CHARACTERIZATION AND SUITABILITY EVALUATION OF KUBANNI FLOODPLAIN AND ADJOINING UPLAND SOILS FOR MAIZE AND RICE PRODUCTION IN ZARIA, NIGERIA

BY

JIMOH Ibrahim Abdulwahab

DEPARTMENT OF GEOGRAPHY,

FACULTY OF SCIENCE,

AHMADU BELLO UNIVERSITY

ZARIA, NIGERIA.

OCTOBER, 2015

CHARACTERIZATION AND SUITABILITY EVALUATION OF KUBANNI FLOODPLAIN AND ADJOINING UPLAND SOILS FOR MAIZE AND RICE PRODUCTION IN ZARIA, NIGERIA

BY

JIMOH Ibrahim Abdulwahab, B.Sc. Geography (ABU) 2011

M.SC/SCI/31915/2012-2013
(M.Sc. Geography)

A DISSERTATION SUBMITED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY ZARIA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER OF SCIENCE DEGREE (M.Sc.) IN GEOGRAPHY

DEPARTMENT OF GEOGRAPHY,

FACULTY OF SCIENCE,

AHMADU BELLO UNIVERSITY

ZARIA, NIGERIA.

OCTOBER, 2015

DECLARATION

I declare that this work in this dissertation titled "**Characterization and suitability evaluation of Kubanni floodplain and adjoining upland soils for maize and rice production in Zaria, Nigeria"** has been carried by me in the department of Geography. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other institution.

Ibrahim Abdulwahab JIMOH

_____ _____ _____

Signature Date

CERTIFICATION

This dissertation entitled **"Characterization and suitability evaluation of kubanni flood plain and adjoining upland soils for maize and rice production in Zaria, Nigeria"** meet the regulations governing the award of the degree of Master Degree in Geography (M.Sc.) in Ahmadu Bello University, and is approved for it contribution to knowledge and literary presentation.

Dr. Yusuf Y. Obadaki

_____ _____ _____

Chairman, Supervisory Committee Signature Date
Department of Geography,
ABU Zaria

Dr. W. B. Malgwi

_____ _____ _____

Member, Supervisory Committee Signature Date
Department of Soil Science,
ABU Zaria

Dr. I. M. Jaro

_____ _____ _____

Head, Department of Geography, Signature Date
ABU Zaria

Professor Kabir Bala

_____ _____ _____

Dean, School of Postgraduate School Signature Date
ABU Zaria

ACKNOWLEDGEMENT

All praises be to Allah, the Almighty for giving me the opportunity, wisdom and ability to carry out this research, Alhamdullilah.

The author is immensely thankful and appreciative of the invaluable assistance provided by the following:

Dr. Yusuf Y. Obadaki and Dr. W. B. Malgwi for their time, guidance, support and encouragement. I am truly grateful.

Head of Department, Dr I. M. Jaro and the post graduate coordinator Dr. R. O. Yusuf, you have been very wonderful for your time, advice and encouragement. May Allah reward you abundantly.

Gombe State University fellowship board; in particular Dr. Dan Yakubu at the Department of Geography, Gombe State University for sponsoring and releasing me to undertake this study. I say thank you.

To all the staff and post graduate students of Geography Department ABU, Zaria and Gombe State University, thank you all.

To Jamila Aliyu, Dr. Sulaiman Yau, all staffs and students of Soil Science Department, thank you all for the valuable input you gave.

Finally, I would like to thank my parents, fiancée, brothers, sisters and friends for their constant prayers, support, love, assistance and motivation at all times.

DEDICATION

This work is dedicated to Almighty Allah who has favoured me to this level.

Abstract

The study was carried out in Zaria, $11^0$06□ 50"- $11^0$07□ 25" N and $7^0$40□ 22"- $7^0$40□ 58"E in the lower Kubanni drainage basin, Kaduna State, Nigeria. The study aim to characterize and evaluate suitability of soils around River Kubanni for maize and rice production. The soils were classified using USDA Soil Taxonomy (Soil Survey Staff, 2010) correlated with FAO World Reference Base for Soil Resource (FAO, 2014). In evaluating land suitability for maize and rice production (qualitatively), land properties were compared with corresponding plant requirements, while for quantitative land suitability evaluation; parametric method (Storie, 1978; 2008) was used. The land suitability classes were arrived at based on the FAO guidelines for land evaluation (FAO, 1985). The morphological and physico-chemical properties of thirty four (34) soil samples were sampled from identified genetic horizons of the ten (10) pedons studied in five (5) soil mapping units denoted as KBI, KBII, KBIII, KBIV and KBV representing the study area. KBI, KBII and KBIII represent the upland while KBIV and KBV represent the flood plain soils. Upland soils were shallow to deep, while flood plain soils were deep to very deep. Soil depth increased down the slope. The soils were predominantly medium texture with sub-angular blocky on the upland, while structureless dominate the floodplain soils. The upland soils were well drained to imperfectly drain, while the floodplains were very poorly drained. Soil colour varied from dark yellowish brown to dark gray brown. Horizon differentiation between Ap horizon and the lower B horizon were clear. The bulk density was moderate and generally increased down the profile with an irregular pattern; total porosity decreased with depth. Soil reaction was slightly acidic to neutral, exchangeable bases were medium to high, indicating moderate basic nutrient status of the soils and occurred in the order Ca^{2+}> Na^{+}>

Mg^{2+}> K^{+}. Base saturation was rated medium to high in the soils. Organic carbon, total nitrogen and available phosphorus of the soils were generally low. Extractable micronutrient content was rated high and occurred in the order: Fe >Mn> Zn > Cu > B in the soils, and decreased down the profile. Electrical conductivity and total soluble salt was also rated low, thus the soils were classified as non-saline while part of the flood plain soils (mapping unit KBIV) with exchangeable sodium percentage of >15 was classified as sodic soils. Generally, there was no significant difference in physical and chemical properties of upland and flood plain. KBI and KBIII were classified as *Typic Plinthustalfs* / *Eutric Lixisols,* KBII were classified as *Torrertic* dystrustepts / *Terric cambisols* on the upland, while soil mapping unit KBIV and KBV on the flood plain were classified as *Fluvaquentic Epiaquepts / Endoeutric Fluvisols*. Soils of the upland and flood plain were classified as currently not suitable (N) based on the qualitative land suitability evaluation for maize and rice production respectively mainly due to limitation imposed by chemical properties. Based on the quantitative land suitability evaluation (storie method), KBI was highly suitable (S1), KBIII, KBIV and KBV were moderately suitable (S2) while KBII was marginally (S3) suitable. The result of socio-economic characteristics of the farmers shows that the land was marginally suitable as results of low outputs recorded by 93% of the farmers while 7% who used adequate fertilizer recorded high output. Soil condition would however be improved for sustainable crop production by incorporation of crop residue and farmyard manure to enhance soils nutrient availability and land preparation such as reduced tillage and contour ridging as well as application of recommended rate of fertilizer for each crop.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

Soil is one of the most important natural resources and proper understanding of its properties is necessary for judicious, beneficial and optimal use on sustainable basis (Jagdish, Ray, Gajbhiye and Singh, 2009). Such basic information about the soils is provided by soil survey (Ray *et al*., 2000). Soil characterization is the categorization of soils into groups at varying levels of generalization according to their morphological, physical, chemical, and mineralogical properties. Classification includes organization of knowledge, which ease in remembering properties, clearer understanding of relationships with ease of technology transfer and communication between scientist and end users (Boul, Southard, Graham and McDaneil, 2003).

Upland soils are soils of the upper to middle slope position which are mostly reddish to yellowish brown in colour due to the presence of sesquioxide in hydrated form, indicating good drainage (Ekwoanya and Ojanuga, 2002). The soils are intensively utilized in Nigeria without proper management practices to replenish soils fertility due to lack of crop suitability maps. As leading to degraded soil and reduced agricultural productivity. Upland soils are reported to have low organic carbon, total nitrogen and CEC (Ekwoanya and Ojanuga, 2002).

Flood plains soils (Fadama soils in Hausa) refer to soils of wetland or the seasonally flooded or floodable plains along rivers and / or depressions on adjacent low terraces (Ibrahim and Omotesho, 2012). They are found scattered in the arid and semi-arid parts of tropical regions. Flood plains are mostly poorly drained and considered marginal land.

Rice and sugar canes are grown on them in the raining season and by irrigation during the dry season. Flood plains in Nigeria are now becoming the "food basket" because they serve as the main source for growing crops for man and food supply to livestock all year round. Flood plain soils are characterized by higher organic carbon, total nitrogen and CEC when compared to upland soils (Ekwoanya and Ojanuga, 2002).

In Nigeria today, the need for increased food production to feed the ever increasing human population and to diversify export base crops of the country is more recognized now than ever before. This has turned the attention of both farmer and government to the exploitation of flood plain, which is believed to have more agricultural potential than the upland soils (Kparmwang and Esu, 1990; Esu, 1999). Land evaluation can tell farmers how suitable their land is in terms of soil limitations, to specified land use and management practices. Land suitability evaluation is the process of making predictions of land performance over time based on specific types of uses (Rossiter, 1996). These predictions are then used as a guide in strategic land use decision making. The process of land suitability classification is the assessment and categorization of specific areas of land in terms of their suitability for defined uses (Food and Agricultural Organization (FAO), 1976). This assessment is always carried out separately for each category of land use (Reshmidevi, Eldho and Jana, 2009).

The role of agriculture in Nigeria's economy cannot be overemphasized given that 70% of the populations derive their livelihood and other related activities. It is also a major source of raw materials for agro-allied industries and a potent source of the much-needed foreign exchange (World Bank, 1998). A significant and positive response from agriculture is justified as a means of improving overall performance of the economy. There are many

types of agricultural goods which range from cash to food crops. This study will focus on two major food crops; maize and rice.

Rice (*Oryza sativa)* and Maize (*Zea mays)* as a cereal grain are the most important staple foods for a large part of the world's human population; rice is the grain with the second-highest worldwide production, after maize (FAOSTAT, 2005). Since a large portion of maize crops are grown for purposes other than human consumption, rice is most important grain with regard to human nutrition and caloric intake, providing more than one fifth of calories consumed worldwide by human species (Smith, 1998). Demand for grains in Nigeria has been established to about 4.75 million metric tons in 2014. However, only about half of that demand is met by domestic production while importing to meet actual demand (United State Department of Agriculture, Foreign Agricultural Service (USDA FAS), 2014). The rate at which Nigeria imports food is not fiscally, economically or politically sustainable, noting that Nigeria is now one of the largest food importers in the world (Raji, 2013). In 2010 alone, Nigeria spent N365 billions on imported rice (that means we spent N1 billion per day on rice alone) (Akinwumi, 2011; Raji, 2013; Henry, 2014). Given the size and value of imports, there is urgent need to reduce rice imports by home production to encourage economic growth and job creation.

Nigerian Government recognizes that agricultural growth is the key to achieving poverty alleviation, food security, and the Millennium Development Goals (MDGs) and that further effort are urgently needed. In an attempt to improve agricultural production, many agricultural development projects have been established; like Fadama I, II and III Project. Recently, Agricultural Transformation Agenda' (ATA) which aims at making Nigeria self-sufficient in terms of food and agricultural productivity, generate employment and transform the country into a leading player in global food markets and to grow the

wealth of the nation (Akinwunmi, 2011). ATA means well for development of Nigeria's economy but a lot more need to be done in terms of research, processes, methods and reach to ensure that 90% of farmers are empowered to provide Nigerians with basic food needed for survival (Henry, 2014). It is in this direction that a land suitability evaluation study is relevant

1.2 Statement of the Research Problem

Agriculture accounts for an estimated 56 percent of Kaduna's GDP and employs approximately 4 million people. Kaduna produces 22 percent of the country's maize, 22 percent rice, 69 percent of soya bean, 36 percent of cotton and 10 percent of grzound nuts (Commercial Agriculture Development Project (CADP), 2010). Agricultural activities are dominated by wet season farming on the uplands and irrigation on the flood plains in dry season. Most farmers currently produce cereal crops such as maize, sorghum, millet and zrice during the rainy season. Kaduna is the largest producer of rice in Nigeria and it exports substantial quantities to other Nigerian states and other African countries (CADP, 2010).

Nigeria's immense agricultural potential is a great asset for the nation and Africa, with promises for food security when fully harnessed (Akinwunmi, 2014). Only 40 per cent of Nigeria's 84 million hectares of arable land is presently cultivated. To increase productivity of agriculture in Kaduna State and Nigeria in general, there is a need for suitability assessment of the land which will assist in identifying key soil properties for optimum yield of rice and maize production.

Studies on suitability evaluation have been carried out in different parts of the world: Singh *et al*. (2013) characterization and evaluation suitability of six lateritic pedons

(soils) in India for rice, sugar cane and potato, for rice, 50% of the land were moderately suitable while the remaining 50% were marginally suitable; for sugarcane; 67% were moderately suitable, while 33% were marginally suitable and for potato, 50 % were marginally suitable, while 50% were not suitable. Joseph, Njoroge and Hunja (2013) examined land suitability for rice growing sites using a multicriteria evaluation and GIS approach in great Mwea region, Kenya. They found from land cover map, that rice cultivated area was 13,369 ha but after suitability analysis of the area, results showed that potential area for rice growing is 86,364 ha and out of this only 12% is under rice cultivation which shows that the land was underutilized.

Fasina, Awe and Aruleba (2008) in their study evaluated suitability of University of Ado Ekiti Teaching and Research Farm; southwest Nigeria, for irrigation agriculture. The study showed that soils evaluated were considered not suitable for gravity irrigation, but suitable for drip irrigation. Aondoakaa and Agbakwuru (2012) investigated land suitability for rice cultivation in Gwagwalada area council, Federal Capital Territory (FCT) Abuja. They found that the area was moderately suitable for rice cultivation. The limiting factor can be ameliorated through management practices. Also, Njar, Iwara, Egbe, Offiong and Essoka (2012) assessed the suitability of two prominent land parcels for maize production in Obiaruku community of Delta state and found that the well-drained soil was classified highly suitable for maize production due to its high level of essential nutrient; whereas soil of the riverine area were classified as moderately suitable for maize production due to its medium level of chemical nutrient. However, good soil conservation practice was suggested to achieve long term sustainable production of maize in the area.

The review of existing literature shows that land suitability assessment for agriculture evaluates the ability of a piece of land to provide optimal ecological requirements of a certain crop variety. Perhaps, assessing the capability of land enables optimum crop development and maximum productivity. Thus suitability evaluation needs a specification of the respective crop requirements and calibrating them with the terrain and soil parameters. According to Dent and Young (1981), optimal crop growth and productivity is based; amongst other factors, on soil conditions, the climate and agricultural practices. They posited that cation exchange capacity, soil organic matter content expressed by the organic carbon content, soil depth and stoniness are amongst the main factors that influence crop adaptability to a given land area. It is also obvious that most studies on land evaluation were carried out at national or regional scales, neglecting the local scale, and most study use the qualitative land evaluation. This study will use both qualitative and quantitative methods of land evaluation. It is in the context of this neglect that this study becomes imperative.

In the views of Esu (2004), studying soil in detail through processes of soil characterization and land evaluation for various land utilization types is one of the strategies for achieving food security as well as sustainable environment. However, despite the importance of land evaluation on sustainable management of land and for enhanced crop production, specific soil suitability studies; such as suitability assessment for rice and maize production have not been properly documented; and available ones show locations and ecological bias (Aondoakaa and Agbakwuru, 2012; Njar, *et al.,* 2012). More so, some of the studies available provide holistic approache on land evaluation and are not crop specific (Rossiter, 1994a; George, 1997; Adeleye, 2002; USDA, 2003).

This study attempts to contribute to existing knowledge, as well as fill the locational gap in knowledge on soil suitability assessment in Zaria.

The study intends to address the following questions:

i) What are the physical and chemical properties of flood plains and adjoining upland soils in the area?
ii) What is the suitability of flood plains and adjoining upland soil for rice and maize production?
iii) What is the classification of flood plains and adjoining upland soils using the United State Department of Agriculture (USDA) method of classification and its correlation with World Reference Base (WRB) for soil resources?

1.3 Aim and Objectives of the Study

The aim of this study is to characterize and evaluate suitability of Kubanni flood plains and adjoining upland soils for rice and maize production in Zaria area of Kaduna State.

The specific objectives are to:

i) assess physical and chemical properties of the flood plains and adjoining upland soils;
ii) determine suitability of the soils for rice and maize production;
iii) classify the flood plains and adjoining upland soils using the United State Department of Agriculture (USDA) method of classification and correlate it with World Reference Base (WRB) for soil resource and
iv) examine socio-economic characteristic of farmers within the study area.

1.4 Hypotheses

Hypothesis derived from the aim and objectives of the study are that?

i) there is no significant differences between the physical and chemical properties of the flood plains and adjoining upland soils for rice and maize production in the study area;
ii) there is no significant relationship between the physical and chemical properties of the flood plains and adjoining upland soils in the study area;
iii) there is no significant differences in suitability of the flood plains and adjoining upland soils in the study area and
iv) there is no significant differences in the classification of the flood plains and adjoining upland soils in the study area.

The hypothesis was tested at 0.05 level of significance.

1.5 Scope of the Study

The study is limited to track of land along part of River Kubanni, located behind College of Aviation Technology, Zaria. The breadth of the subject matter is to characterize physical and chemical properties of the soils and evaluate the area for rice and maize for optimum crop production. There are many varieties of rice and maize crops, rice varieties: paddy, upland and floating rice, while maize varieties include; dent, flour, flint, popcorn and sweet maize. For the purpose of this research, one variety each will be considered; maize will include sweet maize, while rice will include paddy rice. The time span of the study will be within 2014.

1.6 Justification of the Study

Increase in urbanization has led to more agricultural land being converted to housing for the ever increasing human population. The problem of food supply in the country is increasing on a daily basis; especially, rice and maize which are being consumed by majority of rural and urban dweller. Fallow period which help to restore soil fertility are shorten or limited, land use intensification impact negatively on soil quality, hence the need for suitability assessment of the limited land resources. Ever increasing demand for food has intensified quest for more production per unit area, as intensification of land use leads to soil degradation and decreasing crop yield. For increase in area cultivated, fertilizer alone or in conjunction with improved crop varieties and measures to control pest and disease, will not preserve productivity if significant deterioration of physical and chemical condition occurs. It is in the light of this that the study is justified.

1.7 Organization of the Study

This study is organized into five substrate Chapters. Chapter one introduces the study and presents statement of research problems, aim and objectives of the study. Chapter two deals with literature review. Chapter three describes environment of the study area and methodology used in the study. Results obtained from field and laboratory work were described and discussed in Chapter four. Chapter five contains summary, conclusion and recommendation.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter places the research in geographical context. It reviews relevant literature of characteristics of Guinea Savannah soils, climatic and soil requirement for maize and rice production, factor rating of land use requirement for maize and rice and the concepts of land evaluation.

2.2 General Characteristics of Savanna Soils

The savannah soils are generally divided into Sahel, Sudan, Guinea and Derived Savannah zones based on moisture and vegetation (Aduayi, Chude, Adebusuyi and Olayiwola, 2002). There are two major geomorphic units in the region: upland and flood plains soils.

2.2.1 Characteristics of upland soils

The uplands soils are mostly associated with upper to middle slope positions which are well drained. They are widely used for crop production because they are mostly well drained unlike the wetland soils which are partially or completely water logged, though they are low in fertility (Jone and Wild, 1975; Mokwunye and Batiano, 2002). Most of the soils are under continuous cultivation, so they rapidly lose their fertility due to rapid decline in organic matter, leaching of basic cations and high rate of acidification (Jone and Wild, 1975; Ogunwole, 2008).

The soils are deep to very deep; petroplinthites (hardened laterites) are major constraints to depth which are constraints to plant and roots development as reported by (Yaro, Kparmwang, Raji and Chude, 2006). The texture of the soils ranges from sandy loam to sandy clay loam (Oyinlola and Chude, 2010; Shobayo, 2010), while Odunze and Kureh, (2009) reported loam texture at the surface horizons, and clay loam and clay in the

subsoil horizons. Generally, soils of the savannah area are reported to have high sand content at surface, as the soils are formed on aeolian sand cover (Sombroek and Zonneveld, 1971). Silt content of the soils was observed to slightly increase with increasing depth in soil profiles. Morbeg and Esu (1991) and Kparmwang (1993) in their studies of soils in the Savannah region of Northern Nigeria mentioned the influence of Harmattan dust in contributing silt to soil. The higher clay content in the subsurface horizons of many soils maybe attributed to illuviation and pedoturbation processes (Sharu, Yakubu and Tsafe, 2013). The surface of most savannah soil are reported to have high bulk density followed by a decrease in the sub soils and further rose in the lowest horizons (Zafari, 1993; Raji 1995; Maniyunda, 1999). The high bulk density is attributed to compaction caused by grazing animals and tillage operation (Shobayo, 2010; Sharu *et al.*, 2013). Root growth could also be inhibited due to high bulk density because of soil resistance to root perpetration, poor aeration, slow movement of nutrients and water and build-up of toxic gases and root exudates (Brady and Weil, 2002; Odunze, 2006).

The savannah soils are moderately acidic (Oyinlola and Chude, 2010; Shabayo, 2010) Jones and Wild (1975) had earlier reported low values of organic carbon, available P and total N in Nigerian savannah soils which is in accordance with the work of Esu (1991). Several researchers have reported low value of organic carbon in Nigerian savannah (Raji and Mohammed, 2000; Malgwi, Ojanuga, Chude, Kparmwang and Raji, 2000; Shobayo, 2010). Generally, exchangeable bases comprise exchangeable calcium, magnesium, potassium and sodium. Most work in savanna region reveals that calcium dominate exchangeable base (Raji, 1995; Maniyunda, *et al.*, 2007; Hussaini, 2011). Exchangeable cations Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} are low, reflecting the low CEC of the soils. The principal saturating cations in all the soils is Ca^{2+}, followed by Mg^{2+} (Oyinlola and Chude, 2010).

Cation exchange capacity (CEC) are rated low to medium (Hussaini, 2011; Oyinlola and Chude, 2010). The low to medium is an indicative of dominance of sesquioxides and kaolinite clays (Tan, 2000) at these layers. The upland soils had not been reported to have been affected by salts. The range of value of exchangeable sodium percentage (ESP), electric conductivity (EC) and sodium absorption ratio (SAR) had always been reported to be very low; below the critical level, to classify the soils as saline or sodic (Sanda *et al.*, 2007; Yakubu *et al.*, 2011; Maniyunda and Gwari, 2014).

Odunze and Kureh (2009) classified upland as *Alfisols* (*Oxyaquic Vertic Paleustalfs / Gleyic Lixisol*' and '*Aquic Kandiustalfs* / *Gleyic Lixisols'*). Shobayo (2010) classified it as *Alfisols* (*Typic Haplustalf / Eutric Lixisols*) and *Ultisols* (*Typic Haplutsult / Dystric Acrisols*) based on the United State Department of Agriculture (USDA) Soil Taxonomy and Food and Agricultural Organisation (FAO) system respectively.

2.2.2 Characteristics of flood plains soils

The occurrence of wetland soils in Nigeria has been associated with three landforms namely; inland depressions, floodplains and coastal plain (Fasina, 2005). The major morphological features such as grey or low chroma (<3) colour, mottles are characteristic of this soils, and is an indication of soil wetness brought about by oxidation-reduction cycle due to ground water fluctuation (Babalola, Oso, Fasina and Godonu, 2011). Ahn (1970) reported inter-relationship between these features. The reduced Fe present in these soils impact grayish colour on the soil matrix.

The particle size distributions patterns of the soils are dominated by high sand content same as the upland soils. The low to silt ratio is an indication of low weathering intensity as a ratio of <0.15 indicates low to moderate weathering intensity, while a ratio of

>0.15 indicates high intensity of weathering (Young, 1976). Flood plain soils are formed as a result of transportation and redeposition of parent material by river and sea which have higher organic matter content (Wilslow and John, 1989). The wetland soils are reported to have low content of exchangeable cations which were attributed to intense leaching, weathering and ferrolysis hence low inherent fertility status with regard to the major and minor micronutrients (Fasina, 2005; Fasina and Adeyanju, 2007).

Flood plains had been reported to be affected by salts accumulation. Malgwi, (2001) in his work reported that soils of Kadawa and Mijibri in Kano recorded high (ESP) above the critical level of >15 % as such, were classified as sodic. Audu, Noma and Abdulaziz (2009) also reported a high salinity on soils of Wurno irrigation project which was attributed to low quality of irrigation water and impeded drainage (Brady and Weil, 2005). The soils are saline-sodic as such will affect crop growth and development. Major wetland soils in Nigeria have been classified into Gleysols/Fluvisols and Alfisols, Inceptisols, Entisols, Histisols and Vertisols (Olayele, 1998).

2.2.3 Climatic and soil requirements for rice

Rice (*Oryza sativa*) is primarily a tropical and subtropical crop. It is grown in wide variety of climate-soil-hydrological regimes. It is a heat and water-loving plant that requires high temperature and adequate water supply (Matsuo, 1955). Rice lands are classified according to water regimes into upland with no standing water, lowland with 5- 50cm standing water, and deep-water with >50 cm standing water (De Datta, 1981). Average temperature required throughout the life period of the crop ranges from 21 to 35°C. Temperatures of < 30°C retard absorption of nitrogen, phosphorus, potassium and silica without significantly affecting calcium and magnesium (Matsuo, 1955), this will affect

plant growth and development. Water requirement of rice under lowland and uplands ranges from 600-1200 mm (FAO, 1983).

Rice is grown under diverse soil conditions and over a wide range of soil reaction (pH 4.5 to 8.0). The soils most suited to cultivation of the crop are heavy soils (clay or clay loam and loam soils). The broad soil types under rice cultivation are alluvial soils, red soils, mixed red and brown hill soils and lateritic soils, black soil, sub-montane soils, saline and alkali soils and peaty and marshy soils (Ghose *et al*., 1960; Jha *et al*., 1999).

2.2.4 Climatic and soil requirements for maize

Maize (*Zea mays L*.) is one of the most important cereals of the world. It is called queen of cereals. It requires rainfall of 760 – 1520 mm per annum, although it is possible to obtain good yield with 460 – 760 mm of rainfall, if it is evenly distributed during the growing season. Maize crop requires warmth all through its active life period and practically no maize grows where the growing season temperature is < 19 ºC. Maize produces good results with mean temperature of 24ºC and a night temperature above 15ºC (Martin and Leonard, 1967). Maize can be grown on a wide range of soils, buts performs best on well-drained, well-aerated, deep, loam and silt loam containing adequate organic matter and well supplied with available nutrients. Although it grows on a wide range of soils, it does not yield well on poor sandy soils, except with heavy application of fertilizer on heavy clay soils. Deep cultivation and ridging is necessary to improve drainage. Maize is suited for off-season cropping in swamps provided drainage is adequate (though planting in swamps is not always recommended for environmental reasons). Maize is very sensitive to stagnant water, particularly during its early stages of growth. Proper drainage is a must

for the success of crop especially during rainy season, as it does not tolerate water logging. Maize can be grown successfully on soils with a pH of 5.0 – 7.0 but a moderately acidic to neutral environment (5.5 – 7.5) is optimum (Naidu, Ramamurthy, Challa, Rajendra and Krishnan, 2006).

2.3 Land evaluation

Land comprises all elements of the physical environment, including climate, relief, soil, hydrology and vegetation, as well as results of past and present human activity (FAO, 1976).Soil is a subset of land and its characteristics are determined by other land forming factors. Soil evaluation plays important role in sustainable agriculture development. Based on the value of several soil and environment indicators, agricultural land evaluation methodology is applied to land mapping units in order to compute the suitability index. This index characterizes these land-mapping units. However, there are different methodologies which have been reviewed for land capability and suitability evaluation.

Land evaluation is concerned with the assessment of land performance when used for specified purposes. Land evaluation is defined according to Sys, (1979) as a concept that describes the interpretation processes of principal inventories belonging to soil characteristics, vegetation cover, environmental conditions, climatic status and many other aspects related to land to identify best land use among its alternatives (Sayed, 2006). FAO (1985) also defined land evaluation as a process of matching characteristics of land resources for certain uses using a scientifically standardized technique. The results can be used as a guide by land users and planners to identify alternative land uses (Ritung, Agus and Hidaya, 2007). However, land evaluation supplies the technical coefficients necessary for optimal land allocation (Rossiter, 1996).

