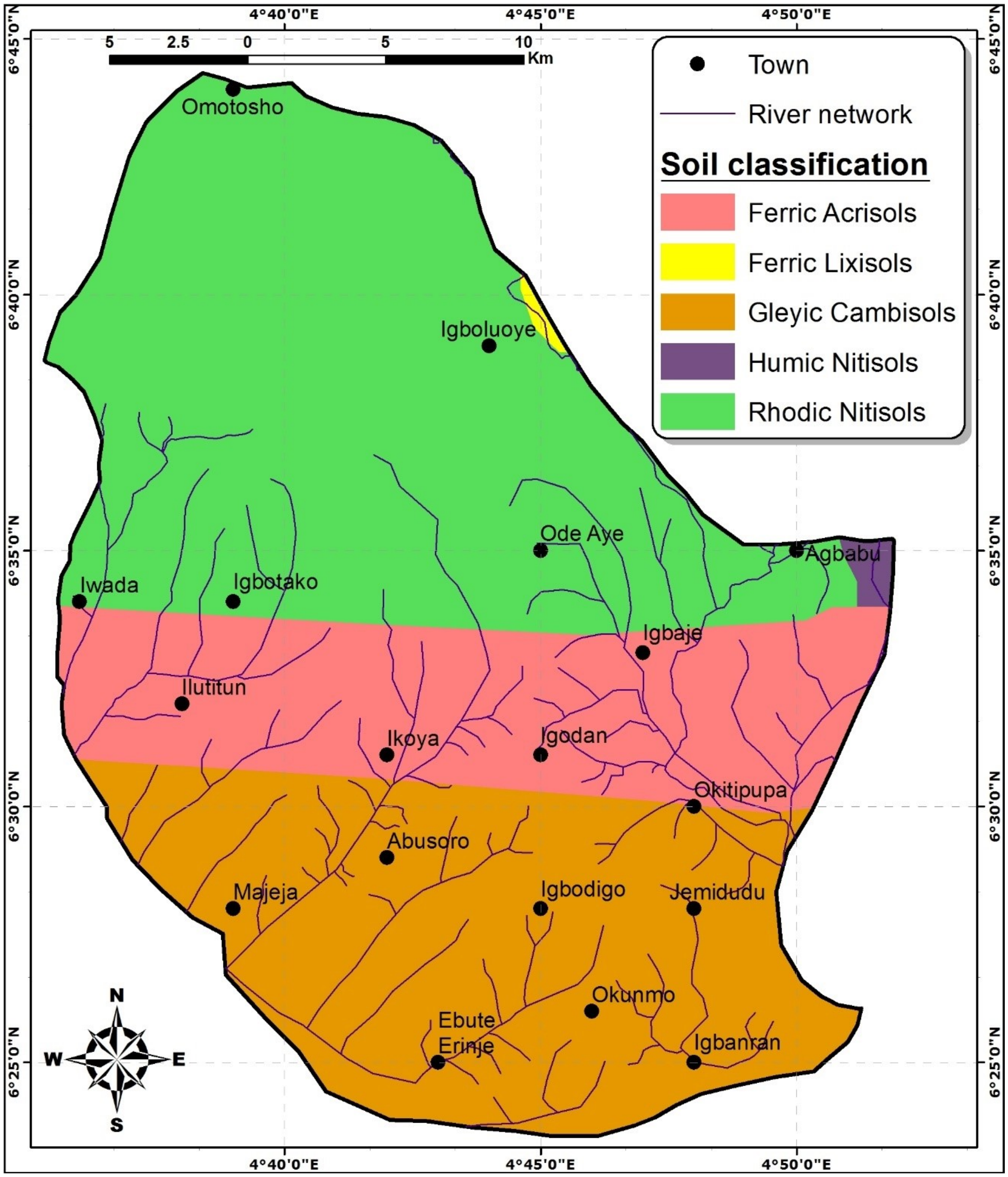
3.3 Okitipupa Location (Okitipupa LGA)

Okitipupa is a town in Ondo State with a population of about 378,754 (UN, 2021) which lies between latitudes 6° 25'N and 6° 35'N and longitudes 4° 35'E and 4° 50'E and is about 126km from Akure the State capital.The town sits at a height of 45 meters above sea level. Okitipupa has a humid tropical climate with two distinct seasons: a shorter dry season (December to February) and a longer rainy season (March to November). The rainy season is bimodal, with two peaks in June and September, as well as a dry spell in August (NIMET, 2017). The town receives about 2100 mm of rain on an annual basis.

The town's temperature is usually high, with a mean annual temperature of 25°C. The mean annual maximum temperature is 30°C, while the mean annual minimum temperature is 22°C (NIMET, 2017). With a value of 80%, the annual relative humidity is high (NIMET, 2017). The percentage sunshine varies from 14 percent in August to 55 percent in February, with a 40 percent average. A large number of trees can be seen in the area, providing a typical rainforest landscape.

The study site is located in Okitipupa local government area, which has two distinct geological formations: Precambrian basement complex rocks in the north and recent to Tertiary sandy sediments in the centre and south. During this study, the soil sampling wasrestricted to the central and southern part of Okitipupa LGA where the parent materials are mainly sedimentary rocks. The area is characterized by sand ridges, lagoons and swampy flats associated with sedimentary terrain. The area of study is characterized by nearly level to gently sloping landscape of 0 to 4% slopes. The drainage pattern in the city is dendritic with the major rivers being River Omiji, River Oluwa with her tributaries River Ofara and River Erinodo. The rivers flow in deeply incised valleys aligned in a north-south direction, into the coastal lagoon.

The soil types in Okitipupa are generally derived from sandstone to terrace sand and river alluvium materials. The soils are grouped into the well-drained, imperfectly drained and seasonally swampy/flooded soils.The main soil series within the area are Alagba, Okitipupa, Ode-Erinje, Ishaga and Mesan series. The general soil map of Okitipupa LGA is presented in Figure 3.3.



Source: Sonneveld (2005)

Fig. 3.3: Soil map of Okitipupa Local Government Area

3.4 Remote Sensing

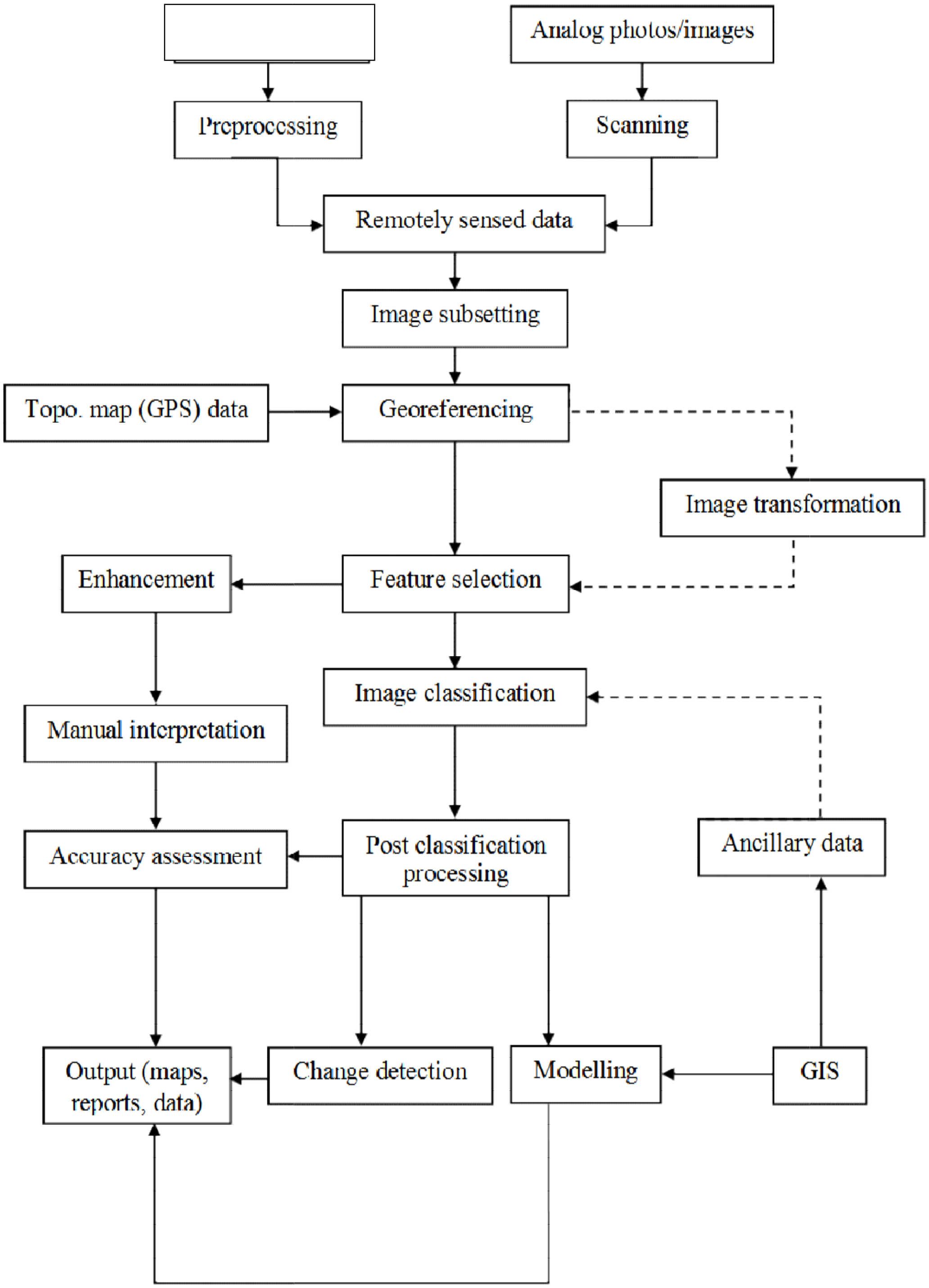
Geographic details (drainage and topography maps) were obtained from Department of Survey, Ondo State Ministry of Lands and Housing. These details collected (paper maps) were scanned andconverted to digital format (shapefiles) through the process of digitization using ArcGIS 10.1 software. In addition tothe geographical details,three (3) cloud-free (11th December 1984, 13th December 2000 and 2nd January 2016) Landsat imageriesof Akure South and Okitipupa LGA were acquired. The Landsat imageries were of two types i.e. the Thematic Mapper (TM) for 1984 imageries, and Enhanced Thematic Mapper (ETM+) imageries for year 2000 and 2016. The remote sensing procedure used in this study was described by Gao(2009). It involved image preprocessing, data transformation, image classification, post classification processing (accuracy assessment and change detection), and map generation. The flowchart of the steps is shown in Figure 3.4.

3.4.1 Image preprocessing and transformation

The preprocessing of the imageries involved geometric rectification and atmospheric correction. The 1984 and 2000 images were geometrically corrected to the previously geo-referenced 2016 images. The 2016 ETM+ images were geo-referenced to the topographic maps of the study locations. Polynomial transformation model in Environment for Visualizing Images version 4.8 software (ENVI 4.8) was then used in the image-to-image registration with the already geo-rectified ETM+reference image. Radiometric correction was not carried out because it had already been done at the ground receiving station when the data was initially received from the satellite.

3.4.2 Image classification

The image classification used in this study was supervised classification. In this classification, fivetraining classes corresponding to spectral signatures of known categories such as built-up, forest, waterbody, farmland, and wetlands were developed for site training. Images acquired in the red, green and blue spectral bands were displayed in colour composite to give a close-to-natural colour sensation. For information in these spectral bands to be visible, they were displayed in the red, green and blue colour planes of the image CRT screen. The resulting combination presented a mixture of colour display called false colour composite (FCC).For each training class, a region of interest (ROI) of the specified colour was defined and signature extraction was done by digitizing the polygons.



Source: Gao (2009)

Fig. 3.4: Flowchart of image analysis procedure

Once the training sites were specified, supervised classification was carried out based on the signature files (ROIs). Each pixel in the study location had a value in each of the 5 bands of imagery. These unique signature values were compared with the earlier created signature files. Each pixel was then classified into cover type which had the most similar signature. The supervised technique used to evaluate how similar the signatures were to each other was through the Maximum Likelihood algorithm in ENVI 4.8.

3.4.3 Post classification

The post classification process involved map accuracy assessment and change detection on the thematic maps produced during image classification.

Map accuracy assessment

On the thematic maps produced, accuracy assessment was carried out using the method proposed by Congalton and Green (1999) to determine how close the classified maps were to the actual features on the field.An error matrix that showed the comparison of the relationship between classified maps and the known ground truthing reference data acquired with GPS during the field work was computed. Assessment on classification accuracy was carried out on land use/cover maps of Akure South and Okitipupa LGA from the 1984, 2000 and 2016 imageries.The total number of pixels in the error matrix was divided by the sum of all correctly classified pixels (diagonal of the error matrix) to get the overall classification accuracy for each map. For each map, the Kappa statistics were determined as defined in equation 10, and it is the proportion of agreements after chance agreement was eliminated.

$$\check{K} = \frac{\sum_{i=1}^{r}(X_{ii} - \Sigma_{ci}\,\Sigma_{ri})}{N^2 - \sum_{i=1}^{r}(\Sigma_{ci}\,\Sigma_{ri})} \qquad (10)$$

where $\check{K}$= expected classification accuracy,

r= number of columns and rows in the confusion matrix,

X_{ii}= number of observations in column i and row i,

Σ_{ri}= marginal total of row i,

Σ_{ci}= marginal total of column i,

N= total number of observations.

Change detection

Changes in land use/coverwithin the different years of 1984, 2000, and2016 at the study locations were monitored using post classification change analysis. In this method, land use/cover maps produced from remote sensing data were subjected to differentiation in order to detect land cover changes. Change information were developed for the period 1984–2000, 2000–2016, 1984–2016 for both Akure South and Okitipupa LGA.

3.5 Field Work and Laboratory Analyses

3.5.1 Sites selection

In the built-up area delineated using remote sensing, five urban land use types (residential, commercial, institution, wetland and agriculture) were further identified for field work.Three (3) sites were selected on each of the five urban land use types (ULUTs) for detailed studies per town (Akure and Okitipupa) resulting in a total of30ULUT sites (Appendix 1 and 2). The site selection was based on the relative importance of the site and permission by landowners to carry out the studies. In Akure the total area for the field work was119km^2 while that of Okitipupa was approximately 114km^2.

3.5.2 Field sampling design

Each of the 30 ULUT sites was divided into four quadrants, with two random soil samples taken from each quadrant at depths of 0-20 and 20-40 cm. A soil auger was used to collect 8 surface samples for physical and chemical analyses from 0-20 and 20-40 cm depths at each of the 30 sites. A total of 480 samples were collected and placed in well labelled plastic bags. Each sample was a composite of 3 random samples properly mixed and bulked. Penetration resistance reading was measured at all the sampling points. Each sampling point was geo-referenced by means of a global positioning system (GPS). Also, fresh samples were collected from 0-20 cm depth at the sampling points and preserved in coolers with ice packs for biological analyses. Aside from the surface sample, 4 undisturbed core samples (5 cm length and inner diameter) were collected from each site with cylindrical core samplers for bulk density,saturated hydraulic conductivity, pore size distribution, and water holding capacity measurements.

At each of the representative ULUTs (residential, commercial, institution, wetland and agriculture), minipits (75 cm x 75 cm x 75 cm) were dug based on position on the toposequence, and a soil auger was used to sample up to 180 cm depth. Minipits were adopted instead of standard soil profiles mainly because of the negative perception of the landownersto digging within an urban area. The site and minipit characteristics were described using the USDA guidelines for soil profile description. Soil samples (38) were collected from the identified horizons to classify the soil types.

3.5.3 Soil preparation and laboratory analyses

To remove artifacts, plant materials, and coarse sized fractions from the samples, the composite samples were air dried, crushed, and sieved using a 2.00 mm sieve. The samples used to quantify soil organic carbon and total nitrogen were then sieved using a 0.5 mm sieve. Each of the sample was analysed forphysical and chemical propertiesfollowing established procedures, while the fresh samples were also analysed for biological properties.

3.5.4 Determination of soil physical properties

The description of methods used in determining the soil physical properties used as indicators in the study sites are given below:

(i) Particle size fractions

The Boyoucos hydrometer technique was used to calculate the percentages of sand, clay, and silt (Gee and Or, 2002). Using a 0.21 mm sieve, coarse sand was removed from the aqueous suspension after mechanical stirring. At 105°C, the coarse sand contents on the sieve were oven-dried to aconstant weight and the percentages were calculated. By subtracting the % coarse sand fraction from the total percentage sand fraction, the fine sand content was determined. A soil textural triangle was then used to establish the soil textural class.

(ii) Water stable aggregates and mean-weight–diameter

On the undisturbed soil samples obtained with a hand trowel from 0-20 and 20-40 cm depths, water stable aggregates (WSA) were determined using a revised wet sieving technique (Nimmo and Perkins, 2002).

Twenty-five grams (25 g) of the soil sample was weighed and another 25 g was weighed into a moisture can and oven dried at 105^{o}Cuntil constant weight was reachedandsubsequently recorded as W_1. The other25 g sample was put on the top sieve (4750μm), and the other sieves, 2000, 1000, 250, and 45 μm, were placed in decreasing order beneath it. The nest of sieves was submerged in water, allowing capillary action to wet the soil on the top sieve. The sieve nest was oscillated 38 mm through the water approximately 30times per minute for 10 minutes. The soils that remained on each sieve were washed with distilled water into moisture cans, oven dried to a consistent weight at 105^{o}C, and the weight was recorded as W2.To remove the sand fraction from the soil aggregate, the dispersion technique was used.Distilled water and 10 ml of Calgon (sodium hexametaphosphate) (0.5% $^{w}/_{v}$) was added to the oven-dried soils for chemical dispersionin dispersion cupsand thereafter dispersed for 10 minutes using a mechanical stirrer. The stirred mixture was then passed through a 250µm sieve. The sand fraction was rinsed into the appropriate moisture container, oven dried to a constant weight at 105°C, and the weight was recorded as W3.

From each sieve size fraction, the percentage of water stable aggregate (% WSA) was determined as follows:

$$WSA_i = \frac{W_{2i} - W_{3i}}{W_{1i} - W_{3i}} \times 100 \tag{11}$$

where i = 1, 2, 3, ……………., n representing nest of sieves

W_1= the oven dried weight of the sample

W_2 = the weight of stable aggregate on each sieve after being oven dried

W_3 = the weight of the sand particles on each sieve after being oven dried

The aggregate size distribution is represented in terms of mean weight diameter (MWD) as follows:

$$MWD = \sum X_i WSA_i \tag{12}$$

where i = 1, 2, 3, 4………, n

X = the mean diameter of the two inter-layered sieve sizes

(iii) Bulk density and total porosity

The bulk density of the soil was determined using the coring technique(Grossman and Reinsch, 2002). A cylindrical metal core sampler (5 cm length and inner diameter) with a sharp end was hammered vertically into the soil. To prevent compaction, a second core sampler of the same size was placed on top of the first before hammering it completely into the soil. Placing a piece of wood on top of the core sampler before hammering it into the soil ensured that the core sampler entered the soil uniformly. The middle of the plank was hammered until the core sampler under it was completely buried in the soil.After that, the core sampler was removed from the soil with a hand trowel, and any surplus soil was trimmed away. The soil from the core sampler was emptied into a moisture can before being oven dried at 105°C to a constant weight. The following relationship was used to calculate the bulk density:

$$\rho_b = \frac{M_s}{V_b} \tag{13}$$

where M_s = weight of oven dried soil (g)

V_b = soil volume in the core (cm^3)

$V_b = \pi r^2 h$; r is the core radius and his the coreheight

Total porosity (TP) was calculatedusing the relationship between particle density and soil bulk density:

$$TP\ (\%) = \left[\frac{1-\rho_b}{\rho_s}\right] \times 100 \qquad (14)$$

where ρ_b= soil bulk density (Mg m^{-3})

ρ_s= soil particle density (2.65 Mg m^{-3})

(iv) Soil penetration resistance

The soil strength was evaluated using a penetration test, as described by Lowery and Morrison (2002). A digital penetrologger (Eijkelkamp Model M1.06.15.SA.E, Giesbeek, Netherlands) with a 30° cone and a base area of 104 mm^2 was used to take the measurement.Soil strength measurementswere taken at 5 cm depth increments at all the ULUT sites by gently pushing the penetrologger into the soil (Plate 3.1). Each of the ULUT sitewas divided into four quadrants, with three soil penetration resistance (PR) readings taken from each quadrantand the mean values calculated.

The volumetric moisture content of the soils at the time of taking the penetrometer readings were recorded using a soil moisture sensor Theta Probe (Eijkelkamp Model 06.15.50, Giesbeek, Netherland) connected to the digital penetrologger.

(v) Saturated hydraulic conductivity

Saturated hydraulic conductivity (K_s) was measured using a constant head water permeameter techniqueas described by Reynolds *et al.* (2002).After being saturated for 24 hours, each core sample was put in a Buchner funnel apparatus. From the start of the experiment, the volume of percolated water was measured, and the saturated hydraulic conductivity (cm h^{-1}) was calculated as defined by Lal and Shukla (2004):

$$K_s = \frac{VL}{tA\Delta H} \qquad (15)$$

where V = volume of water that flowed through the soil column (cm^3)

L = length of soil column (cm)

t = time interval (h)

A = cross-sectional area of soil column (cm^2)

ΔH = hydraulic head (cm)

ΔH = L + h_w, where h_w is the head of water above the soil column

Plate 3.1 Penetration resistance reading taken at an urban agriculture site at Okitipupa

(vi) Pore size distribution

The soil cores were used to determine the water retention capacity and pore size distribution. After being soaked with water for 24 hours, the soil cores were weighed. The water retention capacities of matric potentials at 0.1, 0.5, 1.0, 5.0, and 15.0 bars were evaluated using a pressure plate device, as described by Dane and Hopmans (2002).

Following Flint and Flint(2002), the pore size distribution was determined using data from the water retention capability and capillary rise equation given in Eq. (16).

$$r = -\rho_w g h = -\frac{2\gamma Cos\theta}{\psi} \tag{16}$$

where r = pore radius (m) at matric potential ψ (kPa)

Θ = contact angle

γ = water surface tension (mJ m^{-2})

h = matric suction (cm)

g = acceleration due to gravity (m s^{-2})

ρ_w = water density (g cm^{-3})

According to Are *et al*. (2018), the pores were grouped into:

1. Transmission pores (P_T) corresponding to 2-10 kPa matric suction with equivalent cylindrical radius of50-300 microns;
2. Storage pores (P_S) corresponding to 10-1,500 kPa matric suction with equivalent cylindrical radius of0.5-50 microns;
3. Residual pores (P_R) corresponding to greater than 1,500 kPa matric suction with equivalent cylindrical radius of0.5microns.

(vii) Water holding capacity

Water holding capacity (WHC) for 0-20 and 20-40 cm depth expressed on volumetric basis, was measured as the difference between moisture content at field capacity (FC) measured at 0.1 bar matric suction and at permanent wilting point (PWP) measuredat 15 bar matric suction using Eq. 17:

$$WHC = \frac{(\theta_{FC} - \theta_{PWP})}{\rho_b} \times sampling\ depth\ (cm) \tag{17}$$

where Θ = gravimetric moisture content (%)

ρ_b= bulk density at the required depth (g cm^{-3})

3.5.5 Determination of soil chemical properties

The description of methods used in determining the soil chemical propertiesused as indicators in the ULUT sites are given below.

(i) Soil pH

Soil pH wasmeasured in water and 1 N KCl solution in 1:1 soil to solution ratio (i.e. 10 ml of KCl solution added to 10 g of air-dried soil sample) and mixed thoroughly for 5 seconds with a glass rod(Plank, 1992).The pH reading wastakenwith a calibrated glass electrode pH meter (Jenway 3540 conductivity/pH meter). Also, pH in water wasmeasured by adding 10 ml of de-ionized water to 10 g of air-dried soil sample and subsequently read on a pH meter at 20 to 25^{o}C.

(ii) Electrical conductivity

Twenty grams (20 g) of air-dried soil was scooped into a 50 cm^3 container and 20 ml of de-ionized water was added. The soil mixture was thoroughly mixed, and the suspension was set aside for 15 minutes (Rhoades, 1996). Electrical conductivity was measured at 25^{o}C using an electrode from a Jenway 3540 conductivity/pH meter inserted into the suspension.

(iii) Total nitrogen

The Kjeldahl technique, as defined by Bremner(1996), was used to determine total nitrogen (TN). In a Kjeldahl flask, one gram (1 g) of air-dried soil was added, along with 0.7 g of copper sulphate (digestion catalyst), 1.5 g of K_2SO_4, and 30 ml of H_2SO_4 and heated gently in a digestion block until frothing stopped. The mixture was then heated till the solution became clear, allowed to cool, 50 ml of distilled water was added after which the solution was transferred into a distilling flask. In the receiving flask, 20 ml of standard acid (0.1 M HCl) was added, along with 2-3 drops of methyl red indicator. The distillation unit's condenser was filled with cool tap water.Thirty millilitres (30 ml) of 35% NaOH was added gently into the distilling flask and the content was heated for 30 min to distill the ammonia. The receiving flask was removed and the outlet tube rinsed with distilled water into the receiving flask. The excess acid in the distillate was then titrated with 0.1M NaOH. Blank titration was determined using the same quantity of 0.1M HCl in a receiving conical flask without any soil sample. The percentage total nitrogen (%TN) wasthen calculated as in Eq. (18):

$$\%TN = \frac{(T-B)\times N\times R\times 14.01\times 100}{W\times 1000} \tag{18}$$

where T = titre value

B = blank value

N = normality of standard acid used (0.01)

$R = \frac{50\text{ ml}}{5}$

W = soil sample weight

(iv) Available phosphorus

Plant available phosphorus (AvP) was determined usingMehlich 3extraction method (Mehlich, 1984). Fifty millilitres (50 ml) of Mehlich 3 extractant waspouredinto a 100-ml conical flask containing 5 g of air-dried soil. The mixture was shaken for 5 minutes on a shaker and then filtered. In a measuring flask, 5 ml of the filtered extract was added, followed by 5 ml of molybdate reagent (1.50 g of $(NH_4)_2MoO_4$ in 10 M HCl) and 20 ml of deionized water. The mixture was shaken, and 1 ml of dilute stannous chloride ($SnCl_2$) was added, followed by deionized water to meet the 25 ml level. After calibrating the instrument with the blank, the mixture was read at 660 nm on the spectrophotometer after 10 minutes. A standard curve of 0, 1, 2, 4, 6, and 10 ml of 0.2195 g of pure dry KH_2PO_4 in 1 litre of deionized water was generated prior to the sample reading by adding 5 ml of extractant solution, 5 ml of molybdate reagent, and 1 ml of dilute stannous chloride solution to the separate measurements.The absorbance readingswere plotted against mg P andplant available phosphorus calculated as thus:

$$P\ (mg/kg) = slope \times absorbance \times ef \times df \tag{19}$$

where slope = slope of standard curve

absorbance = absorbance reading on the machine

ef = extracting factor $\left(\frac{50\text{ ml}}{5\text{ml}}\right)$

df = dilution factor

(v) Exchangeable cations

Mehlich 3 extractant was used to extract exchangeable cations [Magnesium (Mg), Calcium (Ca), Potassium (K), and Sodium (Na) (Sen Tran and Simard, 1993). In a 50-ml extraction vessel, 2.5 g of soil was weighed and 25 ml of Mehlich 3 extracting solution was added. On a reciprocating shaker, the mixture was shaken for 5 minutes before being filtered with filter paper. Ca and Mg were determined from the filtrate using an Atomic Absorption Spectrophotometer (AAS) (ASUSY BUCK 211 Model), while Na and K were determined using a Flame Photometer (Jenway PFP7/C Model).

(vi) Heavy metals

The level of heavy metals [Copper (Cu), Chromium (Cr), Cadmium (Cd), Zinc (Zn), Manganese (Mn), Lead (Pb), and Iron (Fe)] in the soil was determined by extraction in 1 M ammonium bicarbonate($NH_4(CO_3)_2$) in 0.005 M DTPA solution (Soltanpour, 1991). Ten grams (10 g) of air-dried soil was weighed into a 125-ml conical flask and 20 ml of extracting solution was added. The mixture was shaken for 15 minutes with the conical flasks kept open. The mixture was filtered and the filtrate was analysed for heavy metals using an Atomic Absorption Spectrophotometer (AAS) (ASUSY BUCK 211 Model).

3.5.6 Determination of soil biological properties

The description of methods used in determining the soil biological properties used as indicators in the study sites are given below.

(i) Soil organic carbon

The dichromate oxidation method was used to determine the amount of organic carbon in the soil (Nelson and Sommers, 1996).Ten millilitres (10 ml) of 0.167 N $K_2Cr_2O_7$ solution and 20 ml of conc. H_2SO_4 was added to 0.3 to 1 g (depending on expected organic content) air-dried soil. The reaction mixture was mixed thoroughly and diluted with 200 ml of distilled water and 10 ml of H_3PO_4. About 2 ml and 10 ml of diphenylamine indicator and NaF respectively, was added into the mixture and it was then titrated with 0.5M $FeSO_4$ solution until a bright green colour was reached. A blank solution without a soil sample wasalso carried through the procedure. The percentage SOC was calculated asshown in Eq. (20):

$$SOC(\%) = (S - T) \times \frac{10 \times 0.003 \times 100 \times cf}{W \times S} \quad (20)$$

where S = vol. of $FeSO_4$ solution neededfor titrating the blank solution(ml)
T = vol. of $FeSO_4$ solution neededfor titrating the soil sample (ml)
W = weight of soil used (g)
cf = correction factor (1.30)

The amount of soil organic matter is given as:

$$SOM\ (\%) = \%\,SOC \times 1.724 \quad (21)$$

(ii) Soil microbial biomass

Using the chloroform fumigation extraction (CFE) technique, soil microbial biomass carbon (C_{mic}) and nitrogen (N_{mic}) were determined (Brookes *et al.*, 1985; Vance *et al.*, 1987).In duplicates, ten grams (10 g) of field wet soil samples were measured. The first portion was fumigated for 24 hours with ethanol-free chloroform and labelled as fumigated sample. The non-fumigated sample was the other weighed sample that had not been fumigated.Soluble carbonand nitrogen from fumigated and non-fumigated soil samples were extracted with 50 ml of 0.5M K_2SO_4 by shaking on an orbital shaker for 60 minutes.The organic carbon in the extract was then determined by dichromate oxidation. The C_{mic} (mg C kg^{-1} soil) was calculated as shown in Eq. (22):

$$C_{mic} = \frac{(C_{org}\ in\ fumigated\ \ soil - C_{org}\ in\ unfumigated\ \ soil)}{k_{ec}} \tag{22}$$

where C_{org} = organic carbon

k_{ec}= 0.33, factor used to convert extracted organic carbon to C_{mic}

Nitrogen in the extract was determined after oxidation with $K_2S_2O_8$ using the Kjeldahl method. The N_{mic}(mg N kg^{-1} soil) was calculated using equation 23.

$$N_{mic} = \frac{(N\ in\ fumigated\ \ soil - N\ in\ unfumigated\ \ soil)}{k_{ec}} \tag{23}$$

where N = total nitrogen

k_{ec} = 0.54, factor used to convert extracted nitrogen to N_{mic}

(iii) Soil respiration

Anderson(1982) described a method for measuring soil respiration. Twenty grams (20 g) of wet soil samples were weighed and placed in Mason jar with a suspended beaker containing 5 ml of 0.5 N NaOH. After sealing, the container was instantly incubated at 25°C in the dark. The beaker was removed after the seventh day of incubation, and the CO_2 trapped in the NaOH was titrated with 0.1 N HCl. A blank solution with no soil sample was also prepared and the NaOH was titrated with HCl. Using equation 24, the soil respiration (mg CO_2- C kg^{-1} soil d^{-1}) was calculated.

$$Soil\ Respiration = \frac{(V_o - V)\times 1.1}{dwt} \tag{24}$$

where, V_o = vol. of HCl used for titrating the soil sample (ml),

V = vol. of HCl used for titrating the blank (ml),

dwt = dry weight of 1 g wet soil,

1.1 = conversion factor.

(iv) Potentially mineralizable nitrogen

The ammonium produced by incubation under anaerobic conditions, as defined by Guginoet *al.* (2007), was used to estimate potentially mineralizable nitrogen (PMN). Two 8 g moist field soil samples were weighed and placed in 50-ml centrifuge tubes. 40 ml 2 M KCl was added to the first tube, which was shaken for 1 hour, centrifuged for 10 minutes, and 20 ml of the supernatant was decanted and analysed for ammonium (T0). 10 mL deionized water was added to the second tube, which was hand shaken and incubated at 30°C for 7 days.After the seventh day of incubation, 30 ml of 2.67 M KCl was added, shaken for 1 hour on a shaker, centrifuged for 10 minutes, and 20 ml of the supernatant was decanted and ammonium analysis was done (T7). The difference between ammonium at T0 and T7 was used to calculate PMN concentration (mg N kg^{-1} soil 7 d^{-1}).

3.6 Soil Quality Assessment

3.6.1 Weighted additive soil quality index

In assessing soil quality, the Soil Management Assessment Framework (SMAF) of Andrews *et al.* (2004), wasused. Indicator selection was based on the sensitivity of that indicatorto cause changes in soil function under environmental protection in urban environment andthey were grouped according to critical soil function (Table 3.1). The soil functions are rainwater infiltration, sorption of pollutants, sorption and transformation of nutrients, soil carbon sequestration, habitat for micro-organisms and foundation for plant growth.In this framework, each indicator was converted into a unitless value (0 to 1) using linear scoring curves, and the scores were then added together to produce a value.

Indicators impacting a certain function were pooled together, evaluated, and assigned relative weights depending on their perceived relevance.According to Beniston and Lal(2012), the functions chosen for the soil quality indices were developed from critical ecological functions provided by urban soils.The soil quality score for each function was multiplied by the relative weight to produce a matrix that wasadded up to give a soil quality index for environmental protection in urban soil management, following a model proposed by Karlen *et al.* (2001). The model was modified as in Equation 25.

$$SQI_{wa} = \sum_{i=1}^{n} WS = qt.si \times wt + qt.sp \times wt + qt.stn \times wt + qt.scs \times wt + qt.hmo \times wt + qt.fpg \times wt \qquad (25)$$

where, SQI_{wa}= weighted additive soil quality index

S = relative score of the functions

W = total weighted average of the soil functions

Table 3.1: Soil functions and indicators relating to environmental protection in urban environment as management goal and their relative weights

Soil functions	Weight	Indicators	Weight
Rainwater infiltration	0.20	Hydraulic conductivity	0.25
		Bulk density	0.25
		Penetration resistance	0.25
		Water holding capacity	0.25
Sorption of pollutants	0.20	Heavy metal	0.75
		pH	0.25
Sorption and transformation of nutrients	0.15	Total nitrogen	0.25
		Available phosphorus	0.25
		Exchangeable cations	0.25
		Electrical conductivity	0.25
Soil carbon sequestration	0.15	Organic carbon	1.00
Habitat for micro-organisms	0.15	Microbial biomass carbon	0.25
		Microbial biomass nitrogen	0.25
		Potentially mineralizable nitrogen	0.25
		Soil respiration	0.25
Foundation for plant growth	0.15	Water stable aggregates	0.35
		Mean weight diameter	0.30
		Total porosity	0.35

Modified after Beniston and Lal (2012)

qt.si = soil quality score for stormwater infiltration

qt.sp = soil quality score for sorption of pollutants

qt.stn = soil quality score for sorption and transformation of nutrients

qt.scs = soil quality score for soil carbon sequestration

qt.hmo = soil quality score for habitat for micro-organisms

qt.fpg = soil quality score for foundation for plant growth

wt = relative weight

3.6.2 Statistically modelled soil quality index

A statistically basedapproach was used to calculate soil quality using principal component analysis. This approachinvolved the reduction in the number of indicators through the creation of a minimum data set (Andrews *et al*., 2002).To choose the most suitable indicators, principal component analysis was chosen as a data reduction technique. The Kaiser-Meyer-Olkin (KMO) and Bartlett tests were carried out on the indicators to ascertain if they were appropriate for principal component analysis.

Measurements from the total data set (TDS) were included in the PCA model with a correlation matrix input. Only those indicators that showed significant differences among the urban land use types (residential, commercial, institution, wetland and agriculture) were considered as members of the TDS. The principal components (PC) with high eigen values (usually > 1.0) indicated the maximum variation in the data set. Under a given PC, each indicator had a corresponding factor loading and only indicators with highly weighted factor loading waschosen. The highly weighted indicators were indicators with the highest factor loading under a particularprincipal component and those with absolute factor loading value within 0.1 of the highest value under the same principal component (Andrews *et al*., 2002). However, when more than one indicator met the criteria for selection under a particular principal component, multivariate correlation was used to determine the correlation coefficients between the indicators. If there was significant correlation between the indicators, then the indicator with the highest factor loading was selected.

The measurements of the indicators selected for the minimum data set were transformed into numerical scores (0 to 1) using scoring curves and the scores were integrated into an index. This was done by dividing the amount of variation explained in each principal component by the maximum total variation of the principal components selected to arrive at a weight value under a particular principal component. Thereafter, the $SQI_{sm}$was computed using equation 26.

$$SQI_{sm} = \sum_{i=1}^{n} W_{PC1} \times S_1 + W_{PC2} \times S_2 \ldots . + W_{PCn} \times S_n \quad (26)$$

where, SQI_{sm} = statistically modelled soil quality index

W_{PC1}= weight of 1st principal component

W_{PC2}= weight of 2nd principal component

W_{PCn}= weight of nth principal component

S = score of quality indicator

3.6.3 Urban soil environmental quality evaluation

Urban soil environmental quality evaluation as described by Vrscaj *et al*. (2008) was also used in quality assessment. This evaluation method was based on the relevance of different soil functions within a particular urban land use and, as a result, the soil quality definition varied within different urban land use types. The quality indicators were pre-defined into 5 soil quality classes (QC). The classes are:

1	very low class
2	low class
3	medium class
4	high class
5	very high class

In this study, the soil quality indicators and corresponding QC values used are given in Table 3.2. The level of significance of the pre-defined soil quality indicators was given by the value of the indicator weight (IW) such that an indicator could have different weight under different land use types. The values ranged from 1 - 3 where: 1 is less important indicator, 2 is usually evaluated indicator, and 3 is very important indicator.

When carrying out the evaluation, indicators important to a present land use type were chosen. The measured soil data were scored using Table 3.2 to determine the quality of each, and the results were represented as quality class values. The soil quality for each of the 5 urban land use types was then estimated by using quality class values of their indicators and pre-defined IWs.