In general, land evaluation provides essential information on land resource, landform, land use, vegetation, and climate and soil properties for a defined area. Concepts, definitions and case studies of Land Evaluation can be found in numerous publications such as Storie (1933), Klingebiel and Montgomery (1961), Dent and Young (1981) and Rossiter (1996). The evaluation process does not in itself determine land use changes that are to be carried out, but provides data on the basis of which such decisions can be taken. To be effective in this role, the output from an evaluation normally gives information on two or more potential forms of use for each area of land, including the consequences, beneficial and adverse of each (FAO, 1976).

2.3.1 Method of land evaluation

A number of evaluation methods are used under diverse philosophies and techniques. Some methods value the degree of suitability of the properties, while others place more emphasis on the possible limiting factors for soil use. These latter methods are more consistent, since the true limits of soil use are the negative characteristics (according to Liebig's law of the minimum), regardless of degree of suitability of the most favourable properties. Some methods use qualitative criteria while others use quantitative. The qualitative systems are normally used in examinations aimed at a general evaluation of broad zones. The quantitative methods are used more often in detailed studies and need more information on the soils, both to construct the evaluation system as well as to apply it. They are more objective and results are therefore more reliable. Other methods begin with qualitative data which are weighted to reach a final numerical result.

Some systems (qualitative methods) group the classes into a series of levels of importance (order, class, subclass, type, etc.), and are thus hierarchical systems while

systems have one category and are frequently parametric (Dorronsoro, 2002). In these latter systems, mathematical formulae are applied so that the final result is expressed in numerical terms. These can be additive (Index = A + B + C + D + ... N) or with a multiplicative scheme (Index = A x B x C x D x ... N), the latter offering better results for following the minimum law. The additive systems give an evaluation that is usually correct from the theoretical standpoint but can give evaluations that are not realistic since they do not represent the serious consequences implicit in a highly limiting soil factor (Dorronsoro, 2002).

Generally the parametric methods are; according to McRae and Burnham (1981), simple, objective, quantitative, reliable, easy to understand and apply, even by non-specialist, easy to modify and adapt to new uses. Their main disadvantage is that their objectivity and precision are illusory. Their formulation is difficult and, if they are not well applied their results can be completely erroneous. The scheme is too artificial and the relationship between soil properties and result of evaluation is poorly defined. The results from this type of system; perhaps, need careful validation by values for soils under practical use.

2.3.1.1 Land suitability evaluation

The methods of land suitability evaluate the aptness of land for certain crops and specific management. These are the most logical systems, as each soil use has its own demands. The evaluations of land capability of general uses are considered limitations with mean values that affect the most usual uses. In FAO land suitability evaluations, socio-economic factors take on great importance. It requires that the benefits exceed the necessary investment, and for evaluation, the local or national determinants should be

considered. The evaluation has two focuses: to determine either which lands are best for a certain crop or which crop is suitable for each type of land. These evaluation systems can be as numerous as the soil uses. To homogenize the criteria, FAO has proposed an evaluation system which is a scheme with general guidelines to formulate specific evaluation systems.

The FAO Framework for Land Evaluation (FAO, 1976) guidelines is considered to be a standard reference system in land evaluation throughout the world (Dent and Young, 1981) and has been applied both in developed as well as developing countries. This framework is an approach, not a method. It is designed primarily to provide tools for the formulation of each concrete evaluation. The system is based on the following concepts:

i) The land is qualified, not only the soil.

ii) Land suitability must be defined for a specific soil use (crop and management).

iii) Land evaluation was to take into account both the physical conditions as well as economic ones;

iv) The concept of land evaluation is essentially economic, social and political.

v) The evaluation requires a comparison between two or more alternative kinds of use.

vi) The evaluation must propose a use that is sustainable.

vii) A multidisciplinary approach is required (Van Diepen *et al*., 1991).

In this schemes, four categories are recognized. The highest category is the order that reflects; in broad features, whether a soil is suitable or not for a given use. Two orders are recognized:

S = Suitable. Land in which benefits exceed the costs and sustained use does not incapacitate the soil over a sufficiently long period of time.

N = Not suitable: Land can be classified as not suitable for a certain use for diverse reasons. The use proposed may be deemed technically impractical, as in irrigation of abrupt rocky terrain, or that it causes serious environmental degradation, for example, cultivation on steep slopes. Frequently, however, the reason is economic, in that the profit expected does not justify the cost required.

The second category is the class that reflects degrees of suitability with in the order. These are numberedconsecutively in Arabic numerals.

For the order S, three to five classes are normally considered. For example, the three classes are:

S1 = Highly suitable: without limitations for sustained use or minor limitations that do not affect productivity nor appreciably increase costs.

S2 = Moderately suitable: moderately serious limitations that reduce profits or involve risks of degradation in sustained use of the soil.

S3 = Marginally suitable: the limitations for sustained use are serious and the balance between costs and benefits make the use only marginally justifiable. Its use is normally justified on other purpose than economic grounds.

In the order N, three classes are also recognized:

N1 = Not currently suitable: land with limitations that could be eliminated by technical means or investment, but that these changes are at present unfeasible.

N2 = Permanently unsuitable: serious limitations of generally physical nature, which are assumed to be beyond solving over long term.

X = Land for conservation: unsuitable for exploitation, being lands of special protection, due to their conservation, wildlife, of special scientific, ecological or social interest (example, parks, reserves or recreational zones).

Limits between the orders (S and N) and between the different classes (S1, S2, S3 and N1, N2) are established by the presence of limiting factors. One limiting factor is a characteristic of soil that hampers its use, reduces productivity, increases costs and implies degradation risk, or all of the above. This limiting factor is used to define the third category of the system, which is the subclass. In the symbol of each subclass, the number of limitations involved should be kept to the minimum of one letter or rarely two. Limitations proposed include: t, slope; e, erosion risk; p, depth; s, salinity; d, drainage; c, bioclimatic deficiency; r, rockiness; i, flood risk.

Finally, the fourth category is the unit that establishes the differences within the subclasses as a function of the desired use. All of the units within a subclass (S2rA, S2rM, ...) have the same degree of suitability at the subclass level (S2) and analogous characteristics of limitation at the subclass level (r). The units differ from each other in their characteristics of production or in secondary aspects of their management demands. Their examination enables a detailed interpretation at the planning level of exploitation. The units are distinguished by upper-case letters that are placed at the end. There is no limit at all for the number of units examined within a subclass. These defined are: A, intensification in the agricultural use without need of great improvements; M intensification in the agricultural use with need of major improvements (irrigation, etc.); P, use for pasture for livestock; F, forestation.In some cases, the designation “conditionally suitable” can be added so long as certain conditions are satisfied

2.3.1.2 Storie index method

This represents the first parametric approach that was developed as storie index (1933) which was later revised to Storie (1978) and latest version O’Geen *et al*., (2008).

The latest version generates rating digitally from the USDA Natural Resource Conservation Service (NRCS) and National Soil Information System (NASIS). The Storie index is a semi quantitative method of rating soils used for mainly irrigation agriculture based on the crop productivity data collected from major California soils in the 1920s and 1930s (Storie, 1933). The Storie index assess the productivity of soils from the following four characteristics: Factor A, degree of soil profile development; Factor B, surface texture; Factor C, slope and Factor X, other soil and landscape condition including sub factors like drainage, alkalinity, erosion, and micro relief. A score range from 0 to 100% is determined for each factor and the score is then multiplied together to generate an index rating (Storie, 1978; O'Geen *et al*., 2008).

Storie Method: $I = A \times \frac{B}{100} \times \frac{C}{100} \times \frac{X}{100}$ ….(1)

It is an index that uses the multiplicative scheme. In addition, it uses intrinsic properties of the soils (genetic profile, parent material, profile depth, texture, drainage, nutrients, acidity an alkalinity), characteristics of the soil surface (slope and micro relief) and aspects of soil conservation (degree of erosion). The evaluation properties are grouped into four factors that are quantified in the corresponding tables. The factors are weighed *a priori*; the more important being related on a scale from 5 to 100, the less important factors from 80 to 100.With this index, general agricultural soil uses can be evaluated (hence it is a soil-capability evaluation method). To formulate the index, the four factors are multiplied together and the index is expressed as a percentage.

2.3.1.3 Land Capability Classification.

This method was established by the Soil Conservation Service de USA according to the system proposed by Klingebiel and Montgomery (1961) and has been widely used throughout the world with numerous adaptations. It is a categorical system that uses qualitative criteria. The inclusion of a soil within a class is made in the inverse manner, that is, without directly analysing its capacity, but rather its degree of limitation with respect to a parameter according to a concrete use. Some factors that restrict soil use can be used to define productive capacity (intrinsic: soil depth, texture, structure, permeability, rockiness, salinity, soil management; extrinsic: temperature and rainfall) and yield loss (slope of the terrain and degree of erosion). Five systems of permanent agricultural exploitation are considered: permanent soil cultivation, occasional soil cultivation, pasture, woods and natural reserves. This system seeks maximum production with minimum losses in potential.

Three levels of classification ware established: classes, subclasses and units. Also, 8 classes with increasing limitations in use are defined from I to VIII. Depending on the type of limitation, various subclasses of capacity are established: e, for erosion risks; w, for wetness and drainage; s, for rooting and tillage limitations resulting from shallowness, drought risk, stoniness, or salinity; c, for climatic limitations. The capability units represent similar proposals of use and management. Many authors have amplified the number of limiting characteristics used. Furthermore, it is frequent that in their application, quantitative criteria are introduced (Bartelli, 1978) and have even changed the number of classes and subclasses defined in Nigeria, (Carroll, 1974).

2.3.1.4 Productivity index

Riquier, Bramao and Cornet (1970) developed the concept of productivity index which is defined as the capacity to produce a certain harvest per hectare per year, expressed as a percentage of optimal productivity. The introduction of improvement practice leads to potential productivity. The quotient between the productivity and potentiality is called improvement coefficient.

Productivity Index = H×D×P×T×N×S×O×A×M

Where H: wetness, D: drainage, P: depth, T: texture, N: base saturation, S: soluble-salt concentration, O: organic matter, A: cation exchange capacity and M: mineral reserve. The parameters of soil surface (e.g., slope, erosion, flood tendency, or climate) are not considered.

Productivity is expressed as the product of all these factors expressed in percentages. Five productivity classes are defined: class P1 = excellent; class P2 = good, valid for all types of agricultural crops; class P3 = medium, for marginal agricultural use, suitable for non-fruiting trees; class P4 = poor, for pasture or forestation or recreation; class P5 = very poor or null, soils not adequate for any type of exploitation. The improvement coefficient is the ratio between productivity and potentiality; and represents a good index for evaluating feasibility of these posible improvements. This is a quantitative method, precise, simple and easy to calculate. The evaluations reflect degree of suitability of the different evaluation parameters, so that it proves easy to determine possible improvements for each soil. The evaluation parameters as well as the resulting assessment can be adapted to local conditions.

2.3.1.5 Soil fertility capability classification (FCC).

This was developed by Buol, Sanchez, Cate and Granger (1975) and modified by Sanchez, Couto and Boul (1982) to evaluate soil fertility. In this system, three levels or categories were established. The first, the type, was determined by texture of the arable layer, or of the first 20 cm, if this is thinner. Its denomination and range are: S, sandy (sandy and sandy loam); L, loams <35% clay (excluding sandy and sandy loam); C, clayey > 35% clay; O, organic > 30% organic matter to 50 cm or more.The type of substrate is the second level and is used when there is a significant textural change in the first 50 cm of the soil. It is expressed with the same letters, adding "R" when a rock or a hard layer is found within this depth. The third level is comprised of the modifiers, which are the chemical and physical parameters that negatively influence soil fertility. Modifiers are numerous and are represented by lower-case letters. In the denomination of the soils class, the principle limitations for use are directly represented. For example, for an Orthic Solonchak, the FCC class that represents it is LCds, which signifies that it is a soil susceptible to severe erosion (L), limited drainage (C), dry soil moisture regime (d) and with salinity (s).

2.4 Related Studies on Land Characterization and Suitability Evaluations.

Studies on land characterization and suitability evaluation are few in Nigeria as reported by Atofarati, Ewulo and Ojeniyi (2012) that the major factor limiting agricultural productivity in the country is inadequate information on land characterization. A number of studies have been carried out in the country to enrich soil data bank, this include: Olaleye, Ogunkunle, Sahrawat, Osiname, and Ayanlaja, (2002) evaluated thirty-eight wetland soils in four agro-ecological zones in Nigeria for their suitability for rice (*Oryza sativa L*.)

cultivation using parametric and none parametric method. The results of their research indicated that climatically, all the soils were near optimum. Currently, by non-parametric method, all the pedons were found to be marginally suitable (S3). With the parametric method about 3% were highly suitable (S1), 74% marginally suitable (S3) and 23% not suitable (NS). Potentially by non-parametric method, 18% were of high (S1) and moderate (S2) suitability respectively, 58% were marginally suitable (S3) and 6% not suitable (NS). With parametric method, 24% were highly suitable (S1), 45 and 31% were of moderate (S2) and marginal (S3) suitability. The major limitations to rice cultivation on these soils are low CEC, organic carbon, exchangeable cations and available P. They recommended good soil management practices for substantial improvement in rice production.

In another study, Oluwatosin (2005) assessed suitability of some land in Northwestern Nigeria for rainfed crop production using a qualitative physical land evaluation method. The study revealed that all the soils were currently not suitable (N1) for cereals but were marginally suitable (S3) for grain legumes. Potentially all the soils were moderately suitable (S2), while those on the plain were highly suitable (S1) for grain legumes. Soils on plains were potentially more suitable than soil of the upland and valley bottom. The major limitations were nutrient availability (F) which cut across all the soil while erosion hazard and drainage were major limitation in the upland and valley bottom respectively. For sustainable crop production, the use of high fertility management practice was recommended to make the land highly suitable for both cereals and legumes.

Odunze and Kureh (2009) assessed land use limitation and management option for *Alfisols* of Institute for Agricultural Research (IAR) farm in Zaria. Two soil units were delineated. Their results showed that soil unit one had within its subsoil *Argillic* horizons,

mottling and *Gleyic* properties, without subsoil acidity problems. The subsoil had increasing clay with depth, and temporary stagnation of water. The second soil unit had *Kandic* subsoil properties, *Gleyic* and mottled subsoil horizons at shallow depths to the surface horizons, and with a slight acidic problem. They also reported that extractable Zn values were very high and could adversely affect growth and production of crops. However, for sustainable crop production, liming and incorporation of farmyard manure, contour ridging and construction of field drainage ditches to conduct excess field and subsoil stagnated water away from the fields, control soil acidity build up and improve aeration conditions in the plow layer.

Furthermore, Shobayo (2010) evaluated the morphological, physical and chemical properties of soils developed on two parent materials (gneiss and schist) in Zaria to examine the effect of parent material on the soils properties. The soils were well stratified, deep to moderately shallow, clay content increased with depth down the pedons. Blocky structure dominated the soils developed on two parent materials. Soils of all the pedons generally had weak, fine to moderate sub-angular blocky structures on the surface with strong, fine to coarse sub-angular to angular blocky structures in the sub-surface horizons. The pH values of soils indicate extremely acidic to strongly acidic reaction. Exchangeable acidity values were generally low; except for a few horizons, which were in the range of medium and this suggests that the soils have little or no acidity problems. Total exchangeable bases were generally low to medium indicating low basic nutrient status in the soils. The soils were classified as *Typic Haplustult (Dystric Acrisols), Typic Haplustalf (Eutric Lixisols) and Typic Plinthustalf (Eutric Lixisols).*

Hussaini (2011) evaluated suitability of Institute for Agricultural Research (IAR) farm, Zaria for some selected crops. The study shows that the soils were shallow to very deep, well to poorly drain and were medium textured soils with blocky structure dominating the soil and increasing clay with depth were observed in the subsoils. The pH was low to medium, high exchangeable bases and high base saturation characterized the soils. The soils were reported to have low organic carbon, total nitrogen and available phosphorus which were general characteristic of savanna soils (Jones and Wild, 1975). Three soil units were delineated and classified as *Typic Haplustalf, Lithic Ustipsamment* and *Typic Endoaqualfs/ Endoaquepts*. Two of the soil units were moderately suitable (S2) for cotton and maize and highly suitable for sorghum while the third soil unit was marginally suitable (S3) for cowpea and not suitable (N1) for cotton and maize. Constraints to agricultural productivity in the farm were low organic matter, total nitrogen, available phosphorus and poor drainage. Thus for optimal agricultural productivity, they recommended standard rates of N and P from inorganic fertilizers, incorporation of crop residue and application of organic manure to invariably increase productivity of the soils.

In addition, Lawal *et al*. (2012) evaluated suitability of soils of lower river Oshin flood plains in Kwara State, Nigeria for rainfed arable crops, using the FAO land suitability evaluation method. They reported that there are three soils units in the study area. The soils were generally sandy loam in texture and had moderate bulk density which could favour good agricultural production. All the soils were reported to have medium to high organic carbon, available phosphorus and CEC. All the soil units were moderately suitable (S2) for maize production. The major limitation was drainage. For sustainable yield of maize in the area, adequate drainage need to be constructed to conduct excess water out of the field as

maize are not tolerant to water logging. For rice production, the area were marginally suitable (S3) with topography, soil texture and soil fertility being the major limitationS. For sustainable production of rice, application of organic and inorganic fertilizer was recommended.

Sharu *et al.* (2013) conducted a semi-detailed soil survey of Dingyadi District in Sokoto, Nigeria in order to characterize and classify the soils. Result of the survey revealed that three soil units were identified on the basis of land forms and surface texture. The soils were deep to shallow, well to imperfectly drain and the texture varied from loam, sandy loam and sandy clay loam. The soils were relatively high in bulk density and low porosity. The dominant exchangeable bases were calcium and magnesium with the soils having high base saturation. The soils were neutral to slightly alkaline in reaction. Organic matter, available P, total N and CEC contents of the soils were generally low and the soils were classified as *Typic Endoaqualfs (Haplic Luvisols), Typic Haplustepts (Argic Lixisols)* and *Lithic Ustorthents (Ruptic Cambisols*) respectively based on USDA and correlate with WRB system of Classification. Owing to fact that this current study area is an agrarian community outskirt of Zaria town and not much study has been done on soils of the area, characterization and classification will help reveal information that could be useful in the management and use of the soils for sustainable agricultural production.

2.5 Summary of Literature Review

The literatures reviewed established that land performance for agricultural production is a major concern in all part of the world. Human activities continue to degrade the limited land. Therefore the need arises to make good use of this limited natural resource

(soil) and is the major aim of land evaluation. Land suitability evaluates the ability of a piece of land to provide optimal ecological requirements of a certain crop variety.

Several method of land evaluation; such as FAO land suitability evaluation, fertility capability classification, productivity index, storie index and land capability classification method have been used by different scholars for land evaluation. All these methods have their advantages and limitations. However, the storie index being a quantitative method has high accuracy compared to the FAO simple limitation method which is qualitative. Storie Index is a widely known and accepted method of rating soils for agricultural potential in the world, as it based soil rating on characteristics that govern the soil's potential utilization and productivity capacity. It is independent of other physical or economic factors that might determine the desirability of growing certain plants in a given location. The evaluation is easy to be realized, being an advantage of this method (Storie, 1978). Behzad *et al.*, (2009) reported that storie index (parametric method) has better precision than simple limitation method (nonparametric method) and was used for this current study.

More so, the review of related literatures enables researcher to understand nature of the problem, factors limiting agricultural productivity and it consequence on sustainable crop production. It also affords the researcher opportunity to appraise available methods used to resolve the problem and choose a suitable one for the present study.

CHAPTER THREE: STUDY AREA METHODOLOGY

3.1 Study Area

The study area is located in Zaria, Kaduna State, Nigeria along the lower Kubanni drainage basin, behind Nigeria College of Aviation Technology (NCAT) in Zaria, $11^{0}06'$ 50"- $11^{0}07'$ 25" N and $7^{0}40'$ 22" - $7^{0}40'$ 58"E. Federal Survey Topographical Sheet 102, Zaria S. W. (Fig.3.1).

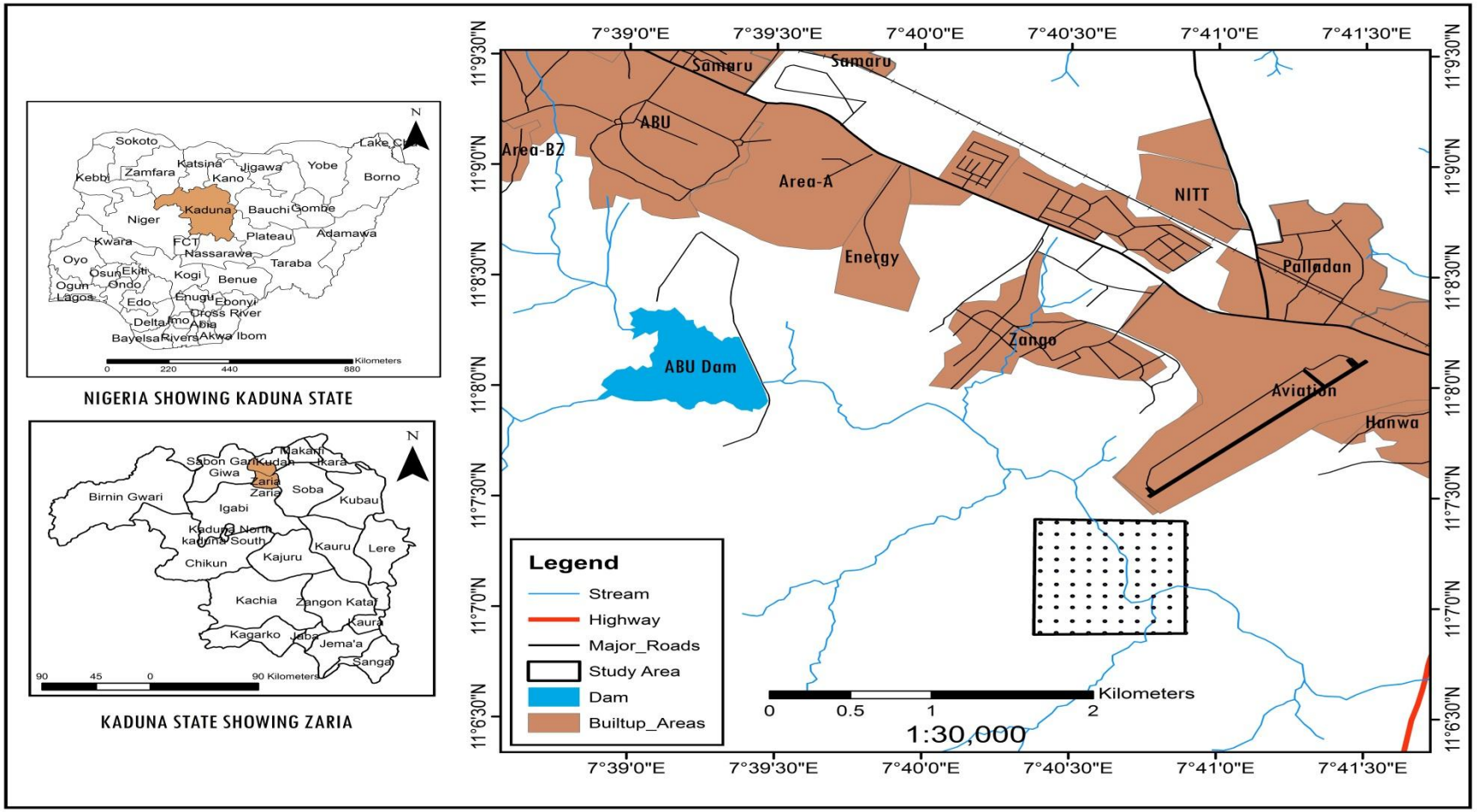


Fig. 3.1: Zaria Showing the Study Area.

3.1.1 Geology

The study area is located within Basement Complex Rocks in north central Nigeria. Russ (1977) described the Basement Complex Rocks as rich in high grade meta-sediments of mainly quartzite's (forming ridges) containing schist and phyllites. Wright and McCurry (1970) classified the basement complex rocks of Zaria into 3 principal groups:

1. Younger metasediments found in a north –south trending belt, which includes; Quatzites, Schist sand Phylites.
2. A re-mobilised older crystalline complex made up of Gneisses, Migmatite and Ancient metasediments.
3. Granites and Granodiorite of late Precambrian to lower Paleozoic age which includes groups one and two above.

The granites are grouped into porphyro blastic, biotie granite, porphyro blastic hornblende granite, granodiorites-porphyroblastic and fine to medium grained biotite granite. These rocks are thoroughly weathered. Chemical weathering has created pockets of classic humid tropical processes that have also evolved distinctive lateritic landscape (Thorp, 1970). Superficial materials on the plain include laterites, alluvium metasediments and aeolian drift.The laterites and alluvium are further differentiated into older and younger types dependingon their origin, formation and age. Also found in the basin are thin deposits of windblown brown silt from Sahara during many decades of hamattan season (Wright and McCurry 1970; Bello, 1973).

Along the stream channels are found younger laterites which are generally light brown thanthe older laterites found on the summit of the plainsbeing mostly residuals and have been dissected to form isolated tabular hills (mesas and buttes) (Thorp, 1970). Also alluvium occurs within the inner valleys of the catchment with distinctive characteristics. These characteristics of the superficial materials have important implications for the ongoing degradation in the basin (Fig. 3.2).

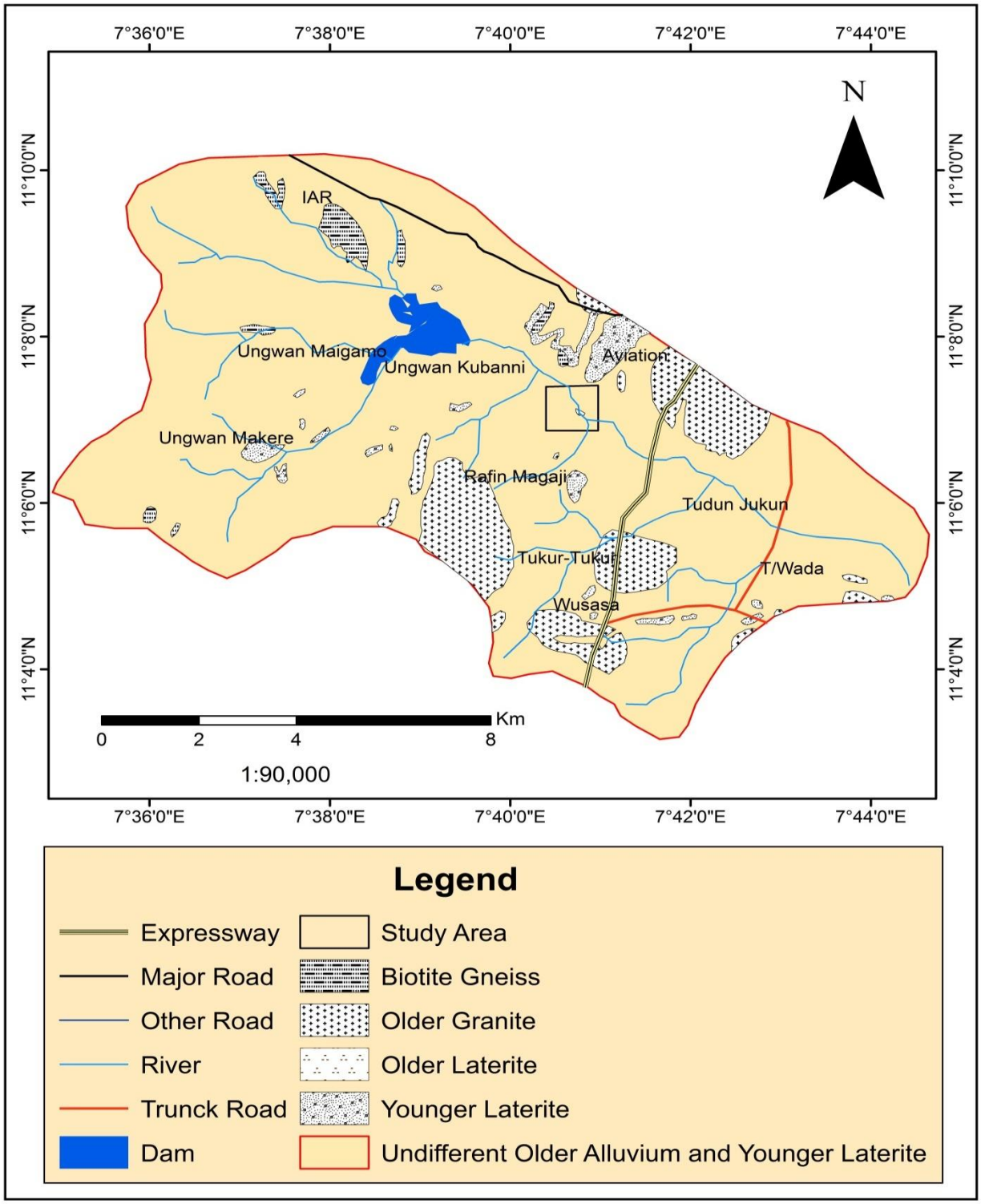


Fig. 3.2: Geology of Kubanni River Basin and the Study Area

3.1.2 Relief and drainage

Kubanni Basin is part of the undulating Zaria plain which in turn forms the extension of high plains of northern Nigeria. In addition, to the infinite horizontality, the relief is dotted with isolated rocky hills of different shapes and configuration called inselbergs. Among these are rocky hills rising to 820m and the Tukur tukur hills 797m lying immediately to south of the Kubanni Dam. Kubanni River has its source from the Kampagi Hill, in Shika, near Zaria. It flows in southeast direction through Ahmadu Bello University to join River Galma (Yusuf, 2006). The valleys are incised into surrounding plains. Continued erosion processes have formed distinctive micro-landforms including degraded bluffs and erosional scarps and stripped micro pediment (Bello 1973; Duniya, 2006). The plains with some pockets of hills being thoroughly weathered are stripped of their regolith and prevailing land use contributes to the ongoing degradation in the basin. Kubanni basin system is ephemeral, intermittent and assumes dendritic patterns which are deeply incised by numerous systems of gullies (Ologe, 1971; Bello 1973) (Fig. 3.3).

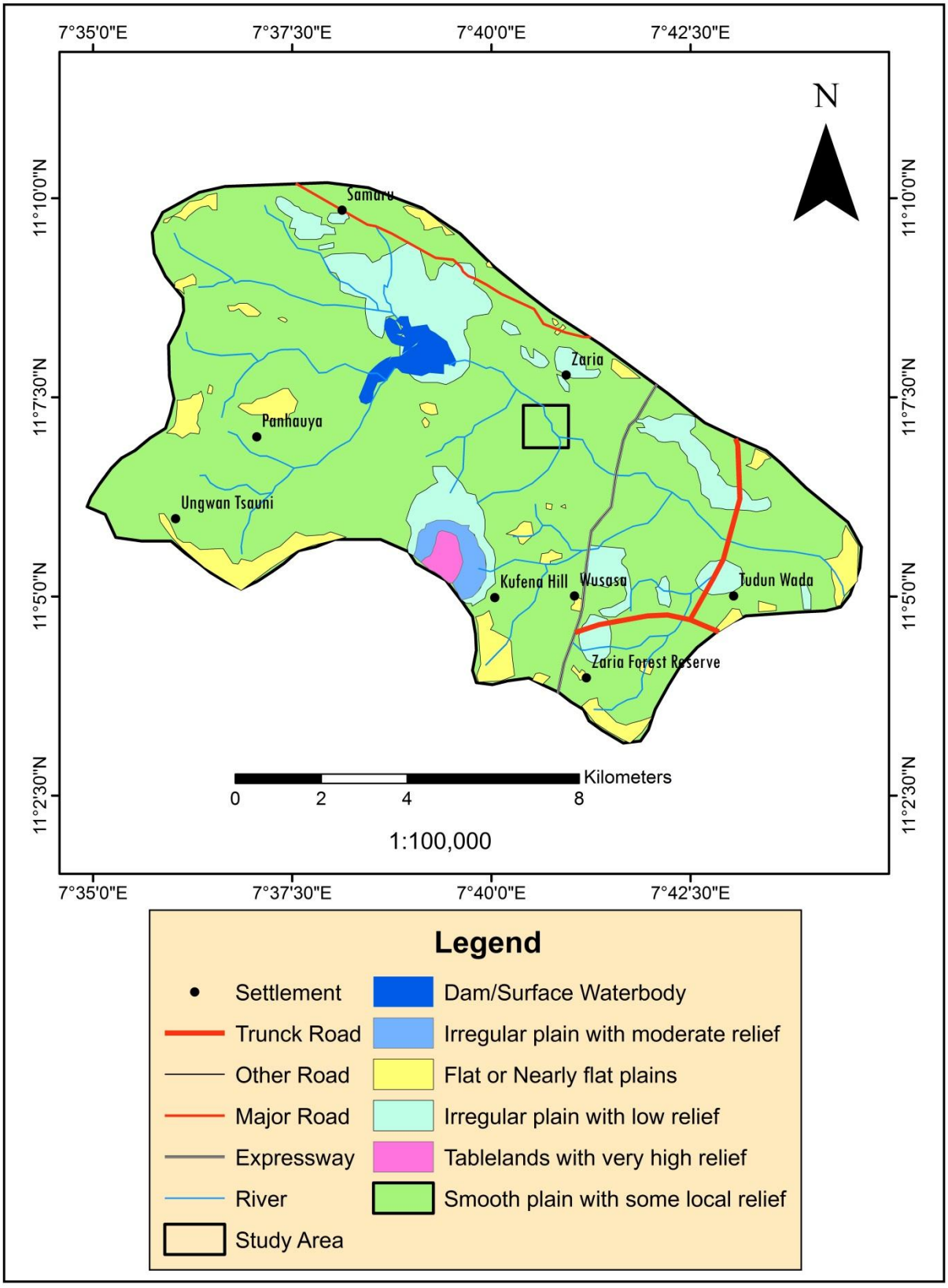


Fig. 3.3: Drainage and Landform of Kubanni River Basin and the Study Area

3.1.3 Climate

The climate of Kubanni basin in Zaria region is the Aw type characterized by distinct wet and dry seasons (Hore, 1970). Characteristics of the climate are determined by oscillations of two contrasting air masses: Tropical Maritime and Tropical Continental Air Masses. The tropical maritime originates from Gulf of Guinea and ushers in rainy season. The tropical continental originates from Sahara Desert ushers in the dry cold and dusty season called the harmattan that occasionally limits visibility and reduces solar radiation (Hore, 1970). The two air masses are separated by a discontinuity zone known as Inter Tropical Discontinuity (ITD). The ITD moves north and south of the country. Location of zones is in relation to surface position of ITD and determines the weather condition at any time of the year. Orientation of surface position of ITD over the country reaches northernmost and southern most positions in August and January respectively on the average. However, southward movement is usually faster than the northward movement.

Fig. 3.4 shows the approximate average monthly surface positions of ITD during its south ward movement along the meridian of Zaria. Thus from October/November -April Zaria lies north of the surface position of the ITD and under the influence of north-east depending on the synoptic condition over Africa and for the rest of the year, from May– October Zaria is under the domain of tropical maritime air.

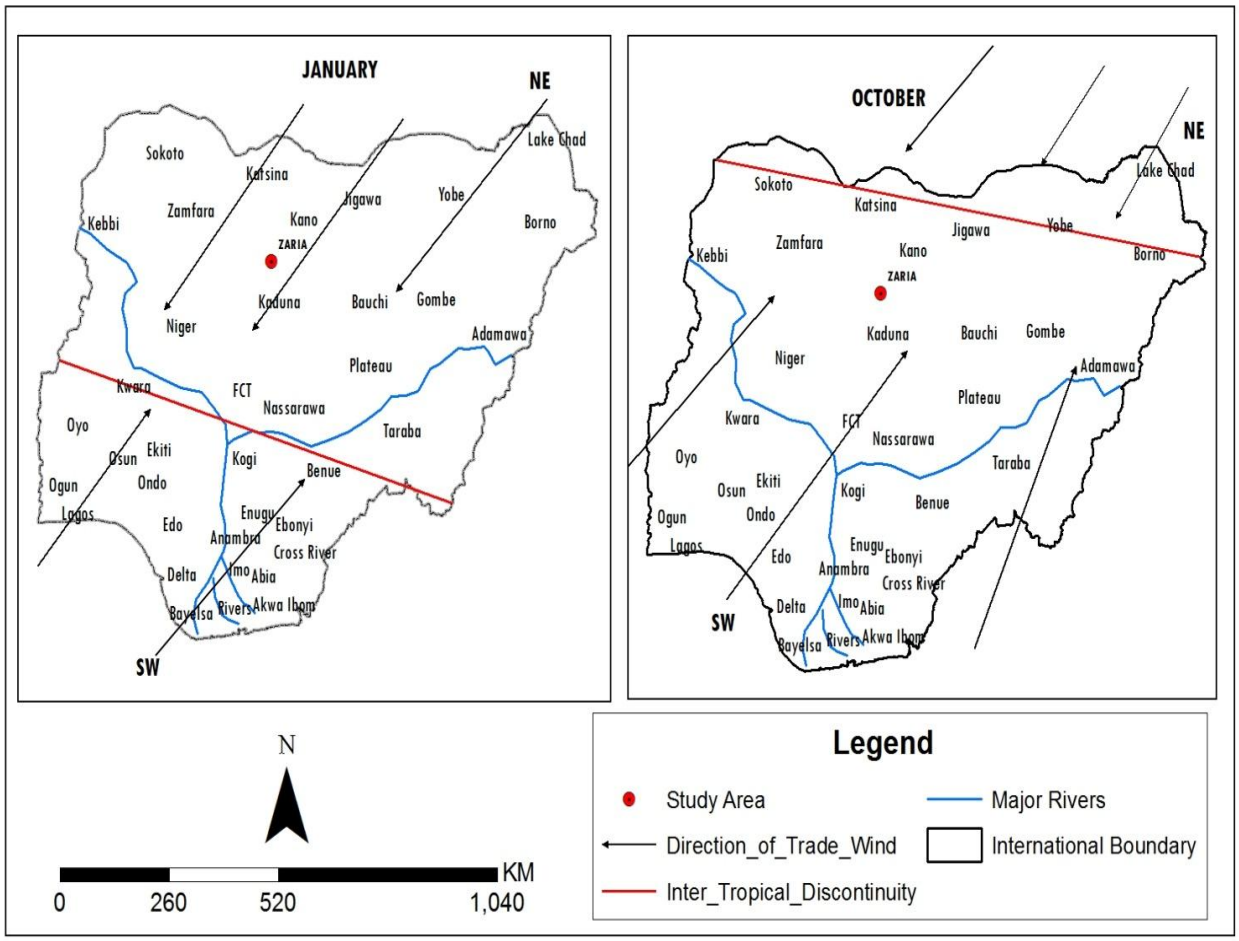


Fig. 3.4: Surface position of ITD relative to Zaria Location.
Source: Adapted from Yakubu (2004)

Analysis of long term records of rainfall data (1964-2013) in Table 3.4 shows that the catchments area has a mean annual rainfall of 1004mm. It is important to note that variations in total distribution and intensity have also occurred in the basin. For example, total annual rainfall of 682mm was recorded in 1983 and 1322.3mm in 2001. The mean monthly temperature is about 27^{o}C but it is highest between the months of March and May which represent the hot dry period. It is lowest in December/January dropping to about 22^{o}C. The extreme variation in the climatic condition plays important role in the determination of state of the land; viz a viz the water resource development (the reservoir) in Kubanni basin.

Relative humidity of the study area follows a similar trend with rainfall. As wet season progresses, relative humidity increases. With the progress of dry season the air become drier and relative humidity falls from 23.78% (average at 10 a.m.) in December to 13.34% (average at 10 a.m.) in February. Table 3.1 shows that Zaria has relatively high humidity in the rainy season (82.35%) and low during the dry months, reaching as low as 13.34% during harmattan period.

Sunshine hours varied throughout the year. It is indirectly related to rainfall, as wet season progresses, cloudiness increases with subsequent reduction in the daily hours of sunshine. Cloudiness reaches a maximum in August and subsequently the hours of sunshine are least. Table 3.1 shows that Zaria has the least sunshine hours at the peak of the rainy season (5.63) and highest during the dry months, reaching as high as 8.96 during harmattan period.

Table: 3.1. 1964-2013 Mean Monthly summary of some weather parameters in Zaria

Months	Rainfall	Temp.(^{0}C)			Relative humidity (%)		Sunshine	Wind speed	Potential Evaporation
	Mm	Max	min	mean difference	Max	Min	Hours	(km/day)	(mm/day)
January	0.00	21.50	20.63	0.87	19.85	15.94	8.31	152.46	6.84
February	0.29	23.33	21.76	1.57	17.03	13.34	7.78	146.16	8.24
March	17.22	27.31	22.76	4.55	23.37	16.41	7.53	133.17	9.16
April	367.39	32.12	30.06	2.06	45.95	28.38	7.45	161.27	8.51
May	1217.19	32.06	30.83	1.23	66.52	46.43	7.70	175.39	6.80
June	1689.35	31.01	29.35	1.66	74.37	59.81	7.23	174.02	5.25
July	2573.08	29.73	26.15	3.58	81.11	67.83	5.98	166.60	4.51
August	2826.42	27.16	22.50	4.66	82.35	71.99	5.63	119.96	4.24
September	2387.31	28.76	25.14	3.62	77.64	69.05	6.79	90.25	4.34
October	958.31	30.89	27.40	3.49	61.74	47.44	8.15	76.37	5.34
November	14.24	23.65	22.95	0.70	28.58	37.19	8.98	90.42	5.72
December	0.10	22.40	20.50	1.90	46.66	23.78	8.53	110.95	6.82
Mean	1004.24	27.49	25.00		52.10	41.47	7.51	133.09	6.31

Source: IAR, 2013.

3.1.4 Soil

Considerable variations exist in the soil types. However, it is described as leached ferruginous, specifically as *Acrisol* in the FAO system (2014) and *Alfisols* in the USDA soil Taxonomy system (2010). Topographical factors play a vital role in determining their detailed characteristics. For instance, around Kufena hills the soils are young coarse or weakly developed and are classified as *Regosols* in the FAO system (2014). But soils in the valley bottom (flood plains) belong to the *inceptisols* group, especially hydromorphic soils due to the accumulation of organic matter, alluvium and presence of moisture (Klinkenberg, 1970). The soils are mostly dark-grey clays (vertisols) and poorly drained; most of which have formed in alluvial material. Therefore, variations in texture can be expected. The flood plains are of special importance. They are fairly rich in nutrients and have ample water supply which persists into the dry season. Generally character of the soil is such that as soon as rainfall begins infiltration process could be high but the pores soon get sealed up (Kyari, 1995).

3.1.5 Vegetation

Vegetation of the region is described as Northern Guinea Savanna type. The term connotes woodland vegetation type characterized by large surface coverage with few scattered trees and shorter grasses with tuff and occasional gallery forest along the watercourses (Hore, 1970). The dominant tree species include; *Isoberlinadoka, Isoberlina tometosa, Acacia albida, Parkia clappertoniana and Uapacotogoensis*. The grass layer is made up of mostly tufted *Andropogoneae.* However due to man's activities such as construction activities, over grazing and cultivation, the natural vegetation had been modified resulting mostly in a type of vegetation commonly known as parkland (Jackson, 1970). Manmade vegetation consists of trees like mango, guava, silk cotton tree and neem tree.

3.1.6 Land use

The most prominent land use practice in the study area is agricultural land use i.e. cultivation and animal husbandry. This is because the economic base of virtually all rural and semi urban settlement in Northern Nigeria is agriculture and it is subsistent. The use of land for agricultural activities is influenced by several factors such as land per resident ratio and location of soil quality. As the land per resident ratio increase (population density increases) the percentage of land in fallow decreases due to increase in farming intensities. The increase in intensity in land use as population density increase creates problem in maintenance of soil fertility. Two types of agricultural land use are found in Zaria namely upland farm and Flood plains. Upland is cultivated during the wet season only while the flood plains are cultivated year round through irrigation. Other land uses are pastoral farming for meat and dairy production, establishment of settlements and industrial expansion (Fig. 3.5).

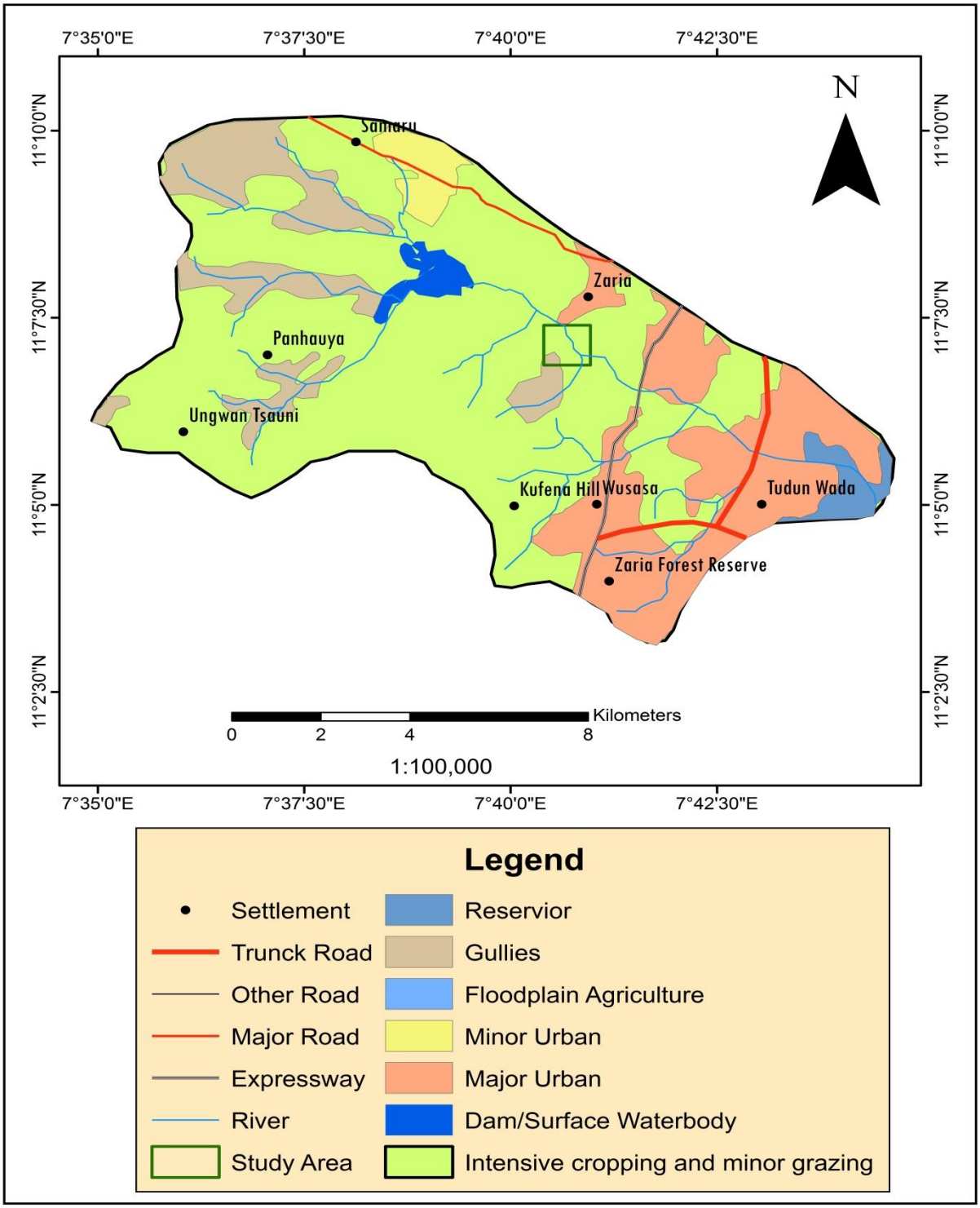


Fig. 3.5: Land use Map of Kubanni River Basin and the Study Area

3.2 Methodology

3.2.1 Types and sources of data

3.2.1.1Types of Data

The type of data used to achieve set objectives includes.

Satellite image of Zaria with 5m resolution (quick bird);

Digital Elevation Model (DEM) of the study area;

Climatic data of the study area;

Topographic map of the study area;

Geological map of the study area;

Data on morphological and physico-chemical property of flood plains and upland soils and

Data on socio-economic characteristics of the farmers.

3.2.1.2 Sources of Data

Both primary and secondary data were sourced for the study. Data on physico-chemical property of the soils and socio-economic characteristics of farmers were sourced through soil survey and administration of questionnaires respectively, while Satellite image of the study area for year 2011, Shuttle Radar Topographic Mission (SRTM) with 5 meters resolution and Climatic data was sourced from National Centre of Remote Sensing Jos, Global Land Cover Facility and Institute for Agricultural Research (IAR). Existing literature from journals, textbooks, conference proceedings, seminar papers, thesis, reports and web references were also used.

3.2.2 Reconnaissance

3.2.2.1: Image acquisition and base map delineation

Landsat image (Quick bird with 5m spatial resolution) was acquired and processed to identify land cover map showing the land use which include cultivated land, uncultivated land, fallow land, settlement and road and drainage network. Digital Elevation Model (DEM) was acquired from which contours map and landforms such as high land, plain and flood plain in the study area was generated and geological map covering the study area was acquired, digitized and geo-referenced. Base map of 100 hectares of land in the study area was delineated with a grid interval of 100m created perpendicular to River Kubanni (Fig.4.1). The grid points which are the soil observation points was uploaded into global positioning system (GPS) to be used for detailed field work. Reconnaissance survey was undertaken for identification of roads and foot paths and ground truthing of landforms identified from DEM and setillite image. The village head was informed about the survey.

3.2.2.2: Sampling Design

The outcome of reconnaissance survey revealed that there are thirty farmers in the study area, for the purpose of sampling; entire farmers were sampled since they are of manageable number. Thirty copies of questionnaire were administered to the farmers.

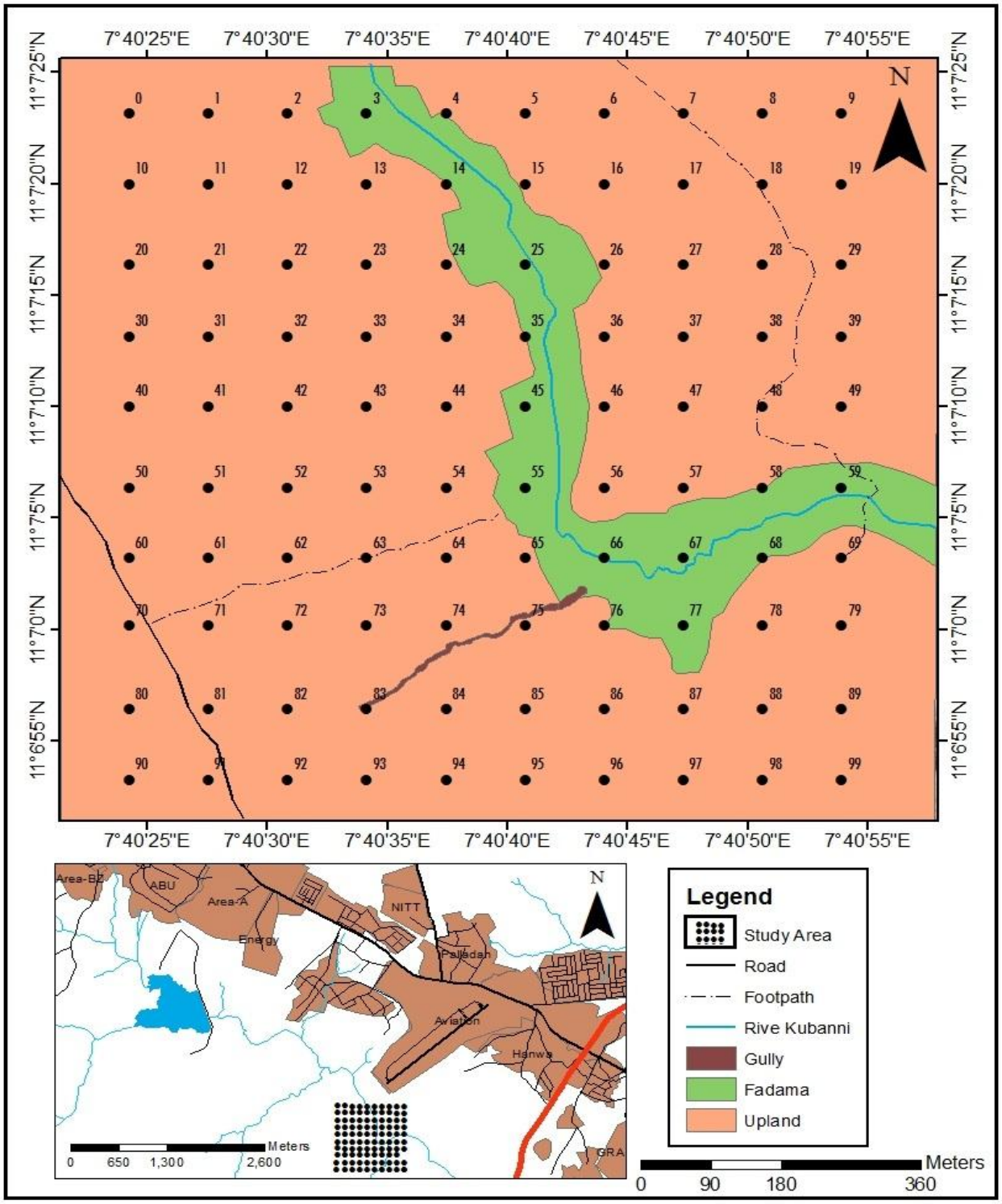


Fig. 3.6: Base Map of the Study Area

3.2.3 Detailed Field Work

Along the transverses created, soil were augered at the grid interval of 100m to examine change in soil properties, Soil morphological features such as soil colour, texture, soil depth, consistence and drainage was used to identify the soil mapping units. Soils with similar characteristic were grouped into a soil mapping units. Five (5) soil mapping units were delineated and coded as KBI, KBII and KBIII which are located on the upland, KBIV and KBV on the flood plain. Two (2) profile pits were dug at center of each of the soil mapping unit identified to a depth of 200cm × 150cm × 150cm except if hard pan/parent materials is encountered. Ten (10) pits were dug and described according to the procedure described in the Soil Survey Manual (Soil Survey Staff, 2010). This method takes into cognizance the morphological parameters; soil depth, colour, mottling, texture, drainage, consistence, horizon boundary, roots, concretions, pores and structure.

3.2.4 Soil Sampling

Two types of soil sampling were carried out within the sample area. Bulk and Core sampling was carried out on the genetic horizons identified. Bulk samples were used to determine the physico-chemical parameters of soil while the core samples were used to determine bulk density and total porosity. The coordinates of soil profile pits were recorded.

3.2.5 Soil Analyses

3.2.5.1 Laboratory analysis

Soil samples collected from the various pedogenic horizons were air-dried, crushed with porcelain pestle and mortar and sieved to remove materials greater than 2mm (gravel). Percent gravel of total soil was calculated. The less than 2mm material was used for physical and

chemical analyses. The following parameters were determined using standard procedures as presented in Table 3.2.