Table 3.2: Soil quality classes

Indicator	Low		Medium	High	
	1	2	3	4	5
Heavy metal contamination	High contamination	Medium contamination	Low contamination	No contamination	No contamination – tracelevel
Soil pH	pH less than 4.5/pH greater than 9.5	pH 4.5 to 5.0/pH 8.5 to 9.5	pH 5.0 to 5.5/pH 7.5 to 8.5	pH 5.5 to 6.0/ pH 7.0 to 7.5	pH 6 to 7
SOM	SOM less than 1.0%	SOM 1.0 to 2.0%	SOM 2.0 to 4.0%	SOM 4.0 to 6.0%	SOM greater than 6.0%
Soil texture	Clayey, Sandy	Sandy clay, Loamy sand	Silty clay, Silt, Loam, Sandy loam,	Silty clay loam, Sandy clay loam	Loam, Clayey loam, Silty loam
Soil strength	PR greater than 2.5MPa	PR 2.0 to 2.5MPa	PR 1.5 to 2.0MPa	PR 1.0 to 1.5MPa	PR less than 1.0MPa
Infiltration ability	Infiltration less than 0.001 cm/hr	Infiltration 0.001 to 0.01 cm/hr	Infiltration0.01 to 0.05 cm/hr	Infiltration0.05 to 0.15 cm/hr	Infiltration greater than 0.15 cm/hr
Nutrient level	Very poor nutrient level	Poor nutrient level	Moderatenutrient level	High nutrient level	Optimum nutrient level
Soil structure	WSA less than 5.0%	WSA 5.0 to 25%	WSA 25 to 50%	WSA 50 to 75%	WSA greater than 75%

SOM = soil organic matter; PR = penetration resistance; WSA = water stable aggregate

Adapted from Vrscaj *el al*.(2008)

Firstly, to calculate quality difference (QD), the quality of individual indicator wascontrasted to the quality pre-defined for the chosen land use using equation 27.

$$QD = \left(QC_{identified} - QC_{required}\right) \tag{27}$$

where, $QC_{identified}$ = quality class of individual indicators evaluated

$QC_{required}$ = quality class of individual indicators pre-defined

The quality difference indicated how the evaluated soil quality indicator differed from that required for the evaluated land use such that when;

- QD is between -4 and -1, then quality is lower than needed
- QD is approximately -1, then quality is just below that needed
- QD is -4, then quality is well below that needed
- QD is approximately 0, then quality of the indicator matches that needed
- QD is between 1 and 4, then quality exceeds that needed

Secondly, the quality difference and the indicator weights (Table 3.3) were then integrated into an index of soil quality (ISQ) using equation 28.

$$ISQ = \sum_{i=1}^{n} \frac{[QD_i \times (IW_i/2)]}{6n} \tag{28}$$

where, n = number of evaluated soil quality indicator

QD_i = quality difference for each individual i

IW_i = indicator weight for individual i

2 = factor to normalize the IW_ivalues

6 = the factor used to distribute the output ISQ values in a range from −1 to 1

The interpretation of ISQ was:

- If ISQ is less than 0, then soil quality is a little lower than that needed
- If ISQ is approximately -0.5, then soil quality is not satisfactory
- If ISQ is between -0.5 and -1.0, then soil quality is not suitable for the selected land use
- If ISQ is approximately 0, then soil quality is the levelneeded
- If ISQ is greater than 0, then soil quality is higher than the levelneeded for the land use evaluated
- If ISQ is approximately 0.5, then land use with higher soil quality requirement should be considered
- If ISQ is approximately 1, thenland use over exceed the needed quality

ality class values and IW values for diff

I3	IW3	I4	IW4	I5
4	3	3	2	4
4	3	4	3	3
5	3	4	3	4
4	3	4	3	4
4	2	3	2	4

, I3 = SOM content, I4 = soil texture, I5 =
eight

Thirdly, soil environmental quality index (SEQI) was calculated using equation 29.

$$SEQI = 100 \times \left(\sum_{i=1}^{n} \frac{QC_i}{5n} \right) \tag{29}$$

where, $SEQI$ = soil environmental quality index

QC_i= soil quality indicator quality class

n = number of soil quality indicator

5 = normalization factor

3.7 Statistical Analyses

To achieve the stated objectives of this study, Pearson chi-square (χ^2) test was used to assess the association between the major land use/land cover types and their expansion or otherwise over the period (1984-2016).Multivariate statistical analysis was used to determine if the soil properties differed among land uses using SAS statistical software (SAS Institute,2007).In order to evaluate thedifferences in soil indicators under the urban land use types at the two study locations, analysis of variance (ANOVA) test was carried out. Means were separated using Duncan's Multiple Range Test (DMRT) or Least Significant Difference (LSD)at $P \leq 0.05$, unless otherwise stated.

Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett test of sphericity were carried out on the dataset before principal component analyses was conducted. Principal component analysis was carried out on the indicators to select appropriate indicators for soil quality assessment in an urban environment. Correlation analysis was conducted between indicators selected for assessment of soil quality and also between the methods of assessment of soil quality. Correlation and principal component analyses were performed using SAS statistical software.

CHAPTER 4

RESULTS

4.1 Analysis of Land Use/Cover Types

4.1.1 Akure South Local GovernmentArea

The land use/cover maps of Akure South LGA for 1984, 2000 and 2016 are presented in Figure 4.1, and the area coverage of the various land use/cover is presented in Table 4.1.In general, land use/cover types in the LGA were associated with their rates of change (χ^2 = 136.62, $P \leq 0.001$). The chi squared (χ^2) related the major land use/cover types (waterbody, built-up, forest, wetland, and farmland) with their rates of change in order to show the response of land use/cover types to the demands for land over the 32-year period.In 1984, forested area with thick vegetation occupied 239 km^2 which was 68.3% of the total area. This cover type was found across the whole sectors of the LGA. Built-up areas accounted for 2.4% of total land cover and were located in the upper eastern portion of the LGA. Farmlands with light vegetation were often found on the outskirts of the built-up area, covering 19 km^2 or 5.2% of the total area. The proportion of the LGA covered by wetlands, which were strewn across the landscape, was 14.1%. Water was also found all over the local government area and this took up 10.0% of total land area.

Built-up areas accounted for 13.1% of the land cover in the LGA in 2000, up from 2.4% in 1984. (Table 4.1). Forested areas reduced noticeably in coverage area from 239 km^{2}in 1984 to 187 km^{2}in 2000. Farmland coverage grew slightly from 5.2%in 1984 to 6.2% of overall land area in 2000. Wetlands occupied 36 km^2, a decrease from the previous year's total of 49 km^2. The amount of land covered by water in Akure South LGA increased marginally, with 16.9% of the total land area covered.

Land cover stretched outwards into the middle areas of the LGA in 2016, with scattered occurrences in the northern parts, bringing the total built-up area to 20.6% in 2016. Forest occupied 32.0% of Akure, a decline of 21.4% from the area covered in 2000. Wetland area fell from 36 km^2 in 2000 to 34 km^2. In 2000, farmlands covered 22 km^2, but by 2016 they had increased to 29 km^2. Throughout the 32-year cycle, water bodies gradually grew in coverage area, with the overall surface area covering more than 25% of the total land area in 2016.

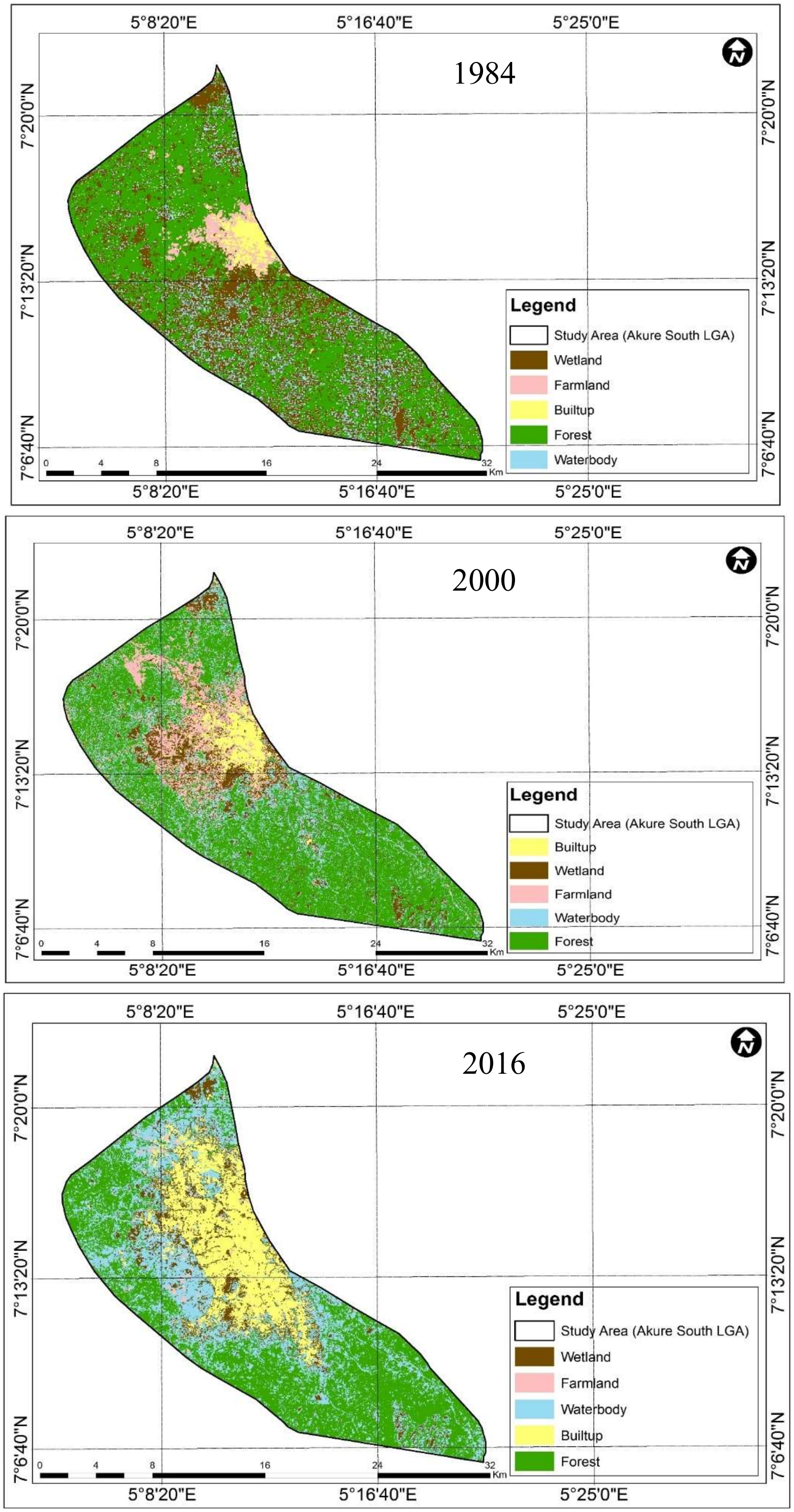


Fig. 4.1: Generalized trend of land use/cover in Akure South Local Government Area from 1984-2016

Table 4.1: Area coverage for different land use/cover for Akure South Local Government Area for 1984, 2000 and 2016

Years	1984		2000		2016	
Land cover	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Waterbody	35	10.0	59	16.9	103	29.5
Built-up	8	2.4	46	13.1	72	20.6
Forest	239	68.3	187	53.4	112	32.0
Wetland	49	14.1	36	10.4	34	9.8
Farmland	19	5.2	22	6.2	29	8.1
Total	350	100.0	350	100.0	350	100.0

4.1.2 Okitipupa Local Government Area

The land use and land cover maps of Okitipupa LGA for 1984, 2000 and 2016 were presented in Figure 4.2, and the area coverage of the different land use is given in Table 4.2. Land use/cover types in Okitipupa LGA were associated with their rates of expansion or reduction (χ^2 = 602.87, $P \leq 0.001$). The chi squared (χ^2) related the major land use/cover types (water body, built-up, forest, wetland, and farmland) with their rates of change in order to show the response of land use/cover types to the demands for land over the 32-year period.

In 1984, the largest area of 595 km^2 was covered by forest and this was 74.1% of the total area. This land cover occurred throughout the local government area. The built-up area occurred in isolated clusters in the LGA and occupied approximately 14.9% of total land cover. Farmlands in Okitipupa LGA like Akure South LGA were found around the built-up area and they occupied 29 km^2 which was 3.7% of the total area. Wetlands were concentrated within the southern part of the LGA. Water was found all over the local government area and they took up 1.2% of total land cover.

In year 2000, the built-up area almost doubled in area from 120 km^2 in 1984 to 221 km^2. These areas represented a land coverage of 14.9% in 1984 and 27.5% in 2000 (Table 4.2). There was a marked reduction in forest areas from 595 km^2 in 1984 to 363 km^2. Farmlands doubled from 29 km^2(3.7% of total land cover) in 1984 to 60 km^2(7.5% of total land area). Wetlands in Okitipupa LGA covered an area of 129 km^{2}which was an increase from the 49 km^{2}recorded in 1984. Waterbodies increased greatly from 1.2% of the area to 3.7% of total land cover.

In 2016, there were further increments in built-up areas to over 50% of the total land cover. Urbanization occurred throughout the area with the highest growth occurring in the western and northern sector of Okitipupa LGA. Forested areas decreased further from 363 km^{2}in 2000 to just 127 km^2 in 2016. Wetlands that increased earlier by 10.0% from 1984 to 2000, later experienced a reduction from 129 km^{2}in 2000 to 95 km^2 in 2016. Farmlands within Okitipupa LGA experienced progressive increase throughout the 32-year period. The area coverage of 60 km^{2}in 2000 increased to 101 km^{2}in 2016 (Table 4.2). Waterbodies also experienced progressive increase from 1.2% of total area in 1984 to 3.7% in 2000, and to 8.5% of total area in 2016.

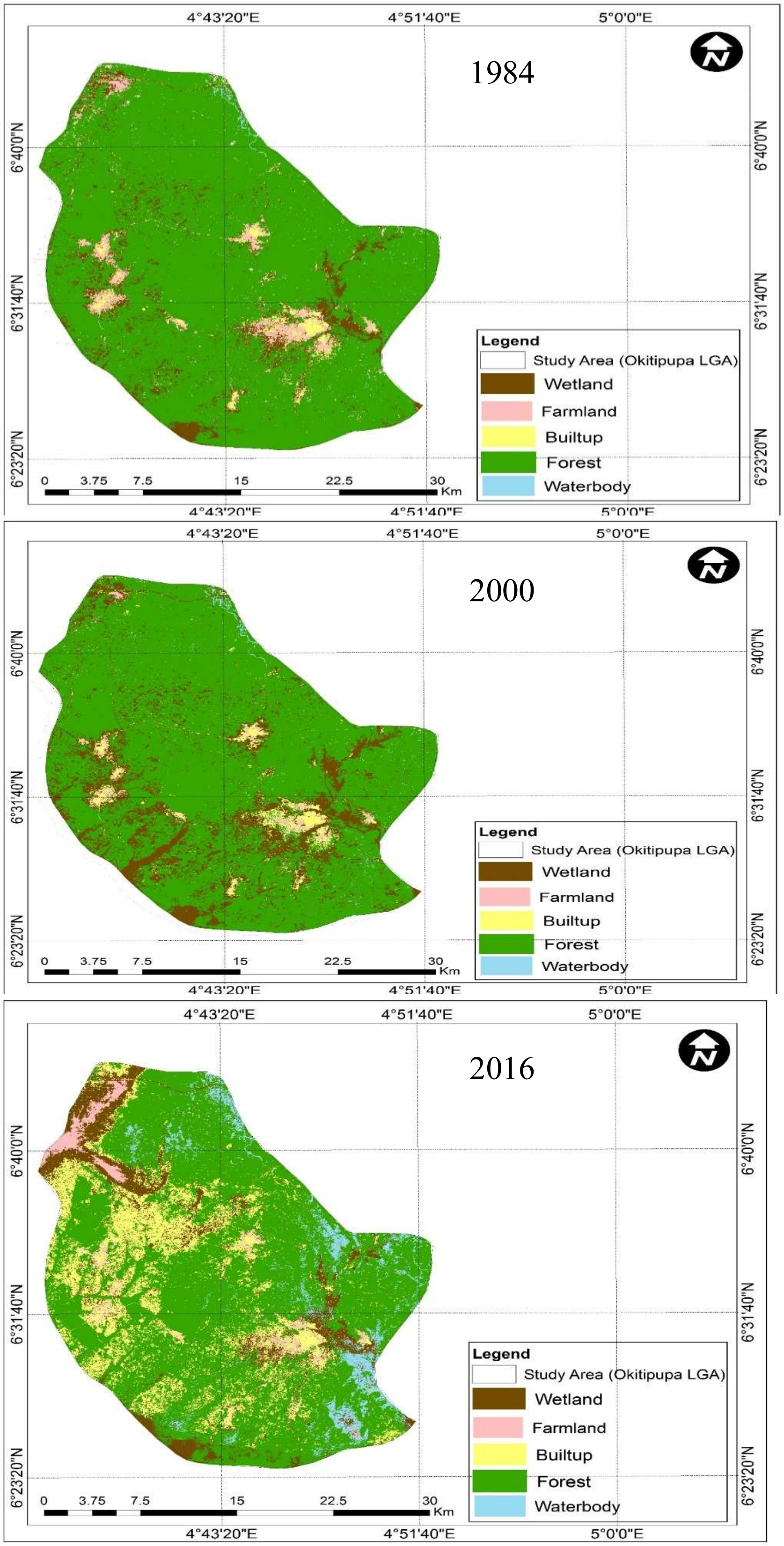


Fig. 4.2: Generalized trend of land use/cover in Okitipupa Local Government Area from 1984-2016

Table 4.2: Area coverage for different land use/cover for OkitipupaLocal Government Areafor 1984, 2000 and 2016

Years	1984		2000		2016	
Land cover	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Waterbody	10	1.2	30	3.7	68	8.5
Built-up	120	14.9	221	27.5	412	51.3
Forest	595	74.1	363	45.2	127	15.8
Wetland	49	6.1	129	16.1	95	11.8
Farmland	29	3.7	60	7.5	101	12.6
Total	803	100.0	803	100.0	803	100.0

4.2 Land Use/Cover Map Accuracy Assessment

4.2.1 Akure South Local Government Area

Error matrix that showed the producer, user and overall accuracy, and also the Kappa statistics for land use/cover maps of Akure South LGA derived from 1984, 2000 and 2016 imageries is presented in Table 4.3.Results from the error matrixshows that overall classification accuracy of land use/cover classification maps of Akure South LGA varied from a minimum value of 79.5% to a maximum of 93.7% (Table 4.3). The Kappa statistics values of the land use/cover maps of Akure South LGA for the year 1984, 2000 and 2016 was 0.72, 0.80 and 0.91, respectively (Table 4.3).

The average producer and user accuracies of land use/cover classification maps of Akure South LGA are 85.3% and 76.5%. User's accuracy values affirm that 76.5% of all classes identified on the classified maps for Akure South LGA are true representation of the reality on ground.On the other hand, the producer's accuracy values indicate that 85.3% of the actual land use/cover information (reference pixel) matches with the classified results for land use/cover for Akure South LGA (Table 4.3).

The lowest and highest producer's accuracy values observed for built-up are 68.9% (Akure South LGA; Year 1984) and 99.6% (Akure South LGA; Year 2016). For forest, these values are 75.2% (Akure South LGA; Year 1984) and 94.5% (Akure South LGA; Year 2016).For farmland, the lowest producer's accuracy value observed is 68.2% (Akure South LGA; Year 1984), while the highest value is 97.9% (Akure South LGA; Year 2010).For wetland, the lowest producer's accuracy value observed is 72.9% (Akure South LGA; Year 2000), while the highest value is 89.2% (Akure South LGA; Year 2016). In Akure South LGA, average producer's accuracies from the 1984, 2000 and 2016 imageries range between 79.5% for waterbody and 88.9% for built-up whereas the values for forest, wetland and farmland are 87.1%, 83.0% and 87.9%, respectively (Figure 4.3).

The lowest and highest user's accuracies recorded for waterbody are 10.4% (Akure South LGA; Year 2000) and 23.1% (Akure South LGA; Year 2016). For wetland, these values are 86.8% (Akure South LGA; Year 2000) and 99.5% (Akure South LGA; Year 2016). For built-up, the lowest user's accuracy value observed is 99.0% (Akure South LGA; Year 2016), while the highest value is 100.0% (Akure South LGA; Year 1984 and 2000). The average user's accuracies range between 17.6% for waterbody and 99.7% for built-up in Akure South LGA. The values for forest, wetland and farmland are 84.9%, 94.2% and 86.0% respectively (Figure 4.3).

Table 4.3: Error matrix of the land use/cover classification map of Akure South Local Government Area derived from 1984, 2000 and 2016 imageries

Classified data (land cover type)	Reference data					Classified total	Producer's accuracy (%)	User's accuracy (%)
	1	2	3	4	5			
Year 1984 Landsat-5 TM								
1. Waterbody	26	9	50	30	19	134	66.7	19.4
2. Built-up	0	348	0	0	0	348	68.9	100.0
3. Forest	8	99	245	40	33	425	75.2	57.7
4. Wetland	4	9	3	757	14	787	86.8	96.2
5. Farmland	0	30	11	35	148	224	68.2	66.1
Reference total	38	495	309	862	214	1918		
Overall classification accuracy = 79.5%								
Kappa statistics = 0.72								
Year 2000 Landsat-7 ETM+								
1. Waterbody	11	0	15	80	0	106	84.6	10.4
2. Built-up	0	111	0	0	0	111	98.2	100.0
3. Forest	0	0	758	18	0	776	91.7	97.7
4. Wetland	2	0	40	277	0	319	72.9	86.8
5. Farmland	0	2	2	0	46	50	97.9	92.0
Reference total	13	113	815	375	46	1362		
Overall classification accuracy = 88.3%								
Kappa statistics = 0.80								
Year 2016 Landsat-8 ETM+								
1. Waterbody	34	1	18	93	1	147	87.2	23.1
2. Built-up	0	503	0	1	4	508	99.6	99.0
3. Forest	2	0	308	0	0	310	94.5	99.4
4. Wetland	3	1	0	778	0	782	89.2	99.5
5. Farmland	0	0	0	0	212	212	97.7	100.0
Reference total	39	505	326	872	217	1959		
Overall classification accuracy = 93.7%								
Kappa statistics = 0.91								

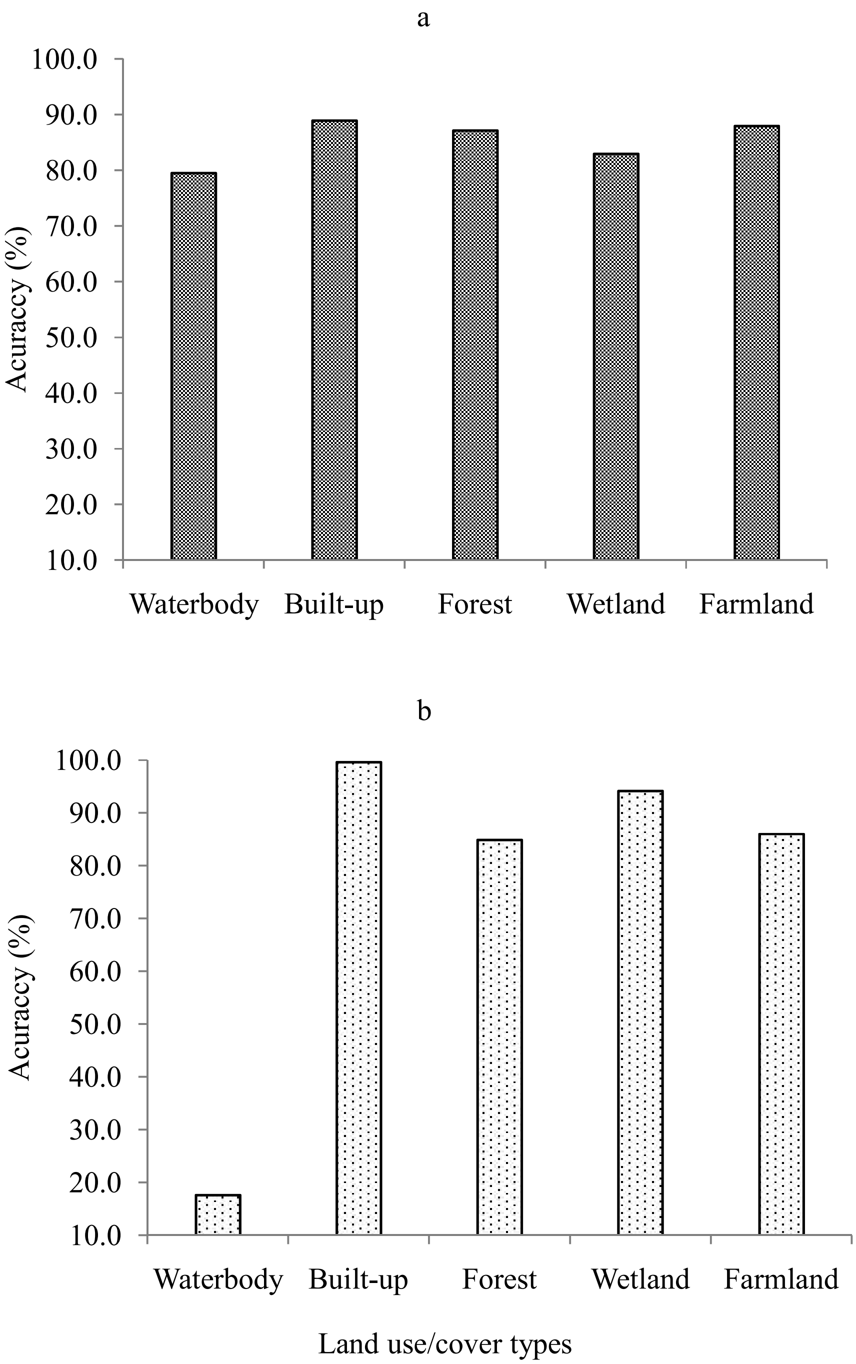


Fig. 4.3: Average (a) producer's and (b) user's accuracy of land use/cover maps of Akure SouthLocal Government Area

4.2.2 Okitipupa Local Government Area

Error matrix that showed the producer, userand overall accuracy, and also the Kappa statistics for land use/cover maps of Okitipupa LGA derived from 1984, 2000 and 2016 imageries are presented in Table 4.4.Results from the error matrix showed that overall classification accuracy of land use/cover classification maps of Okitipupa LGA varies from 89.8% to 97.5% (Table 4.4). The Kappa statistics values of the land use/cover maps of Okitipupa LGA were 0.85, 0.85 and 0.96 for the year 1984, 2000 and 2016, respectively (Table 4.4).

The average accuracies for producer and user are 89.3% and 80.4% for Okitipupa LGA, respectively. User's accuracy values affirm that 80.4% of all classes identified on the classified maps for Okitipupa LGAis a true representation of the reality on ground. While, the producer's accuracy values indicate that 89.3% of the actual land use/cover information (reference pixel) matches with the classified results for land use/cover for Okitipupa LGA (Table 4.4).

The lowest and highest producer's accuracy values observed for built-up are 81.0% (Okitipupa LGA; Year 2000) and 99.1% (Okitipupa LGA; Year 2016). For waterbody, these values are 77.4% (Okitipupa LGA; Year 1984) and 97.4% (Okitipupa LGA; Year 2000). For forest, the lowest producer's accuracy value observed is 89.9% (Okitipupa LGA; Year 1984), while the highest value is 97.7% (Okitipupa LGA; Year 2000). For wetland, the lowest producer's accuracy value observed is 83.9% (Okitipupa LGA; Year 2000), while the highest value is 96.8% (Okitipupa LGA; Year 2016). The average producer's accuracy values for waterbody, built-up, forest, wetland, and farmland in Okitipupa LGA are 90.4%, 90.8%, 94.8%, 89.9%, and 80.4% respectively (Figure 4.4).

The lowest and highest user's accuracies recorded for waterbody are 39.9% (Okitipupa LGA; Year 1984) and 88.4% (Okitipupa LGA; Year 2000). The lowest and highest user's accuracy values observed for built-up are 93.0% (Okitipupa LGA; Year 2000) and 100.0% (Okitipupa LGA; Year 2016). For wetland, these values are 95.2% (Okitipupa LGA; Year 1984) and 98.1% (Okitipupa LGA; Year 2016). For forest, the lowest user's accuracy value observed is 87.1% (Okitipupa LGA; Year 2000), while the highest value is 99.2% (Okitipupa LGA; Year 2016). In Okitipupa LGA, the user's accuracy values are 67.1% for waterbody, 97.5% for built-up, 94.8% for forest, 96.8% for wetland and 45.9% for farmland.

Table 4.4: Error matrix of the land use/cover classification map of Okitipupa Local Government Area derived from 1984, 2000 and 2016 imageries

Classified data (land cover type)	Reference data					Classified total	Producer's accuracy (%)	User's accuracy (%)
	1	2	3	4	5			
Year 1984 Landsat-5 TM								
1. Waterbody	89	45	16	70	3	223	77.4	39.9
2. Built-up	3	1008	0	0	1	1012	92.4	99.6
3. Forest	1	1	1856	23	11	1892	89.9	98.1
4. Wetland	19	1	22	836	0	878	89.1	95.2
5. Farmland	3	36	171	9	65	284	81.3	22.9
Reference total	115	1091	2065	938	80	4289		
Overall classification accuracy = 89.9%								
Kappa statistics = 0.85								
Year 2000 Landsat-7 ETM+								
1. Waterbody	38	0	0	5	0	43	97.4	88.4
2. Built-up	0	239	7	7	4	257	81.0	93.0
3. Forest	0	22	553	59	1	635	97.7	87.1
4. Wetland	1	11	0	448	1	461	83.9	97.2
5. Farmland	0	20	0	5	9	34	60.0	26.5
Reference total	29	292	560	524	15	1420		
Overall classification accuracy = 89.9%								
Kappa statistics = 0.85								
Year 2016 Landsat-8 ETM+								
1. Waterbody	27	0	4	6	0	37	96.4	73.0
2. Built-up	0	211	0	0	0	211	99.1	100.0
3. Forest	1	0	237	1	0	239	96.7	99.2
4. Wetland	0	0	4	211	0	215	96.8	98.1
5. Farmland	0	2	0	0	15	17	100.0	88.2
Reference total	28	213	245	218	15	719		
Overall classification accuracy = 97.5%								
Kappa statistics = 0.96								

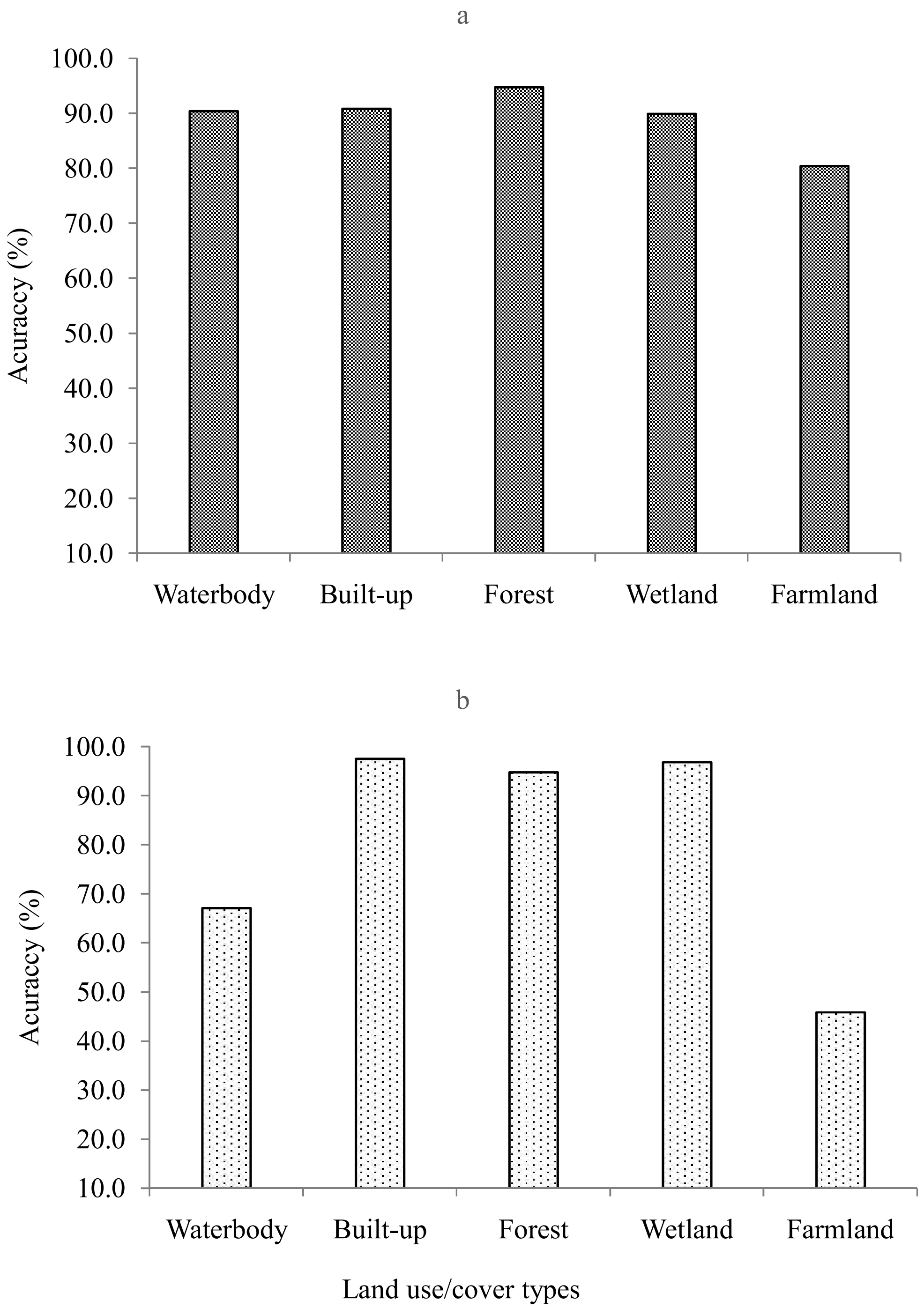


Fig. 4.4: Average (a) producer's and (b) user's accuracy of land use/cover maps of Okitipupa Local Government Area

4.3 Land Use/Cover Change Detection

4.3.1 Akure South Local Government Area

The results of change detection in land use/cover changes in Akure South LGA between the years 1984-2000, 2000-2016 and 1984-2016 are presented in Figure 4.5.

4.3.1.1 Land use/cover change during 1984-2000

In Akure South LGA, results show that waterbody, built-up and farmland increased in area by 6.9%, 10.7% and 1.0% respectively. The forest area and wetland decreased by 15.0% and 3.7% (Figure 4.5).During this period, the area coverage of the waterbody increased by 24.3 km^2, that of built-up was 37.4 km^2, while the farmlands increased by 3.6 km^2. On the other hand, the area covered by forest reduced by 52.3 km^2 and for wetlands, it reduced by 13.1 km^2.

4.3.1.2 Land use/cover change during 2000-2016

During this period, notable changes were observed under all land use/cover types in Akure South LGA. An increase of 12.6% in waterbody, 7.5% in built-up and 1.8% in farmland were observed. In contrast, the forest showed a decreasing trend of 21.4% and the wetland areasalso decreased slightly by 0.5% (Figure 4.5). The area cover increase was 44.1, 26.3 and 6.4 km^2 in the waterbody,built-up and farmland respectively, while forested areas decreased by 74.9 km^2 and wetlands also reduced by 1.9 km^2.

4.3.1.3 Land use/cover change during 1984-2016

The total long-term change rate of the increase in waterbody, built-up and farmland was 19.6%, 18.3% and 2.9%, respectively in Akure South LGA(Figure 4.5). In contrast, there was a decrease in change rate of wetlands by 36.4% and forest by 58.3% in Akure South LGA during the 32-year period.These changes corresponded to 68.4, 63.8 and 10.0 km^2 increase in waterbodies, built-up and farmlands respectively. The forest decreased in area by 127.2 km^2, and the wetlands also decreased by 15.0 km^2 during the 32-year period.

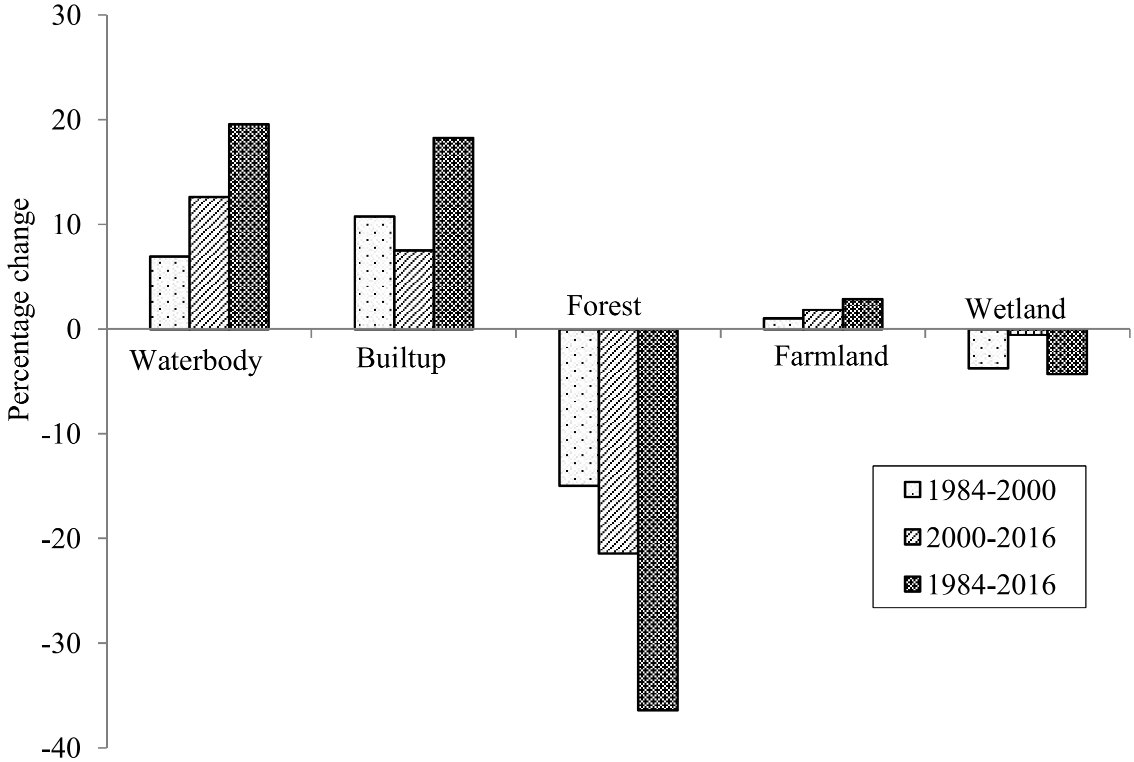


Fig. 4.5: Percentage change in land use/cover of Akure South Local Government Area

4.3.2 Okitipupa Local Government Area

Results of change detection used to analyse land use/cover changes in Okitipupa LGA between years 1984-2000, 2000-2016 and 1984-2016 are presented in Figure 4.6.

4.3.2.1 Land use/cover change during 1984-2000

In Okitipupa LGA, all the land use/cover types except for forest increased in area between 1984 and 2000. Waterbody, built-up, farmland and wetland respectively increased by 2.5%, 12.6%, 3.9% and 10.0%, while forest areas decreased by 28.9% within the 16-year period (Figure 4.6). The increase in waterbodies was 20.0 km^2, built-up area was 101.8 km^2, farmland increased by 31.6 km^2, while wetlands increased by 80.4 km^2.

4.3.2.2 Land use/cover change during 2000-2016

During this period, the changes observed in Okitipupa LGA were similar to those of Akure South LGA. Waterbody, built-up areas and farmlands increased by 4.7%, 23.8% and 5.1%, respectively, while forest decreased by 29.4% and wetland decreased by 4.2%(Figure 4.6). These changes corresponded to 38.1 km^2 increase in the waterbodies, while in the built-up areas, the increase was 191.4 km^2, and it was 41.6 km^2 in the farmlands. The corresponding decrease in forested areas was 235.5 km^2 and the observed decrease in wetlands was 34.8 km^2.

4.3.2.3 Land use/cover change during 1984-2016

The total long-term rate of change in Okitipupa LGA showed an increase of 7.2%, 36.4%, 5.7% and 9.0% inthe waterbody,built-up areas, wetlandsand farmlands, respectively (Figure 4.6). In contrast, there was a decrease in change rate of forest areas by 58.3% in Okitipupa LGA during the 32-year period. During this period, the area coverage of the waterbody increased by 58.1 km^2. The built-up areas increased by 292.2 km^2, while the wetlands and farmlands increased by 46.8 and 72.6 km^2, respectively. On the other hand, the area covered by forest reduced by 468.9 km^2.

4.4 Soil Profile Properties on Selected Urban Land Use/Cover Types in Akure

The detailed physical and chemicalproperties of the representative soil profiles of the ULUTs in Akure are given in Appendices 3-4. The summary of the morphological description of the profile soils in Akure is given in Appendix 5.