Table 3.2: Parameters for Soil Characterization and Suitability Evaluation

N0	Parameters	Method of Analysis	Author
1	Particle size distribution	Hydrometer Method	Gee and Bauder, (1979)
2	Bulk density	Core Method	Blake and Hartge (1986).
3	Particle density	Pycnometer Method	Blake and Hartge (1986).
4	Total porosity	$T.P(\%) = 100(1 - {}^{\rho b}/_{\rho p})$	Agbenin, (1995).
5	Electrical conductivity	Wheatstone Bridge Method	Agbenin, (1995)
6	Total Salt concentration	Electric Conductivity Method	Dregne, (1976)
7	Cation Exchange Capacity (CEC)	NH_4OAc Saturation Method Ca, Mg = A.A.S. K, Na = flame photometer.	Rhoades, (1982)
8	Exchangeable Bases (Ca, Mg, K and Na)	NH_4OAc Saturation Method	Thomas, (1982).
9	pH	Electrometric Method	Agbenin, (1995)
10	Carbonate and Bicrbonate	Rapid Titration Method	Agbenin, (1995).
11	Exchange Acidity	NH_4OAc Method	IITA, (1979).
12	Organic Carbon	Walkley Black Method	Nelson and Sommers (1982).
13	Total nitrogen	Micro Keldahl Method	Bremner and Mulvaney, (1982)
14	Available phosphorus (Ap)	Bray-1 Extraction Method Spectronic 20	IITA (1979)
15	Sulphate	Turbidimetric Method	Agbenin, (1995).
16	Extractable micronutrients (Fe, Zn, Cu, Mn)	DTPA and AAS Method	Agbenin, (1995).
17	Boron	Colorimetrical Method	Agbenin, (1995).
18	Chloride	Titration Method	Agbenin, (1995).
19	Exchangeable Sodium Percentage	ESP = $\frac{\text{Exchangeable sodium}}{\text{CEC } (NH_4OAc)} \times 100$	Agbenin, (1995).
20	Sodium Adsorption Ratio	$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$	Agbenin, (1995).
21	Adjusted SAR (Adj.SAR)	$Adj.SAR = \left(\frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}\right)(1 + 8.4 - pHc)$	Agbenin, (1995).
22	Base Saturation Percentage	% B.S= $\frac{\text{Total exchangeable bases}}{\text{CEC}} \times 100$	Agbenin, (1995)

3.2.6 Land suitability map

Soil map was interpreted to land suitability map by incorporating data of all soil parameters, climatic data and economic analysis data into the digitized map of the area using FAO land suitability evaluation and Storie index method.

3.2.6.1 Land Suitability Evaluation for Rice and Maize Production.

In evaluating the land suitability for rice and maize production, land properties such as: soil depth, texture, drainage, pH, available P, organic C, exchangeable K, CEC, base saturation, Fe, Ece and ESP compared with corresponding plant requirements based on FAO guideline for land evaluation (FAO, 1985), while for quantitative land suitability evaluation, parametric methods (Storie, 1978 and O'Geen *et al.,* 2008) were used. Simple limitation method compares the plant requirements with its corresponding qualitative land and climatic characteristics and the most limiting characteristics defines land suitability class. The measurement of these characteristics was determined using the following:

Storie Method: $I = A \times \frac{B}{100} \times \frac{C}{100} \times \frac{X}{100}$ ….(1)

Where I is the specified index and A, B, C…X are different ratings given for each property.

By determining specific land index and using the guidelines given by Sys, Vanranst and Debvay (1991), qualitative land suitability classes (Table 3.3) and limiting factors of plant growth in different soil mapping units for each crop were determined.

Table 3.3: Qualitative land suitability classes for the different land indices

Specified index (I)	Definition	Symbol
75-100	Highly suitable	S1
50-75	Moderately suitable	S2
25-50	Marginally suitable	S3
12.5-25	Currently not suitable	N1
0-12.5	Permanently not suitable	N2

3.2.7 Soil classification

Soils were classified according to the Soil Taxonomy (USDA, 2010) at Great Group and Subgroup and correlated with FAO World Reference Base for Soil Resource (FAO, 2014).

3.2.7.1 Land suitability classification

The land suitability classes and sub classes was arrived at based on the FAO guidelines for land evaluation (FAO, 1985) as outlined in 2.3.1.1.

3.2.8 Statistical analysis

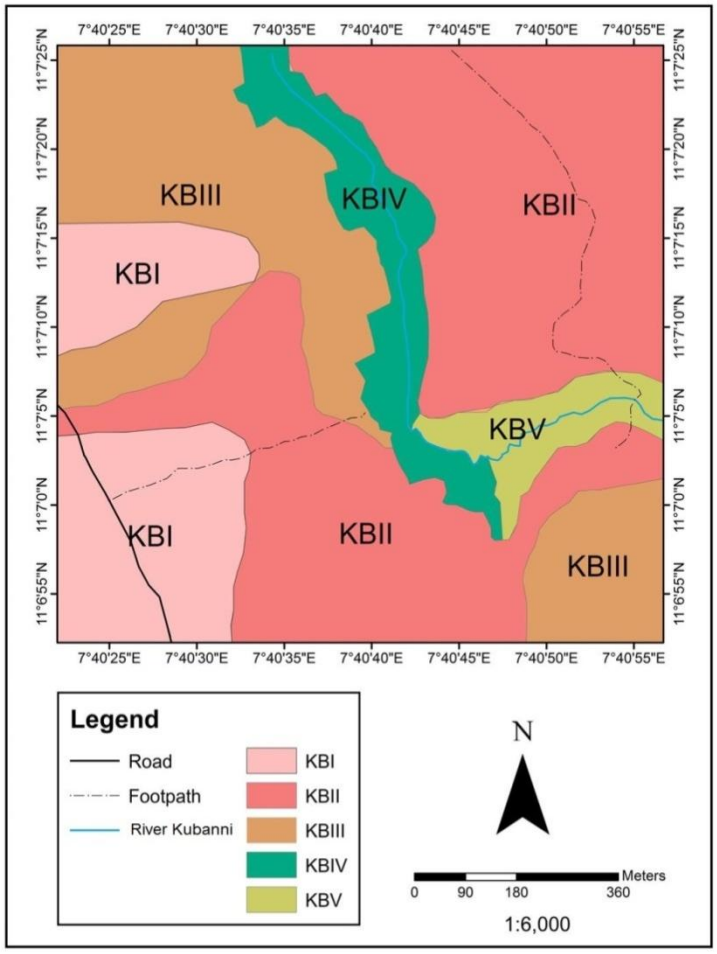
Student t-test were used to analyse variation between the flood plains and adjoining upland soils, while linear correlation analyses were used to correlate the various soil parameters.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Soil Mapping Units of the Study Area

A soil mapping unit is a collection of areas defined and named the same in terms of their soil components and miscellaneous areas. Five (5) soils mapping units were delineated in the study area. They are denoted as soil mapping units KB1, KBII, KBIII, KBIV and KBV. Soil mapping units KB1, KBII and KBIII were located on the uplands while KBIV and KBV were on the flood plain.

Soil Mapping Unit KBI was deep, well drained, dark yellowish brown (10YR4/4), sandy loam to loam, well developed pedon and covers an area of 12.3ha. Soil unit KBII was shollow to deep, well drain, strong brown (10YR5/8) to light gray brown (10YR4/1) and loam. Associated with deep gully erosion and covers an area of 38.8ha. Soil unit KBIII was deep, imperfectly drained, yellowish brown (10YR5/4) to light gray brown (10YR6/2), loam, well developed pedon and covers an area of 18.9ha. Soil unit KBIV was deep, very poorly drained, yellowish brown (10YR5/4) to dark yellowish brown (10YR4/6), loam to sandy loam, weakly developed pedon and covers an area of 7.9ha. Soil unit KBV was deep, very poorly drained, dark yellowish brown (10YR4/6) to dark gray brown (2.5YR4/2), loam, weakly developed pedon and covers an area of 3.7ha. A total of ten (10) pedons were dug and described. Evaluations of the morphological, physical and chemical characteristic of representative pedons are discussed below. The soil map of study area is shown in Fig 4.1.



Soil Mapping Unit Symbol	Dominant Topography	Area Ha	Major characteristics
KBI	Crest	12.3	Deep (140cm) well drained, dark yellowish brown (10YR4/4) loam to sandy loam, overlying strong brown (7.5YR 5/6) to yellowish brown (10YR5/6) loam few medium distinct redish brown mottles, overlying brownish yellow (10YR 6/6) to pale brown (10YR6/3) loam to sandy clay loam, few fine mica flakes, iron and magnesium concretion, limited by plinthite
KBII	Middle to Gentle slope	38.8	Deep to very deep (120-170cm) well drained, strong brown (10YR 5/8) to very pale brown (10YR 7/4) loam, overlying dark gray brown (10YR 4/1) to light gray brown (10YR6/2) clay loam to sandy clay loam, few fine mica flakes, many coarse magnesium concretion, these unit was characterized by deep gully erosion.
KBIII	Lower slope	18.9	Deep to very deep (140-165cm) imperfectly drained to ell drained Brown (10YR 5/3) loam, overlying brown (10YR 4/3) loam, overlying yellowish brown (10YR 5/4) loam overlying gray brown (10YR5/2) to light gray brown (10YR6/2) loam to silt loam, many magnesium concretion limited by plinthite and characterize by gully erosion
KBIV	Valley floor to flood-plain	7.9	Deep to very deep (145-160cm) very poorly drained yellowish brown (10YR 5/4) loam to sandy loam, overlying dark yellowish brown (10YR 4/4) loam to sandy loam, overlying dark yellowish brown (10YR4/6) to yellowish brown (10YR5/4) loam to sandy loam overlying brown (10YR 5/3) overlying dark yellowish brown 10YR (4/6) to brown (10YR5/3) loam overlying dark yellowish brown (10YR4/6) sandy loam, many coarse gravels. Limited by water table.
KBV	Floodplain	3.7	Deep to very deep (135-170cm) very poorly drained Dark yellowish brown (10YR 4/6) to brownish yellow (10YR6/6) loam overlying Pale brown (10YR 6/3) to dark yellowish brown (10YR4/4) loam overlying strong brown (7.5YR 3/8) to dark gray brown (2.5YR4/2) gravelly sandy loam to loam, few fine mica flakes. Limited by water table.

Figure 4.1 Soil map of the study area showing the five mapping units

4.1.1 Soil morphological properties

Soil morphological properties studied were summarized in Table 4.1. Detailed profiles descriptions are given in Appendix A. Morphological properties considered in classification of soils include soil depth, colour, texture, structure, consistence and horizonation. These indicate the degree of soil development which influenced their fertility status.

Table 4.1: Summary of soil morphological properties of the study area.

Soil mapping Unit	Horizon	Depth (cm)	Munsell colour (moist)	Texture	Structure	Consistency			Boundary	Features
						Wet	Moist	Dry		
KBI										
	Pedon 1		Latitude	N11º 06□□ 58□		Longitude	E7º 40□ 28□		Elevation 640m	
	Ap	0 – 21	10YR4/4	L	Wfsbk	Sssp	vfr	Sh	Cs	common medium roots
	Bt1	21 – 114	7.5YR5/6	L	Wmsbk	Sssp	fm	H	Gs	few fine mica flakes
	Bt2cv	114 -140	10YR6/6	L	Mmabk	Vsvp	fm	Vh	□□□	iron and magnesium concretions
	Pedon 2		Latitude	N11º 07□ 12□		Longitude	E7º 40□ 25□		Elevation 635m	
	Ap	0 – 40	10YR4/4	SL	Mmsbk	Sssp	vfr	Sh	Cs	common medium roots
	Bt1	40 – 70	10YR5/6	L	Mmsbk	Sssp	fm	H	Gd	few fine root, fine mica flakes
	Bt2cv	70 – 140	10YR6/3	SCL	Sg	Vsvp	fm	H	-	few fine mica flakes
KBII	Pedon 1		Latitude	N11º 07□ 0□		Longitude	E7º 40□ 40□		Elevation 624m	
	Ap	0 – 50	10YR5/8	L	Scabk	Nsnp	fm	H	-	few fine root, fine mica flakes
	Pedon 2		Latitude	N11º 07□ 07□		Longitude	E7º 40□ 32□		Elevation 624m	
	Ap	0 – 40	10YR5/4	L	Sg	Nsnp	fm	Sh	Cw	common medium root.
	2Bt1	40 – 120	10YR6/2	SCL	Ma	Sssp	fm	H	-	few fine root

Table 4.1: Summary of soil morphological properties of the area Cont'd

Soil mapping Unit	Horizon	Depth (cm)	Munsell colour (moist)	Texture	Structure	Consistency			Boundary	Features
						Wet	Moist	Dry		
KBIII										
	Pedon 1		Latitude	N11º 07□ 19□		Longitude	E7º 40□ 29□		Elevation 625m	
	Ap	0 – 27	10YR5/3	L	Wfsbk	sssp	Fr	Sh	As	common coarse roots
	Bt1	27 -75	10YR4/3	L	Mmabk	sssp	Vfr	Sh	Gs	common fine roots
	Bt2	75 – 148	10YR5/4	SiL	Ma	sssp	Vfr	H	Gw	few fine roots, many termites holes
	Bt3cv	148 -165	10YR6/2	L	Ma	vsvp	Fm	H	-	iron and magnesium concretion
	Pedon 2		Latitude	N11º 07□ 9□		Longitude	E7º 40□ 39□		Elevation 623m	
	Ap	0 – 42	10YR4/4	L	Mfsbk	nsnp	Vfr	S	As	common medium root
	Bt1	42 – 70	10YR5/6	L	Mmsbk	nsnp	Vfr	Sh	Cw	channel voids, few fine mica flakes
	Bt2	70 – 120	10YR4/3	L	Smabk	sssp	Vfr	H	Gw	few fine root , few fine mica flakes
	BC	120- 170	10YR3/4	L	Scabk	sssp	Vfr	Vh	-	few fine root , few fine mica flakes
KBIV										
	Pedon 1		Latitude	N11º 07□ 03□		Longitude	E7º 40□ 44□		Elevation 621m	
	Ap	0 – 25	10YR5/4	SL	Sg	nsnp	Vfr	S	Aw	common medium roots and mica flakes
	BC	25 – 36	10YR4/4	SL	Sg	nsnp	L	S	Sw	few fine root , many fine mica flakes
	2Bt1	36 – 58	10YR4/6	SL	Sg	nsnp	Vfr	S	Sw	few medium root , many fine mica flakes
	2Bt2	58 – 90	10YR4/6	SL	Ma	sssp	Fm	S	Sw	few fine root , common coarse gravels
	2Bt3	90 – 135	10YR5/3	L	Ma	vsvp	Vfr	Sh	Sw	few fine root , few fine mica flakes
	2Cr	135 -145	10YR4/6	SL	Sg	nsnp	L	Sh	-	many coarse gravels and stones

Table 4.1: Summary of soil morphological properties of the study area Cont'd.

Soil mapping Unit	Horizon	Depth (cm)	Munsell colour (moist)	Texture	Structure		Consistency		Boundary	Features
						Wet	Moist	Dry		
	Pedon 2		Latitude	N11º 07□ 18□	Longitude	E7º 40□ 8□			Elevation 620m	
	Ap	0 -54	10YR5/4	L	Sg	Nsnp	vfr	S	As	many medium roots.
	Bt1	54 – 78	10YR4/4	L	Ma	Sssp	Vfr	S	Csg	few medium root,
	Bt2	78 – 122	10YR5/4	L	Ma	Sssp	Vfr	Sh	Gw	few fine mica flakes
	Bt3	122 –160	10YR5/3	SL	Ma	Sssp	Fm	Sh	-	few fine roots, few medium gravels
KBV										
	Pedon 1		Latitude	N11º 07□ 02□	Longitude	E7º 44□ 49 6□			Elevation 619m	
	Ap	0 -20	10YR4/6	L	Ma	Nsnp	Vfr	S	Aw	many fine roots
	Bt1	20 – 80	10YR6/3	L	Ma	Nsnp	Vfr	S	Cw	many fine mica flakes
	Cr	80 – 135	7.5YR5/8	SL	Sg	Nsnp	L	S	-	common medium gravels
	Pedon 2		Latitude	N11º 07□ 06□	Longitude	E7º 40□ 51□			Elevation 619m	
	Ap	0 – 40	10YR6/6	L	Sg	Nsnp	L	S	As	many fine roots,
	Bt1	40 – 135	10YR4/6	L	Ma	Sssp	Vfr	S	Gw	many fine mica flakes
	Bt2	135- 170	2.5YR4/2	L	Ma	Vsvp	Fm	S	-	many fine mica flakes

Source: Authors Field work (2014)

Legend

Horizon: Ap = plough layer, Bt = B horizon with silicate clay, C = C horizon, v = plinthite c = concretion

Texture: Sic = Silty clay, SiCL = silty clay loam, LS = Loamy Sand, L = Loam, SL = Sandy loam, S= sand and C = Clay

Structure: Wfcsb = Weak, fine, sub angular blocky, Mmabk=medium moderate angular blocky, Scabk=strong coarse angular blocky Ma = massive, Sg=single grain

Consistence Dry: L = Loose, Moist: fr = friable, vfr = Very friable, fi= Firm Consistence Wet: vs = very sticky, Ss = slightly sticky, s= sticky, and ns = non sticky

Plasticity: vp= very plastic, sp= slightly plastic, p= slightly plastic, np= non plastic.

Boundary Distinctiveness: a = abrupt, c = clear, g = gradual and d= diffuse, Boundary Topography: s = smooth, w = wavy and i = irregular

4.1.2 Soil depth

Soil mapping units KBI and KBIII on the upland were deep to very deep (140-170cm), KBII was shallow to deep (50 – 140cm), restriction to depth were as a result of hard pan and plinthite. The mapping units KBIV and KBV on the flood plain were deep to very deep (145cm to 170cm), restriction to depth were water table. The depth of all soil profiles would permit crop root proliferation and elongation since the hard pan and water table were deep enough not to constitute hindrance to root development except part of mapping unit KBII. The soil depth increased from the upland to flood plain.

4.1.3 Soil Colour

The most obvious feature of a soil layer is its colours. Soil colour may be inherited from the mineral parent material, from organic matter decomposition and drainage. Generally soil colour is generated by soil forming processes. The upland soil colour varied from dark yellowish brown (10YR4/4), strong brown (10YR5/8) to yellowish brown (10YR5/4) and brown (10YR5/3) to dark yellowish brown (10YR4/4) in surface horizon of mapping unit KBI, KBII and KBIII, while the flood plain soils varied from yellowish brown (10YR5/4) and dark yellowish brown (10YR4/6) to brownish yellow (10YR6/6) in surface horizon of the mapping unit KBIV and KBV respectively. The sub soils of uplands varied from strong brown (7.5YR5/6) to yellowish brown (10YR5/6), dark gray (10YR4/1) to light gray brown (10YR6/2), brown (10YR4/3) to yellowish brown (10YR5/6) on unit KBI, KBII, and KBIII. The flood plains varied from dark yellowish brown (10YR4/6) to yellowish brown (10YR5/4) and pale brown (10YR6/3) to dark gray brown (2.5YR4/2) on unit KBIV and KBV.

The upland soils were dominated by brown colour which could be attributed to oxidation state of the soils. The flood plain soils are brown to gray in colour which could be attributed to

poor drainage condition of the soils. The mottles observed on sub soil of the upland is an indication of soil wetness brought about by oxidation-reduction cycles due to ground water fluctuation (Malgwi, 2001; Babalola, Oso, Fasina and Godonu, 2011). Ahn (1970) reported inter-relationship between these features. The reduced Fe present in these soils impact grayish colour on the soil matrix.

4.1.4 Soil drainage

The soils were characterized by three different drainage classes based on their landscape position. The mapping unit KBI and KBII on the upland was well drain to imperfect drained which may be attributed to the upper to middle slope position while unit KBIII on the lower slope was imperfectly to poorly drained as evidenced by mottling and hard pan at 160cm depth which could be as a result of the lower slope position. The mapping unit KBIV and KBV on the flood plains were poorly drained which was as a result of the valley floor position which receives runoff of water and sediment from the upland. Atofarati *et al.* (2012) reported similar findings on soils of toposequence in Ile-Oluji, Ondo State, Nigeria. Soil mapping units KBI and KBII will support maize production, while KBIII will require drainage because maize is sensitive to water logging condition. KBIV and KBV will both support for rice production because rice is a water loving crop.

4.1.5 Structure

The upland soils were generally weak, fine to moderate sub-angular blocky to angular blocky structured on surface horizon of mapping unit KBI, KBII and KBIII, while structureless (single grain) characterized mapping unit KBIV and KBV on the flood plain soils. Sub soils of the upland are strong, fine to coarse sub-angular to angular blocky structures for unit KBI, KBII and KBII and structureless (massive) for unit KBIV and KBV on the flood plain (Table 4.1).

Blocky structure is often found in B horizons on the upland due to higher clay content (Singer and Munns, 1999). Structureless soils are said to be either massive or single-grained (Singer and Munns, 1999). The type found in the subsoil of unit KBI, KBII and KBIII on the upland were massive, which means that all of the particles were stuck together. There were no aggregates and no natural planes which may be caused by the presence of plinthites which had hardened irreversibly. Top soils of unit KBIV and KBV on the flood plain were structureless (single grain). The dominance of single grain structure could be as a result of low content of clay in the soils, which act as binding agent. These confirm findings of Shobayo (2010); Hussaini (2011) who reported subangular to angular soil structure on upland soils.

Generally the upland soils were structurally well developed than the flood plain which could be attributed to its high clay content. Subangular blocky to blocky structure of the upland is marginally suitable to maize due to moderate compaction which could hinder root growth and development. Single grain to massive structure of the flood plain is moderately suitable to rice crop since the surface soils will allow root penetration and development.

4.1.6 Consistency

Soil consistence comprises the attributes of soil materials that are expressed by the degree, kind of cohesion and adhesion or the degree of resistance to deformation or rapture. Mapping units KBI, KBII and KBIII on the uplands were generally slightly sticky and plastic (wet), very friable to friable (moist) and soft to hard (dry) in the surface horizon. The subsoil were slightly sticky to very sticky (wet), friable to very firm (moist) and hard to very hard (dry). The units KBIV and KBIV on the flood plain were non sticky and non-plastic (wet), very friable (moist) and soft (moist) on the surface while the sub soils were slightly sticky to sticky (wet), loose to firm (moist) and soft (dry). The upland soils were more sticky and hard than the flood plain which may be attributed to its high clay content. The increase in stickiness and hardness

down the profile might be attributed to the increase in clay content (Raji, 1995). Maniyunda (1999); Hussaini (2011) also reported increase in stickness and hardness down the profile. High clay content of upland soils will affect its workability and could cause compaction if tillage operation is not properly done. Flood plain soils are easily workable due to low clay content.

4.1.7 Horizonation

Generally, horizon differentiation between Ap and lower B horizons on the upland were quite clear due to mineralization from humufication of organic matter in the Ap of unit KBI and KBIII; except in part of KBII, where there were no clear horizonation and may be attributed to the young stage of the soils. The presence of clay cutans and mottling were helpful in horizon differentiation on the upland soils. Horizon boundaries in the top soils were abrupt smooth to wavy, clear smooth to wavy and gradual smooth to diffuse boundary. Mapping unit KBIV and KBV on the flood plains were characterized by wavy boundary which may be attributed to the irregular rate of eroded materials deposited.

4.1.8 Included materials

Presence of fine mica flakes and quartz grain in most of the mapping unit is an indication that the parent materials were derived from Basement Complex rocks containing mica (Ayolagha and Opene, 2012). The root ranged from many to few and fine. They decreased with increase in soil depth. Many roots were found in the surface horizons since it is the zone of active root activities. The upland soils were characterized by concretions which are few to many and coarse mostly in the B-horizons. Iron and magnesium nodules present in the subsoil of mapping unit KBI, KBII and KBIII on the upland have been reported as constituent of plinthite (Sivarajesingham *et a.,* 1962). Gravels were also few and either medium or coarse and like concretions were mostly confined to the B-horizons on unit KBV of floodplains. Tubular pores

(macro-micro) were present in the soils in both surface and sub-surface horizons; termite and ant holes were common features especially within the upper parts of the profiles, indicating that ants and termites contributed significantly to faunal pedoturbation in soils of both upland and floodplains.

4.2. Physical Properties

4.2.1. Particle size distribution

Gravels

Gravel content in the soils was insignificant. Soil mapping unit KBIV on flood plain recorded 200 g/kg of gravels in subsoils, while there was no gravel in the other mapping units.

Particle-size distribution of the soils was presented in Table 4.2 which constitutes the sand, silt and clay content of the soils.

Table 4.2 Physical properties of study area.

Soil Mapping Units	Horizon	Depth (cm)	Gravels	Sand (gkg^{-1})	Silt (gkg^{-1})	Clay (gkg^{-1})	Textural Class	Bulk Density ($mgcm^{-3}$)	Silt/Clay Ratio	Particle Density ($mgcm^{-3}$)	Total Porosity %
KB I											
	Pedon 1			Latitude	N11º 06□ □ 58□		Longitude	E7º 40□ 28□	Elevation 640.00m		
	Ap	0 – 21	-	430	460	110	Loam	1.59	4.18	2.65	40.00
	Bt1	21 – 114	-	410	380	210	Loam	1.45	1.81	2.65	45.28
	Bt2cv	114 -140	-	410	340	250	Loam	1.56	1.36	2.65	41.13
	Pedon 2			Latitude	N11º07□ 12□		Longitude	E7º 40□ 25□	Elevation 635.00m		
	Ap	0 – 40	-	510	360	130	Sandy Loam	1.48	2.77	2.65	44.15
	Bt1	40 – 70	-	410	360	230	Loam	1.52	1.57	2.65	42.64
	Bt2cv	70 – 140	-	530	240	230	Sandy Clay Loam	1.29	1.04	2.65	51.32
KB II											
	Pedon 1			Latitude	N11º 07□ 0□		Longitude	E7º 40□ 04□	Elevation 624.00m		
	Ap	0 – 50	-	410	380	210	Loam	1.44	1.81	2.65	45.66
	Pedon 2			Latitude	N11º 07□ 07□		Longitude	E7º 40□ 32□	Elevation 624.00m		
	Ap	0 -40	-	410	500	90	Loam	1.3	5.56	2.65	50.94
	2Bt1	40 – 120	-	510	280	210	Sandy Clay Loam	1.54	1.33	2.65	41.89

Table 4.2 Physical properties of the study area Cont'd.

Soil Mapping Units	Horizon	Depth (cm)	Gravels	Sand (gkg^{-1})	Silt (gkg^{-1})	Clay (gkg^{-1})	Textural Class	Bulk Density ($mgcm^{-3}$)	Silt/Clay Ratio	Particle Density $mgcm^{-3}$	Total Porosity %
KB III											
	Pedon 1			Latitude	N11º 07□ 19□		Longitude	E7º 40□ 29□	Elevation 625.00m		
	Ap	0 – 27	-	310	500	190	Loam	1.56	2.63	2.65	41.13
	Bt1	27 -75	-	310	500	190	Loam	1.51	2.63	2.65	43.02
	Bt2	75 – 148	-	210	560	230	Silt Loam	1.36	2.43	2.65	48.68
	Bt3cv	148 – 165	-	410	400	190	Loam	1.71	2.11	2.65	35.47
	Pedon 2			Latitude	N11º 07□ 09□		Longitude	E7º 40□ 39□	Elevation 623.00m		
	Ap	0 – 42	-	410	480	110	Loam	1.29	4.36	2.65	51.32
	Bt1	42 – 70	-	390	420	190	Loam	1.4	2.21	2.65	47.17
	Bt2	70 – 120	-	410	460	130	Loam	1.42	3.54	2.65	46.42
	Bt3cv	120 – 170	-	510	300	190	Loam	1.44	1.58	2.65	45.66
KBIV	Pedon 1			Latitude	N11º 07□ 02□		Longitude	E7º40□ 44□	Elevation 619.00m		
	Ap	0 – 25	-	620	280	100	Sandy Loam	1.67	2.8	2.65	100.00
	Bt1	25 – 36	-	630	260	110	Sandy Loam	1.44	2.36	2.65	36.98
	Bt2	36 – 58	-	610	280	110	Sandy Loam	1.44	2.55	2.65	45.66
	2Bt1	58 – 90	-	710	100	190	Sandy Loam	1.35	0.53	2.65	45.66
	2Bt2	90 – 135	-	350	460	190	Loam	1.45	2.42	2.65	49.06
	2Cr	135 – 145	-	710	200	90	Sandy Loam	1.41	2.22	2.65	45.28

Table 4.2 Physical Properties of the study area Cont'd.