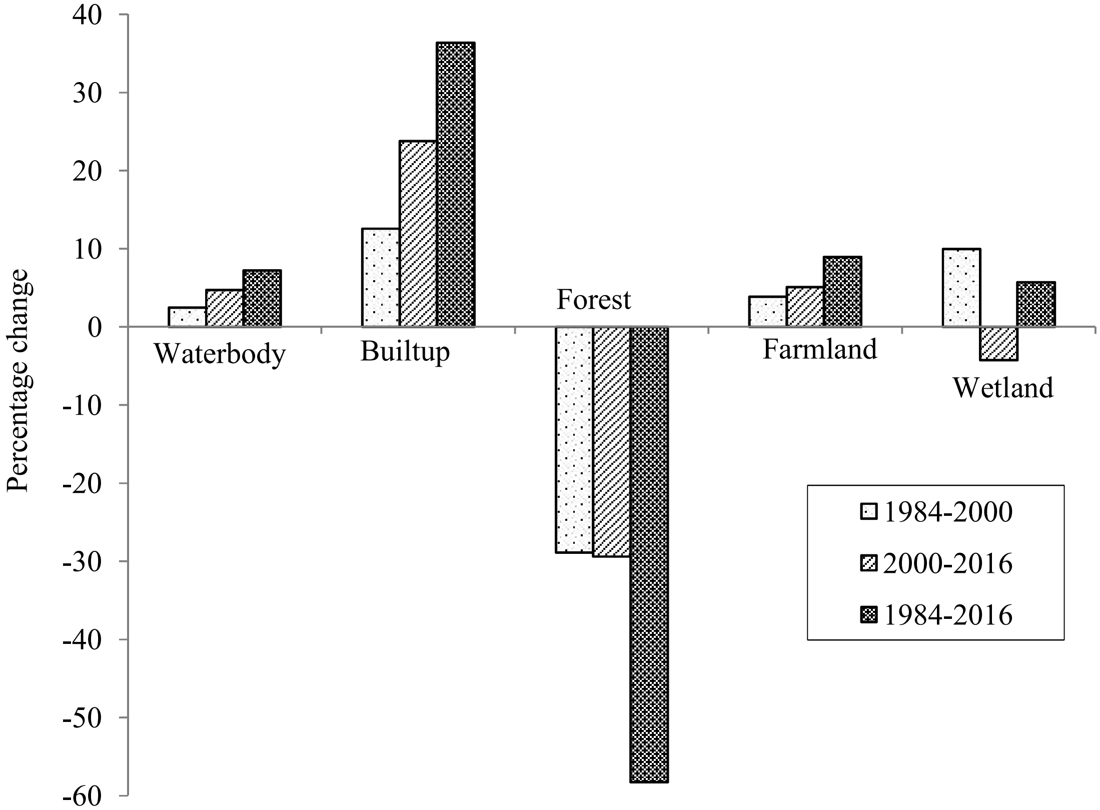


Fig. 4.6: Percentage change in land use/cover of Okitipupa Local Government Area

(i) Akure 1

Typic Kandiudalf (USDA); Ferric Lixisol (FAO); Ondo Series

The profile was located on the upper slope and is developed on medium grained granite gneiss. The soils are shallow, well drained, dark brown loamy sand to red sandy clay loam (Appendix 5). There was auger restriction resulting from a pan at greater than 76 cm. Coarse sand was 385-507 g kg^{-1}with the lowest value occurring at 27-45 cm. Clay fraction increased with depth with the highest value of 267 g kg^{-1}occurring at 27-45 cm. There was also an increase in silt fraction down the profile (Appendix 3). There was an increase in bulk density down the profile with values of 1.64 Mg m^{-3}at 0-27 cm and 1.68 Mg m^{-3}at 59-76 cm. Total porosity decreased with increase in depth with values of 25.2% at the bottom of the profile and 34.3% at the topmost horizon. Water stable aggregates of the profile soils was 0.400 kg kg^{-1} (59-76 cm) to 0.578 kg kg^{-1} (0-27 cm). The soilsareslightly acidic, ranging from 6.5 at the topmost horizon to 6.4 at (59-76 cm).Soil organic carbon declined down the profile, with the maximum value (21.8 g kg^{-1}) at the uppermost horizon (0-27 cm) and the lowest (7.5 g kg^{-1}) at the bottommost horizon (59-76 cm). Total nitrogen is low (1.20 to 0.54 g kg^{-1}) and follows the same pattern as organic carbon. Base saturation is high at the top of the profile and decreases along the profile, with values ranging from 90.4 percent at the top to 80.3 percent at the bottom (Appendix 4).

(ii) Akure 2

Typic Kanhapludalf (USDA); Ferric Lixisol (FAO); Owo Series

The profile was located on the middle slope and is developed on medium grained granite gneiss. The profile was located within an area used for urban agriculture. The area cultivated are vacant parcels of land along the road with stands of dry maize – *Zea mays* (Plate 4.1).The soilsare shallow, well drained, dark reddish-brown sandy loam to red sandy clay (Appendix 5). There was auger restriction resulting from a pan at greater than 86 cm.The coarse sand content ranged from 269 to 428 g kg^{-1}, with the greatest value at 0-10 cm. The clay fraction increased with depth, reaching a maximum of 204 g kg^{-1} at 40-64 cm. Silt content reduced as one progressed down the profile (Appendix 3). Bulk density increased down the profile, reaching 1.15 Mg m^{-3} at 0-10 cm and 1.55 Mg m^{-3} at 64-86 cm. Total porosity decreased with increase in depth with values ranging from 32.3% at the bottom of the profile to 48.9% at the topmost horizon. The water stable aggregate was from 0.300 to 0.603kg kg^{-1} with the greatest value at 0-10 cm and least at 64-86 cm. The soilsareslightly acidic, ranging from 6.0 at 0-10 cm horizon to 6.5 at 64-86 cm.Organic

Note the built-up area at the background and the dry maize stands at the foreground.

Plate 4.1: Urban farm in the month of December, 2016 at Kajola, beside Greenwich Strategic Grain Reserve, Akure

carbon decreased down the profile, with the greatest amount (26.4 g kg^{-1}) at the uppermost layer (0-10 cm) while the least (4.2 g kg^{-1}) was at the bottom (64-86 cm). Total nitrogen followed a similar pattern to organic carbon and the concentrations are low (1.7 to 0.11 g kg^{-1}). Base saturation is high at the top of the profile and decreases along the profile, and the values rangedbetween 91.0% at the top and 78.6% at the bottom (Appendix 4).

(iii) Akure 3

Aquic Dystrudept (USDA); Haplic Cambisol (FAO); Apomu Series

The profile was located on the lower slope and is developed on coarse grained granite gneiss. The soils are deep, well drained, very dark grey sandy loam to brown sandy clay (Appendix 5).The mean value of coarse sand was 428 g kg^{-1}, with a range of 324 to 478 g kg^{-1}.The content of clay and silt rose down the profile in general, but not in a consistent pattern (Appendix 3). The bulk density ranged from 1.46 to 1.65 Mg m^{-3}, with a mean of 1.57 Mg m^{-3}. Total porosity declined along the profile, and the values rangedbetween 38.3 percent at the top and 30.4 percent at the bottom. The water stable aggregates ranged between 0.334 and 0.407 kg kg^{-1}, with the maximum value at 0-14 cm and the least at 62-78 cm. The soilsare moderately acidic with values ranging from 5.4 to 6.0. Organic carbon is limited in the profile and reduces as the profile gets deeper. The highest value of 6.2 g kg^{-1} was found at a depth of 0-14 cm, while the lowest value of 4.7 g kg^{-1} was found at a depth of 37-62 cm. Total nitrogen is low, ranging from 0.33 to 0.73 g kg^{-1}, which had a similar trend as organic carbon. The base saturation is moderate, with values ranging from 62.2 percent at the surface to 54.0 percent at the bottom (Appendix 4).

(iv) Akure 4

Aeric Aquept (USDA); Eutric Fluvisol (FAO); Adio Series

The profile was located on the valley bottom and is developed on granite gneiss. The profile was located within a wetland under arable cultivation. Leafy vegetables (*Corchorus olitorius* and *Amaranthus hybridus*)were planted on this land cover type (Plate 4.2). The soil is shallow, poorly drained, strong brown sandy loam to grey loam(Appendix 5).The shallowness was exacerbated by the high-water table. The surface horizon had an average coarse sand of 51 g kg^{-1}, while the subsoil horizon had 42 g kg^{-1}. The silt in the surface and subsoil horizons was 394 g kg^{-1}. Clay varies from 104 g kg^{-1} in the surface horizon to 124 g kg^{-1} in the subsoil horizon (Appendix 3). The soils have low bulk densities, and it ranges from 1.09 to 1.39 Mg m^{-3}, with the subsoil having the

Note the encroaching built-up structures at the background.

Plate 4.2: Wetland cover type in the month of December, 2016at Shagari Estate, Akure

maximum. The water stable aggregates in the subsoil horizon ranged from 0.596 kg kg^{-1} to 0.691 kg kg^{-1} in the surface horizon.The soils are slightly acidic to neutral (pH 6.4-7.3). Soil organic carbon is generally high ranging from 10.8 to 21.8 g kg^{-1}. Total nitrogen is low, ranging from 0.60-1.2 g kg^{-1}(Appendix 4). Base saturation is high and ranged from 95.4% to 96.5%, with the upper limit value occurring at the soil surface.

(v) Akure 5

Aquic Kanhapludalf (USDA); Gleyic Fluvisol (FAO); Matako Series

The profile was located on the valley bottom and is developed on granite gneiss. The soil is shallow, poorly drained, very dark grey sandy loam to grey sand(Appendix 5). The soil was shallow due to the high-water table encountered at 45 cm depth.The concentration of coarse sand particles ranged from 489 to 402 g kg^{-1}, with the least value occurring at 23-45 cm depth and the greatest at 0-23 cm depth. The clay fraction increased noticeably down the profile, with the maximum value of 284 g kg^{-1} occurring at a depth of 23-45 cm. Silt content decreased as one progressed down the profile (Appendix 3). The bulk density increased with depth, ranging from 1.21 to 1.31 Mg m^{-3}. Total porosity declined with depth, and the values rangedbetween 50.5 percent at the surfaceand 40.5 percent at the bottom. Water stable aggregateswas between 0.371 and 0.668 kg kg^{-1}, with the greatest at 0-23 cm and the least at 23-45 cm.The soilsareslightly acidic, where pH in water increased down the profile ranging from 6.3 to 6.8.Soil organic carbon is high in the profile and decreases with depth, with the greatest amount (32.0 g kg^{-1}) at the uppermost layer (0-23 cm). Total nitrogen followed the same pattern as organic carbon, ranging from 0.6 to 1.5 g kg^{-1}. With measurements ranging from 98.3% to 98.5%, base saturation was high and it increasedwith depth (Appendix 4).

4.5 Effects of Urban Land Use/Cover Types on Surface and Sub-Surface Soil Properties in Akure

4.5.1 Soil physical properties

(i) Soil particle fractions

Coarse sand: Coarse sand fractions at both 0-20 and 20-40 cm in Akure significantly differed under the ULUTs (Table 4.5). At 0-20 cm, coarse sand fraction was from 249 g kg^{-1}on wetland to 551 g kg^{-1}oninstitution. At 20-40 cm, coarse sand decreased when compared with 0-20 cm on commercial, residential, wetland and institutionalULUT by 16.1, 13.2, 44.6 and 0.2% respectively, while it increased on agricultural land use type by 3.2%.

oil physical properties at 0-20 and 20-40 cm depths in Akure

Fine sand 0.05-0.25 mm	Silt	Clay	Bulk density	Total porosity	WSA>250 µm	M
(g kg^{-1})			(Mg m^{-3})	(%)	(kg kg^{-1})	(r
			0-20 cm			
133±16^{a}	273±10^{c}	104±9^{ns}	1.46±0.03^{b}	35.7±1.2^{a}	0.502±0.01^{a}	0.70
265±7^{b}	269±10^{bc}	93±5	1.31±0.06^{ab}	43.2±2.0^{c}	0.650±0.02^{c}	1.04
415±10^{c}	245±16^{bc}	91±5	1.18±0.02^{a}	49.8±1.6^{d}	0.681±0.01^{c}	1.38
151±28^{a}	234±11^{ab}	93±3	1.37±0.03^{b}	36.9±1.0^{ab}	0.494±0.02^{a}	0.70
150±18^{a}	203±13^{a}	96±3	1.35±0.10^{b}	41.6±2.8^{bc}	0.577±0.02^{b}	0.86
			20-40 cm			
143±27^{a}	343±15^{c}	104±9^{a}	1.57±0.03^{bc}	33.2±1.2^{a}	0.380±0.02^{a}	0.43
174±7^{a}	352±20^{c}	90±4^{a}	1.60±0.03^{c}	36.6±1.8^{a}	0.428±0.02^{ab}	0.91
462±5^{c}	260±16^{b}	140±16^{b}	1.35±0.01^{a}	44.6±1.4^{b}	0.502±0.04^{b}	1.04
252±28^{b}	192±14^{a}	103±1^{a}	1.47±0.03^{b}	31.3±1.6^{a}	0.441±0.03^{ab}	0.60
128±22^{a}	216±14^{a}	106±5^{a}	1.48±0.06^{b}	35.9±3.1^{a}	0.454±0.02^{ab}	0.80

column followed by different letter(s) differ at the 0.05 probability level; ns = not significant. WSA>250 µm
ieter, WHC = water holding capacity, K_{sat} = saturated hydraulic conductivity.

Fine sand: Fine sand fraction followed a similar pattern to coarse sand in that there were significant variations across ULUTs in Akure (Table 4.5). Fine sand was 133 g kg^{-1} in commercial and 415 g kg^{-1} in wetland at 0-20 cm, and 128 g kg^{-1} in institution and 462 g kg^{-1} in wetland at 20-40 cm. When compared with 0-20 cm, fine sand fraction at 20-40 cm increased on all ULUTs except agriculture and institutionalULUTs. The increase was by 7.5% on commercial, while it was 11.3% on wetland and 66.9% on residential ULUT.

Silt: Silt fraction differed significantly among the ULUTs at both depths in Akure (Table 4.5). The silt fractionwas 203-273 g kg^{-1}at 0-20 cm, while it was 192-352 g kg^{-1}at 20-40 cm. The silt fractions under commercial and agricultural ULUTs were significantly higher when compared with other ULUTs at both depths. In comparison to 0-20 cm, silt at 20-40 cm increased by 25.6, 30.9, 6.1 and 6.4% on commercial, agriculture, wetland and institutionalULUT respectively.

Clay: There were no significant variations in clay content across the ULUTs in Akure at 0-20 cm, however there were significant variations at 20-40 cm (Table 4.5). The commercial, agriculture, residential and institutionalULUTs had their clay fraction higher than wetland at 0-20 cm. Clay on agricultural land use type was the least and was not significantly different from others except under wetland where it was 55.6% significantly lower at 20-40 cm. When compared with clay fraction at 0-20 cm, clay increased under wetland, residential and institutional ULUT by 53.8, 10.8 and 10.4%, respectively, while it decreased by 3.2% under agriculture and it was unchanged under commercial at 20-40 cm.

(ii) Bulk density and total porosity

Soil bulk density (SBD) showed significant differences among the ULUTsin Akure at both 0-20 and 20-40 cm depths (Table 4.5). Soil bulk densityat 20-40 cm depthconsistently increased in value compared with 0-20 cm. The SBD increased from 1.46 to 1.57, 1.31 to 1.60, 1.18 to 1.35, 1.37 to 1.47, and 1.35 to 1.48 Mg m^{-3}for commercial, agriculture, wetland, residential,and institution ULUT respectively.

Total porosity increased with decrease in SBD, and the ULUTs differed significantly from one another in Akure (Table 4.5). At 0-20 cm depth, total porosity under wetland was higher than agriculture, residential, institution and commercial ULUT by 13.3, 25.9, 16.5 and 28.3%, respectively. At 20-40 cm depth, total porosity under residential was lower than commercial, institution and agriculture by 6.1, 14.7 and16.9%

respectively,while it was significantlylower than wetland by 42.5%. In comparison with porosity at 0-20 cm, total porosity decreased under commercial, agriculture, wetland, residential and institutionalULUTby 7.0, 15.3, 10.4, 15.2 and 13.7%, respectively at 20-40 cm.

(iii) Water stable aggregates and meanweightdiameter

Water stable aggregates (WSA>250 μm) and mean weight diameter (MWD) demonstrated significant differences between ULUTs at both depths (Table 4.5). The WSA>250 m varied between 0.494 kg kg^{-1} in residential to 0.681 $kgkg^{-1}$ in wetlands at 0-20 cm. At 0-20 cm, the WSA>250 μm under wetland was 26.3, 27.5, 15.3, and 4.6 percent higher than under commercial, residential, institution, and agricultural ULUT, respectively. At 20-40 cm depth,WSA>250 μm under wetland increased by 24.3% over values under commercial. The increase over residential was 12.2%, over institution it was 9.6% and over agricultural ULUT it was 14.7%.When compared with WSA>250 μm at 0-20 cm, the aggregates decreased under commercial, agriculture, wetland, residential and institution by 24.3,34.2, 26.3,10.7 and 21.3%, respectively at 20-40 cm.

The mean weight diameter (MWD) followed similar trends withWSA>250 μm as presented in Table 4.5. Among all the ULUTs, MWD under wetland (1.38 mm) was significantly higher than others at 0-20 cm depth. At 20-40 cm depth, the ULUTs also significantly influenced MWD values. The value recorded under commercial (0.43 mm) was significantly lower than other ULUTs. The soil under commercial land use type consistently had the least MWDs (0.70 mm at 0-20 cm and 0.43 mm at 20-40 cm), and the highest (1.38 mm at 0-20 cm and 1.04 mm at 20-40 cm) were under wetland.

(iv) Saturated hydraulic conductivity and water holding capacity

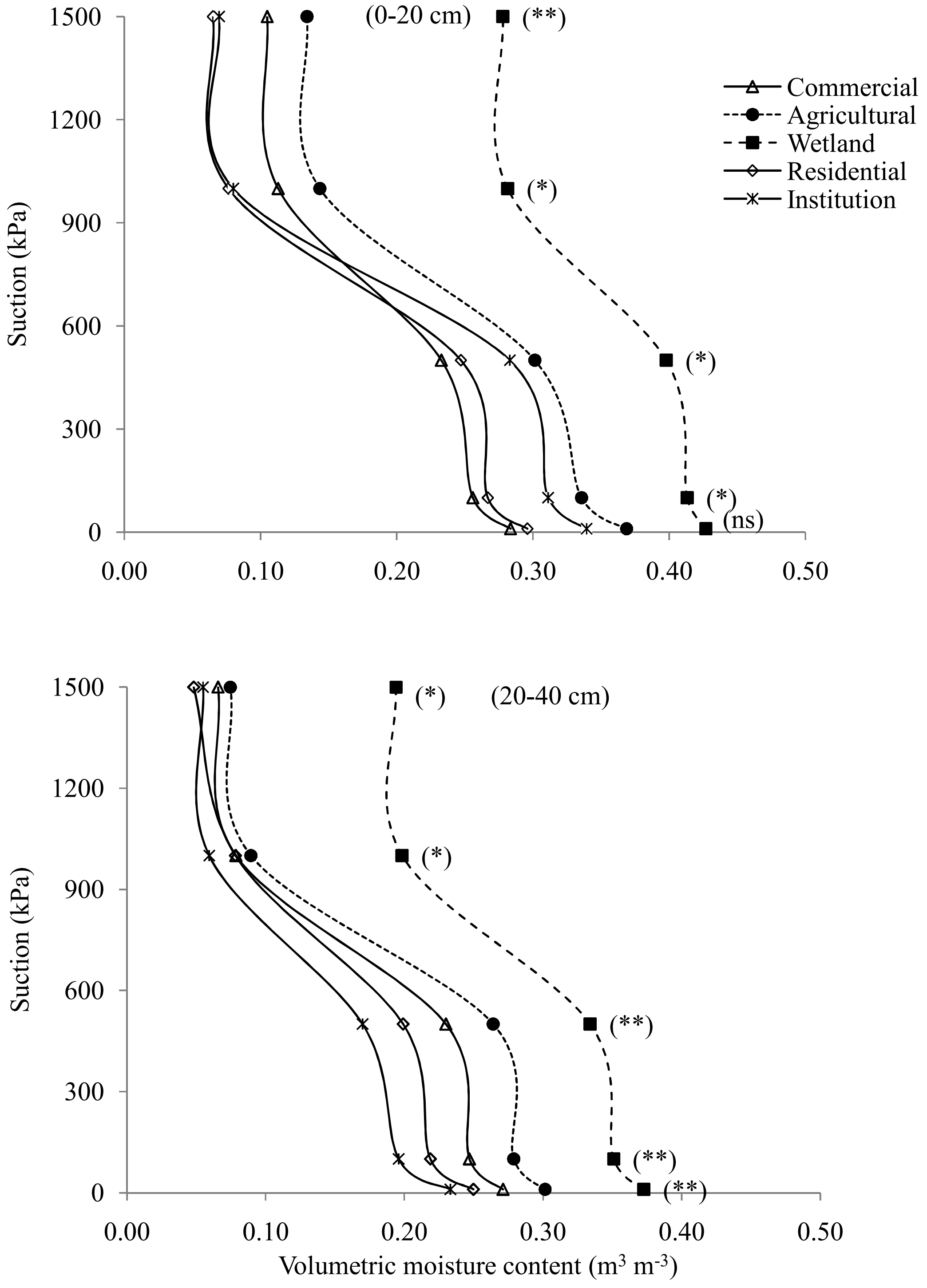
The mean saturated hydraulic conductivity (K_{sat}) values ranged from 6.1 to 23.6 cm hr^{-1}at 0-20 cm depth and 3.5 to 6.1 cm hr^{-1}at 20-40 cm depth (Table 4.5). In Akure, the K_{sat}value under wetland (23.6 cm hr^{-1}) was significantly higher than other ULUTs at 0-20 cm depth. Water conductivity across the soil column was higher in the residential land use type at 20-40 cm depth than in other ULUTs. When compared with 0-20 cm depth, soil hydraulic conductivities decreased at 20-40 cm depth under all ULUTs with the highest percentage (83.5%) decrease obtained under wetlands.

The water holding capacity (WHC) of the soils in Akure at 0-20 cm and 20-40 cm under the different ULUTs is given in Table 4.5. The water holding capacity at 0-20 cm under wetland (3.76 cm) was the highest and significantly different from values under agriculture (2.32 cm), institution (2.43 cm), residential (1.42 cm) and commercial ULUT(1.10 cm). At 20-40 cm, WHC followed a similar trend to that observed at 0-20 cm. The water holding capacity under wetland (1.62 cm) was significantlydifferent from values under agriculture (1.02 cm), residential (0.70 cm), institution (0.72 cm) and commercial ULUT (0.70 cm). The values of WHC at 20-40 cm as against 0-20 cm decreased under commercial, agriculture, wetland, residential and institutional ULUT by 36.4, 56.0,56.9, 50.7 and 70.4% respectively.

(v) Soil moisture retention and pore size distribution

Soil moisture functions at 0-20 cm in Akure as influenced by ULUTsare presented in Figure 4.7. At Akure, ULUT significantly affected moisture retention at all suctions except for at 10 kPa. The greatest retention was found under wetland at all suctions (10-1500 kPa). With increasing suctions, the variations in moisture retention among the ULUTs became smaller. At suctions between 10 and 500 kPa, wetland had a significantly higher moisture content than under other ULUTs except at 10 kPa. At 10 kPa, moisture under wetland (0.427 m^3 m^{-3}) was not significantly different from agriculture (0.369 m^3 m^{-3}), institution (0.339 m^3 m^{-3}), residential (0.296 m^3 m^{-3}) and commercial ULUT (0.283 m^3 m^{-3}). There were significant variations in soil moisture retention among the ULUTs at suctions greater than 500 kPa. At Akure, the least volumetric moisture recorded at permanent wilting point (1500 kPa) was 0.067, 0.065, 0.105, 0.134 and 0.278 m^3 m^{-3} under institution, residential, commercial, agriculture and wetland, respectively.

The soil moisture retention curves at 20-40 cm revealed that the ULUTs at Akure had significant variations in moisture retention (Fig. 4.7). The effects of wetland on soil moisture retention were clearly evident at lower suctions (10-500 kPa) and significantly different from other ULUTs. With values of 0.373 m^3 m^{-3} at 10 kPa, 0.351 m^3 m^{-3} at 100 kPa, and 0.334 m^3 m^{-3} at 500 kPa, wetland had the maximum moisture retention at Akure. The ULUTs showed significant difference in their impacts on volumetric moisture content at higher suctions (>500 kPa). For example, suction at 1000 kPa showed that volumetric moisture content under wetland (0.198 m^3 m^{-3}) was significantly higher than agriculture (0.089 m^3 m^{-3}), commercial (0.079 m^3 m^{-3}), residential (0.078 m^3 m^{-3}) and institutional ULUT (0.059 m^3 m^{-3}).



The asterisk (*) indicates significant difference at $P \leq 0.05$; (**) indicates significant difference at $P \leq 0.01$; (ns) indicates no significant difference at $P \leq 0.05$ among the ULUTS at each suction.

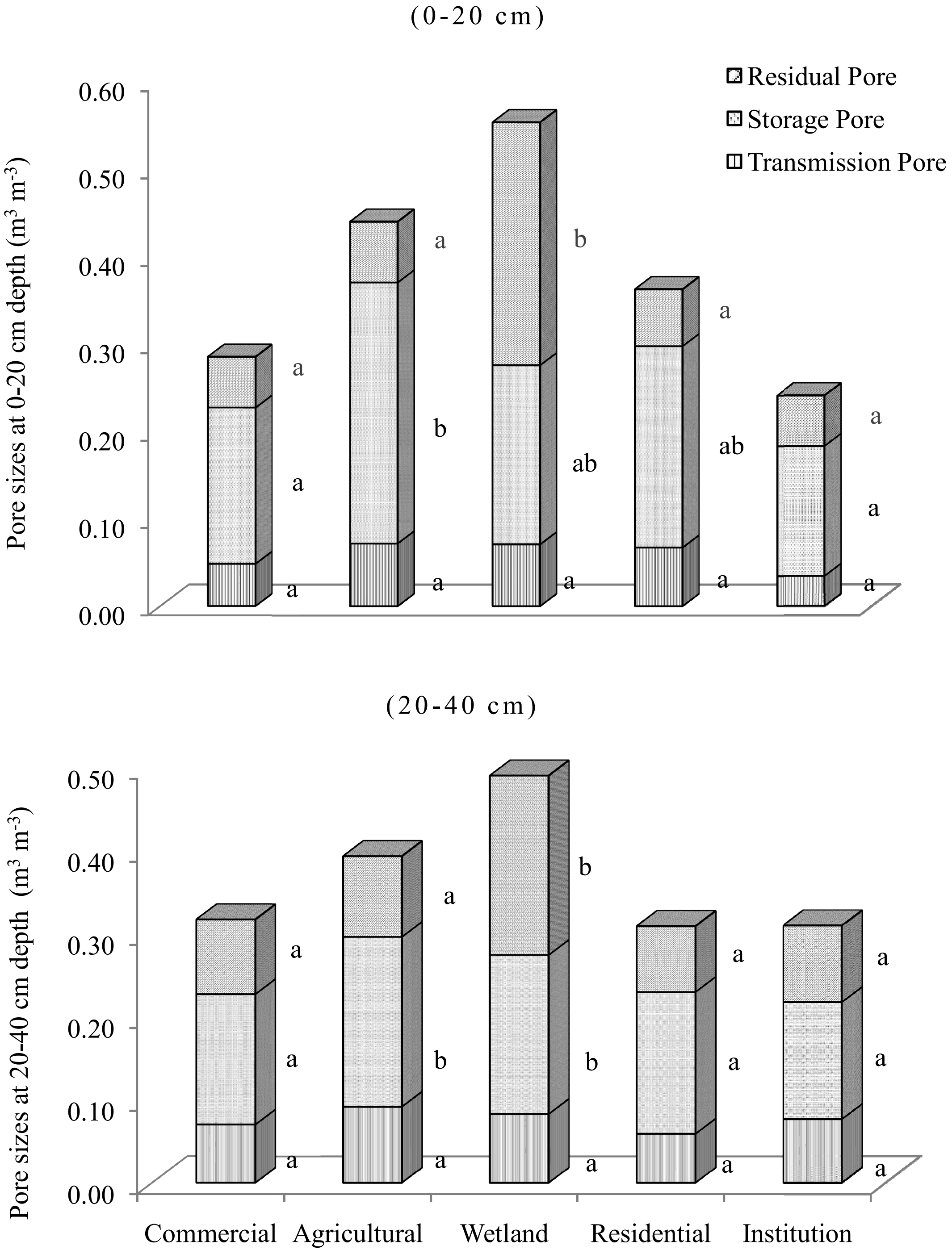
Fig. 4.7: Soil moisture function at 0-20 cm and 20-40 cm in Akure as influenced by ULUTs

Figure 4.8 depicts the variance in pore size distribution at 0-20 cm depth among Akure's ULUTs. Transmission and storage pores together accounted for 49.8 percent to 84.2 percent of total pore spaces in the soils in Akure.The agricultural ULUThad significantly greater amount of storage pores (0.299 m^3 m^{-3}). The transmission pores under agricultural ULUT in Akure (0.071 m^3 m^{-3}) was also greater than others although the transmission pores were not significantly different. Conversely, soil under institutional ULUT in Akure had the least transmission pores (0.034 m^3 m^{-3}) and storage pores (0.149 m^3 m^{-3}). The soil residual pores among the various ULUTs were consistently and significantly greater under wetland (0.278 m^3 m^{-3}).

The pore size distribution at 20-40 cm(Fig. 4.8) showed that there were significant differences among the ULUTs. The mean total pore volume in Akure ranged from 0.309 to 0.490 m^3 m^{-3} across the various ULUTs. Wetlands had the greatest mean total pore volume (0.490 m^3 m^{-3}) followed by agricultural ULUT (0.393 m^3 m^{-3}).The least mean total pore volumein Akure (0.309 m^3 m^{-3})was observed under residential.The storage pores were significantly higher under agriculture and wetland, while residual pores under wetlands were significantly higher than others.

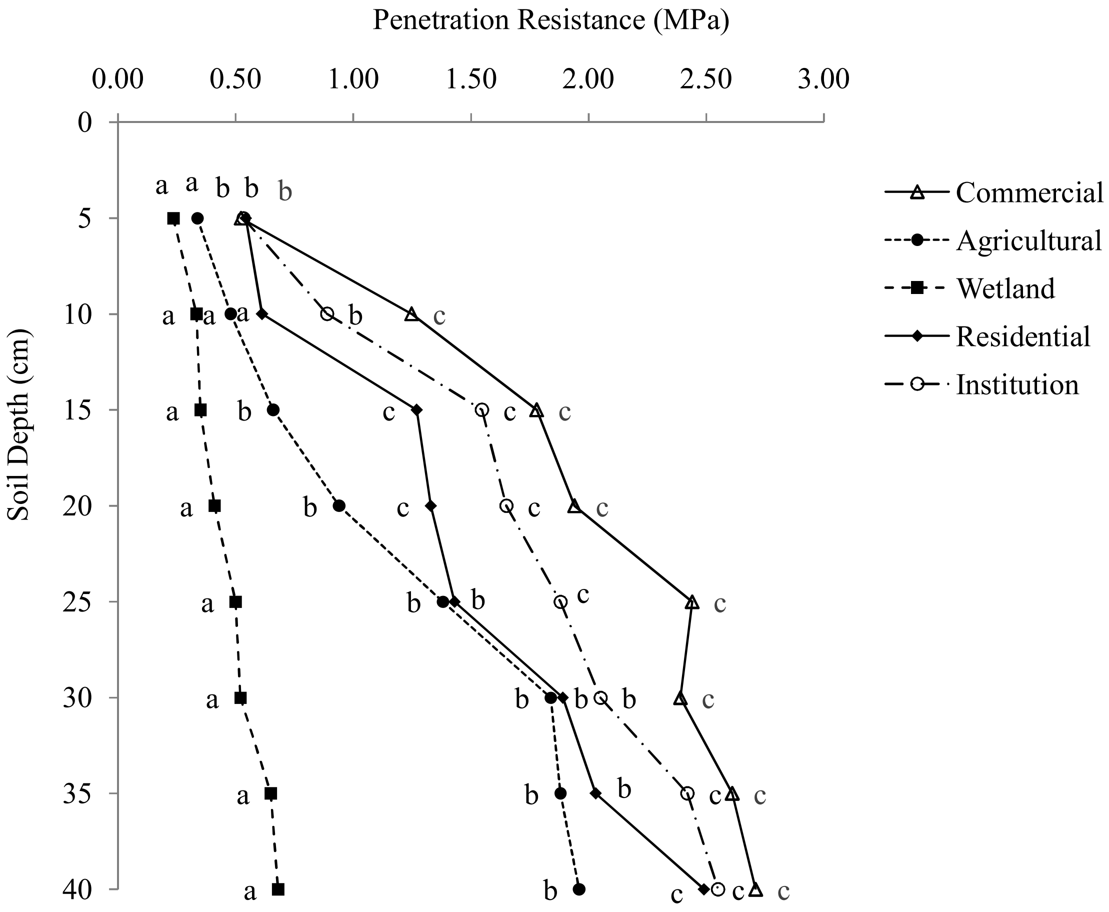
(vi) Soil strength

Soil strength at different depths as determined by penetration resistance at Akure showed significant differences among the ULUTs (Fig. 4.9). The penetration resistance under wetland was significantly lower than under other ULUTs throughout the soil column (0-40 cm). At Akure, penetration resistance reading under agricultural ULUT were not significantly different from wetland especially at 0-10 cm depth. Penetration resistance readings measured under commercial, institution and residential ULUTs were not significantly different from each other at deeper depths (≈ 40 cm).



Means across the bars for a poresize fraction containing the same letter(s) are not significantly different ($P \leq 0.05$).

Fig. 4.8: Pore size distribution at 0-20 cm and 20-40 cm in Akure as affected by ULUTs



Values within the same depth followed by the same letter(s) are not significantly different (P≤0.05).

Fig. 4.9: Variation in soil penetration resistance in Akure under commercial, agricultural, wetland, residential and institutionalULUT

4.5.2 Soil chemical properties

(i) Soil pH

The pH of the soils indicated that they were slightly acidic, and at both 0-20 and 20-40 cm depths, there were no major variations between the ULUTs in Akure (Table 4.6). At 0-20 cm depth, pH values were 7.0, 6.6, 6.5, 6.8 and 6.1 under commercial, agriculture, wetland, residential and institution, respectively. The corresponding pH values at 20-40 cm was 6.9, 6.5, 6.3, 6.5 and 6.2 under commercial, agriculture, wetland, residential and institution, respectively. In comparison to 0-20 cm, the pH at 20-40 cm decreased by 0.8, 1.1, 3.0 and 4.5% under commercial, agriculture, wetland and residential, respectively while it increased by 2.6% under institution.

(ii) Electrical conductivity (EC)

The soil electrical conductivity in Akure varied significantly among the ULUTs at both depths (Table 4.6). At 0-20 cm, EC ranged between 0.26-0.63 dS m^{-1}, while it was 0.13-0.39 dS m^{-1} at 20-40 cm depth. Electrical conductivities under urban agriculture (0.63 dS m^{-1}) and commercial ULUT (0.43 dS m^{-1}) were higher than other ULUTs at 0-20 cm depth. At 20-40 cm, EC under institution (0.13 dS m^{-1}) and residential (0.16 dS m^{-1}) were lower than urban agriculture (0.38 dS m^{-1}), commercial (0.33 dS m^{-1}) and wetland (0.39 dS m^{-1}).

(iii) Soil organic carbon (SOC)

The SOC contents of the ULUTs at 0-20 cmwas18.4-29.8 g C kg^{-1}, and at 20-40 cm it was 8.4-17.5 g C kg^{-1}(Table 4.6). The differences between SOC under the different ULUTs in Akure were significant at 0-20 cm. Soil organic carbon under wetland (29.8 g C kg^{-1}) was higher than commercial (27.3 g C kg^{-1}) and agriculture (26.1 g C kg^{-1}), while it was significantly higher than residential (18.4 g C kg^{-1}) and institution ULUT (18.8 g C kg^{-1}). At 20-40 cm, significant differences in SOC under the ULUTs were also observed. Although SOC was greatest under wetland (17.5 g C kg^{-1}), it was however not significantly different from commercial (17.1 g C kg^{-1}) but significantly different from institution (9.8 g C kg^{-1}), urban agriculture (8.4 g C kg^{-1}) and residential (14.6 g C kg^{-1}) ULUT. The SOC at 20-40 cmdepth decreased under commercial, agriculture, wetland, residential and institution ULUT by 37.4, 67.8, 41.3, 20.7 and 47.7%, when compared with their respective SOC at 0-20 cmdepth.

on soil chemical properties at 0-20 and 20-40 cm depths in Akure

EC	Org C	Total N	AvP	Ca	Mg
(dS m^{-1})	(g kg^{-1})		(mg kg^{-1})		(cmol
			0-20 cm		
0.427±0.07b	27.3±1.4b	2.22±0.20b	7.61±0.85b	6.79±0.48c	2.84±0.70c
0.406±0.06b	26.1±0.9b	1.97±0.26ab	8.48±0.78b	1.53±0.26b	0.38±0.07a
0.630±0.19c	29.8±2.1b	3.00±0.29c	13.29±1.32c	1.69±0.19b	0.50±0.09a
.381±0.05ab	18.4±2.2a	1.83±0.20ab	4.95±0.68a	1.43±0.23b	0.47±0.10a
0.255±0.05a	18.9±1.5a	1.40±0.12a	4.59±0.47a	0.77±0.09a	0.71±0.08b
			20-40 cm		
0.327±0.06b	17.1±1.5c	1.35±0.08a	3.75±0.35b	0.93±0.04ab	0.56±0.09ns
0.380±0.14b	8.4±1.3a	1.23±0.14a	4.48±0.39b	0.74±0.07a	0.41±0.08
0.388±0.06b	17.5±1.3c	1.83±0.21b	6.06±0.64c	0.97±0.15b	0.47±0.08
.163±0.01ab	14.6±1.4b	1.14±0.09a	1.85±0.17a	0.63±0.05a	0.38±0.07
0.126±0.01a	9.9±1.4a	1.05±0.14a	1.45±0.06a	0.51±0.05a	0.40±0.04

hin a column followed by different letter(s) differ at the 0.05 probability level; ns – not significant. EC
gen; AvP = available phosphorus.

(iv) Total nitrogen

At both 0-20 and 20-40 cm depths, total nitrogen in Akure had a pattern close to that of SOC, and it differed significantly among ULUTs (Table 4.6). Total nitrogen was 1.40 g kg^{-1} under institution and 3.00 g kg^{-1} under wetland at 0-20 cm, and 1.05 g kg^{-1} under institution and 1.83 g kg^{-1} under wetland at 20-40 cm. At all depths, total nitrogen in the wetland was greater than total nitrogen in the other ULUTs. Total nitrogen levels at 20-40 cm depth decreased by 39.2, 37.6, 39.0, 37.7, and 25.0% in commercial, agricultural, wetland, residential, and institutional ULUT, respectively, as compared to total nitrogen levels at 0-20 cm.

(v) Available phosphorus

The effect of ULUTs on available phosphorus concentrations at 0-20 and 20-40 cm in Akure is presented in Table 4.6. The concentration of available phosphorus under wetland was significantly higher than those recorded under other ULUTs. In comparison with wetlands, concentration of available phosphorus decreasedunder commercial, agriculture, residential and institution ULUT by 42.7, 36.2,62.8 and 65.5% at 0-20 cm depth. The corresponding reductions at 20-40 cm depth was38.1, 26.1, 69.5 and 76.1% under commercial, agriculture, residential and institution, respectively. Average concentrations of available phosphorus across the 2 depths was 6.0, 6.0, 9.0, 4.0 and 4.0 mg kg^{-1} under commercial, agriculture, wetland, residential and institutionalULUT respectively.