Soil Mapping Units	Horizon	Depth (cm)	Gravels	Sand (gkg^{-1})	Silt (gkg^{-1})	Clay (gkg^{-1})	Textural Class	Bulk Density ($mgcm^{-3}$)	Silt/Clay Ratio	Particle Density ($mgcm^{-3}$)	Total Porosity %
	Pedon 2			Latitude N11º 07□ 18□			Longitude E7º 40□ 38□		Elevation 620.00m		
	Ap	0 -54	-	310	500	190	Loam	1.41	2.63	2.65	100.0
	Bt1	54 – 78	-	490	400	110	Loam	1.51	3.64	2.65	46.79
	Bt2	78 – 122	-	410	480	110	Loam	1.27	4.36	2.65	43.02
	Bt3	122-160	-	590	300	110	Sandy Loam	1.46	2.73	2.65	52.08
KB V											
	Pedon 1			Latitude N11º 07□ 02□			Longitude E7º 40 □ 49.6□		Elevation 619.00m		
	Ap	0 -20	-	410	480	110	Loam	1.6	4.36	2.65	100.00
	Bt1	20 – 80	-	410	500	90	Loam	1.61	5.56	2.65	39.62
	Cr	80 – 135	200	530	380	90	Sandy Loam	1.28	4.22	2.65	39.25
	Pedon 2			Latitude N11º 07□ 06□			Longitude E7º 40□ 51□		Elevation 619.00m		
	Ap	0 – 40	-	510	400	90	Loam	1.29	4.44	2.65	100.00
	Bt1	40 – 135	-	510	400	90	Loam	1.6	4.44	2.65	51.32
	Bt2	135- 170	-	410	400	190	Loam	1.47	2.11	2.65	39.62

Sand:

Sand fraction ranged from 410 to 530 gkg^{-1} (mean, 470 gkg^{-1}), 330 to 510 gkg^{-1} (mean, 420 gkg^{-1}) and 210 to 510 gkg^{-1} (mean, 360 gkg^{-1}) in the surface horizon of mapping unit KBI, KBII and KBIII on the upland,310 to 710 gkg^{-1} (mean, 510 gkg^{-1}) and 410 to 530 gkg^{-1} (mean, 470 gkg^{-1}) in unit KBIV and KBV on the flood plains. The mean sand content in sub soils was 440 gkg^{-1}, 415 gkg^{-1} and 373 gkg^{-1} for the upland, 549 gkg^{-1} and 465 $gkg^{-1}$for the flood plain. Sand fraction dominates the particle size distribution with the flood plain recording highest value. The high total sand content of the soils reflect granitic origin of parent materials (Wilson, 2010), and partly to geological processes involving sorting of soil materials by biological activities, clay migration through eluviation and illuviation, or surface erosion by runoff or their combinations (Malgwi *et al*., 2000; Akinbola, 2009). The mean sand fraction was significantly ($p<0.05$) higher on the flood plain than the upland. This could be attributed to eroded sediment deposited down slope. Aweto and Enaruvbe (2010) also reported higher sand value occurring in the lower slope soils of the catena. Sandy soils are easily worked, but with high rainfall may result to leaching of nutrient out of the pedon and easily eroded. Soils will also losse water easily due to large pore space, and might lead to water stress.

Silt Fraction:

Silt content was next to sand (Table 4.2), ranged between 240 and 460 gkg^{-1} (mean, 350 gkg^{-1}), 280 gkg^{-1} to 500 gkg^{-1} (mean, 390 gkg^{-1}) and 300 gkg^{-1} to 560 gkg^{-1} (mean, 430 gkg^{-1}), in mapping KBI, KBII and KBIII on the upland, 100 gkg^{-1} to 500 gkg^{-1} (mean, 300 gkg^{-1}), 380 gkg^{-1} to 500 gkg^{-1} (mean, 425 gkg^{-1}) in unit KBIV and KBV on the flood plain respectively. While the mean silt content in the sub soils were 330 gkg^{-1}, 295 gkg^{-1} and 440 gkg^{-1} on the upland, 326 gkg^{-1} and 420 gkg^{-1} on the flood plain. Soil unit KBIII on the upland which is located on the lower slope, recorded the highest silt value which could be attributed to fine sediments eroded

from upland to the lower slope position (Maniyunda and Gwari, 2014). The above finding was in contradiction with the result of Abdullahi (1997) and Ogbodo (2011) who reported higher silt content on the flood plain as compare to upland. This could be arributed to nature of parent material and stage of soil development. There was no significant ($p>0.05$) difference with silt content between the upland and flood plain. Silts are good soils for cultivation but prone to structural problems as such, the need for organic matter to stablized the soils.

Clay Fraction:

Clay content ranged from 110 gkg^{-1} to 130 gkg^{-1} (mean 120 gkg^{-1}), 90 gkg^{-1} to 210 gkg^{-1} (mean 150 gkg^{-1}) and 110 gkg^{-1} to 190 gkg^{-1} (mean of 150 gkg^{-1}) in the surface horizon of mapping unit KBI, KBII and KBIII on the upland, 90 gkg^{-1} to 190 gkg^{-1} (mean 140 gkg^{-1}) and 90 gkg^{-1} to 110 gkg^{-1} (mean of 100 gkg^{-1}) in unit KBIV and KBV on the flood plain. Mean clay content in the sub soils were 230gkg^{-1}, 290gkg^{-1} and 187gkg^{-1} on the upland, 124$gkg^{-1}$and 115gkg^{-1} on the flood plain. Clay content tends to increase with depth in all the soils indicating possible clay migration by eluviations – illuviation process within profile of the upland.

The upland soils were characterized by high clay content when compare with flood plain. Generally, values increased from A-horizon to B-horizons. The higher clay content often observed in subsurface horizons of many soils may be attributed to illuviation and pedoturbation processes (Malgwi, 2001). This confirms the presence of *argillic* horizons (accumulation of clay in B-horizon) in all the pedon on the upland. The lower clay content of the surface soil could be characteristic of soils formed on Basement Complex in Nigeria (Kparmwang, 1993; Lawal, Ojanuga, Tsado and Mohammed, 2013). This finding confirms the work of Mosugu (1989) which stated that the lower clay content of surface soils relative to the subsoils could also mean a more intensive chemical weathering at the subsoils relative to the surface soil. There was no significant ($p>0.05$) difference of the clay content between the upland and flood plain though the

clay content was higher on the upland soils. Clay soils are difficult to work, sticky and plastic when wet and prone to drainage problems, and hard when dry.

4.2.2 Silt/clay

The mean silt/clay ratio (Table 4.2) were 2.61, 3.2 and 3.11 in mapping unit KBI, KBII and KBIII on the upland, 2.45 and 3.85 in unit KBIV and KBV on the flood plain. Van Wambeke (1962) reported that "old" parent materials usually have a silt/clay ratio below 0.15 while silt/clay ratios above 0.15 are indicative of "young" parent materials. Results of this study show that, both upland and flood plain have silt/clay ratio above 0.15, indicating that they are relatively young with high degree of weathering potential. Silt/clay ratios have an irregular pattern. The decrease in silt/clay ratio with depth is an indication that subsoil horizons are more weathered than surface horizons. Yakubu (2006); Sharu *et al*., (2013) reported similar results on soils of Sokoto State. There was no significant ($p>0.05$) difference between the upland and flood plain though the flood plain recorded higher value which could be attributed to the young age of the soil. The silt/clay ratio shows that flood plains soils are younger than upland soils.

4.2.5 Bulk density

Bulk density (Table 4.2) mean values were 1.54 Mgm^{-3}, 1.37 $Mgm^{-3}$and 1.42 Mgm^{-3} in surface horizon of mapping unit KBI, KBII and KBIII on the upland, 1.54 Mgm^{-3} and 1.44 Mgm^{-3} in mapping unit KBIV and KBV on the flood plain. Corresponding, mean bulk densities for sub soil were 1.45 Mgm^{-3}, 1.66 Mgm^{-3} and 1.47 Mgm^{-3} on the upland, 1.41 Mgm^{-3} and 1.49 Mgm^{-3}on the flood plain. The bulk density values of surface horizon were lower than 1.6Mgm^{-3}, thus rated medium, a range considered not to impede root penetration (Donahue, Raymond and Schick, 1990). Therefore bulk density will not be a retarding factor for crop cultivation in the study area. Bulk density showed irregular pattern down the profile. The relatively high values of bulk

density on the upland were attributed to compaction by grazing animal and constand use of farm implements. There were no significant ($p>0.05$) difference between the soil bulk density of upland and flood plain, though the upland recorded higher value which could be attributed to compaction caused by grazing animals.

4.2.6 Soil porosity

The ranges in values of surface porosity were 40.0 to 44.15% (mean 42.08%), 45.66 to 50.94% (mean 43.3%) and 41.13 to 51.32% (mean 46.23%) in mapping unit KBI, KBII and KBIII on the upland, 36.98 to 46.76% (mean 41.89%) and 39.62 to 51.32% (mean 45.47%) in unit KBIV and KBV on the flood plain. Values for sub soil ranges from 45.21 to 46.98% (mean 45.09%), 32.83 to 41.89% (mean 37.36%) and 42.39 to 46.42% (mean 44.4%) on the upland, 46.49 to 46.67% (mean 46.58%) and 42.08 to 45.47% (mean 43.77%) on the flood plain.

The soils on the upland and flood plain were porous as Riue and Sposito (1991) recommended that soils having porosity of 45-50 percent by volume are good agricultural soils. Therefore, porosity is not a limiting factor in this present study since all the soils are within a range of 45-50%. Generally, the porosity increased with depth in unit KBI on the upland and KBIV on the flood plain which was as a result of better structural development in the subsoil while unit KBII and KBIII on the upland decreases with depth. This could be as a result of significant illuviation of clay in the units, thereby reducing the pore spaces (Sharu *et al.,* 2013). The low values in the surface horizon may be attributed to surface crust formation (Switzer and Pettry, 1992). There were no significant ($p>0.05$) difference between the soil porosity of upland and flood plain though the flood plain recorded higher value and it is attributed to lower clay content.

4.3 Chemical Properties

The parameters considered under chemical properties include pH, organic carbon (OC), total nitrogen (TN), available phosphorus (Ap), exchangeable bases (Ca, Mg, Na and K), exchangeable acidity (H+Al), cation exchange capacity (CEC), electrical conductivity (ECe), exchangeable sodium percentage (ESP), sodium absorption ratio (SAR), adjusted sodium absorption ratio (Adj SAR), carbonate (CO_3) and bicarbonate (HCO_3) and percentage base saturation (PBS). Data on soil chemical properties are given in Table 4.3

4.3.1 Soil pH

pH values in water of the upland soils (Table 4.3) ranged from pH 6.4 to 6.8 (mean pH 6.6), pH 6.5 to 6.8 (mean pH 6.65) and pH 6.4 to 6.8 (mean pH 6.6) in mapping unit KBI, KBII and KBIII on the upland, pH 6.9 (same value) and pH 6.3 to 6.5 (mean pH 6.4) in unit KBIV and KBV on the flood plain. Corresponding values in the subsoils varied from pH 6.65 to 6.75 (mean pH 6.7), pH 6.6 to 6.9 (mean pH 6.75) and pH 6.56 to 6.63 (mean pH 6.15) on the upland, pH 6.6 and pH 6.4 to 6.8 (mean pH 6.6) on the flood plains. Soil reaction was slightly acidic to neutral (malgwi, 2007). Similar result had been reported by Audu, Abdullahi, Noma, and Abdulaziz (2009); Lawal *et al.* (2012). These values are within the pH requirement for most arable crops for nutrient up take (Brady and Weil, 1999).

The pH values in most cases followed a regular pattern across soil units having pH values of surface soil were higher than the underlying subsoil horizons in both upland and flood plain. This may be attributed to influence of organic matter through biogenetic cycling of bases, a process which reduces acidification of soils (Jones and Wild, 1975; Mosugu, 1989; Maniyunda, 1999; Shobayo, 2010). There were no significant ($p>0.05$) difference between pH of the upland and flood plain, though the upland recorded higher value.

Table: 4.3 Chemical properties of soils of Kubanni Soils.

Soil Mapping Units	Horizon	Depth (cm)	pH H_2O	pH CaCl	O C	T N	C/N	Ap	Ca	Mg	K	Na	TEB	H+Al	CEC (cmol(+)/kg)	
					----g/kg---			mg/kg	---- ----------cmol(+)/kg---------					cmol(+)/kg	CEC	ECEC
KB I					Latitude	N11º 06□	57□	Longitude	E7º 40□	28□	Elevation	640m				
	Pedon 1															
	Ap	0 – 21	6.80	5.8	7.3	0.14	52.14	2.10	4.24	0.43	0.19	0.50	5.36	0.40	9.00	5.76
	Bt1	21-114	6.70	5.5	2.5	0.21	11.90	1.93	3.49	0.51	0.17	0.46	4.63	0.30	7.50	4.93
	Bt2cv	114-140	6.80	5.5	2.1	0.21	10.00	1.75	4.30	0.50	0.45	0.35	5.60	0.20	12.50	5.80
	Pedon 2				Latitude	N11º 07□	12□	Longitude	E7º 40□	25□	Elevation		635m			
	Ap	0 – 40	6.40	5.3	8.8	0.21	41.90	4.03	3.90	0.44	0.12	0.33	4.79	0.40	7.80	5.19
	Bt1	40 – 70	6.90	5.6	2.7	0.28	9.64	2.45	3.97	0.49	0.21	0.38	5.05	0.20	6.70	5.25
	Bt2	70 – 140	6.40	5.7	3.8	0.14	27.14	3.68	3.74	0.41	0.08	0.30	4.53	0.60	8.40	5.13
KB II																
	Pedon 1				Latitude	N11º 07□	0□	Longitude	E7º 40□	40□	Elevation		624m			
	Ap	0 – 50	6.80	5.6	1.9	0.14	13.57	2.10	4.46	0.49	0.16	0.33	5.44	0.40	13.90	5.84
	Pedon 2				Latitude	N11º 07□	07□	Longitude	E7º 40□	32□	Elevation		624m			
	Ap	0 -40	6.50	5.7	7.3	0.14	52.14	3.15	5.29	0.41	0.11	0.46	6.27	0.60	9.30	6.87
	2Bt	40-120	6.60	5.3	1.0	0.07	14.29	2.28	2.83	0.51	0.22	1.91	5.47	0.60	7.60	6.07

Table: 4.3 Chemical properties of Kubanni Soils Cont'd.

Soil Mapping Units	Horizon	Depth (cm)	pH H_2O	pH CaCl	O C g/kg	T N g/kg	C/N	Ap mg/kg	Ca	Mg	K	Na	TEB	H+Al	CEC (cmol(+)/kg)	
									---------cmol(+)/kg			-----	------	cmol(+)/kg	CEC	ECEC
KB III																
	Pedon 1				Latitude	N11º 07□	19□	Longitude	E7º 40□	29□	Elevation 625.m					
	Ap	0 – 27	6.80	5.5	6.5	0.14	46.43	2.10	5.51	0.46	0.18	0.52	6.67	0.20	11.90	6.87
	Bt1	27 -75	6.70	5.7	2.9	0.14	20.71	2.98	4.19	0.44	0.13	0.32	5.08	0.40	8.50	5.48
	Bt2	75 - 148	6.90	5.4	3.8	0.07	54.29	3.15	4.29	0.47	0.18	0.45	5.39	0.20	7.70	5.59
	Bt3c	148-165	6.30	5.3	3.8	0.14	27.14	2.28	3.96	0.46	0.18	0.49	5.09	0.60	8.70	5.69
	Pedon 2				Latitude	N11º 07□	09□	Longitude	E7º 40□	39□	Elevation 623.m					
	Ap	0 – 42	6.40	5.4	2.9	0.14	20.71	5.08	3.44	0.41	0.08	0.48	4.41	0.40	13.40	4.81
	Bt1	42 - 70	6.40	5.4	1.7	0.07	24.29	1.93	4.51	0.46	0.17	1.39	6.53	0.40	9.70	6.93
	Bt2	70 - 120	6.70	5.6	1.9	0.07	27.14	2.98	5.07	0.46	0.15	1.48	7.16	0.20	9.00	7.36
	Bt3c	120-170	6.60	5.7	3.1	0.14	22.14	3.15	3.32	0.41	1.23	1.74	6.70	0.40	8.20	7.10
KB IV																
	Pedon 2				Latitude	N11º 07□	2□	Longitude	E7º 40□	44□	Elevation 623.m					
	Ap	0 – 25	6.90	5.6	3.6	0.07	51.43	4.38	3.50	0.46	0.24	2.17	6.37	0.20	7.00	6.57
	Bt1	25 - 36	6.80	5.6	4.0	0.14	28.57	3.15	3.74	0.46	0.20	0.32	4.72	0.20	5.80	4.92
	Bt2	36 - 58	6.50	5.9	3.6	0.14	25.71	4.73	5.76	0.41	0.19	0.34	6.70	0.60	9.80	7.30
	2Bt1	58 - 90	6.30	5.8	3.4	0.14	24.29	4.90	4.30	0.43	0.19	0.30	5.22	0.80	8.30	6.02
	2Bt2	90 - 135	6.70	5.6	4.4	0.21	20.95	6.13	3.52	0.47	0.34	0.46	4.79	0.20	7.60	4.99
	2Cr	135-145	6.70	5.7	0.6	0.14	4.29	3.85	5.90	0.46	0.15	0.33	6.84	0.20	10.20	7.04

Table: 4.3 Chemical properties of Kubanni Soils Cont'd.

Soil Mapping Units	Horizon	Depth (cm)	pH	pH	O C	T N	C/N	Ap	Ca	Mg	K	Na	TEB	H+Al	CEC (cmol(+)/kg)	
			H_2O	CaCl	----g/kg-----			mg/kg	---------cmol(+)/kg---			-------		cmol(+)/kg	CEC	ECEC
	Pedon 2				Latitude N11º 07□ 18□			Longitude E7º 40□ 38□			Elevation 621m					
	Ap	0 -54	6.90	5.7	3.4	0.14	24.29	4.55	7.06	0.45	0.17	0.43	8.11	0.20	9.80	8.31
	Bt1	54 – 78	6.80	5.6	5.0	0.21	23.81	3.50	4.84	0.44	0.44	0.50	6.22	0.20	7.40	6.42
	Bt2	78 – 122	6.60	5.8	4.4	0.21	20.95	4.90	3.34	0.43	0.23	1.48	5.48	0.40	7.90	5.88
	Bt3	122 - 160	6.40	5.8	3.8	0.14	27.14	3.50	2.92	0.44	0.87	1.57	5.80	0.60	6.80	6.40
KB V																
	Pedon 1				Latitude N11º 07□ 02□			Longitude E7º 40□ 49□			Elevation 620m					
	Ap	0 -20	6.30	5.6	5.2	0.07	74.29	5.43	3.20	0.38	0.18	0.43	4.19	0.60	8.10	4.79
	Bt1	20 – 80	6.80	5.7	1.7	0.28	6.07	5.08	3.45	0.35	0.21	0.64	4.65	0.20	6.90	4.85
	Cr	80 – 135	6.80	5.8	1.7	0.28	6.07	6.65	4.29	0.40	0.14	0.34	5.17	0.20	7.20	5.37
	Pedon 2				Latitude N11º 07□ 06□			Longitude E7º 40□ 51□			Elevation 619m					
	Ap	0 – 40	6.50	5.7	4.6	0.21	21.90	7.00	5.48	0.41	0.36	0.52	6.77	0.40	8.20	7.17
	Bt1	40 – 135	6.30	5.7	5.2	0.21	24.76	4.03	5.37	0.48	0.23	0.37	6.45	0.40	9.50	6.85
	Bt2	135 - 170	6.50	5.8	5.7	0.14	40.71	5.43	5.58	0.44	0.21	0.78	7.01	0.60	8.70	7.61

Soil pH measured in 0.01N $CaCl_2$ was in all the mapping units lower than pH measured in water. Delta pH value [pH ($CaCl_2$) – pH (H_2O)] were therefore, negative in all cases. This indicates that the soils had net negative charge on their colloids (Uehara and Gillman, 1981; Kparmwang, 1993). The means of delta pH values for the entire profile were -1.1, -1.15, -1.1, -0.95 and -0.61.This indicates that the soil have high negative charge density on their colloids (Uehara and Gillman, 1981). Uehera and Gillman (1981) submitted that a positive, zero or small negative delta pH value (< -0.5) generally indicates a soil dominated by variable charge minerals. The soils under study had delta pH values greater than -0.5, and can be said to contain significant amounts of independent charge minerals or 2:1 clays.

4.3.2 Exchangeable Acidity (H^++Al^{3+})

Exchangeable acidity comprises exchangeable hydrogen and aluminium. The values were given in Table (4.3). The exchange acidity mean values were 0.4cmol(+)kg^{-1}, 0.5cmol(+)kg^{-1} and 0.5cmol(+)kg^{-1} in surface horizon of mapping unit KBI, KBII and KBIII on the upland, 0.2cmol(+)kg^{-1} and 0.5cmol(+)kg^{-1} in unit KBIV and KBV on the flood plains. The sub soil mean values were0.27cmol(+)kg^{-1}, 0.4cmol(+)kg^{-1} and 0.55cmol(+)kg^{-1} on the upland, 0.35cmol(+)kg^{-1} and 0.35cmol(+)kg^{-1} on the flood plain. Exchangeable acidity values were classified as generally low (<1.0cmol(+)kg^{-1}), and suggests that the soils have little or no acidity problems. Raji and Mohammed (2000) reported similar results and submitted that the contribution of exchange acidity to potential acidity is very low in soils of Nigerian savannas. The low exchangeable acidity could be a reflection of the low amount of exchangeable Al^{3+} and H^+ in the soils. Similar result was reported on the pattern of change in exchangeable acidity, though the value obtain in this present study is lower than the value submitted by Shobayo (2010) and Hussaini (2011). There was no significant ($p>0.05$) difference in exchangeable acidity between the upland and flood plain, though the upland recorded higher value.

4.3.3 Exchangeable Bases

The exchangeable bases comprised of exchangeable calcium, magnesium, potassium and sodium (Table 4.3). Calcium was the dominant exchangeable base in all the soils.

4.3.3.1 Exchangeable Calcium

The ranges in values for exchangeable Ca of surface soils ranged from 3.9 to 4.24 (mean, 4.07cmol(+)kg^{-1}), 4.46 to 5.29(mean, 4.87cmol(+)kg^{-1}) and 3.44 to 5.57 (mean 4.50cmol(+)kg^{-1}) in surface horizon of mapping unit KBI, KBII and KBIII on the upland,3.5 to 7.06 (mean 5.28cmol(+)kg^{-1}) and 3.2 to 5.48 (mean 4.34cmol(+)kg^{-1}) in unit KBIV and KBV on the flood plain. In the same order, subsoil values ranged from 3.85 to 3.89 (mean, 3.87cmol(+)kg^{-1}), 3.46 to 2.83(mean, 3.15cmol(+)kg^{-1}) and 4.14 to 4.3 (mean 4.22cmol(+)kg^{-1}) on the upland, 3.7 to 4.48 (mean 4.09cmol(+)kg^{-1}) and 3.87 to 5.47 (mean 4.67cmol(+)kg^{-1}) on the flood plain. The upland was rated medium while the flood plain was rated medium to high (Appendix C).

The low values obtained in some horizons may be due to cation removal by plant uptake or leaching. Generally, surface soils recorded higher values than underlying subsoils, which could be attributed to plant uptake and minimal leaching in the soils. This is contrary to Shobayo, (2010) who reported that the calcium content of surface horizon was lower than subsoils. Calcium was the dominant exchangeable base in all the soils. Similar result was reported by several researchers (Yaro, 2005; Hussaini, 2011; Singh *et al*., 2013). The predominance of Ca was partly due to exchange sites having high affinity for Ca (Esu, 1982) and also due to calcium bearing parent material (Nahusenay *et al.,* 2014). There was no significant ($p>0.05$) difference in exchangeable Ca between the upland and flood plain, though the flood plain recorded higher value which might be attributed to eroded material from the upland through surface wash.

4.3.3.2 Exchangeable sodium (Na)

Exchangeable sodium (Na) ranked next to calcium on the exchange site, the ranges in values for exchangeable Na of surface soils were 0.33 to 0.5 (mean, 0.42cmol(+)kg^{-1}), 0.33 to 0.46(mean, 0.4cmol(+)kg^{-1}) and0.48 to 0.52 (mean 0.5cmol(+)kg^{-1}) on the surface horizon of mapping unit KBI, KBII and KBIII on the upland, 0.43 to 2.17 (mean 1.3cmol(+)kg^{-1}) and 0.43 to 0.52 (mean 0.47cmol(+)kg^{-1}) in unit KBIV and KBV on the flood plain. The subsoil values ranged from 0.34 to 0.4 (mean, 0.37cmol(+)kg^{-1}), 3.04 to 1.91(mean, 2.47cmol(+)kg^{-1}) and 0.42 to 1.53 (mean 0.97cmol(+)kg^{-1}) on the upland, 0.35 to 1.18 (mean 0.76cmol(+)kg^{-1}) and 0.49 to 0.57 (mean 0.53cmol(+)kg^{-1}) on the flood plain.

The soils were rated high for both upland and flood plains. The values of Na content were irregularly distributed within the soils. Generally, the subsoils had higher value than the surface horizons which could be attributed to leaching of basic cation down the profile. The higher value of Na could distroy soil structure. This findings was in contradiction to most study in the area, but similar to the report of Malgwi, (2001) in Kano and Babalola *et al.*, (2011) in Kogi and Ekiti who reported higher Na and attributed it to the nature of parent material in the location and low quality of irrigation water. There was no significant ($p>0.05$) difference in exchangeable Na between the upland and flood plain; though the upland recorded higher value which could be as a result of available moisture which dissolve the Na of the flood plains into the river.

4.3.3.3 Exchangeable magnesium (Mg)

Exchangeable Magnesium (Mg) ranked next to sodium on the exchange site. The ranges in value for exchangeable Mg of surface soils were 0.43 to 0.44(mean, 0.44cmol(+)kg^{-1}), 0.41 to 0.49 (mean, 0.45cmol(+)kg^{-1}) and 0.41 to 0.46 (mean 0.44cmol(+)kg^{-1}) in mapping unit KBI,

KBII and KBIII on the upland, 0.45 to 0.46 (mean 0.45cmol(+)kg^{-1}) and 0.38 to 0.41 (mean 0.4cmol(+)kg^{-1}) in unit KBIV and KBV on the flood plain. The subsoil values ranged from 0.45 to 0.51 (mean, 0.48cmol(+)kg^{-1}), 0.51 to 0.56 (mean, 0.53cmol(+)kg^{-1}) and 0.43 to 0.45 (mean 0.44cmol(+)kg^{-1}) on upland and 0.43 to 0.44 (mean 0.44cmol(+)kg^{-1}) and 0.37 to 0.46 (mean 0.41cmol(+)kg^{-1}) on the flood plain.

Magnesium values were generally rated medium range for both upland and flood plain (Appendix C). Similar result was reported by Odunze and Kureh (2009) on soils of Zaria. However, Mg content generally increased with depths and was attributed to leaching of basic cations down the profile. The range in value of magnesium were moderate and will not affect plant growth as Garcia (2003) reported that high accumulation of Mg in the soil may cause deterioration of soil structure, lower water intake rates and affect chemical and biological properties of the soil. There was no significant ($p>0.05$) difference in exchangeable Mg between the upland and flood plain, though the upland recorded higher value similar to Na.

4.3.3.4 Exchangeable potassium (K)

Exchangeable potassium (K) ranked next to Mg and range from 0.12 to 0.19 (mean, 0.15cmol(+)kg^{-1}), 0.11 to 0.16 (mean, 0.14cmol(+)kg^{-1}) and 0.08 to 0.18 (mean 0.11cmol(+)kg^{-1}), in surface horizon of mapping unit KBI, KBII and KBIII on the upland, 0.17 to 0.24 (mean 0.21cmol(+)kg^{-1}) and 0.18 to 0.36 (mean 0.27cmol(+)kg^{-1}) in KBIV and KBV on the flood plain. The subsoil values ranged from 0.31 to 0.15(mean, 0.23cmol(+)kg^{-1}), 0.22 to 0.34 (mean, 0.28cmol(+)kg^{-1}) and 0.18 to 0.52 (mean 0.35cmol(+)kg^{-1}) on upland and 0.22 to 0.51 (mean 0.37cmol(+)kg^{-1}) and 0.18 to 0.22 (mean 0.2cmol(+)kg^{-1}) on the flood plain.

The K content for surface soils was rated low for upland soils while the flood plain was rated medium. The subsoils were rated medium to high (Appendix C). The K values for surface

soils were generally lower than the underlying subsoil horizon values which could be attributed to leaching and uptake by plants. This is similar to the findings of Hussaini (2011) and Maniyunda and Gwari (2014) but contrary to Shobayo, (2010) who reported that the surface value of K were higher than the subsoils because the exchangeable K could likely be contributed by organic matter in the surface soils. There was no significant ($p>0.05$) difference in exchangeable K between the upland and flood plain, though the flood plain recorded higher values attributed to eroded material deposited on the flood plain.