(vi) Exchangeable calcium

Commercial ULUT at 0-20 cm and wetland at 20-40 cm depth had the highest calcium concentrations, which were significantly greater than other ULUTs (Table 4.6).At 0-20 cm depth, exchangeable calcium varied between 0.7 cmol kg^{-1} in institution and 6.7 cmol kg^{-1} in commercial ULUT, whereas at 20-40 cm depth, it ranged between 0.5 cmol kg^{-1} in institution to 0.9 cmol kg^{-1} in wetland. When compared with exchangeable calcium status at 0-20 cm, the exchangeable calcium decreased by 86.3, 51.6, 42.6, 55.9 and 33.8% under commercial, agriculture, wetland, residential and institutionalULUT respectively at 20-40 cm.

(vii) Exchangeable magnesium

Only at a depth of 0-20 cm did there exist significant variations in exchangeable magnesium between the ULUTs in Akure (Table 4.6).Exchangeable magnesium showed a similar trend to that of calcium in that commercial at 0-20 cm had the highest concentration of magnesium. At 0-20 cm depth, exchangeable magnesium concentrations ranged from 0.4 to 2.8 cmol kg^{-1}, and at 20-40 cm, it was 0.4 to 0.6 cmol kg^{-1}.

(viii) Exchangeable potassium

At Akure, there were significant variations in exchangeable potassium between ULUTs at both depths (Table 4.6). Potassium was significantly higher in commercial (1.0 cmol kg^{-1}) than residential (0.7 cmol kg^{-1}), urban agricultural (0.7 cmol kg^{-1}), wetland (0.5 cmol kg^{-1}) and institutional (0.5 cmol kg^{-1}) soils at 0-20 cm. At 20-40 cm, potassium under wetland was higher than commercial, agriculture, residential and institution ULUT by 25.9, 33.3, 25.9and 44.4%, respectively. When compared with 0-20 cm, potassium concentration at 20-40 cm decreased by 58.8, 45.5, 45.0 and 38.8% under commercial, agriculture, residential and institutionalULUT respectively. In contrast, there was a slight increase of 1.9% under the wetland when comparing potassium at 20-40 cm with concentration at 0-20 cm.

(ix) Exchangeable sodium

While there were no significant differences in soil sodium values between ULUTs at 0-20 cm, there were significant variations in subsurface (20-40 cm) soil sodium concentrations between ULUTs (Table 4.6). At 0-20 cm, exchangeable sodium concentration was 1.0-1.2 cmol kg^{-1}, while at 20-40 cm depth, it was 0.3-0.6 cmol kg^{-1}. Relative to sodium status at 0-20 cm depth, exchangeable sodium decreased by 76.6, 56.6, 45.5, 51.4 and 48.3% under commercial, agriculture, wetland, residential and institution respectivelyat 20-40 cm.

(x) Heavy metals

Zinc: Among ULUTs, the amount of zinc (Zn) present at 0-20 and 20-40 cm depths varied significantly (Table 4.7). At 0-20 cm, zinc levels were between 3 mg kg^{-1} in agriculture and 29 mg kg^{-1} in commercial, while at 20-40 cm, zinc levels were between 1 mg kg^{-1} in agriculture and 43 mg kg^{-1} in commercial. Zn levels in commercial were 45.4, 91.2, 53.6, and 65.4% higher at 0-20 cm than in wetland, agriculture, residential, and institution, respectively.In comparison to Zn concentrations at 0-20 cm, Zn concentrations rose in all ULUTs except wetland and agricultural ULUT, where it fell by 39.8 and 61.5% at 20-40 cm, respectively.

Table 4.7: Effects of ULUTsin Akure on heavy metal concentrations at 0-20 and 20-40 cm depths

ULUT	Zn	Cu	Mn	Pb	Cr	Cd	Fe
				(mg kg^{-1})			
0-20 cm							
Commercial	29±7c	8±0.7b	110±4ns	14±3.d	7±0.9a	3.0±0.5b	127±6ab
Agriculture	3±0.3a	2±0.6a	139±19	6±0.6c	16±2a	0.3±0.1a	158±9ab
Wetland	16±1b	3±0.3a	174±26	4±0.6b	155±9b	1.0±0.1a	330±40c
Residential	14±3b	2±0.5a	130±6	3±0.5a	10±1a	2.0±0.1b	110±21a
Institution	10±3ab	2±0.4a	155±13	3±0.4a	17±2a	1.0±0.2a	207±51b
20-40 cm							
Commercial	43±9b	11±2b	128±14a	10±2b	6±0.5a	2.0±0.2b	266±31b
Agriculture	1±0.2a	3±0.7a	309±20c	4±0.7a	32±11b	0.4±0.1a	202±30ab
Wetland	10±3a	3±0.4a	300±33c	2±0.2a	93±27c	1.0±0.1a	399±53c
Residential	15±2a	3±0.2a	168±23ab	4±0.6a	16±1a	2.0±0.1c	129±6a
Institution	16±1a	2±0.5a	217±15b	3±0.4a	16±1a	1.0±0.2b	135±8a
MPL	50	100	2000	2.0	100	0.76	38000

Means (±standard error of mean) within a column followed by different letter(s) differ at 0.05 probability level; ns =not significant, MPL = maximum permissible level (FEPA).

Copper: At both 0-20 and 20-40 cm depths, the copper (Cu) concentrations of soils under commercial were significantly higher than those under other ULUTs (Table 4.7). Copper concentrations were higher in commercial than agricultural, wetland, residential, and institution at 0-20 cm depth, by 79.3, 68.6, 71.1, and 74.4%, respectively. Copper concentrations in commercial were higher at 20-40 cm than in agriculture, wetland, residential, and institution, respectively, by 72.3, 75.3, 67.9, and 83.8%.

Manganese: There were no significant variations in manganese (Mn) between ULUTs at 0-20 cm, but there were significant variations at 20-40 cm as shown in Table 4.7. At the soil surface (0-20 cm), Mn levels were lower in commercial (110 mg kg^{-1}) than residential (130 mg kg^{-1}), institution (155 mg kg^{-1}), urban agriculture (139 mg kg^{-1}) and wetland (174 mg kg^{-1}). At 20-40 cm depth, soil Mn concentrations in urban agriculture (309 mg kg^{-1}) and wetland (300 mg kg^{-1}) were significantly higher than other ULUTs.Manganese concentrations at 20-40 cm increased by 16.4, 122.3, 72.4, 29.2 and 40.0%, respectively, as compared to concentrations at 0-20 cm in commercial, urban agriculture, wetland, residential, and institution urban land use type.

Lead: Lead (Pb) concentration in Akure varied significantly among the different ULUTs at both depths (Table 4.7). The concentrations of Pb under commercial (14 mg kg^{-1}at 0-20 cm and 10 mg kg^{-1}at 20-40 cm depths), were significantly higher than other ULUTs at both depths. Average Pb concentrations across the two depths were 12, 5, 3, 4 and 3 mg kg^{-1}under commercial,agriculture, wetland, residential andinstitution respectively. In comparison, Pb values at 20-40 cm depth decreased by 4 mg kg^{-1} under commercial, 2 mg kg^{-1} under agriculture and wetland, while under residential it increased by 1 mg kg^{-1} and it was the same under institutionalULUT.

Chromium: At both depths, chromium (Cr) concentrations under wetland in Akure were significantly higher than other ULUTs (Table 4.7). At 0-20 cm depth, Cr concentration measured under wetland was 23.5, 9.6, 14.7 and 9.2 times the concentration under commercial, agriculture, residential and institution respectively. On the other hand, it was respectively 16.4, 2.9, 5.9 and 6.0 times under commercial, agriculture, residential and institution at 20-40 cm depth. The mean Cr concentrations over the two depths were 7, 24, 124, 13 and 16 mg kg^{-1} under commercial, agriculture, wetland, residential and institution respectively.

Cadmium: At both depths, the concentrations of cadmium (Cd) varied significantly among the ULUTs in Akure (Table 4.7). Cadmium concentrationswere 0.3-3.0 mg kg^{-1}at

0-20 cm, and 0.4-2.0 mg kg^{-1} at 20-40 cm. Cadmium concentration was higher in commercial and residential ULUT (3.0and 2.0 mg kg^{-1} respectively) than in institution, wetland and urban agriculture (1.0, 1.0and 0.3 mg kg^{-1}respectively) at 0-20 cm.Cadmium concentrations in the 20-40 cm depth followed a similar pattern to those in the 0-20 cm, with levels under commercial (2 mg kg^{-1}) and residential (2 mg kg^{-1}) ULUTs greater than others.

Iron: At both 0-20 cm and 20-40 cm depths, there were significant variations between commercial, agriculture, wetland, residential, and institutionalULUTs (Table 4.7). Iron concentrations at 0-20 cm depth revealed that wetland (330 mg kg^{-1}) had significantly higher Fe than commercial (127 mg kg^{-1}), urban agriculture (158 mg kg^{-1}), institution (207 mg kg^{-1}) and residential (110 mg kg^{-1}).

4.5.3 Soil biological properties

(i) Soil respiration

Table 4.8 shows the rate of soil microbial respiration at 0-20 cm in Akure. At the soil surface, respiration rates under the various ULUTs varied significantly. Wetland respiration (60.5 mg CO_2-C kg^{-1} d^{-1}) was significantly higher than residential, institution, urban agriculture and commercial ULUT with values of 46.5, 46.2, 35.2, and 19.1 mg CO_2-C kg^{-1} d^{-1}, respectively.

(ii) Microbial biomass carbon (C_{mic}) and nitrogen (N_{mic})

The concentration of chloroform fumigation extractable microbial biomass carbon (C_{mic}) and nitrogen (N_{mic}) at the soil surface (0-20 cm) was significantlyinfluenced by ULUTs in Akure (Table 4.8). At 0-20 cm,C_{mic} was lower in residential soil (193.9 mg C kg^{-1} soil) than commercial (224.6 mg C kg^{-1} soil), urban agriculture (290.3 mg C kg^{-1} soil), wetland (307.3 mg C kg^{-1} soil), and institution (253.2 mg C kg^{-1} soil).

Soil microbial N (N_{mic}) at the soil surface followed a similar trend to C_{mic}. At this depth, N_{mic} differed among the ULUTs (Table 4.8). The concentration of N_{mic}ranged between 14.4 mg N kg^{-1}soilin residential and 23.2 mg N kg^{-1}soilin wetland. When compared with N_{mic} under wetland, N_{mic} decreased respectively by 27.6, 6.5, 37.9 and 19.8% under commercial, agriculture, residential and institutional ULUT at the soil surface.

Table 4.8: Effects of ULUTs on surface soil microbiological properties in Akure

ULUT	Soil Respiration (mg CO_2-C kg^{-1} d^{-1})	C_{mic} (CFE) (mgC kg^{-1}soil)	N_{mic}(CFE) (mg N kg^{-1}soil)	PMN (mg N kg^{-1} soil 7 d^{-1})
Commercial	19.1±2.1a	224.6±19.2ab	16.8±0.4ab	33.0±0.4b
Agriculture	35.2±2.4b	290.3±6.5c	21.7±0.5c	41.5±0.9d
Wetland	60.5±3.4d	307.3±4.1c	23.2±0.3c	44.1±0.6d
Residential	46.5±1.9c	193.9±3.0a	14.4±0.3a	27.7±0.4a
Institution	49.2±4.8c	253.2±14.6b	18.6±0.2b	37.0±0.5c

Means (±standard error of mean) within a column followed by different letter(s) differ at 0.05 probability level.C_{mic}=microbial biomass carbon; N_{mic}=microbial biomass nitrogen; CFE =chloroform fumigation extraction; PMN =potentially mineralizable nitrogen.

(iii) Potentially mineralizable nitrogen (PMN)

The surface soil (0-20 cm) potentially mineralizable nitrogen (PMN) ranged from 27.7 to 44.1 mg N kg^{-1} soil 7 d^{-1} with the least concentrations measured under residential and highest concentrations measured under wetland (Table 4.8). The PMN value obtained under wetland (44.1 mg N kg^{-1} soil 7 d^{-1}) was significantly higher than commercial (33.0 mg N kg^{-1} soil 7 d^{-1}), agriculture (41.5 mg N kg^{-1} soil 7 d^{-1}), residential (27.7 mg N kg^{-1} soil 7 d^{-1}) and institution (37.0 mg N kg^{-1} soil 7 d^{-1}). The values obtained under the institution and commercial ULUTs, on the other hand, were not significantly different from each other.

4.6 Soil Profile Properties on Selected Urban Land Use/Cover Types in Okitipupa

The detailed physical and chemical properties of the representative soil profiles of the ULUTs in Akure are given in Appendices 6-7. The summary of the morphological description of the profile soils in Akure is given in Appendix 8.

(i) Okitipupa 1

Rhodic Kandiudult (USDA); Rhodic Lixisol (FAO); Alagba Series

The profile was located on the upper slope and is developed on sandstone parent material. The profile was located within a residential urban land use type (Plate 4.3). In some instances, farming activities occur around some of the buildings and on vacant plots where maize – *Zea mays*, cassava – *Manihot esculenta* and vegetables – *Amaranthus hybridus* are grown.The soils range from dark reddish-brown sand to dark red sandy clay, and are deep and well drained (Appendix 8). The highest value was found at 10-28 cm depth, with coarse sand ranging from 441 to 595 g kg^{-1}. Clay fraction increased with depth, varying between 127 g kg^{-1} at 0-18 cm and 287 g kg^{-1} at 80-110 cm. The concentration of silt reduced from the surface, but there was no obvious pattern. The greatest value was measured at 0-10 cm, and the lowest value was measured at a depth of 28-80 cm (Appendix 6).Bulk density values ranged from 1.24 Mg m^{-3} at 10-28 cm to 1.48 Mg m^{-3} at 80-110 cm. Total porosity reduced with depth and the values rangedbetween 55.0% at the surfaceand 49.2% at 80-110 cm depth. The weight of water stable aggregates varied between 0.355 and 0.512 kg kg^{-1}. The pH of the soils is moderately acidic, varying from 5.9 at the top to 4.8 at the bottom. The amount of organic carbon in the soil is low, and it decreases with depth. At 0-10 cm, the maximum value of 12.3 g kg^{-1} was found, and at 80-110 cm depth, the lowest value of 6.0 g kg^{-1}

was found. Total nitrogen is low, with a range of 0.7 to 1.3 g kg^{-1}, and a trendidentical to that of organic carbon.

Plate 4.3: Residential areas with vacant plots in the month of March, 2017 used for agriculture at Oke Oyinbo, Okitipupa

Base saturation is low and decreasing with depth, and the values rangedbetween 44.3% at the top and 25.9% at the bottom (Appendix 7).

(ii) Okitipupa 2

Rhodic Paleudult (USDA); Rhodic Acrisol (FAO); Okitipupa Series

The profile was located on the middle slope and is developed on sandstone parent material. The profile is very deep, well drained, dark reddish-brown loamy sand to red sandy clay loam subsoils (Appendix 8). The physical properties of the soil showed that coarse sand was from 418 to 649 g kg^{-1}with the lowest value occurring at 9-35 cm and the highest value occurring at 0-9 cm depth. Clay fraction generally increased with depth with values of 107 g kg^{-1}at 0-9 cm and347 g kg^{-1}at 9-35 cm. Silt content progressively decreased with depth but increased appreciably to 96 g kg^{-1}at 90-120 cm depth (Appendix 6). Bulk density values increased with depth, ranging from 1.49-1.59 Mg m^{-3}. Total porosity decreased with increase in depth with values ranging from 30.2% at the bottom of the profile to 40.2% at the topmost horizon. The water stable aggregates were 0.305-0.401 kg kg^{-1}. The soilsare slightly to moderately acidic with pH values ranging from 5.5 at 9-35 cm horizon to 4.9 at 60-90 cm depth. Organic carbon is moderate at the surface horizon and it decreases with depth. The highest value of 20.4 g kg^{-1} occurred at the surface, and the lowest value of 3.4 g kg^{-1} was at 90-120 cm depth. Total nitrogen is low and had a similar trend as organic carbon ranging from 0.29 to 2.9 g kg^{-1}.Base saturation is low and decreasing with depth, and the values rangedbetween52.6% at the top to 21.6% at the bottom(Appendix 7).

(iii) Okitipupa 3

Typic Dystrudept (USDA); Arenic Acrisol (FAO); Mesan Series

The profile was located on the lower slope and is developed on sandstone parent material. The profile was located within an area used for urban agriculture. The crops grown are in mixtures and they include cassava – *Manihot esculenta*, yam – *Dioscorea spp.*, maize – *Zea mays*, plantain – *Musa paradisiaca*, oil palm – *Elaeis guineensis* and vegetables– *Amaranthus hybridus* (Plate 4.4).The soilsare very deep, well drained, dark brown sand to yellowish red sand subsoil(Appendix 8). Coarse sand fraction was 703-768 g kg^{-1}with the lowest value occurring at 15-34 cm and the highest value occurring at 0-15 cm. Clay particles increased with depthalthough without any definite pattern and the values rangedbetween67 and 107 g kg^{-1}. Silt content also increased with depth the least

Plate 4.4: Urban farming in the month of March, 2017 at Ojokodo area, Odo Aye, Okitipupa

value at 0-15 cm and highest value at 60-120 cm.Bulk density was between 1.27and 1.46 Mg m^{-3}.Total porosity reduced with depth and the values rangedbetween53.5% at the surface horizon and50.5% at 60-120 cm.Water stable aggregate was from 0.395-0.503 $kgkg^{-1}$ with the highest found at 0-15 cm and least at 120-175 cm (Appendix 6). The soilsare moderately acidic in reaction, with pH decreasing with depth (but not in anyclear pattern) and the values rangedbetween4.8 at the surfaceand 4.4 at the sub-surface. Organic carbon is moderate at the surface horizon and it decreases with depth. The highest value of 31.9 g kg^{-1} occurred at 0-15 cm and the least of 3.4 g kg^{-1} was at 120-175 cm. Total nitrogen is low (0.11 to 1.3 g kg^{-1}) and had a similar trend as organic matter.Base saturation is low and reduced with depth and the values rangedbetween38.8% and16.3% (Appendix 7).

(iv) Okitipupa 4

Oxyaquic Udipsamments (USDA); Ferralic Acrisol (FAO); Mesan Series

The profile was located on the lower slope and is developed on sandstone parent material. The profile is deep, well drained, dark reddish-brown sand to dark red sand subsoils (Appendix 8). Coarse sand ranged from 606 to 789 g $kg^{-1}$with the highest value occurring at 50-64 cm and the lowest value occurring at 16-30 cm. Clay and silt fractions didn't exhibit any particular distribution pattern with depth and the clay fraction ranged between 107and147 g kg^{-1},while silt fraction rangedbetween 45and105 g kg^{-1}. Bulk density increased with depth, although not in a predictable way, and the values ranged between 1.53 Mg m^{-3} at the uppermost horizon to 1.55 Mg m^{-3} at the bottom. The weight of water stable aggregates was between 0.228 and 0.455 kg kg^{-1}, with the maximum value at 40-50 cm and the least at 16-30 cm (Appendix 6).The soilsare moderately acidic, where pH increasedwith depth and the values rangedbetween 5.52 at the surface and5.96 at depth.Organic carbon is low and generally reducedwith depth with the greatest (16.1 g kg^{-1}) at the surface (0-16 cm) and least (4.6 g kg^{-1}) at lower depth (50-64 cm).Total nitrogen is low and had a similar trend as organic carbon ranging between 0.61and2.0 g kg^{-1}.Base saturation decreased with depth and the values rangedbetween39.0% at the top and 29.7% at lower depth.

(v) Okitipupa 5

Humaqueptic Endoaquent (USDA); Arenic Fluvisol (FAO); Ode Erinje Series

The profile was located on the valley bottom and is developed on sandstone parent material. The profile was located within a wetland under arable cultivation (Plate 4.5).

Plate 4.5: Wetland cover type in the month of March, 2017 at River Oluwa flood plain, Okitipupa

Crops such as maize – *Zea mays*, rice – *Oryza sativa* and vegetables – *Telfairia occidentalis* are planted on this land cover type. The soil is shallow, very poorly drained, very dark brown loam to very dark greyish brown sandy clay loam (Appendix 8). The soil was shallow due to the high-water table encountered at 32 cm. Coarse sand ranged from 326 to 512 g kg^{-1}with the lowest value occurring at 12-32 cm and the highest value occurring at 0-12 cm. Clay fraction increased with depth and the values rangedbetween 87 and 127 g kg^{-1}. Silt content also increased with depth (Appendix 6). Bulk density values decreased with increase in depth and it ranged from 1.03 Mg m^{-3} at 0-12 cm to 0.88 Mg m^{-3} at 12-32 cm. Total porosity increased marginally with increase in depth and the values rangedbetween 68.5% at the surface of the profile and 69.9% at the bottom. Water stable aggregateswasbetween 0.627and 0.727kg kg^{-1} with the highest at 0-12 cm and the least at 12-32 cm (Appendix 6).The soils are fairly acidic, with pH varying from 5.2 to 5.7 with depth. Organic carbon concentrations are high and decreasing with depth, with the greatest value (37.1 g kg^{-1}) at the surface (0-12 cm).Total nitrogen had a similar trend as organic carbon ranging from 2.8 to 4.5 g kg^{-1}.Base saturation increased with depth and the values rangedbetween54.7% and58.1% (Appendix 7).

4.7 Effects of Urban Land Use/Cover Types on Surface and Sub-Surface Soil Properties in Okitipupa

4.7.1 Soil physical properties

(i) Particle size fractions

Coarse sand: Coarse sandfractions differed significantly among the ULUTs at both depths in Okitipupa (Table 4.9). The coarse sand content ranged from 423 to 742 g kg^{-1} at 0-20 cm,and it ranged from 628 to 728 g kg^{-1} at 20-40 cm. The coarse fraction under residential ULUT was higher when compared with others at both depths. In comparison to 0-20 cm, coarse sand at 20-40 cm increased respectively by 0.9, 3.4 and 56.3% on commercial, agriculture and wetland, while it decreased by 1.9% on residential and by 9.6% on institutionalULUT.

Fine sand: Urban land use types significantly influenced fine sand fraction at both 0-20 and 20-40 cm in Okitipupa (Table 4.9). At 0-20 cm, fine sand was 48 g kg^{-1}under residential and 413 g kg^{-1}under wetland. At 20-40 cm depth, fine sand decreased when compared with 0-20 cm depth on commercial, agriculture, wetland, residential and institutionalULUT by 72.7, 63.3, 75.1, 43.8 and 5.6%, respectively.

soil physical properties at 0-20 and 20-40 cm depths in Okitipupa

Fine sand 0.05–0.25 mm	Silt	Clay	Bulk density	Total porosity	WSA>250 µm	MW
(g kg^{-1})			(Mg m^{-3})	(%)	(kg kg^{-1})	(mm
			0-20 cm			
150±10c	88±5ab	104±3ns	1.45±0.02b	42.5±0.6a	0.334±0.01a	0.51±0.
128±11bc	94±5b	99±5	1.37±0.03b	54.7±0.7c	0.587±0.03c	1.41±0.
413±14d	75±4a	89±5	0.90±0.08a	64.7±1.4d	0.686±0.03d	1.94±0.
48±4a	96±3b	114±2	1.51±0.03b	46.4±1.9b	0.422±0.01b	0.85±0.
107±15b	96±5b	102±6	1.44±0.04b	40.7±0.5a	0.414±0.02b	0.84±0.
			20-40 cm			
41±6a	191±11ns	104±3c	1.42±0.06c	39.6±1.4ab	0.264±0.01a	0.39±0.
47±7a	164±7	87±4b	1.22±0.03b	52.0±0.7c	0.462±0.02c	0.97±0.
103±4b	177±10	59±1a	0.86±0.09a	56.1±3.6c	0.602±0.02d	1.11±0.
27±6a	143±11	102±7bc	1.41±0.04c	44.4±3.1b	0.326±0.01b	0.52±0.
101±9b	147±15	124±7d	1.43±0.04c	35.2±1.1a	0.350±0.01b	0.56±0.

a column followed by different letter(s) differ at the 0.05 probability level; ns = not significant. WSA>250 µm
t diameter; WHC = water holding capacity; K_{sat} = saturated hydraulic conductivity.

Silt: There were no significant variations in silt content across the ULUTs in Okitipupa at 20-40 cm, however there were significant variations at 0-20 cm (Table 4.9). The commercial, agriculture, wetland and institutional ULUTs had their silt content higher than residential at 20-40 cm. At 0-20 cm, silt on wetland urban land cover type was the least and was significantly different from others except under commercial where it was 17.3% lower. When compared with silt content at 0-20 cm, silt increased under commercial by 117.0%, agriculture by 74.5%, wetland by 136.0%, residential by 49.0% and institutionalULUT by 53.1% at 20-40 cm.

Clay: Urban land use types in Okitipupa significantly influenced clay fraction only at 20-40 cm but not at 0-20 cm (Table 4.9). At 0-20 cm, clay fractionwas 89 g kg^{-1}under wetland and 114 g kg^{-1}under residential, while it was 59 g kg^{-1}on wetland and 124 g kg^{-1}under institution at 20-40 cm. When compared with 0-20 cm, clay decreased on all land use types except commercial and institutionalULUT at 20-40 cm. The decrease was by 12.1% on agricultural, 33.7% on wetland and 10.5% on residential ULUT.

(ii) Bulk density and total porosity

Soil bulk density (SBD) showed significant differences among the ULUTs in Okitipupa at both 0-20 and 20-40 cm (Table 4.9). Bulk density under wetland was significantly lower than agriculture, residential, institution and commercial ULUT by 52.2, 67.8, 60.0 and 61.1%, respectively at 0-20 cm. Bulk density under institution was higher than commercial by 0.7% andresidential by 1.4%, while it was significantly higher than wetland by 39.9% and agriculture by 14.7% at 20-40 cm. In comparison with bulk density at 0-20 cm, bulk density decreased respectively under commercial, agriculture, wetland, residential and institution by 2.1, 10.9, 4.4, 6.6 and 0.7% at 20-40 cm.

Total porosity increased as SBD decreased, and there were significant variations across Okitipupa ULUTs (Table 4.9). Soil total porosity at 20-40 cm depth consistently decreased in value compared with 0-20 cm. On commercial ULUT, it decreased from 42.5% to 39.6%, agriculture was from 54.7% to 52.0%, wetland decreased from 64.7% to 56.1%, residential was from 46.4% to 44.4%, while institution decreased from 40.7% to 35.2%.

(iii) Water stable aggregates and meanweightdiameter

All the ULUTs in Okitipupa significantly influenced WSA>250 µm and MWD at both depths (Table 4.9). Among the ULUTs, WSA on the wetland (0.686 kg kg^{-1}) was higher than others at 0-20 cm. At 20-40 cm, the ULUTs also significantly influenced WSA>250 μm values. The value recorded under commercial (0.264 kg kg^{-1}) was lower than other ULUTs. The soil under commercial consistently had the least WSA>250 μm values (0.334 kg kg^{-1} at 0-20 cm and 0.264 kg kg^{-1} soil at 20-40 cm), while the highest values (0.686 $kgkg^{-1}$ at 0-20 cm and 0.602 kg kg^{-1} at 20-40 cm) were under wetland.

The mean weight diameter had a trendidentical to water stable aggregates as presented in Table 4.9. At 0-20 cm, MWD was 0.51 mm under commercial and 1.94 mm under wetland. At 0-20 cm, MWD under wetland was higher than under commercial by 73.7%, residential by 56.2%, institution by 56.7%, and agricultural ULUT by 27.3%. At 20-40 cm, MWD under wetland increased by 64.9% over values under commercial. The increase over residential was 53.2%, over institution it was 49.5% and over agricultural ULUT it was 12.6%. When compared with MWD at 0-20 cm, the diameter at 20-40 cm respectively decreased under commercial, agriculture, wetland, residential and institution by 23.5, 31.2, 42.8, 38.8 and 33.3%.

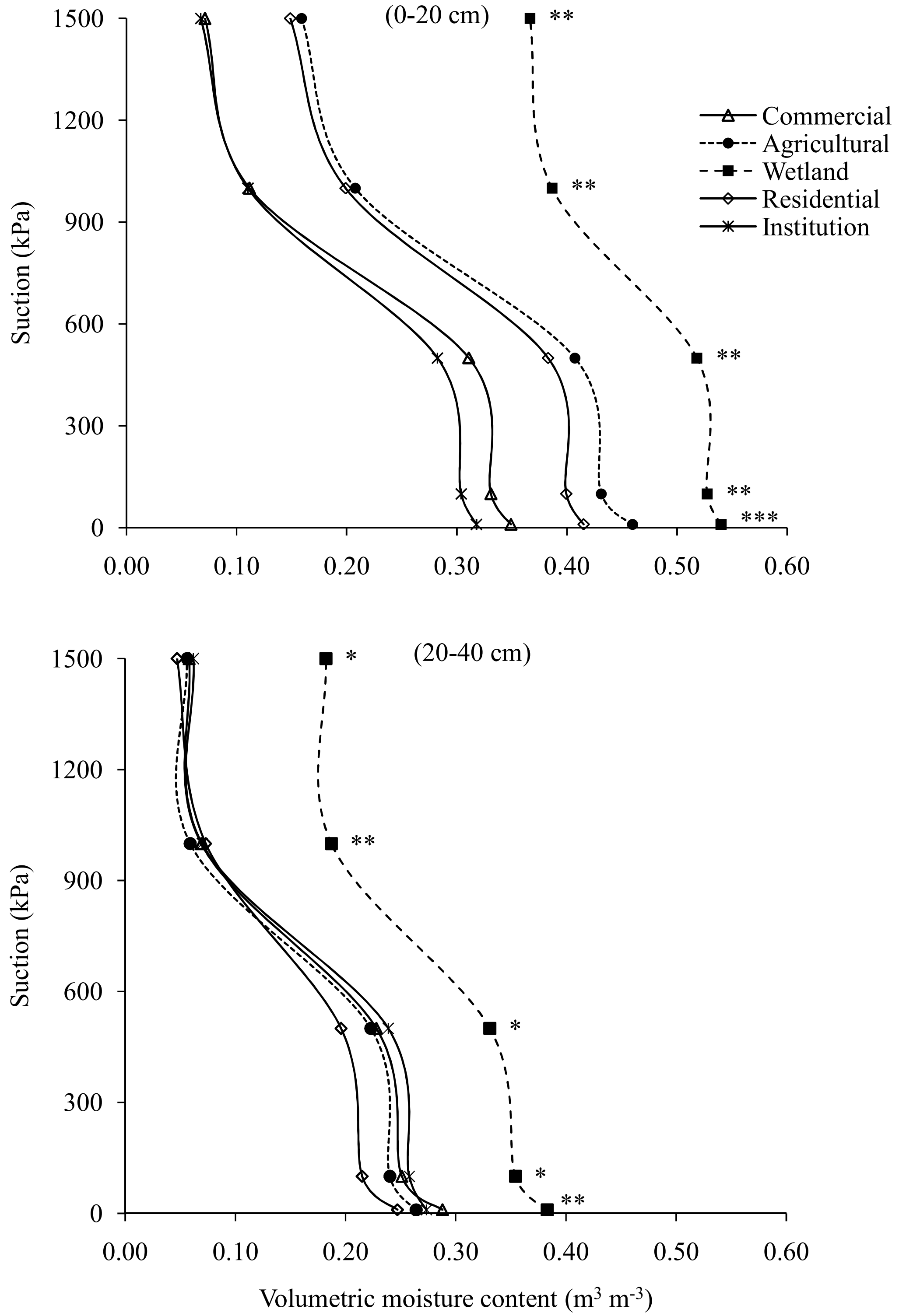
(iv) Saturated hydraulic conductivity and water holding capacity

The saturated hydraulic conductivity (K_{sat}) of the soils in Okitipupa at 0-20 and 20-40 cm under the variousULUTs is given in Table 4.9. The K_{sat} at 0-20 cm under agriculture (75.3 cm hr^{-1}) was significantly higher than under wetland (47.5 cm hr^{-1}), institution (16.6 cm hr^{-1}), residential (22.2 cm hr^{-1}) and commercial (13.4 cm hr^{-1}). At 20-40 cm, K_{sat} followed a similar trend to K_{sat} at 0-20 cm. The K_{sat} underagriculture(56.4 cm hr^{-1}) at 20-40 cm was higherthanwetland (30.6 cm hr^{-1}), residential (12.4 cm hr^{-1}), institution (13.4 cm hr^{-1}) and commercial ULUT (10.1 cm hr^{-1}). The values of K_{sat} at 20-40 cm as against 0-20 cm decreased by 24.6, 25.1, 35.6, 44.1 and 19.3% under commercial,agriculture, wetland, residential and institutional ULUTrespectively.

Mean water holding capacity (WHC) values was 1.35-3.93 cmat 0-20 cm and 0.98-2.74 cmat 20-40 cm (Table 4.9). In Okitipupa, the WHCvalue under wetland (3.93 cm) was significantly higher than other ULUTs at 0-20 cm. At 20-40 cm, there was a higherwater holding capacity under wetland than other ULUTs. When compared with 0-20 cm, the water holding capacity decreased at 20-40 cm under all ULUTs with the highest (1.19 cm) decrease measured under wetland.

(v) Soil moisture retention and pore size distribution

Figure 4.10 depicts the soil moisture functions at 0-20 cm in Okitipupa as impacted by ULUTs. At Okitipupa, ULUTs significantly affected moisture retention at all suctions



The asterisk (*) indicates significant difference at $P \leq 0.05$; (**) indicates significant difference at $P \leq 0.01$; (***) indicates significant difference at $P \leq 0.001$ among the ULUTs at each suction.

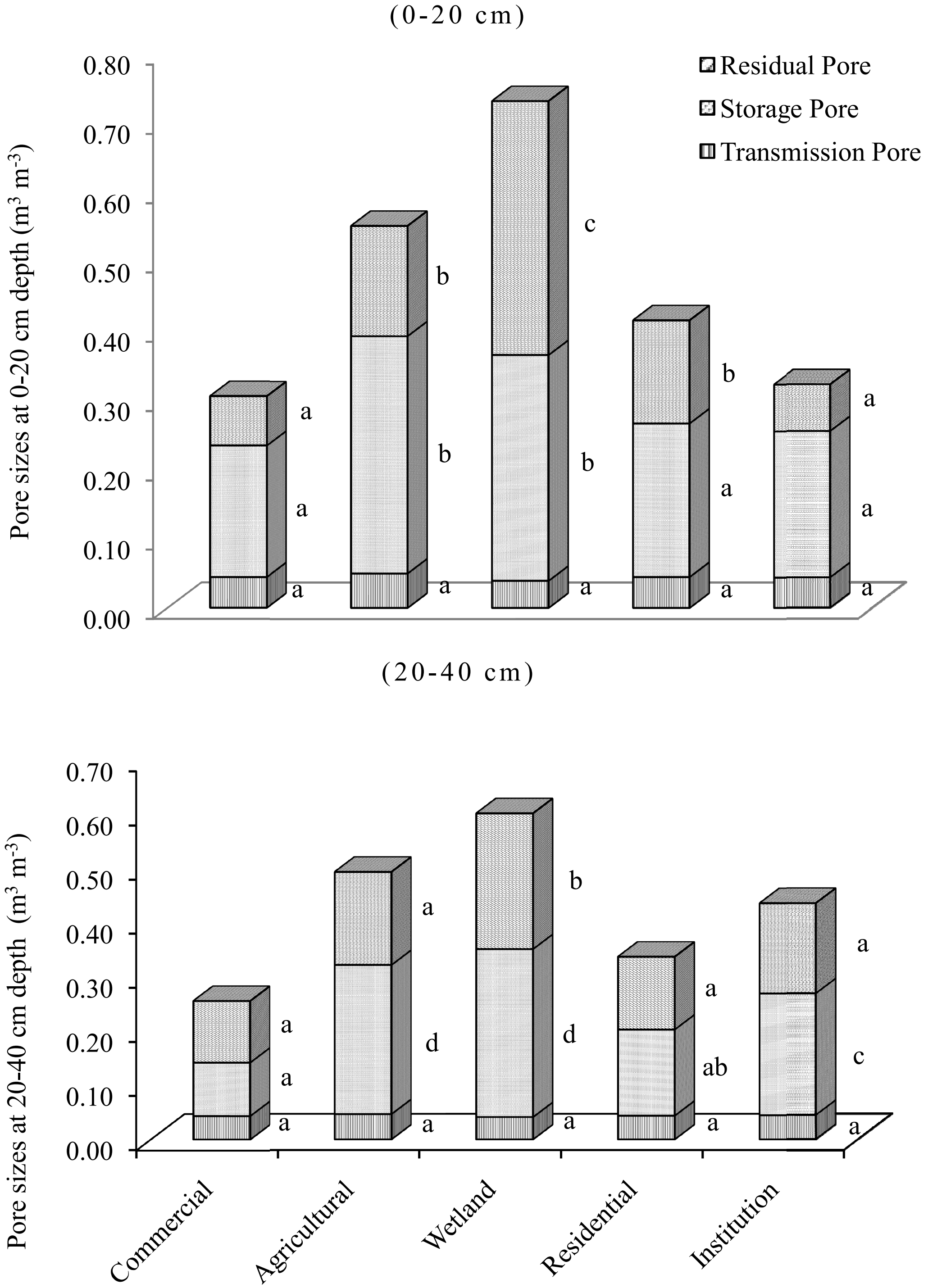
Fig. 4.10: Soil moisture function at 0-20 cm and 20-40 cm in Okitipupa as influenced by ULUTs

with the greatest retention measured under wetland at all the suctions. In Okitipupa, volumetric moisture content at lower suctions (10-1500 kPa) under wetland was higher with values of 0.540 m^3 m^{-3} at 10 kPa, 0.527 m^3 m^{-3} at 100 kPa and 0.518 m^3 m^{-3} at 500 kPa. At higher suctions (> 500 kPa), there were also variations among the ULUTswhen considering soil moisture retention. The least soil moisture recorded at permanent wilting point (1500 kPa) was 0.069, 0.066, 0.149, 0.159 and 0.366 m^3 m^{-3} under institution, residential, commercial, agriculture and wetland respectively.

At 20-40 cm, the soil moisture retention curves showed that there were significant differences in moisture retention among the ULUTs at Okitipupa (Fig. 4.10). The effect of wetland on soil moisture retention was different from that of other ULUTs at lower suctions (10-500 kPa). The highest moisture retention was under wetland with values of 0.383 m^3 m^{-3}at 10 kPa, 0.354 m^3 m^{-3}at 100 kPa and 0.331 m^3 m^{-3}at 500 kPa. At higher suctions (>500 kPa), the ULUTS differed in their influences on volumetric moisture content. A similar trend to that observed in Akure was also observed at 1000 kPa in Okitipupa where moisture retention under wetland (0.182 m^3 m^{-3}) was higher than other ULUTs.

Figure 4.11 shows the variance in pore size distribution at 0-20 cm among the ULUTs.The transmission and storage pores combined accounted for 49.9 to 79.2% of the overall pore spaces in Okitipupa. The agriculturalULUT consistently had greater amount of storage and transmission pores (0.343 and 0.050 m^3 m^{-3}respectively), although the transmission pores did not show any significant differences. Soils under institutionalULUT consistently had the least transmission and storage pores (0.046 and0.190 m^3 m^{-3} respectively). The storage pores were significantly lower than values obtained under wetland and agriculturalULUTs. The soil residual pores among the various ULUTs were significantly greater under wetland in Okitipupa (0.366 m^3 m^{-3}).

The pore size distribution at 20-40 cmshowed that there were significant differences among the ULUTs (Fig. 4.11). The mean total pore volumes of the ULUTs in Okitipupa varied between 0.256 and 0.602 m^3 m^{-3}. Wetlands had the greatest mean total pore volume (0.602 m^3 m^{-3}) followed by agricultural ULUT (0.494 m^3 m^{-3}). The least mean total pore volume (0.256 m^3 m^{-3}) was observed under commercial ULUT. The storage pores in Okitipupa were significantly higher under agriculture and wetland, while the residual pores under wetland was significantly higher than other ULUTs.



Means across the bars for a pore fraction size containing the same letter(s) do not differ significantly ($P \leq 0.05$).

Fig. 4.11: Pore size distribution at 0-20 cm and 20-40 cm in Okitipupa as affected by ULUTs

(vi) Soil strength

The ULUTs had a significant impact on soil strength at different depths as measured by penetration resistance at Okitipupa (Fig. 4.12). The penetration resistance under wetland was lower than under other ULUTs throughout the soil column. Penetration resistance reading under agriculturalULUT were not significantly different from wetland at 0-5 cm but were significantly different at 10-40 cm (Fig. 4.12). At Okitipupa, the penetration resistance under commercial, institution and residential ULUTs were not significantly different from each other at deeper depths (25-40 cm). For instance, at 40 cm, the penetration resistance offered by residential (1.91 MPa) was the highest and it was not significantly different from institution (1.89 MPa) and commercial (1.75 MPa) ULUT.

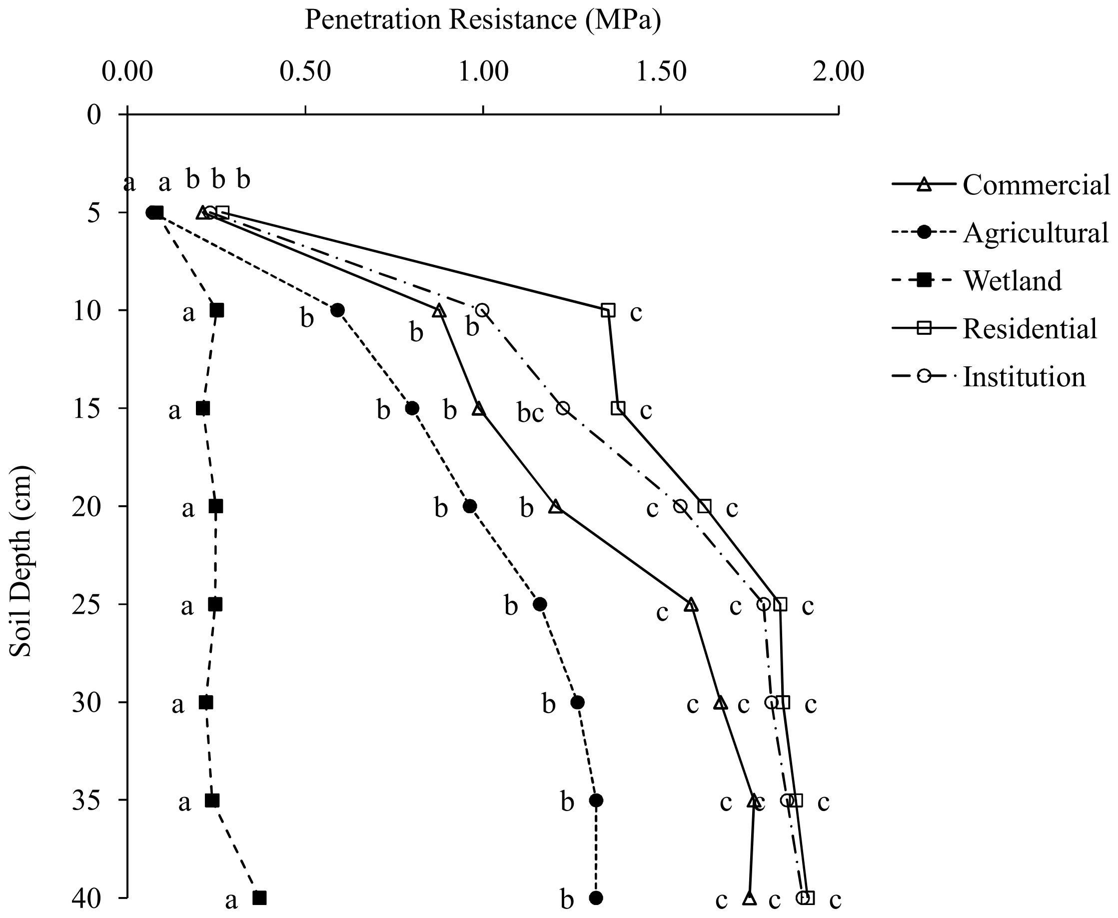
4.7.2 Soil chemical properties

(i) Soil pH

The pH of the soils showed that the soils were moderately acidic, and there were significant differences among the ULUTs in Okitipupa at both 0-20 and 20-40 cm (Table 4.10). Soil pH was 4.8-5.6 at 0-20 cm, and it was 4.9-5.6 at 20-40 cm. Soil pH under residential (5.6) and commercial (5.6) were higher than other ULUTs at 0-20 cm. At 20-40 cm, pH under institution (4.9) was lower than agriculture (5.3), commercial (5.4), residential (5.3) and wetland (5.6).

(ii) Electrical conductivity (EC)

The electrical conductivity of the soil varied significantly among the ULUTs at both 0-20 and 20-40 cm (Table 4.10). Electrical conductivity values under commercial, agriculture, wetland, residential and institutionalULUT was 0.08, 0.11, 0.30, 0.08 and 0.07 dS m^{-1}, respectively at 0-20 cm. The corresponding EC values at 20–40 cm was 0.02, 0.08, 0.24, 0.07 and 0.05 dS m^{-1} under commercial, agriculture, wetland, residential and institutionalULUT respectively. In comparison to 0-20 cm, the EC of the soils at 20-40 cm decreased respectively by 84.8, 33.6, 18.8, 11.9 and 32.9% under commercial, agriculture, wetland, residential and institutional ULUT.



Values within the same depth followed by the same letter(s) are not significantly different (P≤0.05).

Fig. 4.12: Variation in soil penetration resistance in Okitipupa under commercial, agricultural, wetland, residential and institutional ULUTs

on soil chemical properties at 0-20 and 20-40 cm depths in Okitipupa

EC	Org C	Total N	AvP	Ca	Mg
(dS m^{-1})	(g kg $^{-1}$)		(mg kg^{-1})		(cm
		0-20 cm			
.079±0.01a	23.9±0.9a	3.22±0.18b	4.67±0.13a	0.65±0.10a	0.62±0.03a
.113±0.01a	24.3±1.0a	2.34±0.25a	12.05±0.64b	0.78±0.24a	0.46±0.03a
.298±0.04b	34.5±0.8b	4.10±0.48c	14.12±0.90c	2.21±0.17b	0.87±0.08b
.084±0.01a	29.9±1.7b	3.48±0.14bc	10.33±0.63b	0.86±0.08a	0.60±0.03a
.073±0.01a	22.7±0.9a	2.66±0.18ab	5.13±0.62a	2.74±0.19c	1.94±0.04c
		20-40 cm			
.012±0.01a	14.6±0.7b	1.34±0.15a	1.79±0.14a	0.43±0.05a	0.38±0.05ab
.075±0.01b	14.9±0.8b	1.24±0.06a	2.54±0.15a	0.47±0.12a	0.34±0.07a
.242±0.04c	15.0±0.8b	3.01±0.51b	3.48±0.49b	1.09±0.09c	0.78±0.04c
.074±0.01b	11.0±1.1a	1.34±0.09a	2.37±0.23a	0.53±0.06a	0.43±0.06ab
.049±0.01a	10.9±0.8a	1.33±0.11a	1.76±0.15a	0.85±0.03b	0.53±0.05b

in a column followed by different letter(s) differ at the 0.05 probability level; ns = not significant.
en; AvP = available phosphorus.

(iii) Soil organic carbon (SOC)

The SOC contents of the ULUTswas from 22.7-34.5 g kg^{-1} at 0-20 cm, and from 10.9-15.0 g kg^{-1} at 20-40 cm (Table 4.10). At 0-20 cm, the differences between SOC under the different ULUTs in Okitipupa were significant. SOC under wetland (34.5 g kg^{-1}) was higher than commercial (23.9 g kg^{-1}),urban agriculture (24.3 g kg^{-1})and institution (27.7 g kg^{-1}), while it was non-significantly higher than residential (29.9 g C kg^{-1}). At 20-40 cm, SOC under the ULUTs were also significantly different from each other. Although SOC was greatest under wetland (15.0 g kg^{-1}), it was however not significantly different from commercial andurban agriculture (14.6and 14.9 gkg^{-1}respectively)but significantly different from institution and residential ULUT (10.9and 11.0 g kg^{-1} respectively).

(iv) Total nitrogen

Table 4.10 shows the influence of ULUTs on total nitrogen concentrations at 0-20 and 20-40 cm in Okitipupa. The concentration of total nitrogen under wetland was significantly higher than those recorded under other ULUTs. In comparison with wetlands, the concentration of total nitrogen decreased under commercial, agriculture, residential and institution by 21.5, 42.9, 15.1 and 35.1%, respectively at 0-20 cm. The corresponding reductions at 20-40 cm were55.5, 58.8, 55.5 and 55.8% under commercial, agriculture, residential and institution respectively. The average concentrations of total nitrogen across the two depths under commercial was 2.28 g kg^{-1}, agriculture was 1.79 g kg^{-1}, wetland was 3.55 g kg^{-1}, residential was 2.41 g $kg^{-1}$and institution was 1.99 g kg^{-1}.

(v) Available phosphorus

Available phosphorus varied significantly among the ULUTs at both 0-20 and 20-40 cm (Table 4.10). It was between5 mg kg^{-1} under commercial to 14 mg kg^{-1} under wetland at 0-20 cm, while itwas between2 mg kg^{-1} under institution to 4 mg kg^{-1} under wetland at 20-40 cm. At both depths, available phosphorus under wetland was higher than other ULUTs. When compared with available phosphorus at 0-20 cm, available phosphorus at 20-40 cm decreased under commercial, agriculture, wetland, residential and institutionalULUTby 61.7, 78.9, 75.4, 77.1 and 66.0%, respectively.

(vi) Exchangeable calcium

There were significant variations in exchangeable calcium across the ULUTs in Okitipupa at both depths (Table 4.10). At 0-20 cm, calcium under the institution (2.7

cmol kg^{-1}) was higher than residential (0.9 cmol kg^{-1}), agriculture (0.8 cmol kg^{-1}), wetland (2.2 cmol kg^{-1}) and commercial (0.6 cmol kg^{-1}). At 20-40 cm, calcium under wetland was higher by 153.5, 131.9, 105.7 and 28.2% under commercial, agriculture, residential and institutionalULUT respectively. When compared with calcium concentration at 0-20 cm, concentration of calcium at 20-40 cm decreased by 0.2, 0.3, 1.1, 0.4 and 1.8 cmol kg^{-1} under commercial, agriculture,wetland, residential and institutionalULUT, respectively.

(vii) Exchangeable magnesium

InstitutionalULUT at 0-20 cm and wetland at 20-40 cm had the highest concentrations of magnesium, and they were significantly higher than others (Table 4.10). Exchangeable magnesium ranged between 0.5cmol kg^{-1} under agriculture and 1.9 cmol kg^{-1} under institution at 0-20 cm, while at 20-40 cm, it wasbetween 0.3 cmol kg^{-1} under agriculture and 0.8 cmol kg^{-1} under wetland. When compared with exchangeable magnesium status at 0-20 cm, the exchangeable magnesium of the soil at 20-40 cm decreased under commercial, agriculture, wetland, residential and institutionalULUTby 38.7, 26.1, 10.3, 28.3 and 72.7%, respectively.

(viii) Exchangeable potassium

Only at 20-40 cm did the ULUTs in Okitipupa show significant variations in exchangeable potassium (Table 4.10). The concentration of exchangeable potassium ranged from 0.2 to 0.3 cmol kg^{-1} at 0-20 cm, and from 0.1 to 0.3 cmol kg^{-1} at 20-40 cm depth. At 0-20 cm, the highest concentration of potassium was recorded under the wetland (0.3 cmol kg^{-1})although it was not significantly different from commercial (0.3 cmol kg^{-1}), agriculture (0.2 cmol kg^{-1}), residential (0.2 cmol kg^{-1}) and institution (0.2 cmol kg^{-1}). On the other hand, at 20-40 cm depth, exchangeable potassium under wetland (0.3 cmol kg^{-1}) was significantly higher than other ULUTs (Table 4.10).

(ix) Exchangeable sodium

There were significant differences in the values of soil sodium at 0-20 and 20-40 cm among the ULUTs in Okitipupa (Table 4.10). The concentration of sodium wasbetween 0.4 and 0.8cmol kg^{-1} at 0-20 cm, and between 0.2 and 0.5 cmol kg^{-1} at 20-40 cm. Relative to sodium status at 0-20 cm, exchangeable sodium at 20-40 cm decreasedby 56.4, 38.6, 32.5, 25.5 and 15.0% under commercial, agriculture, wetland, residential and institutionalULUT, respectively.

(x) Heavy metals

Zinc: The available zinc (Zn) at 0-20 and 20-40 cm in Okitipupa showed significant ($P \leq 0.05$) differences among the ULUTs (Table 4.11). Zinc concentrationswere1.0 mg kg^{-1} under agriculture to 21 mg kg^{-1} under commercial at 0-20 cm, while at 20-40 cm, it was1 mg kg^{-1} under agriculture to 8 mg kg^{-1}under commercial. At 0-20 cm, Zn under commercial was higher than wetland, urban agriculture, residential and institutionalULUT by 19.8, 93.2, 70.5 and 76.3%, respectively. In comparison to Zn concentrations at 0-20 cm, Zn concentrations at 20-40 cm decreased under all ULUTs.

Copper: The copper (Cu) concentrations of the soils under wetland were significantly higher than other ULUTs at both 0-20 and 20-40 cm (Table 4.11). Concentration of Cu at 0-20 cm, under wetland was higher than agriculture, commercial, residential and institution by 72.1, 40.8, 64.4 and 70.8%, respectively. Moreover, at 20-40 cm, Cu concentrations under wetland was higher than urban agriculture, commercial, residential and institution by 41.1, 87.9, 71.8 and 78.9%, respectively.

Manganese: There were significant variations in manganese (Mn) levels between the ULUTs at 0-20 and 20-40 cm (Table 4.11).Manganese concentration under commercial (60 mg kg^{-1}) was not significantly differentfrom residential (69 mg kg^{-1}) and institution (78 mg kg^{-1}). It was however significantly lower than urban agriculture (112 mg kg^{-1}) and wetland (118 mg kg^{-1}) at 0-20 cm. At 20-40 cm, concentration of soil Mn under commercial (52 mg kg^{-1}) was higher than other ULUTs. When compared with Mn concentration at 0-20 cm, Mn values at 20-40 cm decreased by 13.3, 74.1, 77.1, 65.2 and 82.1% under commercial, agriculture, wetland, residential and institutionalULUT, respectively.

Lead: Lead (Pb) concentrations in Okitipupa varied significantly among different ULUTs at both depths (Table 4.11). The concentrations of Pb under commercial land use type (3 mg kg^{-1}at 0-20 cm and 3 mg kg^{-1}at 20-40 cm depths), were higher than other ULUTs at both depths. Mean Pb concentrations across the two depths were 3.0, 1.0, 2.0, 2.0 and 1.5 mg kg^{-1} under commercial, urban agriculture, wetland, residential and institutionalULUT respectively. In comparison, Pb values at 20-40 cm respectively increased by 1 mg kg^{-1} under institution, while it remained the same under other ULUTs.

Table 4.11: Effects of ULUTs in Okitipupa on heavy metal concentrations at 0-20 and 20-40 cm

ULUT	Zn	Cu	Mn	Pb	Cr	Cd	Fe
				(mg kg^{-1})			
				0-20 cm			
Commercial	21±0.2c	2±0.2b	60±3a	3±0.3c	35±2b	1.2±0.04d	297±9c
Agriculture	1±0.1a	1±0.1a	112±2b	1±0.1a	13±0.4a	0.4±0.08a	166±18b
Wetland	16±0.5b	3±0.2c	118±1b	2±0.3b	79±4c	0.3±0.05a	319±6c
Residential	6±0.3a	1±0.1a	69±10a	2±0.2b	38±7b	1.0±0.1cd	106±5a
Institution	5±0.2a	1±0.3a	78±12a	1±0.2a	12±2a	0.7±0.2b	131±3a
				20-40 cm			
Commercial	8±0.2c	1±0.1a	52±2c	3±0.1b	20±2b	1.6±0.04cd	415±40b
Agriculture	1±0.09a	3±0.1b	29±8b	1±0.05a	11±2a	0.9±0.02b	191±27a
Wetland	5±0.8b	4±0.1c	27±1b	2±0.1a	31±4c	1.4±0.2c	697±31c
Residential	1±0.2a	1±0.1a	24±2ab	2±0.2a	17±1b	1.9±0.1d	173±19a
Institution	2±0.1a	1±0.1a	14±2a	2±0.2a	7±1a	0.3±0.05a	170±27a
MPL	50	100	2000	2.0	100	0.76	38000

Means (±standard error of mean) within a column followed by different letter(s) differ at 0.05 probability level; MPL = maximum permissible level (FEPA).

Chromium: Chromium (Cr) concentration under wetland in Okitipupa was significantly higher than other ULUTs at both 0-20and 20-40 cm depths as shown in Table 4.11. Cr concentration measured under wetland was 2.2, 6.1, 2.1 and 6.7 times the concentration under commercial, urban agriculture, residential and institution, respectively at 0-20 cm. On the other hand, it was 1.6 times under commercial, 2.8 times under urban agriculture, 1.8 times under residential and 4.7 times under institution at 20-40 cm. The mean Cr concentrations over the two depths were 27.5, 12, 55, 27.5 and 9.5 mg kg^{-1} under commercial, urban agriculture, wetland, residential and institutionalULUT, respectively.

Cadmium: The concentrations of cadmium (Cd) differed significantly among the ULUTs in Okitipupa at both depths (Table 4.11). Cadmium at 0-20 cm was from 0.3-1 mg kg^{-1}, and it was 0.3-2 mg kg^{-1} at 20-40 cm.Cadmium concentration values under commercial (1.2 mg kg^{-1}) and residential (1.0 mg kg^{-1}) were higher than values under institution (0.7 mg kg^{-1}), wetland (0.3 mg kg^{-1}) and urban agriculture (0.4 mg kg^{-1}) at 0-20 cm. At 20-40 cm, Cd concentrations followed a similar trend to 0-20 cm with values under commercial and residential (1.6 and 1.9 mg kg^{-1}respectively) higher than other ULUTs.

Iron: The ULUTs influenced the available iron (Fe), and there were significant variations across commercial, urban agriculture, wetland, residential, and institutional ULUTs at both depths (Table 4.11). The concentrations of Fe at 0-20 cm indicated that, wetland (319 mg kg^{-1}) had higher Fe than commercial (297 mg kg^{-1}), urban agriculture (166 mg kg^{-1}), institution (131 mg kg^{-1}) and residential (106 mg kg^{-1}). As against the Fe status at 0-20 cm, Fe increased under commercial, urban agriculture, wetland, residential and institutionalULUT by 39.7, 15.1, 118.5, 63.2 and 28.8% respectively at 20-40 cm.

4.7.3 Soil biological properties

(i) Soil respiration

The rate of soil microbial respiration at 0-20 cm in Okitipupa is presented in Table 4.12. The respiration rate under the different ULUTsdid not differ significantly at the soil surface. Rate of respiration was 26.2, 25.6, 25.3, 24.3, and 24.1 mg CO_2-C kg^{-1} d^{-1}under residential, urbanagriculture, wetland, institution, and commercial ULUT respectively. The rate of respiration under residential as against other ULUTs increased respectively by 8.0, 2.3, 3.4 and 7.3% under commercial, agriculture, wetland and institutionalULUT.

Table 4.12: Effects of ULUTs on surface soil microbiological properties in Okitipupa

ULUT	Soil Respiration (mg CO_2-C kg^{-1} d^{-1})	C_{mic} (CFE) (mgC kg^{-1}soil)	N_{mic}(CFE) (mg N kg^{-1}soil)	PMN (mg N kg^{-1} soil 7 d^{-1})
Commercial	24.1±0.8ns	262.2±8.0ab	17.7±0.4b	15.7±0.4b
Agriculture	25.6±0.6	287.6±3.1c	19.3±0.2c	17.3±0.2c
Wetland	25.3±0.8	327.3±4.4d	22.1±0.2d	20.0±0.2d
Residential	26.2±0.7	270.4±11.0bc	17.9±0.7bc	15.9±0.7bc
Institution	24.3±0.3	244.3±6.5a	15.8±0.5a	13.8±0.6a

Means (±standard error of mean) within a column followed by different letter(s) differ at 0.05 probability level; ns =not significant.C_{mic}=microbial biomass carbon; N_{mic}=microbial biomass nitrogen; CFE =chloroform fumigation extraction; PMN =potentially mineralizable nitrogen.

(ii) Microbial biomass carbon (C_{mic}) and nitrogen (N_{mic})

Urban land use types in Okitipupa significantly influenced concentration of chloroform fumigation extractable microbial biomass carbon (C_{mic}) and nitrogen (N_{mic}) at the soil surface (0-20 cm) (Table 4.12). At 0-20 cm, C_{mic}under wetland (327.3 mgC kg^{-1}soil) was higher than commercial (262.2 mgC kg^{-1}soil), urban agriculture (287.6 mgC kg^{-1}soil), residential (270.4 mgC kg^{-1}soil), and institution (244.3 mgC kg^{-1}soil). Microbial biomass carbon under wetland decreased by 19.9, 12.1, 17.4 and 25.4% under commercial, urban agriculture, residential and institutional ULUT respectively.

Soil microbial N (N_{mic}) at the soil surface followed a similar trend to C_{mic}. At this depth, N_{mic} differed significantly among the ULUTs (Table 4.12). The concentration of $N_{mic}$was between 15.8 mg N kg^{-1}soil under institution and 22.1 mg N kg^{-1}soil under wetland. In contrast to wetland, Nmic reduced by 19.9, 12.7, 19.0, and 28.5% at the soil surface (0-20 cm) in commercial, urban agriculture, residential, and institutional ULUT, respectively.

(iii) Potentially mineralizable nitrogen (PMN)

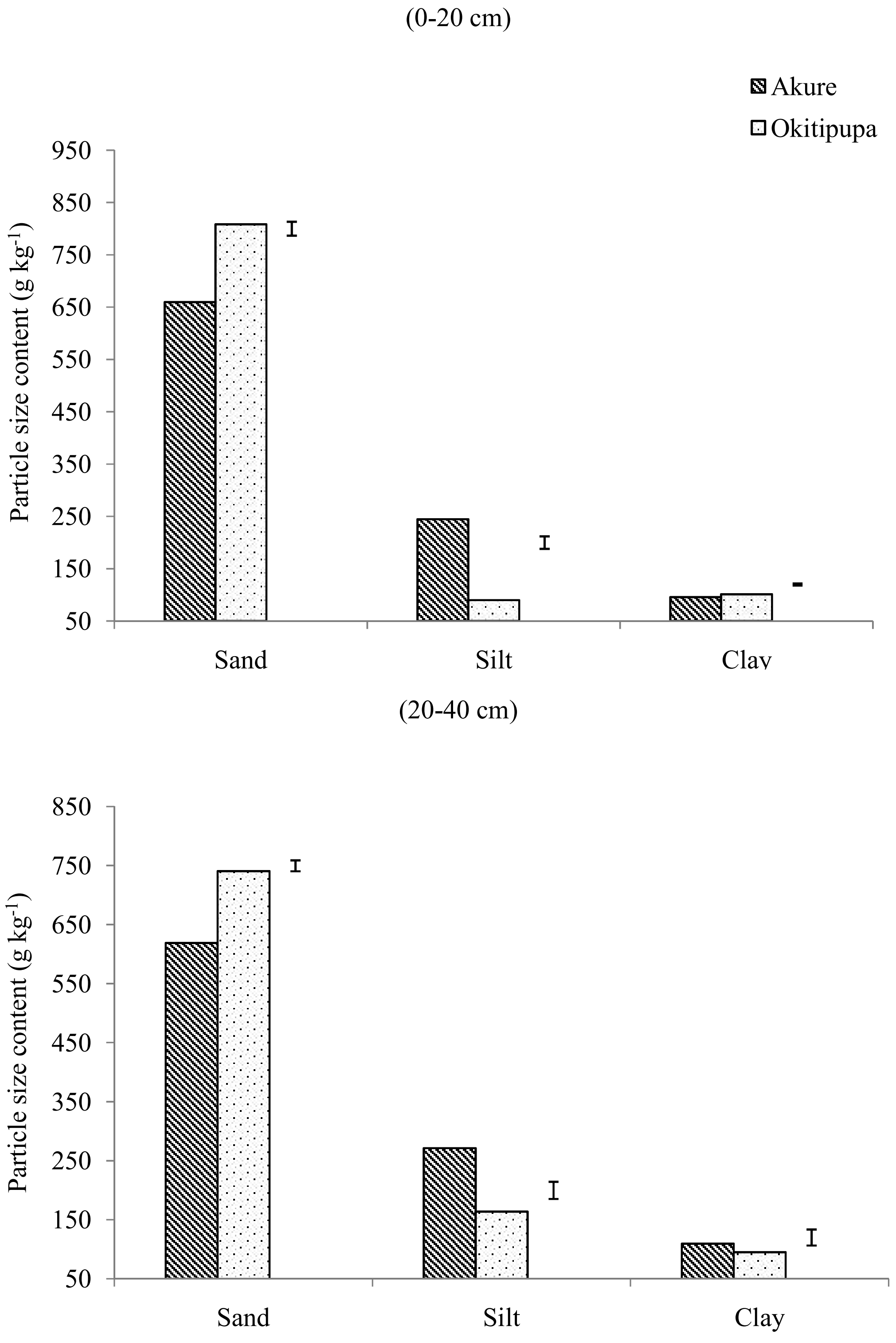
In Okitipupa, the surface soil (0-20 cm) potentially mineralizable nitrogen (PMN) was 13.8-20.0 mg N kg^{-1} soil 7 d^{-1} with the least concentrations measured under institution and highest concentrations measured under wetland (Table 4.12). The PMN value obtained under wetland (20.0 mg N kg^{-1} soil 7 d^{-1}) was significantly greater than commercial (15.7 mg N kg^{-1} soil 7 d^{-1}), urban agriculture (17.3 mg N kg^{-1} soil 7 d^{-1}), residential (15.9 mg N kg^{-1} soil 7 d^{-1}) and institution (13.8 mg N kg^{-1} soil 7 d^{-1}) ULUT.

4.8 Influence of Locations on Soil Properties

4.8.1 Soil physical properties

(i) Particle size fraction

The parent material at the 2 locations had significant influence on sand and silt particles at both 0-20 and 20-40 cm, while clay particles didn't show any significant diffference irrespective of the depth (Fig. 4.13). At 0-20 cm, sand fraction was 587-762 gkg^{-1} in Akure with granite gneiss parent material while it was 756-866 gkg^{-1} in Okitipupa with sandstone parent material. On the other hand, at 20-40 cm,sand was 474-751 gkg^{-1} in Akure and 675-797 gkg^{-1} in Okitipupa. The sand fractions in Okitipupa was significantly higher than that of Akure at both depths. The silt fraction at both depths did not follow the same pattern as the sand fraction even though there was also significant difference between the locations.



Bars indicate least significant differences at 0.05 probability.

Fig. 4.13: Effect of location on particle size distribution at 0-20 and 20-40 cm

Significantly higher silt fractions were observed in Akure at 0-20 cm(245 gkg^{-1}) and at 20-40 cm (272 gkg^{-1}) when compared with Okitipupa at 0-20 cm (90 gkg^{-1}) and at 20-40 cm (164 gkg^{-1}).The clay fractions at both depths varied with location, but there were no significant differences among the location at both depths. At 0-20 cm, mean clay fraction was 96 gkg^{-1} in Akure and 101 gkg^{-1}in Okitipupa, while corresponding values at 20-40 cmwas 109and 95 gkg^{-1}in Akure and Okitipupa respectively.

(ii) Bulk density and total porosity

At both 0-20 and 20-40 cm, there were significant variations in soil bulk density among the parent materials (Table 4.13).In Akure, the soil bulk density at 0-20 cmwas 0.89-1.68 Mg m^{-3}, while in Okitipupa it was 0.46-1.67 Mg m^{-3}. The corresponding values at 20-40 cm in Akure was 1.20-1.69 Mg m^{-3}, while in Okitipupa it was 0.50-1.69 Mg m^{-3}.The mean soil bulk densities in Akure at 0-20 and 20-40 cm (1.34 and 1.49 Mg m^{-3}) were significantly different from those in Okitipupa (1.27 Mg m^{-3} at 0-20 cm and 1.33 Mg m^{-3} at 20-40 cm). When compared with bulk density at 0-20 cm, the soil bulk density at 20-40 cm increased at both Akure and Okitipupa.

Total porosities of the soil under the different parent materials at the 2 locations varied significantly at both depths and followed an opposite trend to soil bulk density (Table 4.13). Soils in Okitipupa significantly had higher amount of total porosity when compared with soils in Akure. In an opposite trend to soil bulk density, total porosity in Okitipupa (49.8% at 0-20 cmand 45.4% at 20-40 cm) was higher than values measured in Akure (41.4% at 0-20 cmand 36.3% at 20-40 cm). When compared to total porosity at 0-20 cm, the porosity at 20-40 cm in Akure decreased by 12.3% and Okitipupa decreased by 8.8%.

(iii) Water stable aggregates and meanweightdiameter

At 0-20 cm, the parent material of the two locations had a significant effect on water stable aggregates, but not at 20-40 cm (Table 4.13). In Akure, water stable aggregates at 0-20 cm ranged from 0.404-0.731 kg kg^{-1}, while in Okitipupa, they ranged from 0.300-0.805 kg kg^{-1}. In Akure, soil aggregates at 20-40 cm was from 0.259-0.601 kg kg^{-1}, while in Okitipupa, they ranged from 0.218-0.699 kg kg^{-1}. Akure had a higher mean water stable aggregate (0.581 kg kg^{-1}) than Okitipupa (0.489 kg kg^{-1}) at 0-20 cm. The corresponding values were 0.441 kg kg^{-1} in Akure and 0.401 kg kg^{-1} in Okitipupa at 20-40 cm, though the differences were not significant.

Table 4.13: Influence of location on some soil physical properties at 0-20 and 20-40 cm

Location/Parent material	Bulk density ($Mg\ m^{-3}$)	Total porosity (%)	WSA>250 µm ($kg\ kg^{-1}$)	MWD (mm)	WHC (cm)	K_{sat} ($cm\ hr^{-1}$)
			0-20 cm			
Akure	1.34±0.03	41.4±1.0	0.581±0.01	1.11±0.08	2.21±0.17	13.1±1.3
Okitipupa	1.27±0.02	49.8±1.4	0.489±0.02	0.94±0.04	2.53±0.18	35.0±4.2
LSD (0.05)	0.05	2.1	0.052	0.05	ns	4.8
			20-40 cm			
Akure	1.49±0.04	36.3±1.0	0.441±0.01	0.76±0.03	0.95±0.07	4.3±0.3
Okitipupa	1.33±0.02	45.4±1.5	0.401±0.01	0.71±0.04	1.87±0.14	24.6±3.5
LSD (0.05)	0.13	1.3	ns	ns	0.20	5.1

Means (±standard error of mean); LSD =least significant difference between parent materials; ns =not significant.WSA>250 µm =water stable aggregates greater than 250 µm sieve size; MWD =mean weight diameter;WHC = water holding capacity; K_{sat}=saturated hydraulic conductivity.

The mean weight diametershowed identical trends to water stable aggregates as presented in Table 4.13. Among the location, mean weight diameter in Akure (1.11 mm) was higher than the value in Okitipupa (0.94 mm) at 0-20 cm. However, at 20-40 cm, the mean weight diameter in Akure (0.76 mm) was also higher than that of Okitipupa (0.71 mm) but there were no significant differences between the 2 locations. In comparison to mean weight diameter at 0-20 cm, mean weight diameter at 20-40 cmin Akure decreased by 31.5% and 24.5% in Okitipupa.

(iv) Saturated hydraulic conductivity and water holding capacity

Saturated hydraulic conductivity at both depths differed significantly with regard to the parent material at the 2 locations (Table 4.13). The mean saturated hydraulic conductivity at 0-20 cmwas 13.1 and 35.0 cm hr^{-1} in Akure and Okitipupa respectively. The corresponding values at 20-40 cm, were 4.3 and 24.6 cm hr^{-1} in Akure and Okitipupa respectively. The saturated hydraulic conductivity in Okitipupa was consistently and significantly higher than values obtained in Akure at both depths.

Table 4.13 presents the water holding capacity at 0-20 and 20-40 cm as influenced by parent material at the 2 locations. Parent material differed significantly in their influences on water holding capacity at 20-40 cm depth but were not significantly different at 0-20 cm. Mean water holding capacity at 0-20 cm ranged from 2.21 cm at Akure to 2.53 cm at Okitipupa, while corresponding values at 20-40 cm depth ranged from 0.95 cm at Akure to 1.87 cm at Okitipupa.

4.8.2 Soil chemical properties

(i) Soil pH

Table 4.14 shows the pH of the soils in Akure and Okitipupa at both depths. There were significant differences among the parent materials at the 2 locations at both depths with regard to the soil pH values. The soils were slightly acidic, and mean values were 5.4 in Okitipupa and 6.6 in Akure at 0-20 cm, and 5.3 in Okitipupa and 6.5 in Akure at 20-40 cm. The pH values of the soils in Okitipupa were consistently and significantly lower than values recorded in Akure at both depths.

(ii) Electrical conductivity

The electrical conductivity of the soils showed that electrical conductivities in Akure were significantly lower than values in Okitipupa at 0-20 cm and 20-40 cm (Table 4.14). In comparison, mean electrical conductivity in Akure (0.42 dS m^{-1}) increased by 69.3% when compared with Okitipupa (0.13 dS m^{-1}) at 0-20 cm.

Table 4.14: Influence of location on some soil chemical properties at 0-20 and 20-40 cm

Location/Parent material	pH	EC (dS m^{-1})	Org. C (g kg^{-1})	Total N (g kg^{-1})	AvP (mg kg^{-1})
			0-20 cm		
Akure	6.6±0.10	0.42±0.04	24.1±1.0	2.08±0.12	9±0.6
Okitipupa	5.4±0.06	0.13±0.01	27.0±1.0	3.16±0.15	7±0.6
LSD (0.05)	0.7	0.11	1.4	ns	1.0
			20-40 cm		
Akure	6.5±0.11	0.28±0.03	13.5±0.8	1.32±0.07	3±0.3
Okitipupa	5.3±0.04	0.11±0.01	13.3±0.4	1.65±0.14	2±0.1
LSD (0.05)	0.7	0.03	ns	ns	0.6

Means (±standard error of mean); LSD =least significant difference between locations; ns =not significant.EC =electrical conductivity; AvP =available phosphorus.

On the other hand, at 20-40 cm, mean electrical conductivity in Akure (0.28 dS m^{-1}) had an increase of 59.6% over value measured in Okitipupa (0.11 dS m^{-1}).

(iii) Organic carbon

The organic carbon at 0-20 cm differed significantly among the parent material at the 2 locations, while there was no significant difference at 20-40 cm (Table 4.14). Organic carbon in Okitipupa at 0-20 cm, was significantly higher than value measured in Akure by 10.7% with mean organic carbon values of 24.1 and 27.0 g kg^{-1}in Akure and Okitipupa respectively. At 20-40 cm, the mean organic carbon values were 13.5 and 13.3 g kg^{-1}in Akure and Okitipupa.

(iv) Total nitrogen

The parent material at the 2 locations had no significant influence on total nitrogen at both depths (Table 4.14). When compared with total nitrogen at 0-20 cm, total nitrogen values at 20-40 cm reduced by 36.5 and 47.8% in Akure and Okitipupa. Average total nitrogen values at 0-20 cmwere 2.08 and 3.16 g kg^{-1}inAkure and Okitipupa, while the corresponding values at 20-40 cmwere 1.32 and 1.65 g kg^{-1}.

(v) Available phosphorus

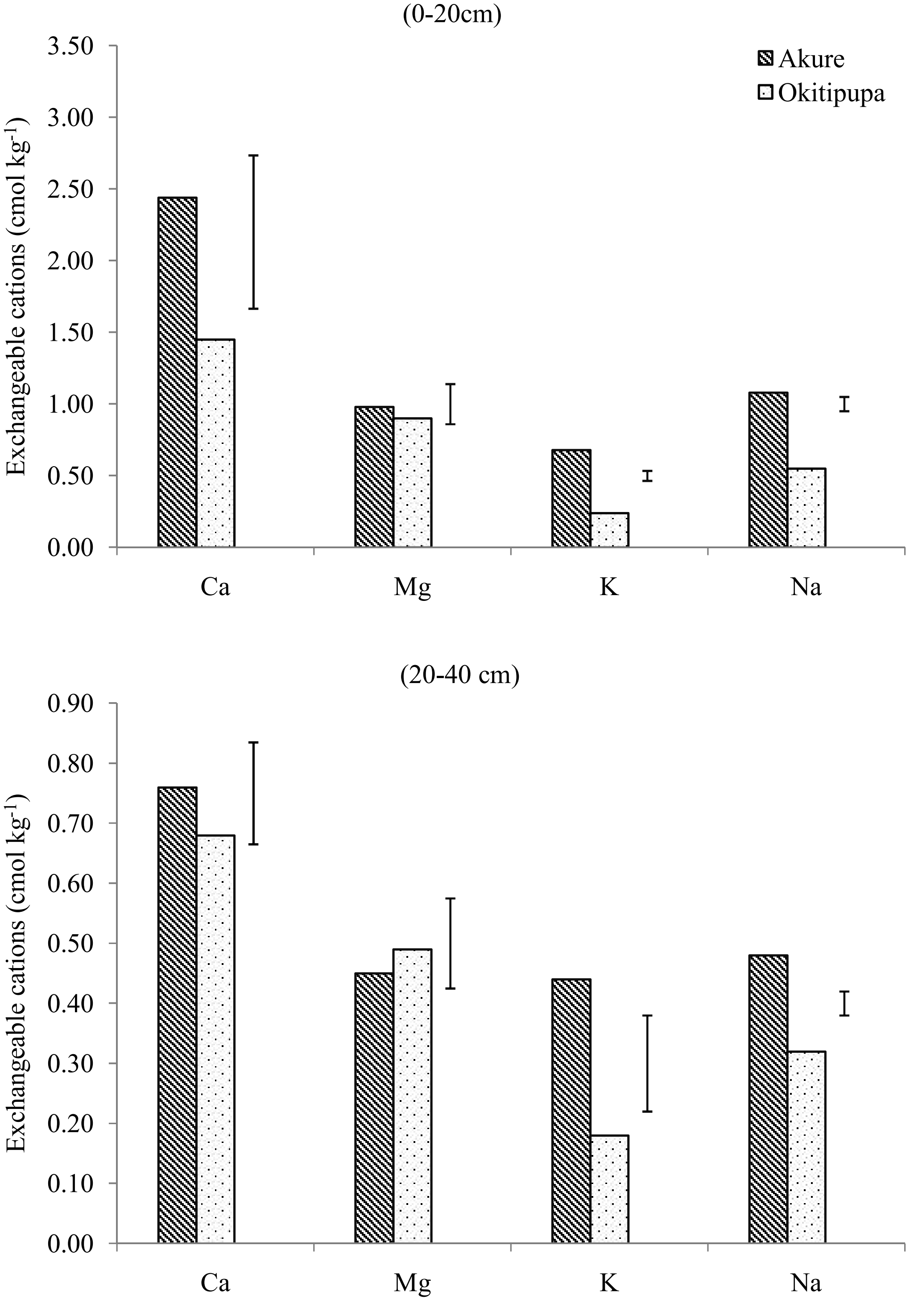
At both depths, available phosphorus differed significantly among the parent material at the 2 locations (Table 4.14). Soil available phosphorus in Akure (9 mg kg^{-1}), at 0-20 cm depth, was higher than that of Okitipupa (7 mg kg^{-1}). At 20-40 cm, available phosphorus in Akure (3 mg kg^{-1}) was also higher than the value obtained in Okitipupa (2 mg kg^{-1}).