Generally, exchangeable bases occurred in the order $Ca^{2+}> Na^{+}> Mg^{2+}> K^{+}$. This result is different from the results of other researchers within the study area due to the high content of sodium in the soils of the present study but was similar to the finding of Malgwi (2001) on salt affected soils in Kano. These show that Zaria soils are now affected by salt accumulation. Therefore, good soil management practices have to be put in place to reduce its side effect on crop. The exchangeable bases were generally medium to high indicating moderate basic nutrient status of the soils. The relatively higher values of exchangeable bases at the surface soil were attributed to application of crop residues as manure, considering the coarse texture of the soils which makes them prone to leaching. For the soil as a whole (upland and flood plain), exchangeable bases were medium to high, losses of nutrients by leaching was moderate in the study area.

The range in values for total exchangeable bases (TEB) of surface soils were 4.79 to5.36 (mean, 5.07cmol(+)kg^{-1}), 5.44 to 6.27 (mean, 5.85cmol(+)kg^{-1}) and 4.41 to 6.67 (mean, 5.54cmol(+)kg^{-1}) in mapping unit KBI, KBII and KBIII on the upland, 6.37 to 8.11 (mean, 7.27cmol(+)kg^{-1}), and 4.19 to 6.77 (mean, 5.48cmol(+)kg^{-1}) in unit KBIV and KBV on the flood plain. Subsoil values ranged from 4.79 to5.11 (mean, 4.95cmol(+)kg^{-1}), 4.7 to 5.47 (mean, 5.08cmol(+)kg^{-1}) and 5.18 to 6.8 (mean, 5.98cmol(+)kg^{-1}) on the upland, 5.65 to 5.83 (mean,

5.74cmol(+)kg^{-1}) and 4.91 to 6.73 (mean, 5.82cmol(+)kg^{-1}) on the flood plain. It was observed that the total exchangeable bases in most cases decreased with depth which may be attributed to loss by erosion and uptake by plants. Similar findings were reported by Raji *et al.* (1996); Nwaka and Kwari (2000); Shobayo, (2010). There was no significant ($p>0.05$) difference in exchangeable base between the upland and flood plain, though the flood plain recorded higher value which might be attributed to eroded sediment from the upland during surface wash/colluviation and deposited on the flood plain.

4.3.4 Cation exchange capacity (CEC)

The mean value of cation exchange capacity (Table 4.3) were 8.40cmol(+)kg^{-1}, 11.60cmol(+)kg^{-1} and 12.65cmol(+)kg^{-1} in surface horizon of mapping unit KBI, KBII and KBIII on the upland, 8.40cmol(+)kg^{-1} and 8.15cmol(+)kg^{-1}in unit KBIV and KBV on the flood plain. While the subsoil values were8.78cmol(+)kg^{-1}, 9.15cmol(+)kg^{-1} and 8.63cmol(+)kg^{-1} for upland and 7.85cmol(+)kg^{-1} and 8.08cmol(+)kg^{-1} for flood plain. CEC were rated medium to high based on the findings of Adepetu, Aduagi, and Alofa (1979) who reported CEC values of < 6, 6 - 12 and > 12 cmol(+)kg^{-1} as low, medium and high respectively. The CEC values of the upland soils were rated medium to high which could be attributed to high clay content while the flood plain were rated medium (Table 4.3). Low to moderate CEC values were reported to be an indication of dominance of sesquioxide and kaolinitic clays in the fine earth fractions (Ojanuga and Awujoola, 1981; Tan, 2000). Surface values were rated medium to high and subsurface was rated medium. This might be a reflection of the intensity of weathering that produced the soils.

The exchange sites were dominated by Ca followed by Na, probably because of soils' affinity for these cations. Similar findings were reported by Ita and Esu (2012) on coastal plain sand in southeastern Nigeria. The high CEC values of A-horizons may be attributed to low leaching in the study area. The slight increase down the profiles was as a result of increase in

clay content. The CEC correlated positively with clay (r = 0.16) (Table 4.4) indicating that clay was a major contributor to the CEC of the soils. Generally, effective CEC (ECEC) followed the same pattern as that of CEC (NH_4OAc) whose values decreased with depth. There was no significant ($p>0.05$) difference in CEC between the upland and flood plain, though the upland recorded higher value, which could be attributed to the high clay on the upland soils (Aweto and Enaruvbe, 2010).

The ranges in values for effective cation exchange capacity (ECEC) of surface soils were 5.19 to 5.76 (mean, 5.48cmol(+)kg^{-1}), 5.84 to 6.87 (mean 6.36cmol(+)kg^{-1}) and 6.87 to 4.81 (mean 5.84cmol(+)kg^{-1}) in surface horizon of unit KBI, KBII and KBIII on the upland, 6.57 to 8.31(mean 7.44cmol(+)kg^{-1}) and 4.79 to 7.14 (5.98cmol(+)kg^{-1}) in unit KBIV and KBV on the flood plain. The subsoil values ranged from 5.19 to 5.37 (mean, 5.28cmol(+)kg^{-1}), 6.07 to 7.6 (mean 6.84cmol(+)kg^{-1}) and 5.59 to 7.13(mean, 6.63cmol(+)kg^{-1}) on the upland and 6.05 to 6.23(mean, 6.14cmol(+)kg^{-1}) and 5.11 to 7.23 (mean 6.17cmol(+)kg^{-1}) on the flood plain. The mean results show that both upland and flood plain are rated medium (Appendix C). CEC values (i.e. CEC-NH_4OAc) were higher than effective CEC values (Table 4.3). This trend was attributed to the CEC of tropical soils being highly pH dependent; i.e., it increased with pH (Balasubramanian, Singh and Mokwunye, 1984). This might be attributed to the pH of soils (pH< 7), since ECEC measures charge at the soil pH, whereas the CEC-NH_4OAc measures the charge on the soil colloids at pH 7. There was no significant ($p>0.05$) difference between the ECEC of the upland and flood plain, though the flood plain recorded higher value. .

Table 4.4 Correlation matrix of physico-chemical properties study area.

	Sand	Silt	Clay	pH	TEA	TEB	CEC	BS	OC	TN	Ap	Fe	Mn	Cu
Silt	-0.8**													
Clay	-0.46*	-0.12												
pH	-0.3	0.12	0.22											
TEA	0.27	-0.17	-0.03	0.81**										
TEB	-0.03	-0.05	-0.07	0.18	-0.13									
CEC	-0.3	0.15	0.16	-0.13	0.12	0.42								
BS	0.25	-0.16	-0.24	0.29	-0.23	0.51*	0.51*							
OC	0.02	0.28	-0.27	-0.29	0.29	-0.08	-0.1	0						
TN	0.12	0.04	-0.23	0.05	-0.22	-0.28	-0.29	-0.03	0.14					
Ap	0.24	0.09	-0.56*	-0.25	0.08	-0.01	-0.15	0.17	0.3	0.27				
Fe	0.34	-0.03	-0.54*	-0.24	0.16	0.26	-0.18	0.43	0.48*	0.02	0.72**			
Mn	0.23	0	-0.37	-0.41	0.29	0.17	-0.06	0.25	0.61**	-0.09	0.54*	0.85**		
Cu	-0.05	0.04	-0.05	0.08	-0.09	0.32	0.11	0.16	0.14	0.02	0.35	0.45*	0.39	
Zn	0.22	-0.09	-0.19	-0.3	0.23	0	0.29	-0.29	0.44	0.19	0.39	0.3	0.43	0.48*

Level of Significance * = P 0.05, ** = P 0.01

4.3.6 Organic carbon

Organic carbon (OC) content of the soils (Table 4.3) ranged from 7.3 to 8.8 (mean 8.1gkg^{-1}), 1.9 to 7.3 (mean 4.6gkg^{-1}) and 2.9 to 6.5 (4.7gkg^{-1}) in surface horizon of mapping unit KBI, KBII and KBIII on the upland, 3.4 to 3.6 (3.5gkg^{-1}) and 4.6 to 5.2 (4.9gkg^{-1}) in unit KBIV and KBV on the flood plain. Subsoil values ranged from 2.3 to 3.3 (2.8gkg^{-1}), 1gkg^{-1} and 2.2 to 3.5 (2.9gkg^{-1}) on upland, 3.2 to 4.4 (3.8gkg^{-1}) and 1.7 to 5.5 (3.6gkg^{-1}) on the flood plain. Organic carbon contents for all the soils were rated low. Organic carbon was generally very low on both upland and flood plain which may be partly due to effect of land use activities and high temperature which favours rapid mineralization of organic matter (Fasina, 1999).

Furthermore, low organic matter content of the soils was attributed to continuous cultivation and addition of organic residues which determines organic matter content in soils is low and their loss through mineralization is high (Binns, Machonachie and Tanko, 2003). The organic carbon decreased sharply down the profiles which may be attributed to immobilization of organic matter by clay in the Ap horizons in forms of organo-clay-complexes (Kparmwang, 1993; Maniyunda, 1999; Shobayo, 2010). There was no significant ($p>0.05$) difference between the O.C of the upland and flood plain though the upland recorded higher value which could be attributed to its higher clay content. Clayey soils generally tend to contain higher organic matter because of the tendency of clay to slow down microbial degradation of organic matter as clay-hums complexes with organic matter (Brady and Weil, 1999). Total nitrogen (TN) shows a positive correlation with organic carbon (Table 4.4), implying that organic matter was the major source of TN in the soils investigated. This is supported by the findings of Lawal *et al.* (2012) that organic matter accounts for between 90 and 98 % of soil nitrogen.

The low organic matter content recorded on the average for the soils cannot sustain crop production on a long term basis under continuous crop production. Therefore, organic matter has

to be substantially increased through effective crop residue management, increased use of leguminous plant as well as the use of nitrogenous and phosphate fertilizers. Maniyunda (1999); Odunze (2006); Shobayo (2010); Maniyunda and Gwari (2014) also reported low organic carbon for soils in the Northern Guinea savanna.

4.3.7Available Phosphorus (Ap)

Available phosphorus content of the soils varied from 2.1 to 4.03 (mean 3.07mgkg^{-1}), 2.1 to 3.15 (mean 2.63mgkg^{-1}) and 2.10 to 5.08 (mean 3.59mgkg^{-1}) in surface horizon of mapping unit KBI, KBII and KBIII on the upland, 4.38 to 4.55 (mean 4.47mgkg^{-1}) and 5.43 to 7.0 (6.22mgkg^{-1}) in unit KBIV and KBV on the flood plain. The subsoil values ranged from 1.84 to 3.07 (mean 2.45mgkg^{-1}), 2.28 to 2.98 (mean 2.63mgkg^{-1}) and 2.69 to 2.8 (mean 2.75mgkg^{-1}) on upland and 3.97 to 4.55 (mean 4.26mgkg^{-1}) and 4.73 to 5.87 (mean 5.3mgkg^{-1}) on the flood plain (Table 4.3).

The Ap were rated low in both upland and floodplain soils. It was observed that phosphorus content decreased with depth and appreciable quantities were found only at the top soils. However, the irregular pattern in accumulation of phosphorus at the surface; a pronounced occurrence in the savanna was attributed to decrease in the return of P to soil surface as the vegetation becomes sparser (Mosugu, 1989; Raji *et al*., 1996). The values were lower than those reported by Ogban *et al.,* (1999) for soils of the South-Eastern Nigeria, and might be due to enhanced recycling in the more luxurious forest vegetation. The higher available P content in the surface horizons of the soils could be due to the high organic carbon in the Ap horizons contained organic based available P. The flood plain had significantly ($p<0.05$) higher phosphorus value than the upland which could be attributed to high rate mineralization of organic carbon due to low clay content in the flood plain. The trend in distribution of available P

also shows a positive correlation with organic carbon (Table: 4.4), this support the fact that available P is largely released from organic matter.

4.3.8 Total nitrogen (TN)

Total nitrogen content in the soils (Table 4.3) ranged from 0.14 to 0.21g/kg (mean 0.2 g/kg), 0.14 g/kg and 0.14 g/kg in surface horizon KBI, KBII and KBIII on the upland, 0.07 to 0.14 g/kg (mean 0.11 g/kg), 0.07 to 0.21 g/kg (mean 0.14 g/kg) in unit KBIV and KBV on the flood plain. The mean subsoil values were 0.2 g/kg, 0.7 g/kg and 0.11 g/kg on the upland, 0.2 g/kg and 0.23 g/kg on the flood plain. The values were rated very low for both upland and flood plain (Appendix C) with higher values concentrating at the surface soils. Total N is mobile in soils, as a result its losses through various mechanism like NH_3 volatilization, succeeding denitrification, chemical and microbial fixation, leaching and runoff results in residual/available N becomes poor in soils (Awanish, Mishra, Srivastav and Rakesh, 2014). Similar results of low N values were reported by Hussaini (2011); Maniyunda (2014) in Zaria, and Sharu *et al.*, (2013) in Sokoto State. Total nitrogen values of the soils changed irregularly with depth which could be attributed to influence of continuous cultivation, a common practice that is accompanied by crop residue removal (Noma *et al,*. 2011). There was no significant ($p>0.05$) difference between the TN of the upland and flood plain, though the flood plain recorded higher value similar to Ap and could be attributed to high rate mineralization of organic carbon due to low clay content in the flood plain as organic carbon is major source of phosphorus.

The carbon nitrogen ratio (C/N) is an indication of the extent of decomposition organic matter and release of nutrient such as nitrogen. The C/N for the surface soils were 52.14 to 41.9 (mean 47.02) over 10.95 to 18.39 (14.67) subsoil. There was decrease in C/N ratio with increase in soil depth. The low value of the subsoils was attributed to plant uptake. The general low value

of C/N was due to low surface organic matter content and leaching (Jones and Wild, 1975). There were no significant (P>0.05) difference of C/N between the upland and floodplain soils.

4.3.9 Micronutrient Levels in the Soils

The values of micronutrient determined in the soils are presented in Table 4.5. The micronutrients considered include copper, zinc, manganese, iron and boron. Of the five extractable micronutrient elements determined, extractable iron (Fe) content was highest in the soil. Extractable manganese (Mn) ranked next, followed by extractable zinc (Zn), then extractable copper (Cu) and extractable boron (B) was found to be lowest in the soils. The nutrients were found to occur in the order: Fe > Mn > Zn > Cu > B in the soils. Similar report was submitted by Shobayo (2010) and Hussaini (2011) in Zaria.

Table: 4.5 Profile Distribution of Micronutrients in the study area.

Soil Mapping Units	Horizon	Depth (cm)	Fe	Mn	Cu	Zn	B
			---	---	mg/kg	---	---
KB I							
		Latitude	N11º 06□ 58□		Longitude	E7º 40□ 28□	Elevation
	Pedon 1	640m					
	Ap	0 – 21	22.68	9.30	2.23	2.90	1.70
	Bt1	21 – 114	17.80	4.96	2.07	2.16	1.36
	Bt2cv	114 -140	20.58	2.73	2.18	2.41	1.36
		Latitude	N11º 07□ 12□		Longitude	E7º 40□ 25□	Elevation
	Pedon 2	635m					
	Ap	0 – 40	56.22	23.58	1.96	4.66	2.44
	Bt1	40 – 70	17.80	2.80	2.07	1.18	0.95
	Bt2	70 – 140	37.92	11.73	2.29	12.68	1.36
KB II							
		Latitude	N11º 07□ 0□		Longitude	E7º 40□ 40□	Elevation
	Pedon 1	624m					
	Ap	0 – 50	28.78	9.63	2.18	4.00	1.36
		Latitude	N11º 07□ 7□		Longitude	E7º 40□ 32□	Elevation
	Pedon 2	624m					
	Ap	0 -40	90.36	11.26	2.08	2.65	1.36
	2Bt1	40 – 120	19.02	5.37	1.85	Trace	0.75

Table: 4.5 Profile Distributions of Micronutrients in the study area Cont'd.

Soil Mapping Units	Horizon	Depth (cm)	Fe	Mn	Cu	Zn	B
			----------	----------	mg/kg	----------	----------
KB III							
	Pedon 1	Latitude	N11º 07□ 19□	Longitude	E7º 40□ 29□	Elevation 625m	
	Ap	0 – 27	60.48	14.64	2.07	2.89	1.97
	Bt1	27 -75	34.87	10.04	1.96	0.00	1.08
	Bt2	75 – 148	37.92	9.30	2.07	0.00	1.97
	Bt3c	148 - 165	17.15	3.40	1.85	1.67	1.70
	Pedon 2	Latitude	N11º 07□ 9□	Longitude	E7º 40□ 39□	Elevation 623m	
	Ap	0 – 42	36.70	13.50	1.85	3.14	1.29
	Bt1	42 – 70	38.53	16.67	1.96	0.00	0.95
	Bt2	70 – 120	51.34	11.60	2.29	0.69	1.15
	Bt3c	120 – 170	81.82	10.92	2.18	0.00	1.36
KB IV							
	Pedon 1	Latitude 621.00m	N11º 07□ 02□	Longitude	E7º 40□ 44□	Elevation	
	Ap	0 – 25	239.75	21.48	2.18	2.26	1.63
	Bt1	25 – 36	135.48	19.18	1.96	0.21	1.97
	Bt2	36 – 58	186.10	25.07	2.18	1.55	1.70
	2Bt1	58 – 90	146.46	19.52	2.28	7.30	0.95
	2Bt2	90 – 135	122.68	21.21	2.72	2.40	1.56
	2Cr	135 – 145	37.92	9.30	2.28	12.18	1.36

Table: 4.5 Profile Distribution of Micronutrients in the study area Cont'd.

Soil Mapping Units	Horizon	Depth (cm)	Fe	Mn	Cu	Zn	B
			----------	----------	mg/kg	----------	----------
		Latitude N11º 07□ 18□ Longitude E7º 40□ 38□ Elevation 620m					
	Pedon 2						
	Ap	0 -54	90.97	15.86	2.61	2.53	0.88
	Bt1	54 – 78	109.27	25.34	2.40	12.06	1.25
	Bt2	78 – 122	116.58	19.85	2.28	3.38	0.75
	Bt3	122 – 160	101.95	21.21	2.18	0.45	1.76
KB V							
		Latitude N11º 07□ 49□ Longitude E7º 40□ 49□ Elevation 619m					
	Pedon 1						
	Ap	0 -20	142.80	25.27	2.61	6.20	1.49
	Bt1	20 – 80	69.63	6.85	2.40	1.30	0.68
	Cr	80 – 135	55.61	3.06	1.96	Trace	1.49
	Pedon 2	Latitude N11º 07□ 6□ Longitude E7º 40□ 51□ Elevation 619m					
	Ap	0 – 40	141.58	17.48	2.17	4.85	2.31
	Bt1	40 – 135	177.56	26.70	2.50	4.48	0.95
	Bt2	135 – 170	248.90	44.57	3.16	7.05	2.03

4.3.9.1 Iron

The 0.1*M* HCl extractable iron (Fe) content in the soils (4.5) varied from 22.68 to 56.22 (mean 39.45mgkg^{-1}), 28.78 to 90.36 (mean 59.57mgkg^{-1}) and 36.7 to 60.48 (mean 48.59mgkg^{-1}) surface horizon of mapping unit KBI, KBII and KBIII on the upland, 90.94 to 239.75 (mean 165.36mgkg^{-1}) and 141.58 to 142.8 (mean 142mgkg^{-1}) in unit KBIV and KBV on the flood plain. The subsoil values ranged from 19.19 to 27.86 (mean 23.53mgkg^{-1}), 19.02 to 25.12 (mean 22.07mgkg^{-1}) and 29.98 to 57.23 (mean 43.61mgkg^{-1}) on the upland and 109.27 to 125.73 (mean 117.5mgkg^{-1}) and 62.62 to 213.23 (137.93mgkg^{-1}) on the flood plain. The soils were rated very high in iron content being generally > 4.5 mgkg^{-1} (Appendix C).

The high Fe content obtained is probably largely neoformed from the transformation product of biotite mica as a result of the geological formation of the study sites been basement complex origin. The values obtained were far above the critical levels of 3.0 to 4.5mgkg^{-1} (Sillanpa, 1982). Generally, extractable iron decreased down the profiles (Table 4.4), which could be as a result of decrease in organic carbon. Generally, the availability of micronutrients is influenced with increase in organic matter, because organic matter helps to protect the oxidation and precipitation of micronutrients into unavailable forms and supply soluble chelating agents which increase the solubility of micronutrient contents. Therefore, the soils were sufficiently supplied with iron with very little chances of deficiency. The result obtain were similar to the report of Odunze and Kureh, (2009); Shobayo (2010); Hussaini (2011) in the study area though the present study recorded higher values than the previous researchers. However the presence of Fe in high concentrations in soils could lead to its precipitation and accumulation and upon complex chemical reactions, lead to the formation of plinthites (laterite). This upon alternate wetting and drying could irreversibly form hard indurated material (petrophlintite or ironstone)

which could restrict root penetration and drainage(Ibrahim and Abubakar, 2013).The flood plains had significant ($p<0.05$) higher Fe value than the upland which could be attributed to high moisture content on the flood plain. Banjoko and Ashaye (1981) reported that soils in southwestern Nigeria extractable iron content decreases drastically when dried.

4.3.9.2 Manganese

The ranges in values for extractable Mn of surface soils ranged from 9.3 to 23.58 (mean, 16.44mgkg^{-1}), 9.63 to 11.26 (mean 10.45mgkg^{-1}) and 13.5 to 14.64 (mean 14.07mgkg^{-1}) in mapping unit KBI, KBII and KBIII on the upland, 15.86 to 21.48 (mean 18.67mgkg^{-1}) and 25.27 to 17.48 (mean 21.38mgkg^{-1}) in unit KBIV and KBV on the flood plain. The subsoil values ranged from 3.85 to 7.27 (mean 5.56mgkg^{-1}), 5.37 to 8.82 (mean 7.1mgkg^{-1}) and 7.58 to 13.06 (mean 10.32mgkg^{-1}) on the upland, 18.86 to 22.13 (mean 20.49mgkg^{-1}) and 4.96 to 35.64 (mean 20.30mgkg^{-1}) in unit KBIV and KBV on the flood plain.

The soils are rated high in Mn content as the critical deficiency of Mn ranges between 1 mgkg^{-1}, for low and 5 mgkg^{-1}for high (Esu, 1991), similar to iron. However, the moderate to high Fe and Mn content of the soils may account for the observed Fe and Mn oxides nodules and concretions found in the upland soils (Odunze and Kureh, 2009). Extractable Mn in the soils decrease with depth (Table 4.5). The sharp decrease in Mn content in pedon from the surface soil may be attributed to the greater contribution by soil organic matter (Shobayo 2010). The flood plain had significant ($p<0.05$) higher Mn value than the upland which could be attributed to contribution of eroded materials from the upland to the flood plain.

4.3.9.3 Copper

Extractable copper content in the soils averaged 1.96 to 2.23 (mean 2.1mgkg^{-1}), 2.08 to 2.18 (mean 2.13mgkg^{-1}) and 1.85 to2.07 (mean 1.96mgkg^{-1}) in mapping unit KBI, KBII and

KBIII on the upland, 2.18 to 2.61(mean 2.4mgkg^{-1}) and 2.17 to 2.61 (mean 2.39mgkg^{-1}) in unit KBIV and KBV on the flood plain. The subsoil values ranged from 2.13 to 2.18 (mean 2.15mgkg^{-1}), 1.85 to3.05 (2.45mgkg^{-1}) and 1.96 to 2.14 (mean 2.05mgkg^{-1}) on upland and 2.28 to 2.29 (2.29mgkg^{-1}) and 2.18 to 2.83 (2.51mgkg^{-1}) on the flood plain. The values were rated high for the upland and flood plain. Extractable copper content in the Ap horizons of soils were lower than subsoils except in KBIV and KBV on the flood plain where extractable copper contents of the soil increased down the profile and could be attributed to contribution of surface washed materials deposited (Table 4.5). This confirms results of Odunze and Kureh (2009) who reported high cupper content but different from reported of Shobayo (2010) who reported trace amount of extractable copper in soils and opined that Cu rarely occur in acid soils unless native reserves are very low. The flood plain had significant ($p<0.05$) higher Cu value than the upland which could be attributed to contribution of eroded materials from the upland to the flood plain similar to Fe and Mn.

4.3.9.4 Zinc

Extractable zinc in surface soils ranged from 2.9 to 4.66 (mean 3.78mgkg^{-1}), 2.65 to 4.0 (3.33mgkg^{-1}) and 2.89 to 3.14 (3.02mgkg^{-1}) in mapping unit KBI, KBII and KBIII on upland, 2.26 to 2.53 (2.4mgkg^{-1}) and 4.85 to 6.2 (5.53mgkg^{-1}) in unit KBIV and KBV on the flood plain. The subsoil values ranged from 2.9 to 6.93 (mean 4.61mgkg^{-1}), 1.67mgkg^{-1} and 1.67 to 0.69 (mean 1.18mgkg^{-1}) on the upland and 4.73 to 5.3 (mean 5.01mgkg^{-1}) and 1.3 to 5.77 (mean 3.53mgkg^{-1}) on the flood plain. Extractable zinc was rated high both on the upland and flood plain, being greater than the critical level of 0.6 mgkg^{-1} soil for Zn (Katyal, 1985). The values of extractable zinc in the soils in most cases decreased irregularly down the profile and this could be attributed to leaching effect on micronutrients and then pumping effect from the underlying soil. There was no significant (0.05) difference in zinc status between the upland and flood plain

though the flood plain recorded higher value. The values of the HCl extractable zinc were generally higher than those reported by Yaro *et al.* (2006) on a plinthitic landscape at Zaria. This confirms the report of Odunze and Kureh (2009); Shobayo (2010); Hussaini (2011) who also reported high value of zinc in Zaria soils.

4.3.9.5 Available Boron (B)

The content of boron (B) ranged from 1.7 to 2.44 (mean 2.07mgkg^{-1}), 1.36mgkg^{-1} and 1.97 to 1.29 (mean 1.63mgkg^{-1}) in mapping units KBI, KBII and KBIII on the upland, 0.88 to 1.63 (mean 1.26mgkg^{-1}) and 1.49 to 2.31(mean 1.9mgkg^{-1}) in unit KBIV and KBV on the flood plain. The subsoil values ranged from 1.36 to 1.16 (mean 1.26mgkg^{-1}), 1.63 to 0.75 (mean 1.19mgkg^{-1}) and 1.58 to 1.15 (mean 1.37mgkg^{-1}) on the upland, 1.25 to 1.51 (mean 1.38mgkg^{-1}) and 1.09 to 1.49 (mean 1.29mgkg^{-1}) on the flood plain. The content of boron was generally higher than the critical value of 0.4 mg kg^{-1} submitted by Wolf (1971) to be considered as low in available B, while the values are within the critical range of value of 0.1-2.0 mg kg^{-1}for hot water soluble B given by (Sims and Johnson 1991).The soils are classified as medium to high base on the rating of (Chude *et al.,* 2004). The result of this study was higher than 0.18 – 0.36 mg kg^{-1} reported by Lombin (1985), 0.08 – 0.17 mg kg^{-1} obtained by Daudu (1989) and 0.04 - 0.28 mg kg^{-1}submitted by Oyinlola and Chude (2010) for soils of Northern Nigeria savanna. Boron content of the soils was higher in the surface horizon which decreased with increasing depth. Malgwi (2001) also reported decrease in B content with increase in depth. The values of B obtain in this study were lower than those reported by Adamu, (2013) in soils of Watari irrigation scheme in Kano. There is no significant ($p>0.05$) difference between boron content of the upland and flood plain though the upland recorded higher value.

4.4 Soil Salinity and Alkalinity (Sodicity)

The most important parameters considered in assessing salinity and alkalinity (sodicity) was presented in Table 4.6.

4.4.1 Salinity

Salinity of the soil can be inferred from the Soil electrical conductivity and Total salt concentration. Results on electrical conductivity (EC) and total dissolved solid (TDS) of the study area were presented in Table 4.6.

Table: 4.6: Salinity and Alkalinity Status of the area.

Soil Mapping Units	Horizon	Depth (cm)	BS NH_4OAC %	BS ECEC %	ESP %	SAR	Adj. SAR	EC ds/m	Total Dissolve Solid mg/kg	SO_4 mg/kg	Cl- mg/kg	HCO_3 cmol(-)/kg	CO_3 cmol(-)/kg	Residual sodium carbonate cmol(-)/kg
KBI	Pedon 1	Latitude	N11 06 57	Longitude	E7 40.28	Elevation				640m				
	Ap	0 – 21	59.56	93.06	5.56	0.24	0.41	0.070	44.80	19.92	0.80	0.60	0.00	-0.62
	Bt1	21 - 114	61.73	93.91	6.13	0.24	0.34	0.070	44.80	1.21	0.70	0.60	0.00	-0.68
	Bt2cv	114-140	44.80	96.55	2.80	0.16	0.29	0.040	25.60	1.81	0.70	0.60	0.00	-0.95
	Pedon 2	Latitude	N11 07 07	Longitude	E7 40 30				Elevation	635m				
	Ap	0 – 40	61.41	92.29	4.23	0.16	0.38	0.075	48.00	14.49	0.80	1.20	0.00	-0.56
	Bt1	40 - 70	75.37	96.19	5.67	0.19	0.43	0.025	16.00	1.21	0.60	1.40	0.00	-0.70
	Bt2	70 - 140	53.93	88.30	3.57	0.15	0.26	0.050	32.00	9.660	0.60	1.00	0.00	-0.49
KB II	Pedon 1	Latitude	N11 07 0	Longitude	E7 40 40				Elevation	624m				
	Ap	0 - 50	39.14	93.15	2.37	0.15	0.27	0.020	12.80	1.210	0.70	0.60	0.00	-0.65
	Pedon 2	Latitude	N11 07 05	Longitude	E7 40 32				Elevation	624m				
	Ap	0 -40	67.42	91.27	4.95	0.20	0.34	0.080	51.20	16.910	0.70	1.00	0.00	-0.52
	2Bt1	40 - 120	71.97	90.12	25.13	1.09	1.58	0.02	14.72	0.60	0.80	0.60	0.00	-0.73

Table: 4.6: Salinity and Alkalinity Status of the study area Cont'd.

Soil Mapping Units	Horizon	Depth (cm)	BS (NH_4OAC)	BS (ECEC)	ESP	SAR	Adj. SAR	EC	Total Dissolve Solids	SO_4	Cl-	HCO_3	CO_3	Residual sodium carbonate
			%	%	%			ds/m	mg/kg	mg/kg	mg/kg	cmol(-)/kg	cmol(-)/kg	cmol(-)/kg
KB III	Pedon 1	Latitude N11 07 19 Longitude E7 40 30 Elevation							625m					
	Ap	0 – 27	56.05	97.09	4.37	0.22	0.38	0.029	18.56	5.130	0.80	1.00	0.00	-0.64
	Bt1	27 -75	59.76	92.70	3.76	0.15	0.36	0.017	10.88	1.210	0.50	1.40	0.00	-0.57
	Bt2	75 - 148	70.00	96.42	5.84	0.21	0.37	0.021	13.44	0.600	0.50	0.60	0.00	-0.65
	Bt3c	148-165	58.51	89.46	5.63	0.24	0.42	0.035	22.40	0.600	0.90	0.60	0.00	-0.64
	Pedon 2	Latitude N11 07 19 Longitude E7 40 39 Elevation 623m												
	Ap	0 – 42	32.91	91.68	3.58	0.25	0.36	0.032	20.48	1.510	0.70	0.60	0.00	-0.49
	Bt1	42 - 70	67.32	94.23	14.33	0.64	1.12	0.080	51.20	1.570	1.20	0.60	0.00	-0.63
	Bt2	70 - 120	79.56	97.28	16.44	0.64	1.13	0.100	64.00	9.060	1.20	0.80	0.00	-0.61
	Bt3c	120-170	81.71	94.37	21.22	0.93	1.34	0.100	64.00	19.320	1.50	0.80	0.00	-1.64
KB IV	Pedon 1	Latitude N11 07 03 Longitude E7 40.42 Elevation 621m												
	Ap	0 – 25	91.00	96.96	31.00	1.12	1.63	0.085	54.40	13.280	0.60	1.00	0.00	-0.70
	Bt1	25 - 36	81.38	95.93	5.52	0.16	0.23	0.070	44.80	10.260	1.00	0.40	0.00	-0.66
	Bt2	36 - 58	68.37	91.78	3.47	0.14	0.24	0.060	38.40	14.490	1.00	0.60	0.00	-0.60
	2Bt1	58 - 90	62.89	86.71	3.61	0.14	0.25	0.055	35.20	7.850	0.80	1.00	0.00	-0.62
	2Bt2	90 - 135	63.03	95.99	6.05	0.24	0.34	0.065	41.60	1.810	0.90	0.80	0.00	-0.81
	2Cr	135- 145	67.06	97.16	3.24	0.13	0.23	0.030	19.20	6.640	0.60	0.80	0.00	-0.61

Table: 4.6 Salinity and Alkalinity Status of the area Cont'd

Soil Mapping Units	Horizon	Depth (cm)	BS NH_4OAC %	BS ECEC %	ESP %	SAR	Adj. SAR	EC ds/m	Total Dissolve Solis mg/kg	SO_4 mg/kg	Cl- mg/kg	HCO_3 Cmol(-)/kg	CO_3 cmol(-)/kg	Residual sodium carbonate cmol(-)/kg
	Pedon 2	Latitude N11 07.16	Longitude E7 40.39.3	Elevation					620m					
	Ap	0 -54	82.76	97.59	4.39	0.16	0.23	0.046	29.44	4.230	0.70	0.40	0.00	-0.62
	Bt1	54-78	84.05	96.88	6.76	0.22	0.39	0.060	38.40	4.230	0.80	1.00	0.00	-0.88
	Bt2	78-122	69.37	93.20	18.73	0.78	1.14	0.050	32.00	0.600	0.70	0.60	0.00	-0.66
	Bt3	122-160	85.29	90.63	23.09	0.89	1.02	0.045	28.80	3.020	1.00	0.40	0.00	-1.31
KB V	Pedon 1	Latitude N11 07.49.6	Longitude E7 44.49.6	Elevation						619m				
	Ap	0 -20	51.73	87.47	5.31	0.23	0.34	0.100	64.00	8.450	1.00	1.00	0.00	-0.56
	Bt1	20-80	67.39	95.88	9.28	0.34	0.49	0.032	20.48	4.830	0.80	0.80	0.00	-0.56
	Cr	80-135	71.81	96.28	4.72	0.16	0.28	0.015	9.60	19.320	0.70	0.60	0.00	-0.54
	Pedon 2	Latitude N11 07 50.3	Longitude E7 40 50.3	Elevation						619m				
	Ap	0 – 40	82.56	94.42	6.34	0.22	0.38	0.060	38.40	10.260	0.70	0.60	0.00	-0.77
	Bt1	40-135	67.89	94.16	3.89	0.16	0.23	0.060	38.40	9.060	0.60	0.40	0.00	-0.71
	Bt2	135-170	80.57	92.12	8.97	0.32	0.57	0.100	64.00	6.640	0.70	0.60	0.00	-0.65

Electrical Conductivity (EC) ranged from 0.07 to 0.08 (mean 0.07dSm^{-1}), 0.02 to 0.08 (mean 0.05dSm^{-1}) and 0.03dSm^{-1} in surface horizon of mapping unit on the upland, 0.05 to 0.09 (0.07dSm^{-1}) and 0.01 to 0.06 (0.08dSm^{-1}) in unit KBIV and KBV on the flood plain. The subsoil values ranged from 0.04 to 0.06 (mean 0.05dSm^{-1}), 0.02 to 0.03 (mean 0.03dSm^{-1}) and 0.02 to 0.09 (mean 0.06dSm^{-1}) on the upland, 0.05 to 0.06 (mean 0.06dSm^{-1}) and 0.02 to 0.08 (mean 0.05dSm^{-1}) on the flood plain. The EC value of soil was rated very low (< 4 dSm^{-1}) which indicates none saline electrical conductivity class. Similar result was also reported by Malgwi (2001) and Maniyunda and Gwari (2013) in Northern Guinea Savanna. The electric conductivity decreased down the profile except in KBIII on the upland which increased down the profiles and may be as a result of the location of the unit (lower slope) in constantly receiving material from the crest through erosion and deposition (Malgwi, 2001).

Generally, the mean values were low indicating non-saline status of the soils according to the limits set by Schoeneberger, Wysocki, Benham and Broderson (2002). These imply that salinization is not a significant pedogenic process in the soil and the soil does not contain a concentration of soluble salt that may hamper the growth of plant. This may be attributed to adequate rainfall to maintain an overall downward movement of salt in the area. The higher EC in the A horizons may be due to accumulation of salts brought to the surface by capillary movement of water and subsequent deposition (Malgwi, 2001). There was no significant ($p>0.05$) difference between the EC of the upland and flood plain, though the flood plain recorded higher value which could be attributed to contribution of eroded materials from the upland.

The total soluble salts (TSS) of the surface soils ranged from 44.8 to 48.0 (mean 46.40mg kg^{-1}), 12.8 to 51.2 (mean 32.0mg kg^{-1}) and 18.56 to 20.48 (19.52mg kg^{-1}) in mapping unit KBI, KBII and KBIII on the upland, 29.44 to 54.40 (41.92mg kg^{-1}) and 38.4 to 64.0 (51.2mg kg^{-1}) in

unit KBIV and KBV on the flood plain. The subsoil values ranged from24.0 to 35.20 (29.6mg kg^{-1}), 14.72 to 18.56 (16.64mg kg^{-1}) and 15.73 to 59.73 (37.65mg kg^{-1}) on the upland and 33.07 to 35.84 (34.45mg kg^{-1}) and 15.04 to 51.2 (33.12mg kg^{-1}) on the flood plain. The TSS was rated very low in the upland and flood plain. The values are below the critical value of 1500 mg kg^{-1} required to define saline soil (Szabolcs, 1989). The trend of decreasing values with depth except in KBIII was exhibited in all the mapping units similar to the EC, probably from the enrichment of TSS at the surface through capillary action (Malgwi, 2001).

When the value of EC and TSS are considered together, salinization is not a significant process in all the mapping units of the upland and flood plain. The high exchangeable sodium contents of the soils together with low salinity give more room for sodium to exercise dispersion power. As a consequence, the surface soils will be prone to surface crusting, a phenomenon closely associated with low salt concentration (Malgwi, 2001) which is evident on the surface of the upland soil of the present study area. There was no significant ($p>0.05$) difference in the TSS between the upland and flood plain though the flood plain recorded higher value.

4.4.2 Soil alkalinity (Sodicity)

The analytical data in Table 4.6on base saturation (BS), exchangeable sodium percentage (ESP), sodium absorption ratio (SAR), carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-), residual sodium carbonate (RSC) and pH can be used to assess the sodicity of the soils.

4.4.2.1 Base saturation (BS)

Base saturation was calculated by two methods, namely the NH_4OAc and ECEC method (Table 4.6). The ranges in values for base saturation (NH_4OAc) of surface soils were 59.56 to 61.41 %(mean, 60.48 %), 39.14 to 67.42 %(mean, 53.28 %) and56.05 to 32.91 %(mean, 44.48 %) in surface horizon of mapping unit KBI, KBII and KBIII on the upland, 91.0 to 82 % (mean,

86.88 %) and 51.73 to 82.56 (mean 67.15) in unit KBIV and KBV on the flood plain. The subsoil values ranged 53.27 to 64.65 % (mean, 58.96 %), 69.16 to 71.97 % (mean, 70.57 %) and62.76 to 76.19 % (mean, 69.48 %) on the upland, 68.54 to 79.58 % (mean, 74.06 %) and 69.6 to 74.23 (mean 71.92) on the flood plain. The upland soils were rated medium (50-80%) in all the units except KBIII which was rated low (<50%) while the flood plain was rated medium to high (50 to >80%). There was increase in base saturation with depth which could be attributed to leaching of basic cation and higher clay content in subsoils. This confirm the report of Atofarati *et al.,* (2012) who also reported higher BS on the subsoils as compare to top soils. The flood plain was significantly ($p<0.05$) higher in BS than the upland, which could be attributed to the eroded materials deposited on the flood plain.

The BS by ECEC gave higher values than the corresponding values obtained by NH_4OAc method in both upland and flood plain. Sanchez (1976) submitted that base saturation (by ECEC) gives a more realistic picture of the acidity level of variable charged soils than base saturation by NH_4OAc which tends to underestimate. The ranges in values for base saturation (ECEC) of surface soils were 92.29 to 96.06 %(mean, 92.67 %), 91.27 to 93.15 % (mean, 92.21 %) and 91.68 to 97.09 %(mean, 94.31 %) in surface horizon of mapping unit KBI, KBII and KBIII, 96.96 to 97.59 % (mean, 97.27 %) and 87.47 to 94.42 (mean 90.95%) in unit KBIV and KBV on the flood plain. The subsoil values ranged from 92.25 to 95.23 % (mean, 93.74 %), 90.12 to 97.37 % (mean, 93.74 %) and 92.86 to 95.29 % (mean, 94.08 %) on the upland, 93.52 to 93.57 % (mean, 93.54 %) and 93.14 to 96.08 (mean 94.61%) on the flood plain.

Both the surface and sub soils of upland and flood plain were rated high (>90%). The rating of BS (ECEC) was higher than >90 %, thus reflecting high corresponding ECEC values. The percentage of sites occupied by ions other than hydrogen is the percent base saturation; however, acid soils may have high cation exchange capacity, but a low % BS, because of

exchangeable hydrogen ions. Soils with a high CEC and a high BS are fertile unless they are saline or contain toxic heavy metals (Isirimah *et al*., 2003).

Generally, ECEC of upland was rated medium while the flood plain was rated high and varied irregularly with depth. The medium values indicate that the soils have moderate potentials for supplying plant nutrients; hence, the necessity for adequate soil management, most especially the upland. Similar result was reported by Shobayo (2010) and Hussaini (2011) on basement complex soils in Zaria. There is no significant ($p>0.05$) difference in the ECEC between the upland and flood plain though the flood plains recorded higher values which might be attributed to contribution of eroded materials down slope.

4.4.2.2 Exchangeable sodium percentage and sodium absorption ratio

The values of exchangeable sodium percentage (ESP) ranged from 4.23 to5.56 (mean 4.89%), 2.37 to 4.95 (mean 3.66%) and 3.58 to 4.37 (mean 3.98%) in surface horizon of mapping unit KBI, KBII and KBIII, 31.0 to 4.39 (mean 17.69%) and 5.31 to 6.34 (5.83%) in unit KBIV and KBV on flood plain. The subsoil values ranged from 4.47 to 4.62 (mean 4.54%), 25 .13 to 28.41 (mean 26.77%) and 5.08 to 17.33 (mean 11.21%) on the upland, 4.38 to 16.19 (mean 10.29%) and 6.43 to 7.0 (mean 6.71%) on the flood plain. KBI, KBII and KBIII on the upland and KBV on the flood plain are rated low being generally below 15% while KBIV on the flood plain are rated high being above 15 % (Appendix C), the critical limit for sodicity (Brady and Weil, 2002).

Exchangeable sodium percentage increased down the profile which could be attributed to leaching of basic cations. These imply that sodification is a significant pedogenic process in the flood plain which is unusual of soils of Zaria as reported by most researchers in Zaria (Maniyunda, 1999; Shobayo, 2010). Sodic soils are usually more dispersed, less permeable to

water and are of poor tilth, usually plastic and sticky when wet and are more prone to form clods and crust on drying (Babalola *et al.*, 2011). High Na^+ content of the soils may be as a result of low lying topography of unit KBIV on the flood plain which have contributed significantly to the development of sodicity in the mapping unit observed to have ESP >15% (Malgwi, 2001).This is similar to the findings of Babalola *et al.*, (2011) on the wetland soils of Kabba. There was no significant ($p > 0.05$) difference in the ESP between the upland and the flood plain though the flood plain recorded higher value which could be attributed to eroded material deposited.

The Sodium Adsorption Ratio (SAR) values ranged from 0.24 to 0.16 (mean 0.2), 0.15 to 0.2 (mean 0.17) and 0.22 to 0.25 (mean 0.23) in surface horizon of KBI, KBII and KBIII on the upland, 0.16 to 1.12 (mean 0.64) and 0.22 to 0.23 (0.23) in unit KBIV and KBV on the flood plain. The subsoil values ranged from 0.11 to 0.2 (mean 0.18), 1.09 to 1.57 (mean 1.33) and 0.2 to 0.74 (mean 0.47) on upland, 0.16 to 0.63 (mean 0.4) and 0.24 to 0.25 (0.24) on the flood plain. The values are rated low, below the threshold value of 13 for sodic soils (Sanda, Ogunwale, Oluwasemire and Raji, 2007). Similar results were obtained by Yakubu, Baraya and Noma (2011) and Sharu *et al.*, (2013) in soils of Sokoto State. The sodium adsorption ratio increased down the profile which could be attributed to leaching. There was no significant ($p > 0.05$) difference in the SAR between the upland and the flood plain though the upland recorded higher value.

The Adjusted Sodium Adsorption Ratio (Adj.SAR) values ranges from 0.38 to 0.41 (mean 0.4), 0.27 to 0.34 (mean 0.3) and 0.38 to 0.36 (mean 0.37) in surface horizon on KBI, KBII and KBIII on the upland, 0.23 to 1.63 (mean 0.93) and 0.34 to 0.38 (0.36) in unit KBIV and KBV on the flood plain. The subsoil values ranged from 0.32 to 0.35 (mean 0.33), 1.58 to 2.75(mean 2.16) and 0.38 to 1.2 (mean 0.79) on upland, 0.26 to 0.85 (mean 0.55) and 0.38 to 0.4 (0.39) on the flood plain. The adjusted sodium adsorption ratios were higher than the sodium

adsorption ratio but they follow similar pattern of distribution in the profiles studied. This indicates the high possibility of precipitating Ca and Mg as carbonate (Malgwi, 2001).When the ESP, SAR and Adjusted SAR are considered together, the picture of sodicity become less clear, but ESP Value of KBIV on the flood plain indicates sodicity, while the SAR indicates marginal sodicity. Similar result was reported by Malgwi (2001) in salt affected soils of Nigeria savanna.

The result shown above reveals that the soils are sodic. Too much sodium can lead to excessive swelling of the soil, which may result in structural collapse referred to as dispersion. Dispersive soil is very prone to water logging, which can greatly reduce the profitability of farmers. When dry, dispersive soil tends to be too hard for roots and seedlings to penetrate. David (2003), recommend the application of gypsum to improve soil structural stability by providing a mildly saline soil solution that is not strong enough to adversely affect water uptake by most crops, but restricts movement of water molecules into the space between clay particles. Gypsum also contains calcium, which displaces sodium and magnesium from the exchange sites between clay particles. There was no significant ($p > 0.05$) difference in the SAR between the upland and the flood plain though the upland recorded higher value similar to SAR.

4.4.3 Carbonate, bicarbonate and residual sodium carbonate (RSC).

The concentration of carbonate (CO_3^{2-}) were absent in all soil mapping units on the upland and flood plain. This indicates that free CO_3^{2-} is very low or absent and they are all rated low (Raji, 1995; Malgwi, 2001; Adamu, 2013). It implies that all the pedons are non-calcareous. The absence of CO_3^{2-} in the study area may be attributed to the presence of calcium silicate which according to Abedi and Talibudeen (1974) in Malgwi (2001) is more soluble than $CaCO_3$.

Bicarbonate (HCO_3^-) content of the soil ranged 0.6 to 1.2 (mean 0.9cmol(+)kg^{-1}), 0.6 to 1.0 (0.8cmol(+)kg^{-1}) and 0.6 to 1.0 (mean 0.8cmol(+)kg^{-1}) in surface horizon of mapping unit

KBI, KBII and KBIII on the upland, 0.4 to 1.0 (mean 0.7cmol(+)kg^{-1}) and 0.6 to 1.0 (mean 0.8cmol(+)kg^{-1}) in unit KBIV and KBV on the flood plain. The subsoil values ranged from 0.12 to 0.6 (mean 0.9cmol(+)kg^{-1}), 0.6 to 1.0 (mean 0.8cmol(+)kg^{-1}) and 0.73 to 0.87 (mean 0.80cmol(+)kg^{-1}) on the upland,0.67 to 0.72 (mean 0.69cmol(+)kg^{-1}) and 0.50 to 0.70 (0.60cmol(+)kg^{-1}) on the flood plain.

The mean values were rated low for both upland and flood plain. The HCO_3^- content shows decrease with increasing depth. Absence of carbonate in the soil and the low to moderate concentrations of bicarbonate further supports acidity in the soil because most dissolved carbon dioxide and carbonates must have been reduced to either carbonic acid (H_2CO_3) or are in the transitional state of bicarbonate (Adamu, 2013). The bicarbonate content of the soils was uniform for both surface and subsoils of KBI, KBII and KBIII on the upland, while KBIV and KBV on the flood plain decreases down the profile. This is similar to finding of Malgwi (2001). The upland was significantly ($p<0.05$) higher in bicarbonate than flood plain, which may be attributed to the use of irrigation and underground water containing HCO_3^- and deposition of aeolian parent material (Malgwi, 2001).

The residual sodium carbonate (RSC) content of the soil ranged-4.07 to -3.14 (mean -3.61cmol(-)kg^{-1}), -4.35 to -4.70 (mean -4.53cmol(-)kg^{-1}) and -3.25 to-4.97 (mean -4.11cmol(-)kg^{-1}) in surface horizon of mapping unit KBI, KBII and KBIII on the upland, -2.96 to -7.11 (mean -5.04cmol(-)kg^{-1}) and -2.54 to -5.29 (mean -3.94cmol(-)kg^{-1}) in KBIV and KBV on the flood plain. The subsoil values ranged from -3.11 to -3.8 (mean -3.45cmol(-)kg^{-1}), -2.74 to -3.02 (mean -2.88cmol(-)kg^{-1}) and -3.74 to -4.01 (mean -3.87cmol(-)kg^{-1}) on the upland,-3.47 to-4.37 (mean -3.94cmol(-)kg^{-1}) and -3.55 to -5.44 (mean -4.49cmol(-)kg^{-1}) on the flood plain.

The ranges of values were rated low on both upland and flood plain. Szabolcs (1989) considered 2.5 as the critical value for RSC. Generally, there was a decrease in RSC with

increasing soil depth. The RSC of the soil exhibited a negative value in all the soil mapping units. This negative value of the RSC of the soil solution may dissolve some carbonate. This may in part explain the lower or absence of free carbonate in the soils (Malgwi, 2001). This will result in decreasing SAR of the soil solution. There was no significant ($p>0.05$) difference between the upland and flood plain though the flood plain recorded higher value.

4.4.4 Available sulphur

The available sulphur content of soils ranged from 14.44 to 19.92 (mean 17.21 mg kg^{-1}), 1.21 to 16.91 (mean 9.06 mg kg^{-1}) and1.15 to 5.13 (mean 3.32 mg kg^{-1}) in surface horizon of mapping unit KBI, KBII and KBIII on upland, 4.23 to13.28 (mean 8.76 mg kg^{-1}) and 8.45 to 10.26 (mean 9.36 mg kg^{-1}) in unit KBIV and KBV on the flood plain. The subsoil values ranged from 1.51 to 5.44 (mean 3.47 mg kg^{-1}),0.6 to 1.21 (mean 0.91 mg kg^{-1}) and 0.8 to 9.98 (mean 5.39 mg kg^{-1}) on the upland, 2.62 to 8.21 (mean 5.41 mg kg^{-1}) and 7.85 to 12.08(mean 9.96 mg kg^{-1}) on the flood plain.

The available sulphur content of all the soils were rated medium, being generally greater than the critical level of 6 mg kg^{-1} as reported by Adetunji and Adepetu (1990) to be sufficient for crop production, except in KBIII on the upland with a lower value below the critical level. The subsoils are generally rated low to medium except KBV on the flood plain, which was rated high. The available sulphur generally decreased with depth. Higher $SO_4^{2-}S$ in surface relative to the sub-soil may be attributed the supply from organic matter. Yaro (2005) reported that 80 to 90% of SO_4^{2-} in the soil is present in organic carbon fraction. The trend of decrease with depth was also reported by (Kparmwang, 1993; Malgwi, 2001). There was no significant ($p>0.05$) difference between the upland and flood plain though the flood plain recorded higher value which could be attributed to eroded materials deposited on the flood plain.

4.4.5 Extractable chloride

The mean extractable chloride (Cl^-) in surface soils ranged from 0.8mg kg^{-1}, 0.7mg kg^{-1} and 0.75mg kg^{-1} in unit KBI, KBII, KBIII on the upland, 0.65mg kg^{-1} and 0.85mg kg^{-1} in KBIV and KBV on the flood plain. The subsoil mean values ranged from 0.65mg kg^{-1}, 0.7mg$kg^{-1}$and 0.97mgkg^{-1} on the upland, 0.85mgkg^{-1} and 0.7mg kg^{-1} on the flood plain. The chloride content of the upland and flood plain were rated low. Adamu (2013) also recorded low Cl^- in Watari irrigation scheme, Kano State. The trends in distributions were either increase or decrease in chloride content with depth. Similar trend was also reported by Malgwi (2001) in salt affect soils of some location in Kano. There was no significant ($p>0.05$) difference between the upland and flood plain, though the flood plain recorded higher values attributed to influence of eroded materials deposited on the flood plain.

Generally, flood plain soils were significantly ($p<0.05$) higher in base saturation, available phosphorus, iron, manganese and copper, upland soilswas significantly ($p <0.05$) higher in bicarbonate. Although when all the parameters were considered, there were no significant ($p>0.05$) differences between the upland and flood plain because the p-value was greater than 0.05. Therefor, the null hypothesis cannot be rejected and the study concluded that there was no significant difference between the upland and flood plain soils Appendix E.

4.5 Soil Classification

The soils studied were classified according to the criteria of USDA soil taxonomy namely: temperature, moisture regimes, morphological, physical and chemical characteristics were considered in classification (USDA, Soil Survey Staff, 2010) and according to the FAO/UNESCO Soil Map of the World Legend (2014).

4.5.1 Criteria for soil classification according to the USDA soil taxonomy, soil survey staff, 2010

4.5.1.1 Soil temperature regime

The mean maximum and minimum annual temperature of the study area was $>22^0$C as shown in Table 3.1. The difference between the mean maximum and minimum annual soil temperature is less than 5°C at the depth of 50cm which qualifies Zaria as iso-hyperthermic temperature regime (USDA, Soil Survey Staff, 2010).

4.5.1.2 Soil moisture regime

The study area has >5 months of dry seasons, with more than 90 cumulative days with dry soil in the moisture control section (upper 50cm). The mean annual rainfall is about 1004mm (Table: 3.1). The moisture regime of soil mapping unit KBI, KBII and KBIII on the upland was *Ustic*, while soil mapping unit KBIV and KBV on the flood plain have *Aquic* soil moisture regime and have a high water table (Soil Survey Staff, 2010).

4.5.1.3 Diagnostic surface horizons (epipedons)

Mapping unit KBII on the upland had a *plaggen epipedon* which is a human-made surface layer 50 cm or more thick that has been produced by long-continued manuring/ locally raised land surfaces while all the other mapping units on the upland and flood plain soil have *ochre*

epipedons because they had medium to low P, poor in humus and they were too thin to be qualified either as *mollic* or *umbric* epipedons.

4.5.1.4 Diagnostic sub-surface horizons

Soil mapping units KBI and KBIII on the upland have significant accumulation of illuviated layered-lattice silicate clays formed below the eluvial horizons. The *argillic* horizons were confirmed to be present by the clay ratio of the illuvial to the eluvial horizon of 1.2 or greater and total thickness was more than 15cm in all the pedons (Soil Survey Staff, 2010),the subsurface horizons are therefore *argillic* B-horizon.

Soil mapping units KBII on the upland, KBIV and KBV on the flood plain showed little or no evidence of development of diagnostic horizons and are therefore classified as *cambic* subsurface horizon.

4.5.2 Classification of the soil mapping units

The Soil mapping units KBI and KBIII on the upland have an *argillic* horizon which increased in clay content with depth. The organic matter content decreased progressively with depth. A high base saturation (>50% by NH_4OAc) characterized the soil and cation exchange capacity is high. Hence, the soil is grouped into the order *Alfisol*. They were placed into sub order *Ustalfs* and *Aqualfs* by virtue of its *ustic and aquic* moisture regime. At the Great Group and Subgroup KBI and KBIII on the upland were classified as *plinthustalf* and *plinthaqualfs* because it has at a depth between 30 and 150 cm from the mineral soil surface plinthite which either forms a continuous phase or constitutes one-half or more of the volume. And at the group level as *Typic Plinthustalfs and Typic Plinthaqualfs* respectively since Sub groups have not been identified for the Great group *Plinthustalfs and Plinthaqualfs* (Soil Survey Staff, 2010).