(vi) Exchangeable calcium

The exchangeable calcium (Ca) did not differ significantly among the parent material at the 2 locations at both depths (Fig. 4.14). It ranged from 1.5 cmol kg^{-1}in Okitipupa to 2.4 cmol kg^{-1}in Akure at 0-20 cm depth. When compared to exchangeable Ca status of the soil at 0-20 cm, the exchangeable Ca of the soils at 20-40 cm depth in Akure decreased by 68.9% and Okitipupa by 53.1%.

(vii) Exchangeable magnesium

There were no significant variations in exchangeable magnesium (Mg) between Akure and Okitipupa at both 0-20 and 20-40 cm (Fig. 4.14). The Mg concentrations, however, ranged from 0.9 to 1.0 cmol kg^{-1} at 0-20 cm. At 20-40 cm, soil in Akure had the lower (0.4 cmol kg^{-1}) and in Okitipupa(0.5 cmol kg^{-1}).



Bars indicate least significant differences at 0.05 probability.

Fig. 4.14: Effect of location on exchangeable cations at 0-20 and 20-40 cm

However, when compared to 0-20 cm, exchangeable Mgconcentration at 20-40 cm decreased by 54.1% and 45.6% in Akure and Okitipupa.

(viii) Exchangeable potassium

The exchangeable potassium (K) of the soils in Akure and Okitipupa showed that potassium concentrations in Akure was significantly higher than values in Okitipupa at both depths (Fig. 4.14). The mean concentrations of exchangeable K at 0-20 cm in Akure was 0.7 cmol $kg^{-1}$and it was 0.2 cmol kg^{-1}in Okitipupa, while corresponding values at 20-40 cm depth was 0.4 and 0.2 cmol kg^{-1}.

(ix) Exchangeable sodium

There were significant differences among the parent materials at the 2 locations with regard to the concentration of exchangeable sodium (Na) at both depths (Fig. 4.14). The concentration of Na followed a similar trend to that of K in that exchangeable Na in Akure (1.1and 0.5 cmol kg^{-1}at 0-20 and20-40 cm respectively) was higher than concentration in Okitipupa (0.5 and 0.3 cmol kg^{-1}at 0-20 cmand20-40 cm respectively).

(x) Heavy metals

Zinc: The extractable zinc (Zn) at both 0-20 and 20-40 cm showed no significant differences among the parent materials at the 2 locations (Table 4.15). The mean concentrations of Zn at 0-20 cm depth in Akure and Okitipupa were 16 and 19 mg kg^{-1} respectively, while corresponding values at 20-40 cm depth was 15 and 13 mg kg^{-1}. As against Zn concentrations at 0-20 cm, the concentrations of Zn at 20-40 cm reduced by 10.4% in Akure and by 31.3% in Okitipupa.

Copper: The concentrations of copper (Cu) as affected by the parent materials are presented in Table 4.15. The Cu concentration was significantly higher in Akure than in Okitipupa at both depths. The mean concentration values were 1 and 3 mg kg^{-1} in Okitipupa and Akure at 0-20 cm, and 2 and 4 mg kg^{-1} in Okitipupa and Akure respectively at 20-40 cm. As against concentration of Cu in Akure at 0-20 and 20-40 cm depths, Cu in Okitipupa reduced by 58.2% at 0-20 cm and 58.6% at 20-40 cm.

Manganese: There were significant differences among the locations with respect to manganese (Mn) concentrations at both depths (Table 4.15). The level of Mn in Akure was higher than values in Okitipupa at both depths. The concentration of soil manganese in Akure was higher than values in Okitipupa at 0-20 and 20-40 cm by 38.0% and 86.7%.

Table 4.15: Influence of location on heavy metal concentrations at 0-20 and 20-40 cm

Location/Parent material	Zn	Cu	Mn	Pb	Cr	Cd	Fe
	(mg kg^{-1})						
			0-20 cm				
Akure	16±0.8	3±0.4	142±7	6±0.8	41±9	1.4±0.1	187±17
Okitipupa	19±0.8	1±0.1	88±4	2±0.1	35±4	0.7±0.07	204±13
LSD (0.05)	ns	0.9	17	1.7	3	0.4	ns
			20-40 cm				
Akure	15±0.2	4±0.7	225±14	5±0.6	35±7	1.4±0.1	326±20
Okitipupa	13±0.4	2±0.2	30±2	2±0.1	17±1	1.3±0.1	329±22
LSD (0.05)	ns	1.4	28	1.3	11	ns	ns

Means (±standard error of mean); LSD =least significant difference between locations; ns =not significant.

However, when compared to Mn concentration values at 0-20 cm, Mn increased by 58.5% in Akure, while it decreased by 65.9% in Okitipupa.

Lead: Table 4.15 shows the influence of location on lead (Pb) concentrations at 0-20 and 20-40 cm. The influence of location differed significantly with respect to Pb concentrations at both depths. The Pb concentration at 0-20 cm in Akure (6 mg kg^{-1}) differed from values measured in Okitipupa (2 mg kg^{-1}). Furthermore, Pb concentration in Akure (5 mg kg^{-1}) at 20-40 cm was still higher than the value measured in Okitipupa (2 mg kg^{-1}).

Chromium: The influence of the parent materials at the locations on concentration of chromium (Cr) at 0-20 and 20-40 cm are presented in Table 4.15. Significant differences were observed among the parent material at the 2 locations at both depths. Chromium concentration in Akure was higher than the values measured in Okitipupa. The mean Cr concentrationswere 35 and 41 mg kg^{-1}in Okitipupa and Akure at 0-20 cm, while corresponding values at 20-40 cm were 17 and 35 mg kg^{-1}in Okitipupa and Akure respectively.

Cadmium: At 0-20 cm, soils in Akure had a significant influence on cadmium (Cd) content, which was much greater than soils in Okitipupa (Table 4.15). However, the difference between soils in Akure and Okitipupa was not significant at 20-40 cm. Cadmium concentrations at 0-20 cm were 0.7 and 1.4 mg kg^{-1} in Okitipupa and Akure respectively. When compared to Cd concentration at 0-20 cm, Cd concentration values at 20-40 cm in Akure reduced by 3.5%, while it increased by 68.9% in Okitipupa.

Iron: The mean iron (Fe) concentrations in Akure and Okitipupa at 0-20 and 20-40 cm are presented in Table 4.15. The differences among the parent materials at the 2 locations with respect to Fe concentration at both depths were not significant. At 0-20 cm, the mean Fe concentration was from 187 to 204 mg kg^{-1}, while at 20-40 cm, mean Fe concentration ranged from 326to 329 mg kg^{-1}.

4.8.3 Soil biological properties

(i) Soil respiration

There were significant differences resulting from the parent materials in respect of soil respiration at Akure and Okitipupa (Table 4.16). The soil respiration improved significantly in Akure (42.1 mg CO_2-C kg^{-1} d^{-1}) than the values recorded in Okitipupa

Table 4.16: Influence of location on surface soil microbiological properties

Location/Parent material	Soil Respiration (mg CO_2-C kg^{-1} d^{-1})	C_{mic} (CFE) (mgC kg^{-1}soil)	N_{mic}(CFE) (mg N kg^{-1}soil)	PMN (mg N kg^{-1} soil 7 d^{-1})
Akure	42.1±2.5	253.9±7.9	18.9±0.6	36.7±1.1
Okitipupa	25.1±0.6	278.3±5.3	18.5±0.3	16.5±0.3
LSD (0.05)	5.7	19.1	ns	2.4
CV%	4.8	1.8	2.1	0.4

Means (±standard error of mean); LSD =least significant difference between locations; CV = coefficient of variation; ns =not significant.C_{mic}=microbial biomass carbon; N_{mic}=microbial biomass nitrogen; CFE =chloroform fumigation extraction; PMN =potentially mineralizable nitrogen.

(25.1 mg CO_2-C kg^{-1} d^{-1}). The variability within the data series is low as shown in the coefficient of variation value of 4.8%.

(ii) Microbial biomass carbon (C_{mic}) and nitrogen (N_{mic})

Table 4.16 shows the influence of parent material at both Akure and Okitipupa on chloroform fumigation extractable microbial biomass carbon (C_{mic}) and nitrogen (N_{mic}). There were significant differences in C_{mic}among the parent material at the 2 locations. The C_{mic}in Okitipupa (278.3 mgC kg^{-1}soil) was higher than the value obtained in Akure (253.9 mgC kg^{-1}soil).

Soil microbial nitrogen (N_{mic}) did not differ among the parent materials at the 2 locations (Table 4.16). The N_{mic}values were 18.5 and 18.9 mg N kg^{-1}soil in Okitipupa and Akure respectively. The coefficient of variability (CV) of the measured values is low with CV value of 2.1%.

(iii) Potentially mineralizable nitrogen (PMN)

The potentially mineralizable nitrogen (PMN) differed significantly among the locations (Table 4.16). The PMN value obtained in Akure (36.7 mg N kg^{-1} soil 7 d^{-1}) was significantly higher than the value measured in Okitipupa (16.5 mg N kg^{-1} soil 7 d^{-1}). The coefficient of variation (CV) is low with a value of (0.4%).

4.9 Quality Assessment of Surface Soils

4.9.1 Weighted additive soil quality index

(i) Akure

Table 4.17 shows the impact of different ULUTs in Akure on the soil quality rating of different urban soil functions. The soil quality ratings of the different urban soil functions differed significantly depending on the ULUT.The result from soil quality rating for stormwater infiltration (qt.si) in Akure show favourable rating for wetland (0.106). The quality rating of soils on commercial ULUT (0.042) was lower than other ULUTs (Table 4.17). The qt.si on institution (0.073) was not different from value obtained under urban agriculture (0.079) but washigher than residential (0.057). Results from soil quality rating for sorption of pollutants (qt.sp) in Akure among the ULUTs showed that commercial ULUT (0.060) also had the lowest score. The qt.sp forurban agriculture (0.088) was not different from wetland (0.087) but higher than residential (0.081) and institution (0.078). The soil quality rating for sorption and transformation of nutrients (qt.stn) was different among the ULUTs (Table 4.17). The trend showed wetland (0.090) > commercial (0.075) = agriculture (0.072) ≥ residential (0.065) ≥ institution (0.053).

's in Akure on soil quality ratings of urban soil functior

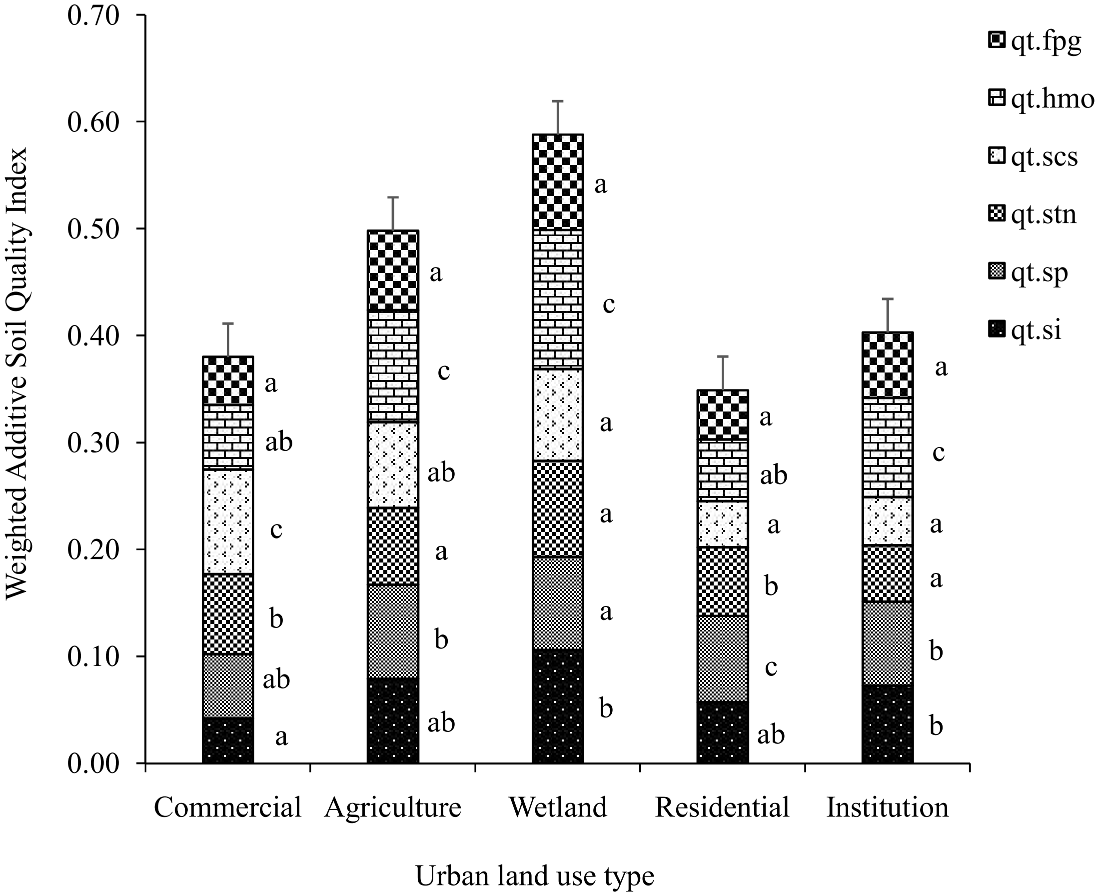
	Urban land use tyı		
	Commercial	Agriculture	Wetland
	0.042±0.005a	0.079±0.004b	0.106±0.004c
	0.060±0.001a	0.088±0.001d	0.087±0.001d
ıutrients	0.075±0.003b	0.072±0.006b	0.090±0.004c
	0.098±0.010b	0.080±0.004b	0.086±0.006b
	0.060±0.010a	0.105±0.003b	0.130±0.002c
	0.045±0.001a	0.074±0.002c	0.089±0.001d

s a soil function followed by different letter differ according to Dunca

The result from soil quality for soil carbon sequestration function (qt.scs) showed that commercial (0.098) had the most favourable rating. The quality rating of soils on residential ULUT (0.043) was lower than other ULUTs (Table 4.17). Results from soil quality rating for habitat for micro-organisms (qt.hmo) in Akure among the ULUTs show that residential (0.058) and commercial ULUT (0.060) had lower scores. The highest score of 0.130 was obtained from wetland for qt.hmo (Table 4.17). In Akure, the soil quality rating for foundation for plant growth (qt.fpg) was different among the ULUTs. The trend showed wetland (0.089) > agriculture (0.074) > institution (0.061) > residential (0.046) = commercial (0.045).

The overall weighted additive soil quality indices (SQI_{wa}) as affected by ULUTs in Akure and contribution of urban soil function to overall soil quality is given in Figure 4.15. Within the ULUTs, there were significant differences in the contribution of the urban soil functions to overall soil quality. On the commercial ULUT, the least contribution to overall soil quality was from stormwater infiltration function (0.042), while the highest was from soil carbon sequestration (0.098). The contributions to overall soil quality on commercial soils from sorption of pollutants (0.060) and habitat for micro-organism (0.060) were lower than sorption and transformation of nutrients (0.075) function. Within agricultural soils, habitat for micro-organism (0.105) function was higher than stormwater infiltration (0.079), sorption of pollutant (0.088), soil carbon sequestration (0.080), foundation for plant growth (0.074) and sorption and transformation of nutrients (0.072) functions. Results of the urban soil functions in the wetlands showed that habitat for micro-organism (0.130) had the highest contribution to overall soil quality (Fig. 4.15). The least was from soil carbon sequestration (0.086) although it was not significantly different from sorption of pollutant (0.087), foundation for plant growth (0.089) and sorption and transformation of nutrients (0.090). Stormwater infiltration (0.106) function had moderate contribution to overall quality on the wetland. Along the residential ULUT, contribution to overall quality was in the order qt.scs (0.043) = qt.fpg (0.046) ≤ qt.si (0.057) = qt.hmo (0.058) < qt.stn (0.064) < qt.sp (0.081). The corresponding order on the institutionalULUT is qt.scs (0.045) = qt.stn (0.053) = qt.fpg (0.061) < qt.si (0.073) = qt.sp (0.078) < qt.hmo (0.093).

Figure 4.15 presents the overall soil quality indices (SQI_{wa}) as affected by ULUTs in Akure. The soil quality rating under wetland was significantly higher than all other ULUTs and soil quality ranged from 0.28 to 0.69. The highest average soil quality index recorded under wetland was 0.59, while the least 0.35 was under the residential ULUT.



Means within an ULUT with different letter(s) differ at 0.05 probability level according to Duncan's multiple range test (DMRT); Bars indicateleast significant difference (LSD) value between the ULUTs at 0.05 probability.

qt.si = soil quality rating for stormwater infiltration; qt.sp = soil quality rating for sorption of pollutants; qt.stn = soil quality rating for sorption and transformation of excess nutrients; qt.scs = soil quality rating for soil C sequestration; qt.hmo = soil quality rating for habitat for micro-organisms; qt.fpg = soil quality rating for foundation for plant growth.

Fig. 4.15: Effects of ULUTs in Akure on weighted additive soil quality index showing relative contribution of urban soil functions to soil quality

The differences in weighted additive soil quality index between commercial (0.38) and institution (0.40) and between residential (0.35) and commercial (0.38) were not significant. However, qualityindex under agriculture (0.50) was significantly higher than values recorded under commercial, institution and residential (Fig. 4.15). As against soil quality under residentialULUT in Akure, soil quality increased by 14.2, 8.6, 42.9 and 68.6%under institution, residential, agriculture and wetland respectively.

(ii) Okitipupa

Table 4.18 presents the results of the influence of ULUTs in Okitipupa on quality rating of the different urban soil functions. Soil quality ratings of the different urban soil functions varied significantly among the ULUTs.Results from soil quality rating for stormwater infiltration (qt.si) in Okitipupa among the ULUTs showed that wetland (0.131) had higher score. The qt.siforurban agriculture (0.117) was higher than residential (0.064),commercial (0.059) and institution (0.053).The result from soil quality rating for sorption of pollutants (qt.sp) function in Okitipupa showed favourable rating for wetland (0.097), although it was not significantly different from agriculture (0.095). The quality rating of soils on commercial ULUT (0.068) was lower than other ULUTs (Table 4.18). The qt.sp on institution (0.071) was different from value obtained under residential (0.076).The soil quality rating for sorption and transformation of nutrients (qt.stn) was different among the ULUTs (Table 4.18). The trend showed wetland (0.085) >residential (0.056) = agriculture (0.054) >commercial (0.043) = institution (0.040). Result from soil quality for soil carbon sequestration function (qt.scs) in Okitipupa showed that wetland (0.120) had the most favourable rating which was not significantly different from residential (0.098). The qt.scs of soils on agriculturalULUT (0.071) was lower thanresidential but not significantly different from commercial (0.069) and institution (0.064) (Table 4.18).In Okitipupa, the soil quality rating for habitat for micro-organism (qt.hmo) was different among the ULUTs. The trend show wetland (0.085) > agriculture (0.066) =residential (0.058) ≥commercial (0.055) >institution (0.044).Results from soil quality rating for foundation for plant growth (qt.fpg) function in Okitipupa among the ULUTs show that commercial ULUT (0.029) had lower score. The highest score of 0.109 was obtained from wetland in Okitipupa for qt.hmo (Table 4.18).

n Okitipupa on soil quality ratings of urban soil functions

	Urban land use types		
	Commercial	Agriculture	Wetland
	0.059±0.002a	0.117±0.004b	0.131±0.002c
	0.068±0.001a	0.095±0.001d	0.097±0.001d
ients	0.043±0.001a	0.054±0.001b	0.085±0.007c
	0.069±0.004a	0.071±0.014a	0.120±0.003b
	0.055±0.002b	0.066±0.001c	0.085±0.001d
	0.029±0.001a	0.083±0.006c	0.109±0.006d

oil function followed by different letter differ according to Duncan multiple ra

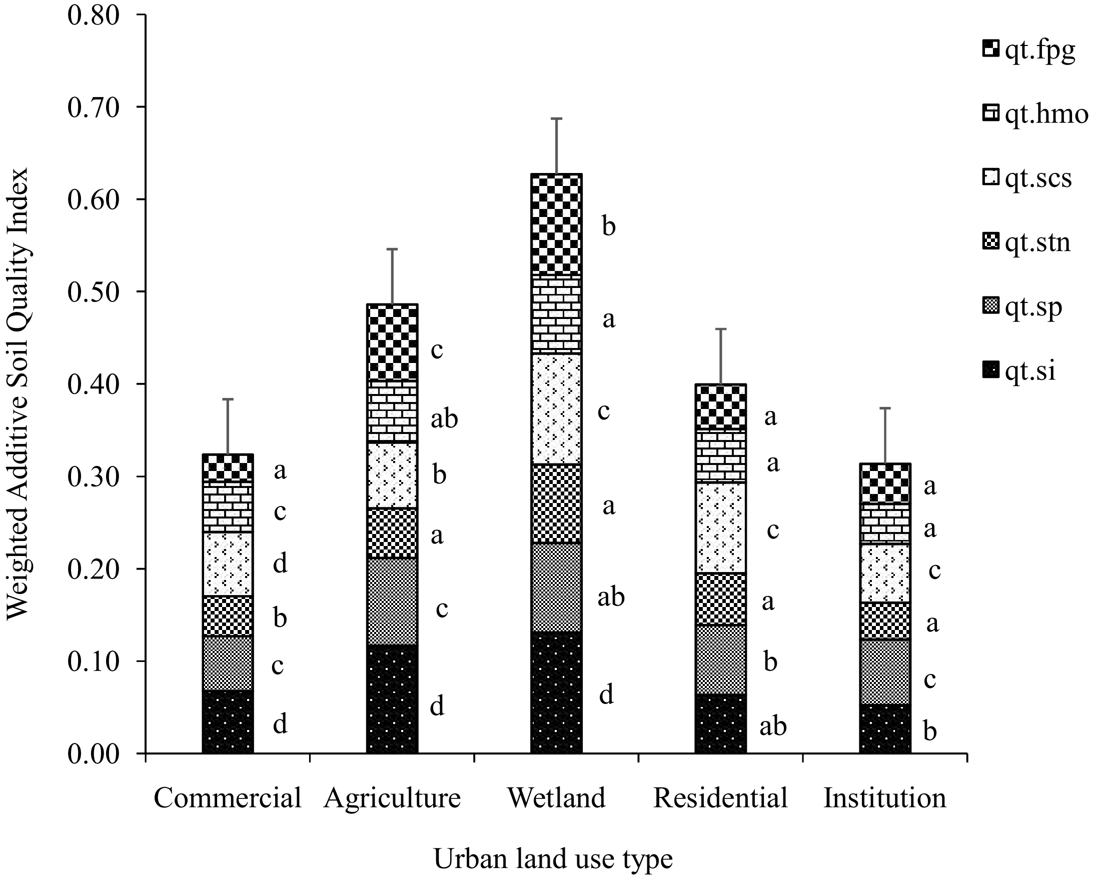
The overall weighted additive soil quality indices (SQI_{wa}) as affected by ULUTs in Okitipupa and contribution of urban soil function to overall soil quality is presented in Figure 4.16. Within the ULUTs, there were significant differences in the contribution of the urban soil functions to overall soil quality. On the commercial ULUT, the least contribution to overall soil quality was from foundation for plant growth function (0.029), while the highest was from soil carbon sequestration (0.069). The contributions to overall soil quality on commercial soils from sorption of pollutants (0.059) and habitat for micro-organism (0.055) were higher than sorption and transformation of nutrients (0.043) function.Results of the urban soil functions on the agricultural soils showed that stormwater infiltration (0.117) had the highest contribution to overall soil quality (Fig. 4.16). The least was from sorption and transformation of nutrients (0.054) although it was not significantly different from habitat for micro-organism (0.065). Sorption for pollutant (0.095) and foundation for plant growth (0.083) functions had moderate contribution to overall soil quality on the agricultural ULUT.Within the wetlands, stormwater infiltration (0.131) function was higher than soil carbon sequestration (0.120), foundation for plant growth (0.109), sorption of pollutant (0.097), habitat for micro-organism (0.085) and sorption and transformation of nutrients (0.085) functions.Along the residential ULUT, contribution to overall quality was in the order qt.fpg (0.048) = qt.stn (0.056) = qt.hmo (0.058) ≤ qt.si (0.063) = qt.sp (0.076) < qt.scs (0.098). The corresponding order on the institutionalULUT is qt.stn (0.040) = qt.fpg (0.043) = qt.hmo (0.044) < qt.si (0.053) < qt.scs (0.064) = qt.sp (0.071).

The overall soil quality indices (SQI_{wa}) as affected by ULUTs in Okitipupa is presented in Figure 4.16. The soil quality rating under wetland was significantly higher than all other ULUTs. The highest mean soil quality index recorded under wetland was 0.63, while the least mean index of 0.31 was under the institutionalULUT. The difference in weighted additive soil quality index between commercial (0.32) and institution (0.31) was not significant. However, quality index under agriculture (0.49) was significantly higher than values recorded under commercial, institution and residential (Fig. 4.16).

4.9.2 Statistically modelled soil quality index

The Kaiser-Meyer-Olkin (KMO) and Bartlett test results are presented in Table 4.19. All the indicator set passed the KMO test, with values greater than 0.60 (i.e. the indicator set has a normal distribution which is ideal for principal component analysis

(PCA). At the end of the KMO test, physical indicators had 0.75, chemical indicators had



Means within an ULUT with different letter(s) differ at 0.05 probability level according to Duncan'sMultiple Range Test (DMRT); Bars indicateleast significant difference (LSD) value between the ULUTs at 0.05 probability level.

qt.si = soil quality rating for stormwater infiltration; qt.sp = soil quality rating for sorption of pollutants; qt.stn = soil quality rating for sorption and transformation of excess nutrients; qt.scs = soil quality rating for soil C sequestration; qt.hmo = soil quality rating for habitat for micro-organisms; qt.fpg = soil quality rating for foundation for plant growth.

Fig. 4.16: Effects of ULUTs in Okitipupa on weighted additive soil quality index showing relative contribution of urban soil functions to soil quality

Table 4.19: Soil physical, chemical, and biological indicators from the Kaiser-Meyer-Olkin and Bartlett sphericity test

	Physical Indicators	Chemical Indicators	Biological Indicators	All Indicators
Kaiser-Meyer-Olkin measure of sampling adequacy	0.75	0.72	0.66	0.74
Bartlett's test of sphericity	477	915	340	2451
Degree of freedom	21	105	10	351
Significance level	0.0001	0.0001	0.0001	0.0001

0.72, and biological indicators had 0.66. Results of the Bartlett test were significant ($P \leq 0.0001$) for all the indicator sets.

(i) Akure

Five components of the PCA had eigenvalues > 1, and they explained 80.8% of the variance in the total data set (Table 4.20). For the first principal component (PC) with variance of 41.0%, microbial biomass carbon (0.892) had the greatest factor loading value and water holding capacity (0.845), total porosity (0.840) and microbial biomass nitrogen (0.885) had a loading value within 0.10 of the greatest value (Table 4.20). These 4 indicators were highly correlated (Table 4.21), therefore microbial biomass carbon was selected from PC-1. For the second PC with variance of 18.3%, organic carbon (0.625) had the highest factor loading and only extractable Pb (0.604) had a factor loading value within 0.10 of the highest loading (Table 4.20). The correlation between organic carbon and extractable Pb was low (i.e. $r < 0.7$) with $r = 0.55$ (Table 4.21), therefore both indicators were selected from PC-2 as valuable indicators. For the third PC with variance of 8.2%, bulk density (0.581) was the only indicator with a high factor loading value and there was no other indicator within 0.10 of that value (Table 4.20). As a result of this, bulk density was selected from PC-3. Electrical conductivity (0.601) was identified as having high factor loading values from PC-4 with variance of 7.8% (Table 4.20). As the only indicator within 0.10 of this value was the already selected organic carbon, only electrical conductivity was then selected as indicator from PC-4 (Table 4.21). In PC-5 with variance of 5.5%, the indicator with high factor loading was water stable aggregate (0.694) (Table 4.20). This variable was considered for the minimum data set (MDS).

The average scores under each urban land use type were calculated and shown in Figure 4.17 to determine the contribution of each indicator to statistically modelled soil quality in Akure. Considering the average scores, the order of importance of the key indicators in influencing soil quality was C_{mic} (0.51) > OC (0.23) = Ext. Pb (0.23) > BD (0.10) > EC (0.09) > WSA (0.07). The corresponding contribution of C_{mic}, OC, Ext. Pb, BD, EC and WSA to statistically modelled soil quality was 38.9, 16.0, 26.8, 3.9, 8.8 and 5.6%, respectively.

Table 4.20: Results of principal component analysis showing indicators consideredin the total dataset (TDS) for Akure

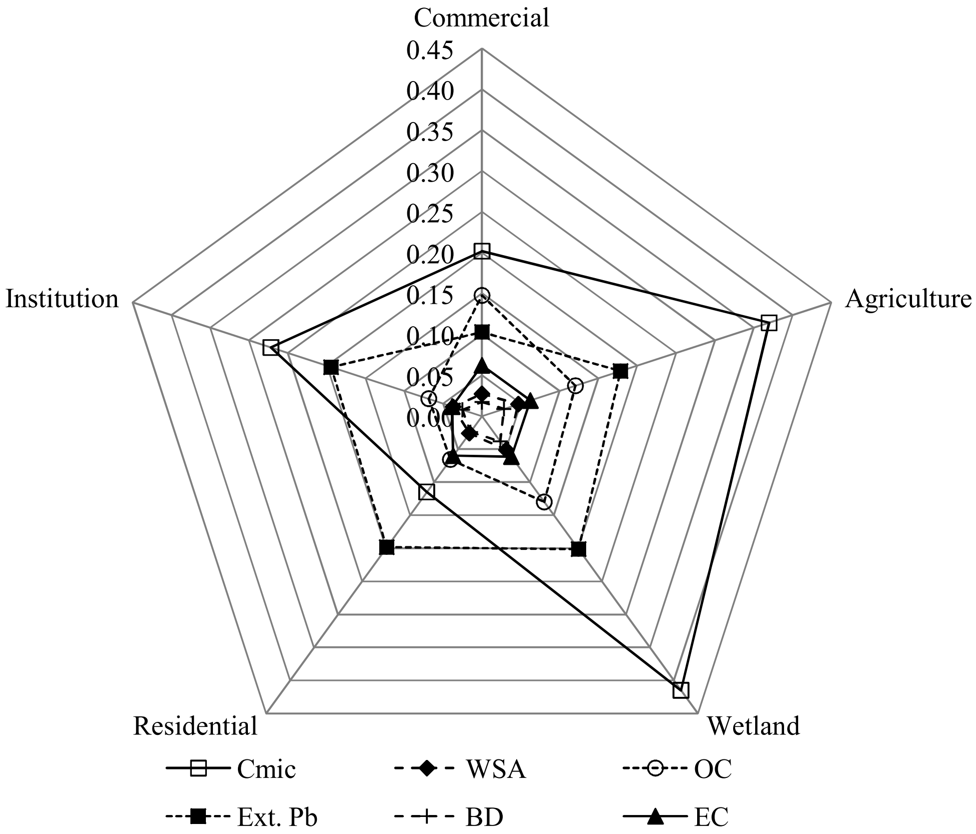
PCs parameters	PC-1	PC-2	PC-3	PC-4	PC-5
Eigenvalue	9.03	4.02	1.80	1.71	1.20
Variance (%)	41.0	18.3	8.2	7.8	5.5
Cumulative (%)	41.0	59.3	67.5	75.3	80.8
Indicators	Factor loading				
WSA	0.688	0.319	0.136	-0.133	**0.694**
MWD	0.690	0.297	-0.122	-0.084	0.089
Bulk Density	-0.642	-0.197	**0.581**	-0.045	0.074
PR$_{dry}$	-0.549	-0.054	0.217	0.157	-0.120
WHC	**0.845**	0.147	-0.297	-0.033	0.120
Total Porosity	**0.840**	0.212	-0.394	-0.027	0.005
K$_{sat}$	0.710	0.380	-0.119	-0.128	-0.103
Soil Respiration	0.656	-0.231	-0.278	-0.320	0.409
C$_{mic}$	**0.892**	0.167	0.162	0.238	-0.201
N$_{mic}$	**0.885**	0.193	0.146	0.242	-0.187
PMN	0.770	0.169	0.201	0.255	-0.232
EC	-0.150	0.498	0.228	**-0.601**	-0.165
K	-0.729	0.534	0.056	-0.211	-0.120
Ca	-0.562	0.524	-0.423	0.260	0.035
Mg	-0.606	0.520	-0.225	0.419	-0.066
Organic Carbon	0.085	**0.625**	0.272	0.566	0.041
Total Nitrogen	0.297	0.497	0.409	-0.058	0.494
AvP	0.375	0.516	0.290	0.109	0.490
Ext. Pb	-0.635	**0.604**	-0.249	0.175	-0.118
Ext. Cd	-0.662	0.069	-0.378	0.129	0.419

Values in bold represent loadings within 0.10 of the absolute value of the highest loading per principal component; PC =principal component; WSA =water stable aggregates greater than 250 µm sieve size; MWD =mean weight diameter; PR$_{dry}$=penetration resistance on dry soil; WHC =water holding capacity; K$_{sat}$=saturated hydraulic conductivity; C$_{mic}$=microbial biomass carbon; N$_{mic}$=microbial biomass nitrogen; PMN =potentially mineralizable nitrogen; EC=electrical conductivity; AvP =available phosphorus; Ext. Pb =extractable lead; Ext. Cd =extractable cadmium.

ts for highly weighted indicators in Akure

TP	C_{mic}	N_{mic}	OC	Ext. Pb	I
1.00					
0.81***	1.00				
0.80***	0.99***	1.00			
0.45*	0.80***	0.35*	1.00		
-0.24	-0.45*	-0.43*	0.55**	1.00	
-0.71**	-0.52**	-0.53*	-0.89***	0.18	1
-0.06	-0.09	-0.10	0.44*	0.32*	(
0.58**	0.72**	0.73**	0.70**	-0.32*	-

= correlation is significant at $P \leq 0.01$; *** = correlation is significant at $P \leq 0.0$
ass carbon; N_{mic} = microbial biomass nitrogen; OC = organic carbon; Ext. Pb =
r stable aggregates greater than 250 µm sieve size.



C_{mic}= microbial biomass carbon; WSA = water stable aggregates greater than 250 µm sieve size; BD = bulk density; EC = electrical conductivity; OC = organic carbon; Ext. Pb = extractable lead.

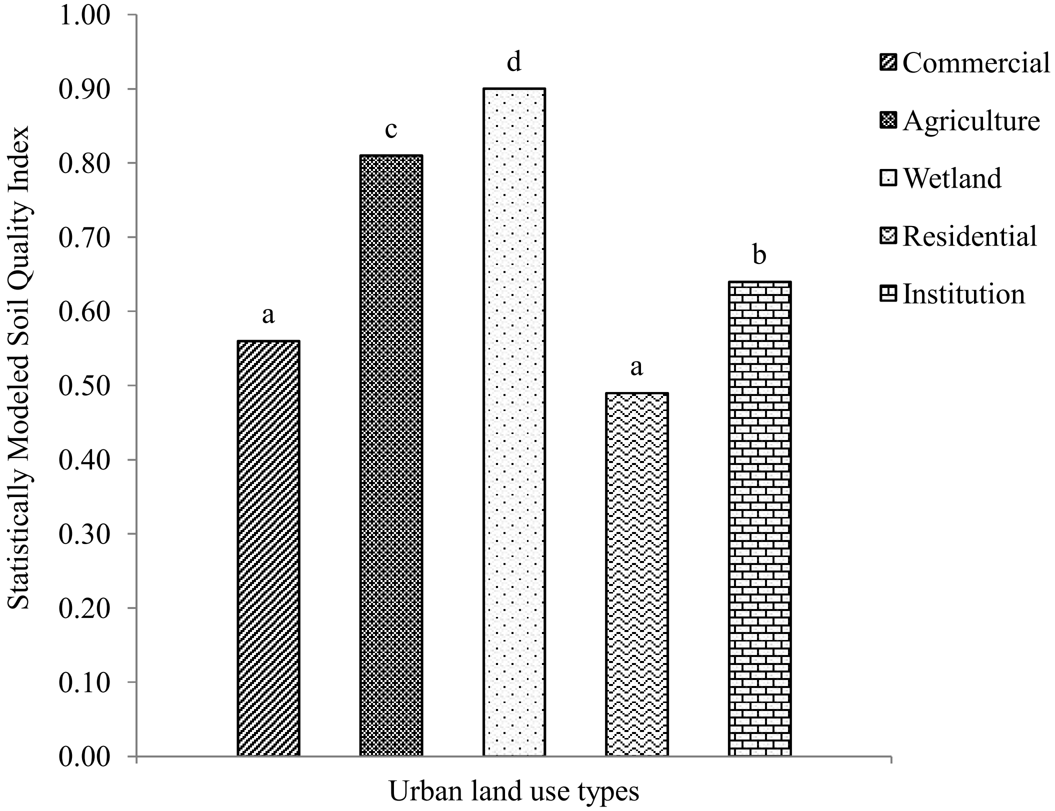
Fig. 4.17: Radar graph depicting average score contribution of key statistically modelled indicators as influenced by ULUTs in Akure

The result of the statistically modelled soil quality index (SQI_{sm}) as influenced by ULUTs in Akure is presented in Figure 4.18. The result revealed that ULUTs significantly influenced soil quality rating. The SQI_{sm} ranged from 0.25 to 0.99. Among the ULUTs, wetland (0.90) showed the highest soil quality which was higher than others. The least rating was recorded under residential (0.49) but it was not significantly different from the value reported under commercial ULUT (0.56). The soil quality rating reported under institution (0.64) was significantly higher than both commercial and residential ULUTs but was significantly lower than agriculture (0.81). In this study, the overall order of superiority of the ULUTs from the viewpoint of statistically modelled soil quality indices was wetland > agriculture > institution > commercial = residential.

(ii) Okitipupa

Five components of the PCA had eigenvalues > 1, and they explained 85.0% of the variance in the total data set (Table 4.22). For the first principal component (PC) with variance of 46.6%, total porosity (0.956) had the greatest factor loading value and

mean weight diameter (0.926), bulk density (0.865) and microbial biomass carbon (0.883) had a loading value within 0.10 of the greatest value (Table 4.22). These 4 indicators were highly correlated (Table 4.23), therefore total porosity was selected from PC-1. For the second PC with variance of 15.3%, total nitrogen (0.710) was the indicator with the highest factor loading and there was no other indicator within 0.10 of that value (Table 4.22). As a result, total nitrogen was selected from PC-2. For the third PC with variance of 11.0%, extractable cadmium (0.660) was the only indicator with a high factor loading value and there was no other indicator within 0.10 of that value (Table 4.22). As a result of this, extractable cadmium was selected from PC-3. Organic carbon (0.639) was identified as having high factor loading values from PC-4 with variance of 6.8% (Table 4.22). As there was no other indicator within 0.10 of this value, only organic carbon was then selected as indicator from PC-4 (Table 4.22). In PC-5 with variance of 5.3%, the indicator with high factor loading was water stable aggregate (0.746) (Table 4.22). This variable was then considered for the minimum data set (MDS).



Columns with different letter(s) differ at 0.05 probability level according to Duncan Multiple Range Test (DMRT).

Fig. 4.18: Effects of ULUTs in Akure on statistically modelled soil quality index

Table 4.22: Results of principal component analysis showing indicators considered in the total dataset (TDS) for Okitipupa

PCs parameters	PC-1	PC-2	PC-3	PC-4	PC-5
Eigenvalue	10.26	3.37	2.41	1.50	1.17
Variance (%)	46.6	15.3	11.0	6.8	5.3
Cumulative (%)	46.6	61.9	72.9	79.7	85.0
Indicators			Factor loading		
WSA	0.813	-0.165	-0.091	-0.162	**0.746**
MWD	**0.856**	-0.093	-0.156	-0.159	0.063
Bulk Density	**0.865**	-0.245	0.139	0.221	0.175
PR_{dry}	-0.760	-0.035	-0.158	0.339	-0.033
WHC	0.793	-0.414	-0.218	0.027	0.300
Total Porosity	**0.956**	-0.058	0.099	0.070	0.149
K_{sat}	0.537	-0.519	0.226	0.069	0.250
C_{mic}	**0.883**	-0.111	0.059	0.157	-0.180
N_{mic}	0.521	-0.038	0.061	0.129	-0.191
PMN	0.523	-0.039	0.054	0.142	-0.185
pH (H_2O)	-0.105	0.443	0.444	0.405	0.361
EC	0.825	0.308	-0.166	-0.258	-0.106
Organic Carbon	0.502	0.552	0.157	**0.639**	0.014
Na	0.589	0.483	0.039	-0.067	0.547
Total Nitrogen	0.391	**0.710**	-0.110	-0.088	0.430
AvP	0.827	-0.245	0.164	0.006	-0.085
Ext. Pb	0.610	0.557	0.009	0.242	-0.126
Ext. Cd	-0.568	0.491	**0.660**	-0.037	-0.099
Ca	0.215	0.256	-0.299	0.350	0.257
Mg	-0.174	0.101	-0.124	0.170	0.126

Values in bold represent loadings within 0.1 of the absolute value of the highest loading per principal component; PC =principal component; WSA =water stable aggregates greater than 250 µm sieve size; MWD =mean weight diameter; PR_{dry}=penetration resistance on dry soil; WHC =water holding capacity; K_{sat}=saturated hydraulic conductivity; C_{mic}=microbial biomass carbon; N_{mic}=microbial biomass nitrogen; PMN =potentially mineralizable nitrogen; EC =electrical conductivity; AvP = available phosphorus; Ext. Pb = extractable lead; Ext. Cd = extractable cadmium.

Table 4.23: Correlation coefficients for highly weighted indicators in Okitipupa

Indicator	MWD	BD	TP	C_{mic}	TN	Ext. Cd	OC	WSA
MWD	1.00							
BD	-0.83***	1.00						
TP	0.87***	-0.75**	1.00					
C_{mic}	0.74**	-0.72**	0.83***	1.00				
TN	0.31	-0.59*	0.26	0.29	1.00			
Ext. Cd	-0.67**	0.34	-0.53*	-0.45*	0.11	1.00		
OC	0.66**	-0.62**	0.68**	0.81***	0.62**	0.27	1.00	
WSA	0.97***	-0.78**	0.88***	0.73**	0.22	-0.65**	0.83***	1.00

* = correlation significant at $P \leq 0.05$; ** = correlation significant at $P \leq 0.01$; *** = correlation significant at $P \leq 0.001$. C_{mic}=microbial biomass carbon; TP =total porosity; WSA =water stable aggregates greater than 250 μm sieve size; MWD =mean weight diameter; OC =organic carbon; BD =bulk density; Ext. Cd =extractable cadmium; TN =total nitrogen.

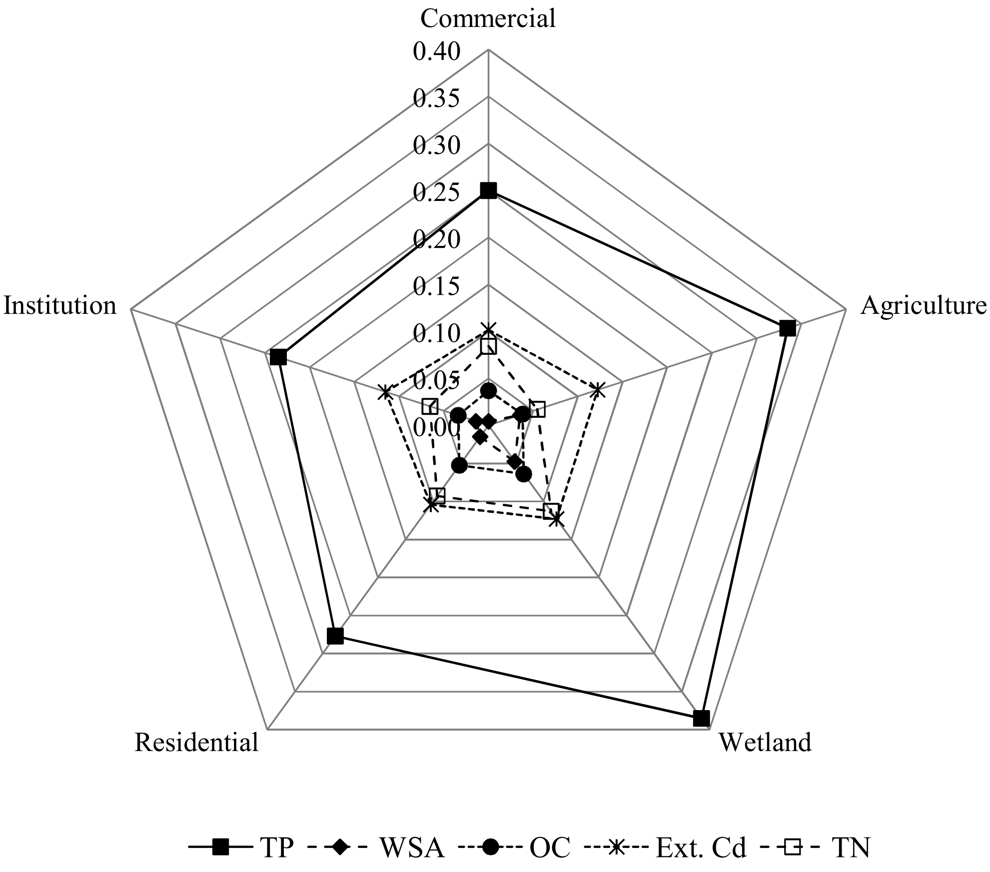
The contribution of each of the selected indicators towards statistically modelled soil quality in Okitipupa was computed and the result presented in Figure 4.19. The order of importance of the key indicators in influencing soil quality was TP (0.55) > TN (0.18) > Ext. Cd (0.13) > OC (0.08) > WSA (0.06). The corresponding contribution to soil quality in Okitipupa of TP, TN, Ext. Cd, OC and WSA was 49.3, 13.8, 17.2, 7.2 and 12.5%, respectively.

Result of the statistically modelled soil quality index (SQI_{sm}) as influenced by ULUTs in Okitipupa revealed that ULUTs significantly influenced soil quality rating (Fig. 4.20). Among the ULUTs, wetland (0.73) showed the highest soil quality which was higher than others. The least rating was recorded under institution (0.46) but it was not significantly different from the value reported under commercial (0.48). Soil quality rating reported under urban agriculture (0.59) was significantly higher than both commercial and institutionalULUTs but not different from residential (0.54). The overall order of superiority of the ULUTS from the viewpoint of statistically modelled soil quality indices was wetland > agriculture = residential > commercial = institution.

4.9.3 Soil environmental quality index

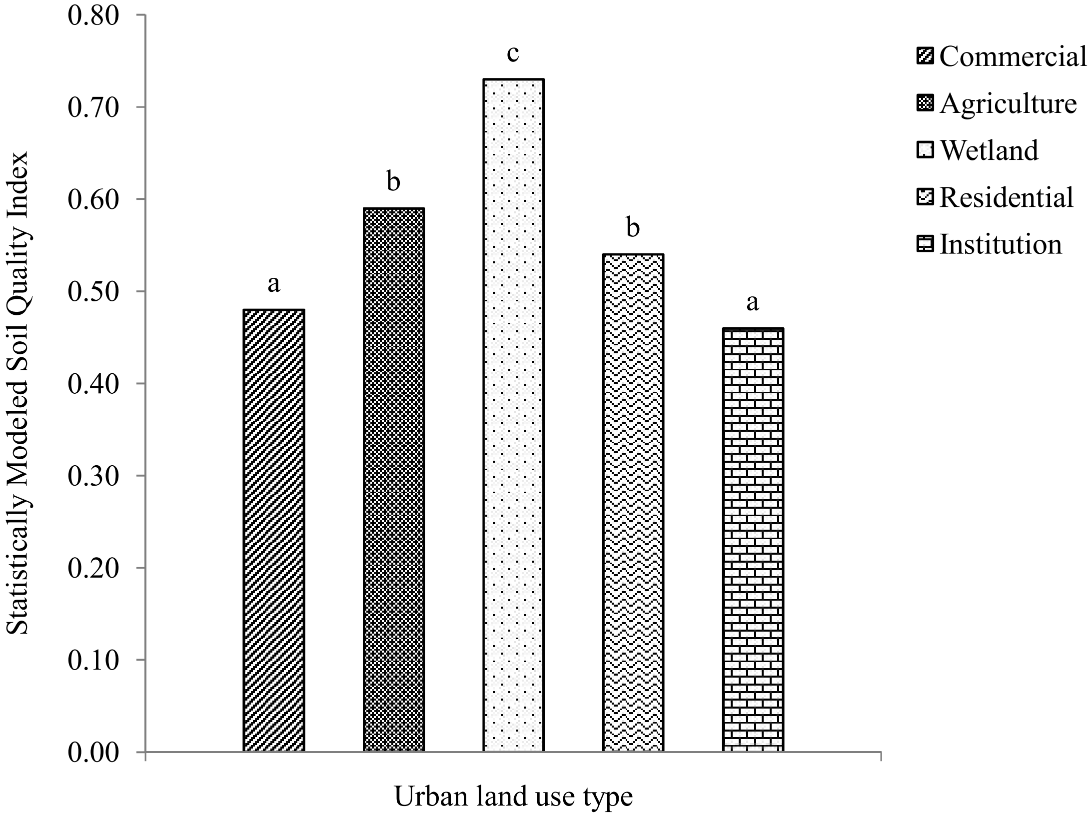
(i) Akure

The results of the quality difference (QD) values of the indicators used in determining soil environmental quality index in Akure are presented in Table 4.24.The QD values indicate how well individual soil quality indicators meet the appropriate quality requirements for the particular land use. With regard to commercial ULUT, all the indicators had QD values that is lower than required except for soil structure (0.9). On soils used for urban agriculture, QD value reported for soil pH was 0.3, SOC content was -2.0, texture was -1.0, soil structure was -1.0 and nutrient status was -1.0 (Table 4.24). On the wetlands, heavy metal contamination and SOC content were indicators that had QD values that were lower than required. Under the residential ULUT, soil heavy metal contamination (-1.0), SOC content (-1.7), infiltration capacity (-0.3), soil structure (-0.4) and nutrient status (-0.4) were indicators that had quality below that required. Under institutional ULUT soils, the indicators with quality lower than the required were SOC content (-1.7), soil texture (-1.0), infiltration capacity (-0.3) and soil structure (-0.7) (Table 4.24).



TP = total porosity; WSA = water stable aggregates greater than 250 µm sieve size; OC = organic carbon; Ext. Cd = extractable cadmium; TN = total nitrogen.

Fig. 4.19: Radar graph depicting average score contribution of key statistically modelled indicators as influenced by ULUTs in Okitipupa



Columns with different letter(s) differ at 0.05 probability level according to Duncan multiple range test (DMRT).

Fig. 4.20: Effects of ULUTsin Okitipupa on statistically modelled soil quality index

Table 4.24: Quality difference (QD) scores of soil quality indicators of different ULUTs in Akure and Okitipupa

Indicator ULUT	Heavy metal contamination	Soil pH	SOC content	Soil texture	Soil strength	Infiltration capacity	Soil structure	Nutrient status
Akure								
Commercial	-2.0	0.0	-1.0	-1.0	-1.4	-0.6	0.9	-0.8
Agriculture	0.0	0.3	-2.0	-1.0	0.9	0.6	-1.0	-1.0
Wetland	-1.0	0.1	-1.1	0.0	1.0	1.8	0.6	0.0
Residential	-1.0	1.4	-1.7	0.0	0.1	-0.3	-0.4	-0.4
Institution	0.0	1.3	-1.7	-1.0	1.3	-0.3	-0.7	0.0
Okitipupa								
Commercial	-2.0	-0.7	-1.2	-1.4	0.6	0.2	0.0	-1.0
Agriculture	0.0	-1.2	-2.4	-1.4	0.8	1.0	-1.9	-1.3
Wetland	-1.0	-0.7	-1.0	-0.9	1.0	2.0	0.3	0.2
Residential	-1.0	0.8	-1.0	-0.1	0.4	0.3	-0.8	-1.0
Institution	0.0	-0.8	-1.2	-1.4	0.7	0.6	-1.0	-1.0

Note:

QD is between -4 and -1, then quality is lower than needed.

QD is approximately -1, then quality is just below that needed.

QD is -4, then quality is well below that needed.

QD is approximately 0, then quality of the indicator matches that needed.

QD is between 1 and 4, then quality exceeds that needed.

The result of the index of soil quality (ISQ) which is an evaluation of quality based on what function the soil is to perform is presented in Table 4.25. All the ULUTs except for wetland and institution (ISQ = 0) had ISQ values that indicated soil quality that marginally deviated from required quality for that particular land use. The ISQ values for commercial, agriculture and residential ULUT was -0.1 (Table 4.25). The soil environmental quality index (SEQI) result is presented in Table 4.25. The result showed that the wetland soil had the best environmental quality rating of 0.66, while that of agriculture was 0.64. The soil environmental quality index rating for commercial was 0.50, residential was 0.54 and institutionalULUT was 0.55 (Table 4.25).

(ii) Okitipupa

The quality difference (QD) values of the indicators used in determining soil environmental quality index in Okitipupa are presented in Table 4.24. On the commercial ULUT, all the indicators had QD values that are lower than required except for soil strength (0.6), infiltration capacity (0.2) and soil structure (0.0). On soils used for urban agriculture, QD value reported for heavy metal contamination was 0.0, soil strength was 0.8 and infiltration capacity was 1.0 (Table 4.24). On the wetlands, heavy metal contamination, soil pH, SOC content and soil texture were indicators that had QD values that were lower than required. Under the residential ULUT, soil heavy metal contamination (-1.0), SOC content (-1.0), soil texture (-0.1) and nutrient status (-1.0) were indicators that had quality below that required. Under institution ULUT soils, the indicators with quality lower than the required were soil pH (-0.8), SOC content (-1.2), soil texture (-1.4), soil structure (-1.0) and nutrient status (-1.0) (Table 4.24).

The result of the index of soil quality (ISQ) in Okitipupa is presented in Table 4.25. All the ULUTs except for wetland (ISQ = 0) had ISQ values that indicated soil quality that was marginally lower than required quality for that particular land use. The ISQ values for commercial was -0.2, agriculture was also -0.2, residential was -0.1 and institutionalULUT was -0.1 (Table 4.25). The soil environmental quality index (SEQI) of soils in Okitipupa (Table 4.25) shows that the wetland soil had the best environmental quality rating of 0.63, while that of agriculture was 0.56. The soil environmental quality index rating for commercial was 0.47, residential was 0.54 and institutionalULUT was 0.49.

Table 4.25: Index of soil quality (ISQ) and soil environmental quality index (SEQI) ratings of different ULUTs in Akure and Okitipupa

ULUT	Akure		Okitipupa	
	ISQ	SEQI	ISQ	SEQI
Commercial	-0.1	0.50	-0.2	0.47
Agriculture	-0.1	0.64	-0.2	0.56
Wetland	0.0	0.66	0.0	0.63
Residential	-0.1	0.54	-0.1	0.54
Institution	-0.1	0.55	-0.1	0.49

Note:

If ISQ is less than 0, then soil quality is a little lower than that needed.

If ISQ is approximately -0.5, then soil quality is not satisfactory.

If ISQ is between -0.5 and -1.0, then soil quality is not suitable for the selected land use.

If ISQ is approximately 0, then soil quality is the level needed.

If ISQ is greater than 0, then soil quality is higher than the level needed for the land use evaluated.

If ISQ is approximately 0.5, then land use with higher soil quality requirement should be considered.

If ISQ is approximately 1, then land use over exceed the needed quality.

The soil quality indices computed from different methods (weighted additive soil quality index, statistically modelled soil quality index and soil environmental quality index) were highly correlated with each other (Table 4.26).

Table 4.26: Pearson's correlation coefficient matrix between soil quality indices computed from different methods

Soil Quality Index	SEQI	SQI_{wa}	SQI_{sm}
SEQI	1.00		
SQI_{wa}	0.80***	1.00	
SQI_{sm}	0.68***	0.92***	1.00

SEQI =soil environmental quality index; SQI_{wa}=weighted additive soil quality index; SQI_{sm}=statistically modelled soil quality index; *** is correlation significant at $P \leq 0.001$.

CHAPTER 5

DISCUSSION

The analysis of the area coverage of various land use/cover types identified from the imageries of Akure South and Okitipupa LGAs revealed the extent of development (categorized as built-up) over a 32-year period. Also revealed, is the expansion of the studied land use/cover types such as agricultural farmland, wetland, forest and waterbodies during this period. The identified land use/cover types did not show any distinct distribution pattern in the study areas. Within the two local government areas, the distribution of the land use/cover types except for the wetlands was not directly related to topographic position or soil types. However, in Akure South LGA, the spatial distribution of the built-up area over the 32-year period showed an increase towards the northern part of the LGA.This is most likely due to the migration of people into Ijapo Estate, a well-known residential estate in the local government area's northern reaches. Furthermore, the Ilesha-Akure-Owo highway appears to have lured growth to the city.Elsewhere, Turker and Asik (2002) in their study on land use changes at the urban fringe in Turkey, reported a 23.6% increase in infrastructural developmentoccasioned by the construction of the outer highway surrounding Ankara.

Analysis of the produced land use/cover maps of both Akure South and Okitipupa LGAs revealed a clear trend in the growth of built-up areas which was more noticeable in historically forested and agricultural areas. This pattern is largely due to the fact that urban land use types provide land speculators with higher and faster economic returns than farmlands and forests (Akinbola and Fagbemi, 2000).Also, this trend could be as a result of the discovery of bitumen and oil in the region which has led to increase in investments,buildings and other physical infrastructures (Owoeye and Ibitoye, 2016). In this study however, the observed expansion of the built-up areas by 19% and 36% in Akure South and Okitipupa LGAs, respectively may be attributed to the establishment of Okitipupa Oil Palm Factory and Ondo State Oil Producing Area Development Commission (OSOPADEC) among others. Furthermore, Akure being the capital city perhaps attracted individuals from other parts of the State seeking greener pastures thereby leading to the physical expansion of the area. Related major shifts in economic development and growth were also observed in these areas by Balogun *et al*. (2011) and Owoeye and Ibitoye (2016). This expansion of built-up areas is often achieved with little or no regard for the impact of such action on the environment as long as there are financial gains and resources to execute such development.Owoeye and Ibitoye (2016)observed that the proposed masterplan for the development of Akure and other major cities in the state are unfortunately not strictly adhered to and has become inactive and old. As the urban area continues to grow, forest lands diminish to thickets and ultimately to built-up areas.

With the competing need for land on the increase, conscious effort ought to be taken to protect prime agricultural lands from urbanization. For instance, Mariwah *et al*. (2017) noted that indiscriminate urban expansion has led to loss of prime agricultural lands in Tema metropolitan, Ghana. Furthermore, the loss of vegetation and construction of concrete and asphaltic surfaces in these areas could also have led to a modification of the local climate resulting in elevated atmospheric temperature.Exacerbating the situation is that natural characteristics of the surface soils in these areas are greatly modified.In most situations, what dictates the use to which a land is put are human needs and location of such needs instead of the inherent land characteristics and potentials for the planned use. This situation has led to the negative alteration of the properties of the soils, and consequently lowering quality of life. The environmental importance of vegetation cover and the need to preserve prime agricultural lands from other uses of land, should be paramount and placed above the immediate returns that other land use/cover types may bring.

Considering the farmlands in the study locations, although they appeared to have increased over the 32-year period of the study at both local government areas, this was achieved to the detriment of the forested lands. This observed increase is primarily due to the severe destruction done on forested lands as the urban sprawls. Having lost existing farmlands to buildings and constructions, new forested lands were opened up for subsistence agricultural purposes. In Zaria, Aminu *et al*. (2013) observed a similar conversion of forested lands to farmlands when assessing changes in land use/cover types in the city.Similarly, the area covered by waterbodies increased marginally over the study period.Abd El-Kawy*et al*. (2011) and Balogun *et al*. (2011) reported similar increase in waterbodies in their studies in the western Nile delta of Egypt and Akure town, respectively. This trend is in contrast to what was reported by Ganasri and Dwarakish (2015) from Harangi catchment in India. The observed increase could be attributed to the removal of thick vegetation that covered the waterbodies thereby masking thesignature of the waterbodies on the imageries over the years. In contrast, wetlands reduced in area coverage over the same period. The wetlands were mainly lost to physical development. The reduction in wetlands could have serious environmental implications in form of increased incidence of pollution and flooding. This is so because wetlands perform important ecosystem services in that they receive runoff water and contaminants (Nyarko *et al*., 2015). In most cases, the forested wetlands are cleared and converted to non-forested wetlands for agricultural purposes before further conversion to other urban land use/cover types such as residential.

For any land use/cover mapgenerated from remotely sensed imagery to be considered a truthful representation of the reality at the time of imaging, the land use/cover maps must be assessed for accuracy. The overall classification accuracy and Kappa statistics results in this study showed that there is a strong consensus between the classification (land use/cover maps) and the actual land use/cover types, with few mis-classifications for almost all land use/cover types. In Nigeria, only a few studies have reported on how reliable remotely sensed imagery can be used to generate land use/cover maps (Aminu *et al*., 2013 and Nnaji *et al*., 2016).In their study in Zaria, Aminu *et al*. (2013) recorded an overall accuracy of 71 percent and a Kappa statistics value of 0.67. On the other hand, Nnaji *et al*. (2016) reported a more accurate mean value of 97 percent overall accuracy and 0.93 Kappa statistics value from analysis of land use/cover changes in Owerri municipal. In general, a Kappa statistic of 0.75 suggests a high degree of classification (Ganasri and Dwarakish, 2015).The mis-classification recorded during the present study was mostly observed under the waterbody land cover type at both local government areas. This mis-classification was due to the fact that very little reference data (ground truth acquired with GPS during field work) was acquired for this land cover type. Moreover, in most places where the waterbodies are found, there are usually thick vegetation which can lead to a mis-classification.In Owerri, Njoku *et al*. (2010) had observed similar mis-classification in waterbodies which was attributed to possible interference of overlying tree cover.

Soil properties are mainly studied in relation to rural activities, but its importance is usually overlooked in an urban environment (Hazelton and Murphy, 2011). The impact of urbanization on the environment is so critical such that the properties of urban soils are key indicators of the health of terrestrial ecosystems. In this study, there is a high degree of divergence in the values of the soil physical and chemical properties observed in the soil profiles.The profiles showed fairly developed structure and the soils were demarcated into horizons.When studying soil characteristics of urban park in Hong Kong, Jim (1998) was able to demarcateurban soil profiles into distinctive strata based on morphological properties. This approach is in contrast to that reported byLehmann and Stahr (2007) who demarcated profiles into pedological horizons when studying the nature and significance of some anthropogenic urban soil profiles.This goes to show that urban soils are not only soils formed through mixing of materials by man but also include natural soils found within urban environment. The presence of artefacts in some of the profiles (Akure 1 and Okitipupa 4) is an indication of the anthropogenic influence on soil formation (Lehmann and Stahr, 2007).

The soils in Akure belong to the order Alfisol and Inceptisol (Soil Survey Staff, 2006) or Lixisol, Cambisol and Fluvisol (FAO, 2015), and Ondo Association (Smyth and Montgomery, 1962). At the series level, the soils were classified as Ondo, Owo, Apomu, Adio and Matako series. On the other hand, the soils in Okitipupa belong to the order Ultisol, Inceptisol and Entisol (Soil Survey Staff, 2006) or Acrisol and Fluvisol (FAO, 2015). The soils were classified into four series: Okitipupa, Mesan, Ode Erinje, and Alagba (Esu*et al*., 2014).

The texture of the profile soilsreflects the parent materials at the various locations in Akure and Okitipupa. Soils in profiles 1, 2, 3, 4 and 5 are predominantly medium textured with the horizons dominated by loamy sand, sandy loam and sandy clay loam. In contrast, the soils in profiles 6, 7, 8, 9 and 10 are coarse textured at all depths, with sand particles exceeding 700 g kg^{-1} at all depths which wasas a result of the sandstone parent material.The creation of a strong soil structure has been hampered by a lack of aggregating materials between coarse grains, especially in profiles 6, 7, 8, 9, and 10.

The strength and size of soil aggregates as reflected by the water stable aggregate and mean weight diameterwere generally low for most samples except for soils in Akure 4, Akure 5 and Okitipupa 5located on the wetlands. In theseprofiles, the high soil organic carbon stock perhaps contributed to the stability and size of the soil aggregates.Xiao *et al*.(2014)were able toestablished a link between soil organic matter and macro-aggregates in wetland soils under various land uses in China. Topsoil, with more organic matter induces resistance to mechanical breakdown, and it was better in aggregate stability than subsoil in most of the profiles. The observed relative stability in the subsoils of some profiles (Okitipupa 1 and Okitipupa 4) despite the low organic matter content could be due to the presence of iron oxides, a common cause of physical stability in humid tropical soil (Lal and Shukla, 2004) and increase in clay content (Sheklabadi*et al*., 2014).

Bulk density, a sensitive indicator of compaction, varied between 0.88 Mg $m^{-3}$and 1.68 Mg m^{-3}, which is close to what Pouyat *et al*. (2007) and Beniston *et al*. (2016) reported from other urban soils.The coarse-textured soils from Okitipupa 1, 2, 3, 4 and 5 generally had lower bulk densities when compared with others. This is so because the coarse matrix contains many interstitial pores irrespective of the level of compaction (Lal and Shukla, 2004), hence the lower density.The less compacted soils except for profile 2 had high total porosity of >50% and saturated hydraulic conductivity of >15.6 cm hr^{-1} with large pore diameters to facilitate drainage and aeration. Most of the remaining samples are compacted with soils in Akure 1 and Akure 3 having bulk density greater than 1.60 Mg $m^{-3}$and total porosity less than 40%. The compaction observed can be attributed to weak interparticle bonding, and externally applied forces resulting in ped breakdown, pore collapse, and hence denser packing. Soils in these profiles have restricted air and water transmission, low water storage which is evident in the depth of available water content of less than 1.5 cm (Gregory*et al*., 2006).Generally, the bulk density increased down the profile except in Okitipupa 3 and 5. This was probably as a result of the presence oforganic materials at the topsoil (Hagan *et al*., 2012)which was able to counteract some of the negative trampling effect caused by human traffic. Beniston *et al*. (2016) reported a similar increase in bulk density down the profileof a degraded urban vacant lot in USA, although this trend was in contrast to what was reported by Jim (1998).Furthermore, the observed increase in bulk densitiesdown the profilescould also be due to increase in clay content (Sheklabadi *et al*., 2014).This demonstrates that, while humans build and change the urban landscape, anthropogenic influences cannot account for all differences in urban soil properties. However, the spatial heterogeneity of soil parent material is also important.

The soil pH showed that the soils are slightly acidic. This couldpartly be due to leaching of cations following high intensity rainfall (Puskas and Farsang, 2009) and the friable nature of the soil inherited from the parent materials. Mao *et al*. (2014) in China observed that the spatial distribution of pH in Xuzhou's urban soils, were inherited from the parent materials. The electrical conductivity,a reflection of the total salt content of the soils in the profiles waslow (< 2.0 dS m^{-1}) especially in Okitipupa1, 2, 3, 4 and 5. These values were as a result of the intensive leaching that occurred in these profiles.

Soil organic carbon (SOC) and total nitrogen (TN)content were generally low at all depths in all the profiles except in Akure 5 and Okitipupa 5 that were located on the wetlands. Furthermore, in all the profiles, there was a general decrease in SOC and TN with increase in depth. The loss of organic matter and total nitrogen could have been due to erosion and high mineralization which is common in tropical soils. Various authors have reported contrasting trends and values in SOC and TNof urban soil profiles. For example, Puskas and Farsang (2009) reported low to very low SOC content in the form of humus from urban soil profiles in Hungary. Their study however showed that the distribution of TN in the profiles was greatly influenced by the soil organic matter content. In contrast, Raciti *et al.* (2011), studying urban soils of different land use histories in Maryland, USA, observedaccumulation of SOC and TN with values comparable to forest soils. In a similar vein, Lorenz and Kandeler (2005) reported that some urban parks in Germany had profiles with substantially greater soil carbon and total nitrogen pools than natural soils. The accumulation of SOC and TN in these soils was largely due to the anthropogenic management practices deployed.

In the profile soils, supply of phosphorus and exchangeable cations are closely linked to SOC content.Most of the soils in the profiles had available phosphorus value below 8 mg kg^{-1} with the values decreasing with increase in depth. The possibility of fixation due to the acidic reaction of the soils may further limit phosphorus availability (Hou *et al.*, 2014).Similarly, the content of exchangeable cations is generally low especially in Okitipupa1, 2, 3, 4, 5, and Akure 1. Gbadegesin and Olabode (2000) also reported low values of exchangeable cations from urban soils in Ibadan metropolis. On the other hand, Schleub *et al.* (1998) recorded higher values of exchangeable cations from urban and peri-urban areas in Germany mainly due to higher SOC content. Of the four cations, exchangeable calcium had the highest concentration, closely followed by magnesium in all the profiles except Akure 2. The dominance of exchangeable calcium could be attributed to calcareous construction rubble in some of the urban soils (Hagan *et al.*, 2012).

The available content of some heavy metals (Mn, Cr, Fe, Cu, Zn, Pb and Cd) was generally low except for Cd in Akure1, 2, 3, 4 and 5. The concentration of these heavy metalswas highest at the top of the profiles and there were unordered vertical reductions down the profiles. The elevated concentration of Cd at the top of the profiles could be attributed to indiscriminate disposal of municipal waste in the study locations (Bins*et al.* 2003). Moreover, high concentration of chloride anion in the soil coupled with low pH might lead to higher Cd concentration (Abdu *et al*., 2011b). In this study, the highest concentration of exchangeable cations was observed in profiles1, 2, 3, 4 and 5 located in Akure, which may be accumulated in the soils as chlorides and thus increasing total salt content. Norvell *et al.* (2000) reported a similar distribution of Cdwhich was related to NaCl concentration in the soil of North Dakota, USA.

In some of the profiles, heavy leaching, along with a decrease in nutrient and water supply due to structural damage and compaction, does not promote nutrient and water retention. The majority of the soils are unsuitable for plant growth due to a lack of organic matter and an intrinsically low nutrient status, as well as a limited ability to retain nutrients in readily available forms. Exacerbating the situation is the presence of heavy metal accumulation of cadmium which is dangerous to human when taken up by plants.

In this study, the impact of various urban land use/cover types and location on surface soil physical properties differed. The soil particle size distribution was significantly influenced by urban land use/cover types, but this impact had no effect on the textural classes of the soils. In addition, comparison of the particle size fractions of sand, silt and clay showed significant differences between the locations. The soils in Okitipupa were coarser textured (mean sand fraction = 740 g kg^{-1}) than soils in Akure (mean sand fraction = 610 g kg^{-1}). This result is consistent with the differences in parent material between the two locations. Pouyat *et al*. (2007) also reported significant differences in particle size distributions resulting from soils of two physiographic provinces in Baltimore, USA.

Generally, urban land use/cover type had a significant effect on soil bulk density with the highest values observed on commercial and residential urban land use types. The observed trend is in accord with the results of Scharenbroch *et al*. (2005) and Pouyat *et al*. (2007).Scharenbroch *et al*. (2005) reported highest bulk densities from residential sites out of an array of urban soils in Washington and Idaho States of USA, while Pouyat *et al*. (2007) recorded significantly higher bulk densities from commercial and residential sites when studying the effect of land use/cover on surface soil properties in Baltimore, USA. These results are in contrast to the non-significant effect of land use/cover on soil bulk density recorded by Hagan *et al*. (2012) from urban soils in Florida, USA. The contrasting results may be due to the magnitude of disturbance and the time since initial disturbance occurred in the soils (Scharenbroch *et al*., 2007).Similarly, location also had a significant effect on bulk density. The soils in

Okitipupa with sandstone parent material were coarser textured than the basement complex soils in Akure hence the significantly lower bulk density.The coarse texturedid not encourage close and tight packing of the soils (Lal and Shukla, 2004). Total porosity, as expected, followed an inverse trend to bulk density. Less compacted wetlands and urban agricultural soils had considerably greater porosities than commercial, residential, and institutional urban land use soils. Some authors have also reported lower porosities from highly compacted institution, residential and commercial urban soils (Gregory *et al.*, 2006; Scalenghe and Marsan, 2009 and Yang and Zhang, 2011). The low porosities in these soils could be attributed to compaction through pedestrian trampling and vehicular movement on the soils (Yang and Zhang, 2011).The location of the soils also influenced the porosities recorded in this study. The coarser sandy soils in Okitipupa were more porous than the medium textured soils in Akure. Increased porosity is not only essential to plant growth in an urban environment but is also crucial to stormwater management and ultimately water quality (Scalenghe and Marsan, 2009).

The ULUTs and location affected the strength and size of soil aggregates. The highest amount of macro-aggregates (aggregates >250 μm) was found in the wetlands and urban agriculture plots, while the highest amount of micro-aggregates was found in the commercial urban land use type. The breakdown of macro-aggregates in the commercial ULUTsmay be due to loss of binding agents (Xiao *et al.*, 2014). Six *et al.* (2002) reported that micro-aggregates are bound together into macro-aggregates by binding agents such as microbial and plant derived polysaccharides, roots and fungal hyphae. Also, aggregate breakdown could have been caused by excessive mechanical force resulting from human activities. Despite recording the lowest amount of clay particle size fractions in the wetlands, the high amount of macro-aggregates in the wetlands confirm the role and importance of organic matter in soil aggregation. The accumulation of organic matter in wetlands is due to the fact that the wetlands are saturated for the majority of the year, hence, the soil organic matter is protected from microbial oxidation (Nyamadzawo *et al.*, 2014). In their study of land use effects on soil aggregates, Sheklabadi *et al.* (2014) also reported significantly higher macro-aggregates in Iran due to soil organic matter build up in wetlands when compared with other land use type.

Saturated hydraulic conductivity was significantly influenced by urban land use types and location. Saturated hydraulic conductivity was consistently and significantly higher on urban agricultural plots in Okitipupa and on wetlands in Akure than other urban land use types. These findings can be due in part to improved soil structure, well-preserved pore networks, and increased macropore drainage as a result of organic material addition (Jiang and Shao, 2014).In their assessment of the long-term impact of municipal waste disposal on soil properties of some urban agriculture sites in Abakaliki, Nigeria, Anikwe and Nwobodo (2002) found a significant increase in saturated hydraulic conductivity.A strong influence of location on saturated hydraulic conductivity was also observed in this study. The hydraulic conductivity in Okitipupa was consistently and significantly higher than values obtained in Akure. The significantly higher sand and lower clay fractions in soils of Okitipupa could have resulted in the observed result. High saturated hydraulic conductivity reported by Jiang *et al*. (2007) from some soils of Missouri, USA was attributed to higher sand fraction in the soils.

The soil moisture retention results emphasized the relevance of organic material and sufficient soil aggregation in enhancing the soil's water holding capacity across urban land use/cover types. The assessment of water holding capacity within 0-20 and 20-40 cm depths showed that water holding capacity under wetlands and urban agriculture plots was consistently higher than other urban land use types. The addition of organic manure to urban agriculture sites may have contributed to the increase in moisture content. Beniston *et al*. (2015) found a 45 percent increase in moisture at 0-10 cm depth on organic matter amended urban land that was used for cultivation in their research. Gbadegesin and Olabode (2000) found that urban soil gardens and waste dump sites in Ibadan metropolis had significantly higher water holding capacity, owing to high organic matter content. High soil organic matter, favourable structural properties, and high soil porosity all contribute to the wetlands' higher water holding capability (Xiao *et al*., 2014).High soil organic matter contributed to improved soil water retention, according to Rawls *et al*. (2003), which agrees with the findings of this study. When considering the impact of location on water holding capacity, moisture retention in Okitipupa soils with sandstone parent material was better than in Akure soils, despite the fact that they were not significantly different at 0-20 cm depth. Textural composition is a major factor impacting the role of organic carbon in estimating water retention, according to Rawls *et al*. (2003).

Significant differences in soil moisture retention were only discernible among the urban land use types at lower suctions at both locations (10-500 kPa). With increasing suction (>500kPa), however, the difference in moisture between urban land use types became smaller. The influence of organic matter on soil water retention has been documented in a variety of ways. Rawls *et al*. (2003), for example, found that soil organic matter had an impact on water retention at both lower (33 kPa) and higher (1500 kPa) suctions. Whereas, Bell and van Keulen (1995) reported that organic matter affected water content at higher (1500 kPa) suction, but not at lower suction. In contrast, Calhoun *et al*. (1973) reported that the use of organic matter only increased water retention at lower (33 kPa) suction.According to Rawls *et al*. (2003), these variations in response can be explained by the proportions of textural components of the soil and the volume of organic matter.Improved soil structure, which results in increased intra-aggregate and inter-aggregate pore spaces, may be attributed to the general improvement in transmission and storage pores at the expense of residual pores. At both locations, the significantly greater storage pores observed on urban agriculture and wetland plots may be as a result of the higher organic matter content in the soils. On the other hand, the structural breakdown perhaps resulted in the increase in residual pores under institution, commercial and residential ULUTs.

A measure of soil strength under the urban land use/cover types shows that soil penetration resistance varied significantly with land use/cover. The observed differences in penetration resistance could be due to variations in soil moisture throughout the soil column at both locations.The more compacted commercial, institution and residential urban land use soils offered higher resistance to cone penetration. Gregory *et al*. (2006) observed that cone index on non-compacted urban soils was lower than cone index measured on similar soils that had been compacted by livestock and vehicular movement.The loosening of the soil during land preparation could have contributed to the lower penetration resistance on soils used for urban agriculture. Adelana *et al*. (2013) reported that penetration resistance of tropical agricultural soils generally decreases with the intensity of soilmanipulation during tillage operations.Furthermore, the soils of the wetlands are young, and are derived from recent alluvial deposits, and with high water table, hence the low penetration resistance (Adelana *et al*., 2016).

Similar to the physical properties, most of the chemical properties of the soils were influenced by urban land use/cover typeand locationin this study. Urban land use type in Akure appeared to have minimal influence on soil pH but there were significant differences with respect to parent material. The soils derived from sandstone parent material in Okitipupa had significantly lower soil pH when compared with soils in

Akure. This observation could be due largely to the highly intensive leaching of cations from the porous soils in Okitipupa. Esu *et al*. (2014) in their characterization of soils in Okitipupa reported similarly low pH values. The generally low electrical conductivity values were also a reflectionof the leaching of cations, although wetland and agricultural soils consistently and significantly had higher conductivity than other urban land use type. Madrid *et al*. (2004) reported that the significantly low electrical conductivity of some soils used for urban agriculture in Sevilla was largely due to heavy leaching of soluble salts from the soils.

Both urban land use type and location had a significant impact on soil organic carbon and total nitrogen in this study. The protection of soil organic matter from microbial degradation could explain the significantly higher soil organic carbon recorded from wetlands (Nyamadzawo *et al*., 2014). Furthermore, the moderate (26.1 g C kg^{-1} soil in Akure and 24.3 g C kg^{-1} soil in Okitipupa) concentration of soil organic carbon may have been explained by the addition of manure on urban agriculture sites (Beniston *et al*., 2015). The fact that total nitrogen followed a similar pattern to soil organic carbon meant that the majority of the nitrogen was closely linked to soil organic carbon (Raciti *et al*., 2011).When comparing soil organic carbon and total nitrogen in Okitipupa and Akure, soils in Okitipupa with lower population density had significantly higher organic carbon and total nitrogen. In their research on subtropical coastal urban soils in Florida, Hagan *et al*. (2012) observed that organic matter and total nitrogen content were lowest in the census population density with the highest population. The removal of topsoil, prevalence of organic matter poor fill materials, and potentially improved nutrient turn-over rates could all have contributed to reduced organic carbon and total nitrogen in the high-population areas (Pouyat *et al*., 2007).

In terms of the impact of ULUTs, soil available phosphorus followed similar trends as soil organic carbon and total nitrogen. Wetland soils had significantly higher available phosphorus than other urban land use types. The high organic carbon content of the wetlands may have resulted in significantly higher soil available phosphorus. According to Hou *et al*. (2014), the deposition of organic carbon in some south Chinese soils may have resulted in increased phosphorus supply. In comparison, Huang *et al*. (2012) reported that the build-up of soil organic carbon will contribute to phosphorus binding, thus reducing the amount of phosphorus available in the soil.Asides the urban land use type, location significantly influenced soil available phosphorus. The lower available phosphorus recorded from soils derived from sandstone in Okitipupa was probably due to the significantly lower soil pH. Hou *et al.*(2014) alsoreported a similar pattern of low available phosphorus from soils of low pH.

Urban land use types had a significant impact on heavy metal concentrations. Zn, Mn, Cr, and Fe concentrations were significantly higher in wetlands, while Cu, Pb, and Cd concentrations were significantly higher in commercial ULUTs. The higher organic carbon content of the soils could explain the significantly higher level of certain metals in the wetland (Adelana *et al*., 2016). Organic matter, according to Madrid *et al*. (2004), provides binding sites that help to hold heavy metals that are found in the soil.The strong correlation result between soil organic carbon and heavy metal content further supported this conclusion. Furthermore, the acidic state of the soils may have influenced the supply of certain heavy metals (Vega *et al*., 2007). According to Vega *et al*. (2007), soil pH plays a role in assessing the availability of Cu in soils. Only Cd and Pb amounts in commercial and residential urban land use types were higher than the Nigerian Federal Environmental Protection Agency's (FEPA) overall permissible limit.On the residential urban land use type, indiscriminate disposal of municipal waste could have resulted in the higher concentration of Cd (Bins*et al*., 2003). In addition, the high level of Cd and Pb in the commercial soils may be as a result of automobile tyre and tubes, engine oil and scrap metals that litter most of the commercial soils coupled with fossil fuel combustion similar to the findings of Nwachukwu *et al*.(2011).The concentration of the heavy metals was also significantly influenced by location. Soils in Akure significantly had higher concentration of Cu, Mn, Pb, Cr and Cd when compared with Okitipupa. It's likely that the higher concentration of these metals is due to the granite gneiss rocks in Akure, which are abundant in Cr, Cu, and Mn (Sparks, 2003). Pouyat *et al*. (2007) found that variations in the concentration of some metals were linked to surface geology in an analysis on chemical properties that distinguish urban land use/cover types in Baltimore, USA. The significantly higher Pb and Cd concentrations in Akure, on the other hand, may be due to the city's more pronounced anthropogenic impact. Akure with a higher population density when compared with Okitipupa could have generated more municipal waste and more heavy metal residue from automobiles and companies.Although the concentration of some of the heavy metals had not reached a toxic level, yet it is however important that their concentrations are monitored considering the fact that some of the soils are used for urbanagriculture.

In this study, the type of urban land use/cover had a major impact on soil microbiological properties. As compared to other urban land use/cover types, the mean value of soil respiration (60.5 mg CO_2-C kg^{-1} d^{-1} in Akure) in wetlands was significantly higher. Tangen *et al.* (2015) found that soil respiration was higher in wetlands than in other upland soils in the Prairie Region of the United States. This was due to the higher soil organic matter input, which serves as food for the microbes, and the wetland soils' favourable moisture conditions.The lowest soil respiration found under commercial soils, in comparison to wetlands, may be due to metal toxicity in the soil (Papa *et al.*, 2010).The inhibition of soil respiration by heavy metals occurred when heavy metals react with sulfhydryl groups thereby causing microbial inactivity (Papa *et al.*, 2010). Also, the structural breakdown resulting from compaction in the commercial soils has led to lower moisture content which could have resulted in less favourable habitat for soil microbe hence lower soil respiration.

Soil microbial biomass carbon (C_{mic}), nitrogen (N_{mic}) and microbial activity as measured through the potentially mineralizable nitrogen (PMN) showed that biomass and activity was highest under the wetlands and closely followed by urban agriculture soils. Lower bulk densities and higher soil organic matter may have led to higher microbial biomass and activities in these soils. According to Papa *et al.* (2010), elevated amounts of organic matter resulted in higher levels of microbial biomass and activity. This view confirms the significant and positive correlation (Pearson correlation coefficient of 0.80, $p \leq 0.001$) between microbial biomass carbon and soil organic carbon measured in this study. In addition, Scharenbroch *et al.* (2005) reported that less compact soils were prone to nitrogen mineralization due to reduction in physical protection of organic matter from microbial attack. The presence of heavy metals could also have influenced the rate of microbial biomass and activity especially under the commercial and residential urban land use types (Papa *et al.*, 2010). This was reflected in the significant and negative correlation between microbial biomass/activity and extractable Pb/Cd in this study. In a study, Kandeler *et al.* (2000) reported a similar decrease in microbial biomass nitrogen with increase in heavy metal concentration.This study has shown that the soil microbial biomass and activity did not depend only on the soil physical and chemical conditions but also on the heavy metal concentration.

In this study, six urban soil functions were used in the computation of weighted additive soil quality index (SQI_{wa}). Integration of soil indicators into SQI_{wa}resulted in a significantly higher score in wetlands for its stormwater infiltration ability, while the least score was observed in the commercial urban land use type. The relatively higher water holding capacity and hydraulic conductivity, coupled with lower bulk density of the wetland soil was mainly responsible for the improvements in stormwater infiltration. Gelaw *et al*. (2015) reported that the significantly higher score in a soil's ability to accommodate water entry was largely due to lower bulk density and higher water holding capacity. The role of urban soils in controlling flooding and erosion throughstormwater infiltration cannot be over emphasized because of the increasing amounts of constructed impervious surfaces within the urban environment.Regarding the soil's ability to adsorb pollutants, the score from the wetland soils was also significantly higher although it was not different from urban agriculture soils. The lowest score reported from the commercial urban land use type could be attributed to indiscriminate disposal of materials containing these pollutants (Bins*et al*., 2003). Extra caution must be taken within this urban land use type because in most of the sites studied, some form of farming was being done.The possibility of heavy metal uptake by the crops could therefore be a health risk. The relatively higher scores in the ability of the wetlands to adsorb pollutants go to show the importance of wetlands in maintaining environmental quality. Therefore, constant destruction and mismanagement of these sites could pose a great danger to humans (Nyarko *et al*., 2015). Urban land use type also had significant effect on the soil's ability to adsorb and transform nutrients, and sequester soil carbon. In the wetlands, higher levels of total nitrogen, available phosphorus and exchangeable bases resulting from higher soil organic carbon must have contributed to the higher scores reported (Nyamadzawo *et al*., 2014).The scores reported for sorption and transformation of nutrients, and soil carbon sequestration from urban agriculture soils were probably improved by the addition of organic residue to the soils. Beniston *et al*. (2015) reported that impaired soil function in a degraded urban soil used for agriculture was significantly improved with the addition of compost produced from urban yard waste. The score of foundation for plant growth and habitat for micro-organism functions were also significantly influenced by urban land use type. For these functions, the role of soil organic carbon in improving aggregate stability, total porosity and providing food for micro-fauna must have led to the higher scores in the wetlands.

Although the soil functions were given closely similar weights, the contributions of the six soil functions to SQI_{wa} differed significantly within each urban land use type. In the commercial urban land use type, the highest contribution of 26% in Akure and 22% in Okitipupa to SQI_{wa} was fromsoil carbon sequestration function. However, the ability of the soil to sequester soil carbon had little impact on soil properties because the majority of the carbon stock occurred as recalcitrant black carbon (Rawlins *et al*., 2008).According to Lorenz *et al.* (2006), black carbon produced by incomplete combustion of materials and fuels can make up nearly 70% of the elemental carbon in some urban soils.Within the wetlands, stormwater infiltration function was the greatest contributor to SQI_{wa}, which comprised approximately 18% in Akure and 21% in Okitipupa of the overall SQI_{wa}value.In these soils, soil organic matter build up in the wetlands could have improved soil structure. On the urban agriculture soils, the least contribution to SQI_{wa}at both locations were from the ability of the soils to adsorb and transform nutrients. On this land use type, the possibility of nutrient mining due to crop harvesting could have resulted in this observation (Gelaw *et al.*, 2015). The integration of these soil functions using a modified Soil Management Assessment Framework as defined by Andrews *et al.* (2004) resulted in the overall SQI_{wa}value. There were significant differences due to urban land use types in the computed SQI_{wa}. In all the urban land use types, only wetlands had a score greater than 50%, and this goes to show that all the other urban land use types were not sustaining environmental quality.

In the computation of statistically modelled soil quality index (SQI_{sm}), six key indicators (C_{mic}, WSA, SOC, Ext. Pb, BD and EC) were selected in Akure. However, in Okitipupa, five indicators (TP, WSA, SOC, Ext. Cd and TN) were selected after the principal component and correlation analyses. The urban land use types significantly influenced these indicators and soil functions, and ultimately overall SQI_{sm}. Among the biological indicators, microbial biomass carbon (C_{mic}) was selected as a key indicator in Akure and it contributed 38.9% towards SQI_{sm}. Soil microbial biomass is an indicator that influenced the soil's function to serve as habitat for micro-organism and is a good indicator of microbial activity (Beniston and Lal, 2012). Any urban land use/cover that maintains or improves C_{mic} would help contribute towards soil aggregation, aggradation and improvement in soil structural quality.From the physical indicators, water stable aggregates (WSA) contributing 5.5% and bulk density (BD)contributing 3.9% towards SQI_{sm}qualified as the key indicators in Akure. On the other hand, in Okitipupa total porosity (TP) and WSA were selected as key indicators. The WSA is a measure that represents a variety of urban soil functions, such as plant growth foundation and stormwater infiltration (Sheklabadi *et al.*, 2014).Further, TP and BD are of importance in urban soil quality assessment, as they also influenced stormwater infiltration, foundation for plant growth and habitat for micro-organism functions (Beniston and Lal, 2012).Among the key indicators, soil organic carbon (SOC) in Akure contributed 15.9% and 7.2% in Okitipupa towards soil quality in the present study. Soil organic carbon played an important role in different soil functions. The soil's ability to sequester soil carbon, provide foundation for plant growth and habitat for micro-organisms, and sorption of nutrients are influenced by SOC (Beniston *et al*., 2016). In addition, among the chemical soil quality indicators, electrical conductivity (EC) in Akure and total nitrogen (TN) in Okitipupa also emerged as key indicator, contributing 8.8% and 13.8% to SQI_{sm}.Zornoza *et al*. (2015) also reported that EC is a key indicator in soil quality assessment.Heavy metal availability as measured through extractable Pb and Cd, contributing 26.8% and 17.3% to SQI_{sm} were also chosen as key indicators. Several authors have reported the importance of heavy metal measurements in urban soil quality assessment (Papa *et al*., 2010; Minca *et al*., 2013). For instance, Minca *et al*. (2013) reported that soil Pb content is a key indicator in urban soil quality assessment.After the integration of the key indicators into SQI_{sm}, there were significant differences resulting from the urban land use/cover types at both locations. When compared with SQI_{sm} in Okitipupa, the SQI_{sm} measured in Akure was higher in all the ULUTs except under residential and institution. This trend could be attributed to the higher population density within the residential and institution in Akure when compared with Okitipupa. The highest SQI_{sm} was found in the wetland while commercial and residential ULUT had the highest negative effect on soil quality. The beneficial effect of SOC perhaps improved microbial activity and soil structure, and increased effective pore volume, which resulted in higher SQI_{sm} under wetland. This view corroborates the findings of Lorenz and Lal (2015) and Beniston *et al*. (2016). Lorenz and Lal (2015) drew a significant and positive relationship between soil carbon content, urban ecosystem services and soil quality. Also, Beniston *et al*. (2016) reported that addition of SOC improved several soil properties resulting in measurable differences in overall soil quality of some urban soils in USA.

Eight indicators (heavy metal contamination, soil pH, SOC, texture, soil strength, infiltration capacity, soil structure and nutrient status) were used in the computation of soil environmental quality index as modified after Vrscaj *et al*. (2008). The results of the quality difference (QD), a measure of the extent to which indicators meet required criteria for the urban land use type varied in this study. On the urban land use types, loss of organic material, structural breakdown from compaction, Pb contamination, sandy soil texture and loss of transmission and storage pores resulted in varyingQD values. For instance, Pb contamination decreased QD in all the urban land use type at both locations except for agriculture and institution urban land use types (Pouyat *et al*., 2008).Furthermore, the sandy texture of the soil also negatively impacted QD in all the urban land use types especially in Okitipupa. Rodrigues *et al*. (2009) observed that the concentration of metals did not only influence urban soil quality of some soils in Glasgow and Aveiro, but also the soil texture, pH and SOM content. The infiltration capacity decreased QD on the commercial, residential and institution urban land use types in Akure. On the other hand, infiltration capacity increased QD on all the urban land use types in Okitipupa. The breakdown in structure resulting from compaction could have resulted in the reduction in QD (Pitt *et al*., 2008). This negative trend was not observed in Okitipupa probably as a result of the inherent porous nature of the soils.The results of the index of soil quality (ISQ) and soil environmental quality index (SEQI) showed that soils on the wetlands had the best quality rating. The ISQ from all the urban land use types except for wetlands showed that soil quality marginally deviated from the required quality, while on the wetlands it marginally exceeded the required. The favourable SOC content, soil structure, nutrient status, infiltration capacity and soil strength could have contributed to better ISQ rating in the wetlands. Similarly, the observed trend in SEQI on the wetlands could be attributed to these favourable conditions.

The soil quality indices (SQI_{wa}, SQI_{sm} and SEQI) computed from different methods were highly correlated to each other. This has shown that the relatively easier and user friendly SEQI can be computed to evaluate urban soil quality. Also, assigning appropriate weighted scores when computing $SQI_{wa}$was useful in predicting urban soil quality. Furthermore, the use of a statistically selected minimum data set when computing SQI_{sm} is appropriate when evaluating urban soil quality. The advantage of using SEQIis that the method is land use based and it combines soil quality evaluation for varying land use/cover within a particular evaluation system (Vrscaj *et al*., 2008). The disadvantage of SEQI is that it is subjective and relied mainly on the user's perspective when assigning scores to the indicator weights. In contrast, advantage of $SQI_{wa}$is that it involved assigning weighted scores based on the ecosystem or soil functions in order to bypass the inherent subjectivity. However, the disadvantage in this approach is that it requires high number of soil indicators which may be expensive and time consuming. The SQI_{sm} is advantageous in its ability to compute soil quality based on reduced dataset with fewer soil indicators. In addition, the subjectivity is removed as the use of statistics in determining the variance in the total dataset helped to select the key indicators.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The trends in land use/cover changes in both Akure South and Okitipupa LGAs between the years 1984 and 2016 have been documented. Through the use of remotely sensed data, an assessment of the pattern of distribution of the identified land use/cover types was made.

Urban land use type in Akure South LGA increased in area coverage from 10.0% to 16.9% and to 29.5% of the total area of 350 km^2in 1984, 2000 and 2016, respectively. The corresponding increase in Okitipupa LGA was from 1.2% to 3.7% and to 8.5% of the total area of 803 km^2.Forests in Akure South decreased in area coverage from 68.3% in 1984, to 53.4% in 2000 and to 32.0% in 2016. In Okitipupa, the decrease was from 74.1% to 45.2% and to 15.8%. Although farmlands increased at both locations, this was achieved to the detriment of the forest lands. The wetlands suffered a similar fate to that of the forests in that there was marginal decrease in their area coverage over the 32-year period at both locations.

Results of the accuracy of the land use/cover maps produced for both locations showed that a good agreement existed between the classification and the actual land use/cover types. The overall accuracy of the land use/cover maps of Akure South LGA varied from 79.5% to 93.7%, while that of Okitipupa was from 89.8% to 97.5%. The Kappa statistics values from this study also corroborated the fact that there was little mis-classification across the identified land use/cover types.

The soils in Akure based on their position on the toposequence were classified as Alfisol and Inceptisol (Soil Survey Staff, 2006), Lixisol, Cambisol and Fluvisol (FAO, 2015) and as Ondo, Owo, Apomu, Adio and Matako series. The soils in Okitipupa on the other hand, were classified as Ultisol, Inceptisol and Entisol (Soil Survey Staff, 2006), Acrisol and Fluvisol (FAO, 2015) and locally as Alagba, Okitipupa, Mesan and Ode Erinje series.The properties of the soils were greatly influenced by the parent material, organic matter and anthropogenic activities. The soils were predominantly sandy with poor aggregate formation throughout the profile except on the Fluvisol.

Anthropogenic influences resulted in restricted water transmission and low water storage, coupled with heavy metal contamination. The influence of organic matter was evident in the physical and chemical properties of the profile soils such as water stable aggregates, mean weight diameter and total nitrogen.

The influence of ULUT and location on the physical properties of the surface soils varied highly.ULUT and location had a significant impact on particle size distribution, bulk density, porosity, strength and size of soil aggregates, soil water retention, pore size distributions, saturated hydraulic conductivity, and penetration resistance. Similar to the physical properties, most of the chemical properties of the soils were also influenced by ULUT and location. Soil pH, SOC, total nitrogen, soil available phosphorus and heavy metal concentration were significantly influenced by location of the soils. The influence of ULUT resulted in differences in some of the soil chemical properties. The differences were greatest and most prominent between wetland and commercial land use type. Soil microbiological properties were also influenced by ULUT. The wetlands showed the most favourable response with regards to soil respiration, soil microbial biomass and microbial activity.

The assessment of urban soil quality was based on functions such as stormwater infiltration ability, sorption of pollutants, sorption and transformation of nutrients, ability to sequester soil carbon, ability to serve as foundation for plant growth and habitat for micro-organism.Among the ULUTs, soils on wetlands consistently had higher scores with regards to the soil functions. At both locations, when the soil functions were integrated into SQI_{wa}, wetland land cover type had the highest soil quality rating of 0.59 in Akure and 0.63 in Okitipupa.

The present study clearly indicated that C_{mic}, WSA, SOC, Ext. Pb, BD and EC in Akure and TP, WSA, SOC, Ext. Cd and TN in Okitipupa were the key indicators of urban soil quality. Principal component analysis and multi-variate correlation were used as tools to identify key soil quality indicators in the form of minimum data set (MDS) which influenced the management goal of environmental protection. The integration of the key indicators resulted in significantly different $SQI_{sm}$with values varying from 0.48 to 0.90 in Akure and from 0.46 to 0.73 in Okitipupa.

Computation of soil environmental quality index (SEQI) was carried out using eight indicators (heavy metal contamination, soil pH, SOC, texture, soil strength, infiltration capacity, soil structure and nutrient status). These indicators demonstrated the ability of urban soils to perform essential environmental soil functions such as water filtering, buffering, pollutant decomposition, and food and fibre processing.The soil environmental quality index varied from 0.50 to 0.66 in Akure and from 0.47 to 0.63 in Okitipupa. The wetlands had higher index, and they were closely followed by urban agriculture soils at both Akure and Okitipupa.

The urban soil quality computed through the different methods clearly indicated that wetlands had significantly higher soil quality among the ULUTs. Also, the soil quality computed using the three methods were all significantly correlated to each other.This has shown that the relatively easier SEQI is useful in the evaluation of urban soil quality, appropriate score weights can predict urban soil's quality (SQI_{wa}) with high accuracy but requires high number of indicators, while, the statistically computed SQI_{sm} with fewer numbers of indicators may also be useful in urban soil quality evaluation.

6.2 Recommendations

Based on the study's findings, the following recommendations are made:

i. There is the need for periodic acquisition of land use/cover data through remote sensing. This will enhance monitoring of land use/cover changesas a way of achieving sustainable environmental conservation;

ii. In the face of stiff competition among land use type, farmland, forest land and wetlands are prone to urban land use demand. This has resulted in loss of prime farmlands and wetlands. There is a need for appropriate government agencies to look into land use allocation in order to arrest the situation;

iii Soils under the different ULUTs are susceptible to various forms of degradation such as structural breakdown and compaction, restricted water conductivity and soil water retention, poor nutrient availability and heavy metal contamination and all these have made the development of site-specific soil management strategies necessary;

iv. The emerged minimum data set for Akure (C_{mic}, WSA, SOC, Ext. Pb, BD and EC) and Okitipupa (TP, WSA, SOC, Ext. Cd and TN) can be used as indicators to monitor changes in soil environmental quality in these locations;

v. Further work is recommended on the development of appropriate end-point measurements for urban soil quality assessment in order to validate the accuracy of urban soil quality indices.

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APPENDICES

Appendix 1: Investigated urban land use types in Akure

Urban land use type	Site	Coordinates
Commercial	Oyaregbulem market abattoir, Akure	Lat: 7° 16ʹN Long: 5° 11ʹE
	Mechanic village along Akure – Ilesha road	Lat: 7° 14ʹN Long: 5° 12ʹE
	Oda market	Lat: 7° 10ʹN Long: 5° 14ʹE
Agriculture	Ologede, alongOwo – Akure road	Lat: 7° 16ʹN Long: 5° 10ʹE
	Kajola, beside Greenwich Strategic Grain Reserve	Lat: 7° 13ʹN Long: 5° 13ʹE
	Isinkan	Lat: 7° 15ʹN Long: 5° 10ʹE
Wetland	Shagari Estate, Akure	Lat: 7° 17ʹN Long: 5° 11ʹE
	Eyin Ala, Akure	Lat: 7° 16ʹN Long: 5° 10ʹE
	Emiloro, Akure	Lat: 7° 10ʹN Long: 5° 13ʹE
Residential	Shagari Estate	Lat: 7° 17ʹN Long: 5° 11ʹE
	Ilotin – Ijoka	Lat: 7° 12ʹN Long: 5° 12ʹE
	Ijapo Estate	Lat: 7° 16ʹN Long: 5° 13ʹE
Institution	St. Aquinas College, Hospital road	Lat: 7° 14ʹN Long: 5° 11ʹE
	Sacred Heart Seminary, Araromi	Lat: 7° 15ʹN Long: 5° 11ʹE
	Staff Secondary School, FUTA	Lat: 7° 17ʹN Long: 5° 9ʹE

Appendix 2: Investigated urban land use types in Okitipupa

Urban land use type	Site	Coordinates
Commercial	Odo Eran abattoir, along Yewa River	Lat: 6° 30'N Long: 4° 46'E
	Mechanic village, along Ode Aye - Ore road, Akintola area	Lat: 6° 31'N Long: 4° 45'E
	Mechanic village, Lupete, Okitipupa	Lat: 6° 30'N Long: 4° 43'E
Agriculture	Extension Service Station, Oke Aye road	Lat: 6° 31'N Long: 4° 47'E
	Ojokodo area, Odo Aye	Lat: 6° 31'N Long: 4° 45'E
	Coastal Hotel, Okitipupa	Lat: 6° 26'N Long: 4° 46'E
Wetland	Oyesanmi Quarters, behind River Ofe	Lat: 6° 31'N Long: 4° 47'E
	Farm Settlement, along Okitipupa – Ore road	Lat: 6° 33'N Long: 4° 45'E
	River Oluwa flood plain	Lat: 6° 30'N Long: 4° 48'E
Residential	Oke Oyinbo GRA	Lat: 6° 30'N Long: 4° 47'E
	Ikoya road, Army Barrack area	Lat: 6° 31'N Long: 4° 45'E
	Akinyemi street, Ajaka area	Lat: 6° 25'N Long: 4° 46'E
Institution	Ofedepe Comprehensive High School, Adeyemi Avenue	Lat: 6° 30'N Long: 4° 46'E
	Ogundubuja High School, Kalejaye area	Lat: 6° 29'N Long: 4° 50'E
	Methodist High School, Odunwo Quarters	Lat: 6° 20'N Long: 4° 43'E

l physical properties of profile pits in Akure

Coarse Sand	Fine Sand	Silt	Clay	Bulk density	Total porosity	K_{sat}	WSA	MWD
(g kg^{-1})				(Mg m^{-3})	(%)	(cm hr^{-1})	(kg kg^{-1})	(mm)
Kandiudalf (USDA); Ferric Lixisol (FAO); Ondo Series								
507	205	202	87	1.64	34.3	1.48	0.578	0.79
385	227	122	267	1.67	26.5	1.36	0.462	0.74
398	219	259	124	1.68	27.5	1.40	0.402	0.67
418	208	230	144	1.68	25.2	1.20	0.400	0.65
Kanhapludalf (USDA); Ferric Lixisol (FAO); Owo Series								
428	269	199	104	1.15	48.9	25.80	0.603	0.80
290	366	239	104	1.48	36.3	4.03	0.392	0.85
279	338	179	204	1.50	35.5	4.00	0.350	0.70
269	358	189	184	1.55	32.3	3.56	0.300	0.66
Dystrudept (USDA); Haplic Cambisol (FAO); Apomu Series								
448	248	199	104	1.46	38.3	3.35	0.407	0.53
460	216	239	84	1.57	36.6	6.58	0.377	0.58
478	139	319	64	1.60	35.5	4.44	0.350	0.45
324	273	219	184	1.65	30.4	3.20	0.334	0.44
Aquept (USDA); Eutric Fluvisol (FAO); Adio Series								
51	451	394	104	1.09	46.1	34.57	0.691	1.44
42	441	394	124	1.39	45.4	4.98	0.596	1.08
Kanhapludalf (USDA); Gleyic Fluvisol (FAO); Matako Series								
489	174	254	84	1.21	50.5	15.49	0.668	1.35

chemical properties of pits in Akure

pH (KCl)	EC (dS m^{-1})	K	Ca	Mg	Na	Al^{3+}	H^{+}	ECEC	BS (%)	OC	TN	AvP	Zn	Cu	Mn	P
		(cmol kg^{-1})								(g kg^{-1})						(mg kg
andiudalf (USDA); Ferric Lixisol (FAO); Ondo Series																
5.84	0.201	0.57	1.60	1.89	2.42	0.60	0.09	7.17	90.4	21.8	1.20	6.93	19.7	2.4	101	5.
5.46	0.095	0.74	1.00	0.81	2.32	1.00	0.09	5.96	81.7	12.1	1.00	3.04	17.9	2.0	610	5.
5.69	0.101	0.89	1.70	1.76	2.57	1.00	0.09	8.01	86.4	8.8	0.91	0.84	0.6	1.7	648	1.
5.70	0.111	0.50	0.52	0.50	2.10	0.80	0.09	4.51	80.3	7.5	0.54	0.77	0.5	0.5	40	0.
anhapludalf (USDA); Ferric Lixisol (FAO); Owo Series																
5.43	0.201	0.82	1.70	1.14	2.53	0.50	0.11	6.80	91.0	26.4	1.70	6.39	4.9	1.4	191	3.
5.73	0.090	0.48	2.04	1.63	2.42	0.60	0.13	7.30	90.0	12.6	1.30	3.48	0.3	2.3	186	3.
5.60	0.053	0.36	1.30	1.40	2.32	0.60	0.14	6.12	87.9	6.7	0.90	1.53	0.1	0.6	173	3.
5.50	0.050	0.22	0.98	0.78	1.50	0.80	0.15	4.43	78.6	4.2	0.11	0.99	0.1	0.5	150	3.
ystrudept (USDA); Haplic Cambisol (FAO); Apomu Series																
5.08	0.123	0.40	4.20	1.32	0.14	3.60	0.12	6.06	62.2	6.2	0.73	8.61	1.9	5.9	111	3.9
4.81	0.011	0.23	3.30	0.95	0.25	3.60	0.11	4.73	56.0	5.1	0.51	7.69	0.1	3.3	94	3.6
5.02	0.106	0.27	1.50	1.09	0.32	2.60	0.11	3.18	54.0	4.7	0.45	2.64	0.3	1.8	101	3.5
4.46	0.084	0.40	2.00	1.71	0.32	2.80	0.14	4.43	60.1	5.7	0.33	1.93	0.2	0.2	20	3.5
quept (USDA); Eutric Fluvisol (FAO); Adio Series																
6.69	0.403	0.31	6.00	9.18	2.28	0.60	0.04	18.41	96.5	10.8	0.60	5.04	8.5	0.2	122	3
5.67	0.141	0.70	2.80	8.19	2.46	0.60	0.09	14.84	95.4	21.8	1.20	5.20	17.2	1.1	186	2
anhapludalf (USDA); Gleyic Fluvisol (FAO); Matako Series																

the morphological description of the profile pits in Akure

Texture[b]	Structure[c]	Consistence[d]	Concretion/ nodule[e]	Quartz stones[f]	Root[g]	Boundary[h]	Drainage[i]
ic Kandiudalf; Ferric Lixisol)							
LS	1,sbk	3,fi,sst,sp	-	2	m,fb,f,w	cls	wd
SCL	1,sbk	1,fi,mst,mp	m,Fe/Mn	3	f,fb	clw	
SCL	stls	3,fi,mst,mp	vm,Fe/Mn	3	f,fb	d	
SC	stls	3,fi,mst,mp	f,Fe/Mn	2	-	-	
ic Kanhapludalf; Ferric Lixisol)							
SL	1, sbk	1,fi,sst,np	m,Fe/Mn	2	m,fb,f,w	d	wd
SL	2, sbk	3,vfi,vst,sp	m,Fe/Mn	2	f,fb	d	
SC	stls	3,fi,sst,sp	vm,Fe/Mn	-	-	d	
SC	stls	3,fi,sst,sp	vm,Fe/Mn	-	-	-	
quic Dystrudept; Haplic Cambisol)							
SL	1,sbk	l,fr,sst,np	-	-	m,fb,f,w	cls	fwd
SL	2,sbk	1,fr,sst,np	-	-	f,fb	clw	
SC	2,sbk	l,fr,nst,np	-	-	vf,fb	d	
SC	3,ab	3,fi,vst,mp	f,Fe/Mn	-	f,fb	-	
ic Aquept; Eutric Fluvisol)							

Gleyic Fluvisol)			
1,fi,sst,sp	-	-	m,fb,m,w
l, sst,np	-	-	f,fb,f,w

Loam, SCL – Sandy Clay Loam, SC – Sandy Clay.
gular blocky, sbk – subangular blocky, stls – structureless.
rm, nst – non sticky, sst – slightly sticky, mst – moderately
c, 1 – soft, 3 – hard.
n – Iron/Manganese concretions.
very stony.
y many, fb – fibrous, w – woody roots.
ffused.
l, pd – poorly drained.

physical properties of profile pits in Okitipupa

Coarse Sand	Fine Sand	Silt	Clay	Bulk density	Total porosity	K$_{sat}$ (cm hr^{-1})	WSA (kg kg^{-1})	MW (mm
(g kg^{-1})				(Mg m^{-3})	(%)			
Kandiudult (USDA); Rhodic Lixisol (FAO); Alagba Series								
583	185	105	127	1.43	55.0	46.7	0.455	0.68
595	163	75	167	1.24	52.9	58.9	0.355	0.45
556	152	65	227	1.45	50.1	20.2	0.512	0.88
441	187	85	287	1.48	49.2	15.6	0.501	0.80
Paleudult (USDA); Rhodic Acrisol (FAO); Okitipupa Series								
649	159	85	107	1.49	40.2	19.4	0.350	0.63
418	170	65	347	1.54	38.0	14.2	0.353	0.47
457	191	45	307	1.55	39.5	10.5	0.401	0.61
455	253	25	267	1.58	35.1	10.1	0.360	0.40
452	245	96	207	1.59	30.2	8.2	0.305	0.35
Dystrudept (USDA); Arenic Acrisol (FAO); Mesan Series								
768	79	66	87	1.46	53.5	72.3	0.503	1.11
703	154	76	67	1.27	51.9	36.6	0.404	0.81
709	88	96	107	1.40	52.0	25.4	0.412	0.85
718	79	96	107	1.35	50.5	20.1	0.401	0.66
739	108	86	67	1.38	51.6	15.6	0.395	0.60
ic Udipsamments (USDA); Ferralic Acrisol (FAO); Mesan Series								
699	129	65	107	1.53	42.7	13.3	0.327	0.4
606	202	85	107	1.53	44.4	8.8	0.228	0.3
650	98	105	147	1.52	45.0	7.9	0.411	0.5
695	113	85	107	1.50	45.2	7.5	0.455	0.5
789	19	45	147	1.55	40.9	5.5	0.352	0.4
758	80	55	107	1.54	41.2	5.2	0.300	0.4
ueptic Endoaquent (USDA); Arenic Fluvisol (FAO); Ode Erinje Series								
512	365	36	87	1.03	68.5	46.3	0.727	2.0
326	471	76	127	0.88	69.9	12.9	0.627	1.0

nical properties of pits in Okitipupa

H Cl)	EC (dS m^{-1})	K	Ca	Mg	Na	Al^{3+}	H^{+}	ECEC	BS (%)	OC	TN	AvP	Zn	Cu	Mn	Pb
		(cmol kg^{-1})								(g kg^{-1})						(mg kg^{-1})
liudult (USDA); Rhodic Lixisol (FAO); Alagba Series																
.54	0.055	0.13	0.87	0.57	0.31	2.20	0.16	4.24	44.3	12.3	1.3	6.83	0.5	1.9	8	1.
.62	0.031	0.07	0.76	0.63	0.28	2.20	0.57	4.51	38.4	7.3	1.1	4.59	0.6	1.8	1	2.
.71	0.024	0.09	0.92	0.25	0.34	3.60	0.97	6.17	25.9	8.0	1.0	2.94	0.5	2.0	1	2.
.73	0.027	0.07	0.86	0.50	0.31	4.80	0.16	6.73	26.3	6.0	0.7	2.65	0.6	1.8	1	3.
ıdult (USDA); Rhodic Acrisol (FAO); Okitipupa Series																
.05	0.115	0.70	0.50	0.89	0.48	2.20	0.11	4.88	52.6	20.4	2.9	4.04	6.5	0.8	8	1.8
.09	0.042	0.09	1.00	0.97	0.24	3.40	0.13	5.83	39.5	13.5	1.7	6.77	4.3	0.8	5	2.1
.87	0.036	0.07	1.25	0.58	0.28	3.60	0.16	5.94	36.6	10.3	1.5	1.44	0.9	0.3	2	2.4
.76	0.035	0.07	0.45	0.30	0.28	3.60	0.16	4.86	22.6	6.7	0.88	1.78	0.2	0.1	3	2.4
.88	0.022	0.07	0.45	0.26	0.31	3.80	0.15	5.04	21.6	3.4	0.29	1.74	0.5	0.1	5	2.2
ıdept (USDA); Arenic Acrisol (FAO); Mesan Series																
.73	0.045	0.20	0.50	0.49	0.31	2.20	0.17	3.87	38.8	31.9	1.3	10.00	0.1	0.1	3	2.
.60	0.032	0.07	0.30	0.31	0.21	4.40	0.18	5.47	16.3	8.0	0.84	6.35	0.2	0.4	2	2.
.77	0.046	0.04	0.80	0.11	0.31	4.40	0.18	5.84	21.6	3.4	0.83	4.82	0.5	0.1	1	2.
.40	0.024	0.09	0.25	0.27	0.31	3.80	0.17	4.89	18.8	5.3	0.56	1.15	0.3	0.1	2	2.
.84	0.016	0.09	0.45	0.53	0.34	4.40	0.14	5.95	23.7	3.4	0.11	0.99	0.2	0.1	3	2.
lipsamments (USDA); Ferralic Acrisol (FAO); Mesan Series																
.65	0.145	0.40	1.00	0.95	0.51	4.4	0.08	7.34	39.0	16.1	2.0	8.30	1.1	1.1	10	1
.50	0.111	0.13	1.00	0.54	0.31	4.6	0.08	6.66	29.7	13.8	1.3	8.61	2.4	1.6	15	5
.65	0.111	0.15	1.38	0.51	0.41	4.6	0.07	7.11	34.3	16.2	1.3	5.89	1.4	0.4	10	2
.26	0.033	0.11	0.50	1.04	0.30	4.2	0.07	6.22	31.4	9.0	0.74	5.57	4.0	0.4	11	2
.44	0.079	0.11	0.63	1.05	0.34	4.4	0.07	6.60	32.2	4.6	0.61	3.82	1.0	0.2	8	2
.57	0.144	0.13	0.63	0.88	0.34	4.4	0.06	6.44	30.7	10.5	1.4	2.89	8.1	1.1	11	2

morphological description of the profile pits in Okitipupa

exture[b]	Structure[c]	Consistence[d]	Concretion/ nodule[e]	Mottles[f]	Root[g]	Boundary[h]	D
odic Kandiudult, Ferric Acrisol)							
SL	f,m,gr	l,fr,sst,np	-	-	m,fb,f,w	cls	
SL	1,sbk	1,fr,sst,np	-	-	f,fb	cls	
SCL	2,f,m,sbk	3,fi,sst,np	vf,m,s,Fe/Mn	-	f,fb	d	
SCL	2,m,sbk	3,fi,sst,np	-	-	-	-	
Rhodic Paleudult; Rhodic Acrisol)							
LS	m,gr	l,fr,nst,np	-	-	m,fb	clw	
SCL	1,sbk	l,fr,nst,np	-	-	m,fb	d	
SCL	sbk	3,fi,mst,np	-	-	f,fb	cls	
SCL	2,m,sbk	3,fi,mst,mp	-	-	-	cls	
SCL	c,sbk	3,fi,mst,sp	f,m,s,Fe/Mn	-	-	-	
pic Dystrudept; Arenic Acrisol)							
S	m,cr	l,fr,nst,np	-	-	m,fb,m,w	d	
S	cr	l,fr,nst,np	-	-	m,fb,m,w	d	
S	cr	l,fr,,nst,np	f,m,s,Fe/Mn	-	f,fb	d	

uic Udipsamments; Ferralic Acrisol)						
	m,gr	l,fr,nst,np	-	-	m,fb,f,w	cls
	cr	l,fr,nst,np	-	-	f,fb	cls
	cr	l,fr,,sst,np	-	-	f,fb	cls
	cr	l,fr,sst,np	-	-	f,fb	cls
	1,sbk	l,fr,nst,np	-	-	f,fb	cls
	cr	l,fr,nst,np	-	-	-	-
ımaqueptic Endoaquent; Arenic Fluvisol)						
	f,m,sbk	1,fi,sst,sp	-	-	m,fb,m,w	cls
L	m,sbk	1,fi,vst,vp	-	7.5YR 2.5/2,m	m,fb,f,w	-

L – sandy clay loam, S – sand, LS – loamy sand, SC – sandy clay.
e, m – medium, c – coarse, cr – crumb, gr – granular, sbk – subangular blocky.
nst – non sticky, sst – slightly sticky, mst – moderately sticky, vst – very sticky, np – non pla
lastic, 1 – soft, 3 – hard.
dium, s – soft, Fe/Mn – Iron/Manganese concretions.

s, w – woody roots.
wavy, d – diffused.
oorly drained.