Soil mapping unit KBII on the upland, KBIV and KBV on the flood plain were classified in the order *Inception* because KBII has plaggen epipedon while KBIV and KBV have o*rchric epipedon* as well as a *cambic* sub-horizon. Mapping unit KBII was classified as *Ustepts* at the suborder level because they have an ustic moisture regime. At the great group as dystrustepts because of the absence of free carbonate. At the group level, it is classified as *torrertic* dystrustepts because of cracks within 125cm of the mineral soil surface.

The flood plain soils KBIV and KBV were classified as *Aquepts* because they have groundwater within 100cm of the mineral soil surface for some time during the year (Aquic moisture regime). They were also all classified as *Endoaquepts*, because the soils are saturated with water in one or more layers within 200cm of the mineral soil surface and also have one or more unsaturated layers, with an upper boundary above a depth of 200cm, below the saturated layer (episaturation) that is, *Aquepts* that have episaturation. At the group level, it is classified as *Fluvaquentic Epiaquepts* because the soil have a slope of less than 25% and at a depth of 125 cm below the mineral soil surface, an organic-carbon content (Holocene age) of 0.2 percent.

4.5.3 Classification base on FAO/UNESCO soil legend (World reference base)

The first level of classification in soil mapping unit KBI, KBIII on the upland were classified as *Lixisols*, because they had an *argic* horizon, which has a CEC (by 1N NH_4OAc) of less than 24 cmol(+)kg^{-1} clay, either starting within 100 cm from the soil surface, or within 200 cm from the soil surface; as the *argic* horizon was overlain by loamy sand or coarser texture throughout and a base saturation (by 1N NH_4OAc) of greater than 50 % in major part between 25 and 100cm. At the second level, the pedons have a base saturation (by 1N NH_4OAc) of 50 % or more at least between 20 and 100 cm from the soil surface for which reason they have been classified as *Eutric Lixisols*.

The soils of soil mapping unit KBIV and KBV on the flood plain were classified as *Fluvisol* because *fluvic* material starting within 25 cm of the soil surface or starting immediately below a plough layer of any depth and continuing to a depth of >50 cm and having irregular distribution of organic matter with soil depth. At the lower level of classification as *Endoeutric Fluvisol* by virtue of it having a base saturation (1N NH_4OAc) of 50 percent or more throughout between 50 and 100 cm from the soil surface.

The soils of soil mapping unit KBII on the upland were classified as *cambisols* because of great influence of human activities such as long-time continued cultivation, cut and fill practice in the unit and are moderately developed soils. At the lower level of classification as *Terric cambisols* because they have surface horizon consisting of mineral materials which has a colour related to the source material; a base saturation (by 1N NH_4OAc, pH 7) of ≥ 50%; does not show stratification; occurs in locally raised land surfaces; has a thickness of ≥ 20cm and have a mineral surface horizon, ≥ 10 cm thick, with ≥ 0.2 and < 0.6% soil organic carbon (weighted average).Table 4.7 shows the summary of the soil classification in the study.

Generally, there were significant differences in classification of upland and flood plain soils, thus we can not reject the null hypothesis and we concluded that there were significant difference in the classification of upland and flood plain soil.

Table 4.7 Summary of Classification of Kubanni Flood plain and Adjoining Upland Soil

Landform	Soil Mapping Units	USDA System	WRB System
Upland	KBI	Typic Plinthustalf fine loamy skeletal, isohyperthermic	Eutric Lixisols
Upland	KBII	Torrertic Dystrustepts fine loamy, isohyperthermic	Terric Cambisols
Upland	KBIII	Typic Plinthaqualf fine, loamy skeletal, isohyperthermic	Eutric Lixisols
Flood plain	KBIV	Fluvaquentic Epiaquepts, fine loamy, isohyperthermic	Endoeutric Fluvisol
Flood plain	KBV	Fluvaquentic Epiaquepts, fine loamy skeletal, isohyperthermic	Endoeutric Fluvisol

4.5.4. Land suitability evaluation classification for maize and rice.

4.5.4.1 Criteria for qualitative land suitability classification.

The main criteria necessary to establish suitability for agriculture are deduced from (i) agronomic factors, (ii) planning, (iii) land enhancement and improvement, (iv) soil conservation and environment protection and (v) socio-economic conditions (FAO, 1989). However, this study focused only on the climatic, agronomic and socio-economic factors. These factors include: Climatic factor: rainfall and temperature. Agronomic factors: soil texture, soil depth, slope, drainage, pH, salinity, sodicity, exchangeable sodium percentage, organic carbon, total nitrogen, potassium, available phosphorus, nutrient retention capacity (base saturation and cation exchange capacity). These factors are discussed below.

a) Climatic Factors:

Prevailing climate within the study area plays a central role in determining yield and quality of maize and rice. Table 4.8 and 4.9 shows the climatic and agronomic suitability rating for maize and rice respectively while Table 4.10 shows land characteristics of the soil mapping units studied.

Table 4.8 Factor Suitability Rating for Maize

Land Characteristic / diagnostic factor	Highly suitable (S1)	Moderately Suitable (S2)	Marginal Suitable (S3)	Not Suitable (N)
Climate				
Rainfall (mm)	>800	700 – 800	600 – 700	□600
Temperature (^{o}C)	24 – 30	20 - 24, 30 – 32	15 - 20, 32 – 35	□15, □ 35
Land/soil physical property				
Slope (%)	0 – 2	4 – 8	8 – 16	□16
Soil depth (cm)	□120	75 - 120	30 – 75	□30
Soil Texture	CL,L	SL, LS	LCS	CS
Volume of coarse fragment	□ 5	5 – 25	46 – 70	> 70
Drainage	Well	Moderately Well	Imperfect	Poor, very poor
Nutrient availability (top soil)				
pH	6 - 6.5	5.5 - 6.0, 6.5- 7	5.0 - 5.5,7.0-8.2	< 5.0 - □ 8.2
Organic Carbon (gkg^{-1})	> 2.0	1.0 - 0.2	0.5 - 1.0	< 0.5
Total Nitrogen (gkg^{-1})	0.08-0.04	0.04-0.02	< 0.02	Any
Available P (mgkg^{-1})	> 40	10-40	3-10	< 3
Exchangeable K (mgkg^{-1})	0.3-0.5	0.2	0.1-0.2	< 0.1
CEC (cmol(+)kg^{-1})	□ 25	13 – 25	6 – 12	□ 6
Base Saturation (%)	□ 80	40 – 80	20 – 40	□ 20
Micro nutrient status				
Fe (mgkg^{-1})	3.5 – 4.5	2.3 – 3.5	1.5- 2.5	< 1.5
Salinity and Sodicity				
Salinity EC (ds/m)	< 1	1-2	2-4	>4
Sodicity ESP (%)	< 10	10- 15	>15	-

Adopted from FAO (1983)

Key: CL=clay loam, L=loam, SL=sandy loam, LS= loam sand, LCS=loam clay sand, CS=clay sand

Table 4.9 Factor Suitability Rating For Rice

Land Characteristic / diagnostic factor	Highly suitable (S1)	Moderately Suitable (S2)	Marginal Suitable (S3)	Not Suitable (N)
Climate				
Rainfall (mm)	800-1200	700 – 800	600 – 700	□600
Temperature (^{o}C)	24 – 28	22 - 24, 30-32	18 - 22, 32-35	□18, □ 35
Land/soil physical property				
Slope (%)	0 – 1	1 – 2	2 – 4	□4
Soil depth (cm)	□75	50 - 75	25 – 50	□25
Soil Texture	C, SiC, CL	SC, SiC, SiL	SL, L, SCL	S, LS
Volume of coarse fragment	□ 15	□35	□55	□55
Drainage	Well	Moderately Well	Imperfect	Poor, very poor
Nutrient availability (top soil)				
pH	5.0 -6.0	6.0 - 7.0	7.0 - 8.0	□ 8
Organic Carbon (gkg^{-1})	2.0 - 4.0	1.0 - 0.2	0.5 - 1.0	< 0.5
Total Nitrogen (gkg^{-1})	> 0.2	0.1- 0.2	0.05-0.1	<0.05
Available P (mgkg^{-1})	> 40	20 – 40	10-20	<10
Exchangeable K (mgkg^{-1})	> 0.2	0.1- 0.2	< 0.1	< 0.1
CEC (cmol(+)kg^{-1})	□ 25	13 – 25	6 – 12	□ 6
Base Saturation (%)	□ 75	50 – 75	30 – 50	□ 30
Micro nutrient status				
Fe (mgkg^{-1})	<0.75	0.75-1	1- 1.25	>1.25
Salinity and Sodicity				
Salinity EC (ds/m)	< 3	3 – 6	6 – 10	>10
Sodicity ESP (%)	< 15	15- 40	40– 50	>50

Adopted from FAO (1983)
and Olaleye *et al*., (2002).

Keys: SiC=silt clay, L=loam, SCL=sandy clay loam, SC=sandy clay, SL=sandy loam, C= clay, LS= loam sand, S=sand

Table : 4.10 Land Qualities/Characteristics of the Soil Mapping Units

Land Characteristic	**Soil mapping units**				
	----------Upland----------			**--Flood plain**	**----------**
Climate	KBI	KBII	KBIII	KBIV	KBV
Mean Annual rainfall (mm)	1004	1004	1004	1004	1004
Temperature (^oC)	26	26	26	26	26
Land/soil physical property					
Slope (%)	0-2	0-4 to >16	0-2	0-2	0-2
Soil Depth (cm)	>140	50-120	>170	>160	>150
Soil Texture Class	L,SL/SCL	L/CL,SCL	L/ SiL	SL,L/SL	L/SL
Volume of coarse fragment					
Drainage	Well	Imperfect to well	Poorly to imperfectly	Poorly	Poorly
Nutrient availability (top soil)					
pH (H_2O)	6.6	6.65	6.6	6.9	6.4
Organic Carbon (gkg^{-1})	0.81	0.46	0.47	0.35	0.49
Total Nitrogen (%)	0.018	0.014	0.014	0.011	0.014
Available P ($mgkg^{-1}$)	3.07	2.63	3.59	4.47	6.22
Exchangeable K ($mgkg^{-1}$)	0.16	0.14	0.13	0.21	0.27
CEC ($cmol(+)kg^{-1}$)	8.4	11.6	12.65	8.4	8.15
Base Saturation (%)	60.48	53.28	44.48	86.88	67.14
Micro nutrient status					
Fe ($mgkg^{-1}$)	39.45	59.57	48.59	165.36	142.19
Salinity and Sodicity					
Salinity EC (ds/m)	0.07	0.05	0.03	0.07	0.08
Sodicity ESP (%)	4.89	3.66	3.98	17.69	5.83

Source: Field work (2014)

CL = Clay loam, L= loam, SL=sandy loam, LS = loamy sand, LCM= loamy coarse sand, CS = coarse sand

Temperature determines the rate of growth and development of crops. Rice and maize being tropical crops require average temperature of 21 to 35°C throughout their life period. The water requirement of rice under lowland conditions is 1110-1250 mm, while well-distributed rainfall of 500-750mm is conducive for proper growth of maize. Matching crop climatic requirement and land characteristic, shows that temperature and rainfall are not limitation for the study crops hence it was classified as highly suitable (S1) for rice and maize based on temperature and rainfall (Table 4.11 and 4.12).

b) Soil Factors:

The soil factors include morphological, physical and chemical properties. Morphological and physical properties include: soil texture, slope, soil depth and drainage

i) Soil Texture:

Texture is an important factor to consider when rating soil for its suitability. Root penetration, nutrition absorption, water holding capacity, water infiltration and percolation are affected by soil texture type (Sys *et al*., 1991). Loam and sandy loam are much more preferred soil texture for arable crop. Soils of the study area ranged from loam, sandy loam to sandy clay loam and silt loam. Texture was not a limitation to the production of maize and rice in upland and flood plain respectively. The upland and flood plain were classified into the order suitable and class highly suitable (S1) (Table 4.11) for maize while marginally suitable (S3) (Table 4.12) for rice due to the loamy nature of their textural class. Application of sufficient quantity of organic matter and incorporation of plant residues would be required for sustainable crop production (Omar, 2011).

Table 4.11: Marching Land use Requirement with Upland Soil Quality for Maize

Land Characteristic / diagnostic factor	Units	Soil Mapping Units KBI	KBII	KBIII
Climate				
Rainfall	(mm)	S1	S1	S1
Temperature	(^{o}C)	S1	S1	S1
Land/soil physical property				
slope (s)	(%)	S1	S3	S1
Soil depth	(cm)	S1	S3	S1
Volume of coarse fragment	(%)	S1	S1	S1
Drainage (d)		S1	S1	S3
Nutrient availability (top soil)				
Ph	(H_2O)	S1	S1	S1
Organic Carbon (m)	(gkg^{-1})	S3	S3	S3
Available P (p)	($mgkg^{-1}$)	S3	N	S3
Total Nitrogen	(gkg^{-1})	N	N	N
Exchangeable K	($cmolkg^{-1}$)	S3	S3	S3
CEC (1N NH_4OAc)(c)	($cmolkg^{-1}$)	S3	S3	S2
Base Saturation (n)	(%)	S2	S2	S2
Micro nutrient status				
Fe	($mgkg^{-1}$)	N1	N1	N1
Salinity and Sodicity				
Salinity EC (e)	ds/m	S1	S1	S1
Sodicity ESP	(%)	S1	S1	S1
Overall Suitability		N1	N1	N1
	Limitation	F	f,s	f,d
		N1f-1	N1fs-2	N1f-3

f = fertility
s= slope

Table 4.12: Matching Land use Requirement with Flood plain Quality for Rice

Land Characteristic / diagnostic factor	Units	Soil Mapping Units KBIV	KBV
Climate			
Rainfall	(mm)	S1	S1
Temperature	(^{o}C)	S1	S1
Land/soil physical property			
slope (s)	(%)	S2	S2
Soil depth	(cm)	S1	S1
Volume of coarse fragment	(%)	S1	S1
Nutrient availability (top soil)			
Ph	(H_2O)	S2	S2
Organic Carbon (m)	(gkg^{-1})	N	S3
Available P (p)	($mgkg^{-1}$)	N	N
Total Nitrogen	(gkg^{-1})	N	N
Exchangeable K	($cmolkg^{-1}$)	S1	S1
CEC (c)	($cmolkg^{-1}$)	S3	S3
Base Saturation (n)	(%)	S1	S2
Micro nutrient status			
Fe	($mgkg^{-1}$)	N1	N1
Salinity and Sodicity			
Salinity EC (e)	ds/m	S1	S1
Sodicity ESP	(%)	S1	S1
Overall Suitability		N1	N1
	Limitation	F	F
		N1f-1	N1f-1

f = fertility, s = slope

ii) Slope:

Slope is important in soil formation and management because it influence the rate of soil formation, runoff, soil drainage, erosion, use of machinery, and choice of crops (Sys *et al*., 1991). The slope gradient of study area ranged from 0 to less than 2 percent and greater than 16 percent. Gentle slope is suitable for agriculture than steep land. The supply of water, leaching, and salt accumulation are often problems of land related to topography. Fasina and Adeyanju (2006) reported that slope of < 3 % favour mechanical operation. Slope of the study area is not a major limitation to the production of these crops, except for mapping unit KBII on the upland. Hence, it is classified as highly suitable (S1) (Table 4.11) for all the soil mapping units, except unit KBII which is classified as marginally suitable (S3) due to its gentle to steep slope (0-4 and >16%).

iii) Soil Depth:

The volume of soil determines the structural support to crops, nutrients and water holding capacities for crops. Deep soil is needed for effective crops growth and performance. The effective soil depth for crops varies according to individual crop requirement. Sys *et al*. (1991) reported that most crops with the exception of tree crops produce excellent yield with an effective root zone depth of 90-100cm. Based on soil depth, KBII was classified as marginally to highly suitable, while all other soil mapping units were classified as highly suitable (S1) since they are within the range described by Sys *et al*. (1991) (Tables 4.11 and 4.12).

iv) Drainage:

The suitability of maize decreased when drainage conditions became impeded while that of rice increased as it is a water loving crop, most especially swampy rice. Maize is considered to

be sensitive to poorly drained soil. The upland soils are generally well drained as such, classified as highly suitable (S1) for maize with the exception of KBIII which is imperfectly to poorly drained as a result of its lower slope position, hence classified as marginally suitable (S3) for maize production. The flood plains were generally classified as highly suitable (S1) for rice production as lowland rice grows well in poorly drained soil.

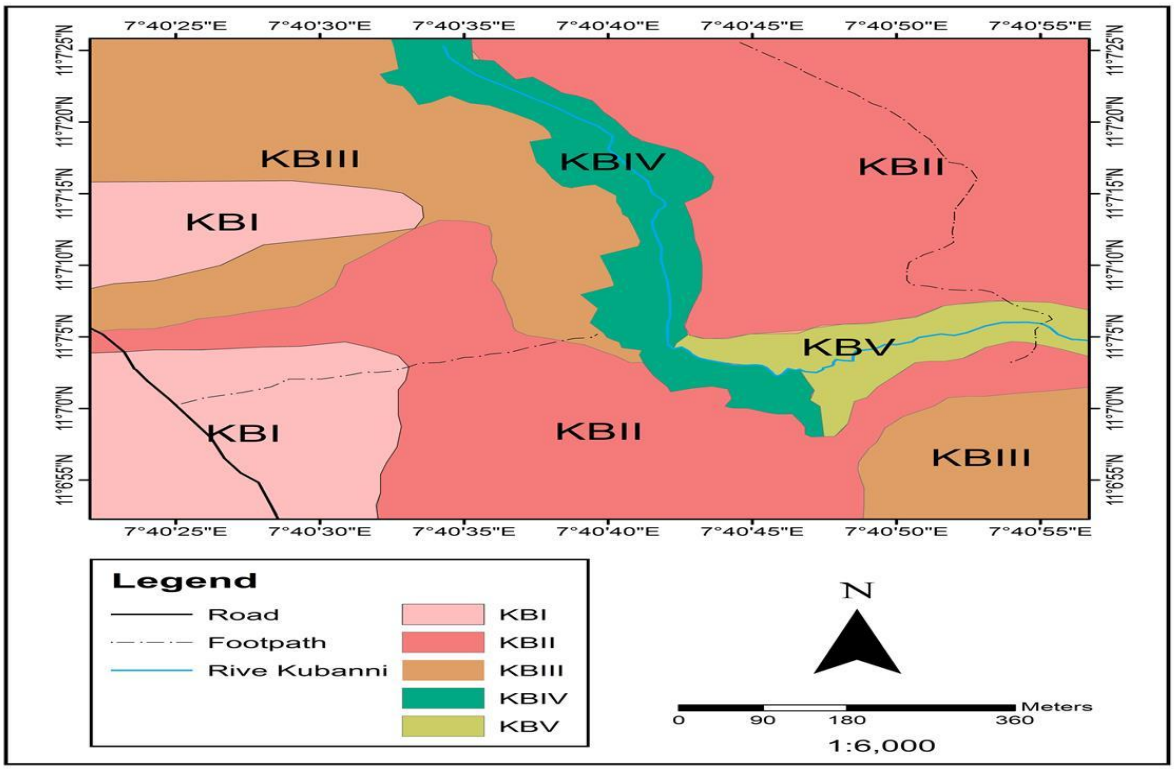
v) Chemical Properties:

The fertility of soil is a decisive factor for plant growth. Nitrogen, phosphorus, potassium, pH, cation exchange capacity and organic matter content, salinity and sodicity were the key parameters that work together for the successful production of these crops. Soil fertility status of the study area is low because organic carbon, total nitrogen and available phosphorus were rated low in the study area. Organic carbon and available P was generally classified as marginally suitable (S3), while total nitrogen was classified as not suitable (N1) for maize production on the upland (Table 4.11). Organic carbon was classified as marginally suitable (S3) to not suitable (N1) in mapping unit KBIV and KBV on the flood plain respectively, while total nitrogen and available p were classified as not suitable (N1) for rice (Table 4.12) on the flood plain. This indicates that, low nutrient status has been identified as a critical factor limiting soil suitability for rice on the flood plain and maize on the upland in Zaria. The iron content in the study was above recommended critical value for crop production. This indicates that with iron deficiencies are unlikely for crops grown on soils of the study area; but the problem of toxicity may occur, hence the soils were classified as not suitable (N1) for rice and maize (Table 4.11 and 4.12).

Sodicity and Salinity affect crop growth and development as well as affect soil structure. Low salinity and high levels of sodicity can cause soil degradation and a reduction in soil permeability. Such degradation results in aeration and water logging problems, which negatively

affect crop yield (Younes, *et al*., 2010). Based on EC, the upland and floodplain (Table: 4.11) were classified as non saline and highly suitable (S1). Based on the ESP (Table: 4.11), they were classified as non sodic and highly suitable (S1) (Table 4.11) with the exception of KBIV, which was marginally suitable (S3) in term of sodicity and will require addition of lime for sustainable crop production.

Generally, the upland was currently not suitable (N) for maize and the flood plain was also currently not suitable (N) for rice production (Fig 4.2) due to low organic carbon, available phosphorus, total nitrogen. All the units on upland and flood plain were not suitable in term of total nitrogen and available P. Mapping unit KBII on the upland was in addition not suitable due to very steep slope. Similar result was reported by Oluwatosin, (2005) in Northwestern Nigerian for cereals crop. Among the limiting factors were erosion hazard and nutrient availability (f) which cut across the land quality. Olaleye *et al.,* (2002) also reported that Nigeria is climatically suitable for rice cultivation. Major limitations to rice cultivation are soil texture, low exchangeable cations (K, Ca and Mg), CEC, and organic carbon. However, for optimum performance and upgrade of suitability of the upland and flood plain to moderate/highly suitable, management practices that will encourage return of plants/crop residues into these soils to increase organic carbon, nitrogen and phosphorus for sustainable cultivation of maize and rice in all the mapping units will be required. KBII with very steep slope limitation will require terracing to reduce high rate of erosion.



Soil Mapping Units	Suitability Class	Sub class	units	Limitation	Recommendation
KBI	N1	N1f	N1f-1	fertility	Judicious use of farmyard manure
KBII	N1	N1fs	N1f-2	fertility and Slope	Addition of Organic Matter, and terracing
KBIII	N1	N1fd	N1f-3	fertility and drainage	use of farmyard manure and drainage channels.
KBIV	N1	N1f	N1f-1	fertility and Sodicity	Judicious use of farmyard manure .
KBV	N1	N1f	N1f-1	fertility	Judicious use of farmyard manure

Legend

N1=Not currently suitable
f=fertility limitation
d=drainage
s=slope

f-1=total nitrogen and available phosphorus
f-2=total nitrogen available phosphorus and slope
f-3=total nitrogen, available phosphorus and drainage

Fig 4.2: Qualitative Suitability Map for Maize on the upland and rice on the flood plain.

4.5.4.2 Demographic and socio-economic characteristics of the farmers

The summarized result of demographic characteristics of farmers in the sample village is presented in Table 4.14. The entire respondents were male, which could be due to the cultural setting of the study area where mostly males do farm work. A significant proportion of the farmers were between 30 and 50 years old indicating that the farmers were mainly middle aged are in their economically active stage. Therefore, they can undergo the stress and this has implication for productivity of the farmers. All the farmers are married with a family size of 5-9 occupying 40% of the population while 1-4 categories occupy the least of 10%. This could imply that labour might not be a problem to the farmers due to their large family size. The study area been rural, majority of the respondents has only primary certification. This might affects their adoption of modern tools for crop productivity.

Table 4.14 Demographic Characteristic of the Respondents

Characteristic	Frequency (n=30)	Percentage (%)
Sex		
Male	30	100
Female	-	-
Age		
20 – 29	7	23
30 – 44	12	40
> 45	11	37
Marital Status		
Single	-	-
Married	30	100
Family Size		
1 □ 4	3	10
5 □ 9	12	40
10 □ 14	7	23
15 □ 20	8	27
Qualification		
Qur'an Knowledge	8	27
Primary	12	40
Secondary	8	27
University	2	7

Table 4.15 presents the summarized result of land use characteristics of the farmers.

Table 4. 15 Land use Characteristic of the Respondents

Land Tenure System	Frequency (n=30)	Percentage (%)
Inherited	22	73
Purchased	8	27
Rent	-	-
Type of Fertilizer used on Farmland		
Only organic fertilizer	-	-
Only inorganic fertilizer	-	-
Both organic and inorganic fertilizer	30	100
Size of Farmland (Hectares)		
1 □ 9	24	80
10 □ 19	4	13
20 □ 29	2	7
Quantity of Fertilizer (Bags)		
1 □ 19	22	73
20 □ 39	6	20
> 40	2	7
Cost of Production (₦)		
< 50, 000	24	80
50, 000 □ 100, 000	4	13
> 100,000	2	7
Quantity of Output (Bags)		
< 50	20	67
50 □ 100	8	27
> 100	2	7
Amount of Profit (₦)		
< 10, 000	18	60
10, 000 □ 50, 000	10	33
> 50, 000	2	7

Source: Field Work, 2014.

Most of the respondents (73%) inherited their farmlands, while 27% purchased theirs. This implies that land was readily available for farming purpose, hence a reduction in cost of production. The entire respondents use both organic and inorganic fertilizer for production; 80% of the farmers only possessed small farmland of 1-9 hectares; which is a major characteristic of farmers in developing country, hence will not encourage mechanization and large scale farming. About 73% of the farmers use the least amount of 1 to 19 bags of fertilizer which was mainly due to inadequate capital and high cost of fertilizer, while 27% of the population which occupies

moderate to larger hectares of land use above 20 bags of fertilizer for their farmland. Most of the respondents; representing 80% spend less than ₦50, 000 as cost of production. The reason is because their farmland are small and they are of lower income class with inadequate capital while 7% spend more than ₦100, 000 as cost of production. Similar to cost of production, quantity of harvest also follow similar trend with majority of the respondents having lower outputs. 67% respondents harvest less than 50 bags of grains, 27% for 50 to 100 bags while 7% harvested more than 100 bags.

This study revealed that most of the respondents realize little profits while smaller percentages; which are those who are educated, had adequate labour, capital and technical skill made reasonable profit. Among the challenges identified by farmers leading to low outputs are: inadequate capital to purchase farm inputs such as fertilizer, improved seeds, storage facilities, irrigation facilities, technical skills and unstable prices of farm produce are major factor affecting maize and rice production in the study area.

4.4.4.3 Overall qualitative suitability of all the mapping units/ landform

The crop requirement and soil qualities in the study area (Table: 4.10) were matched with rating of land use requirement for maize and rice (Table 4.11 and 4.12). Soils of all the mapping units (upland and flood plain) were rated low with respect to organic carbon, total nitrogen and available phosphorus. Soil mapping unit KBII on the upland had in addition steep slope and shallow depth limitation, which could significantly reduce productivity.

Based on the climatic condition, all the units were highly suitable, while based on socio-economic factors, they were marginally suitable. Based on soil factor, overall Suitability of the upland soils for maize were classified into order N (not suitable), class N1 (currently not suitable), and sub class f (fertility) while the units were f-1(fertility), f-2 (fertility and slope) f-3

(fertility and drainage). The upland were classified as N1f-1, which represent deficiency of total nitrogen and available p in soil unit KBI, N1f-2 represent deficiency of total nitrogen, available p and slope limitation in soil unit KBII while N1f-3 represent deficiency of total nitrogen, available p and drainage in soil unit KBIII for maize production at the unit level of classification. For rice, the overall suitability was classified into order N, class N1 (currently not suitable), and sub class f (fertility) while units were f-1 (fertility) for both mapping unit KBIV and KBV on the flood plain. They were both classified as N1f-1, which represents total nitrogen and available phosphorus limitation for the two units (Fig: 4.2).

4.5.4.4 Quantitative land suitability classification for maize and rice based on storie index

Criteria for Quantitative land suitability classification: The land of the present study was rated based on this four characteristic:

Factor A: Soil profile group (soil depth); is a rating of character of soil profiles based on the degree of soil development. The upland and flood plain ware all deep, as such rated 100% except KBII which was rated 75 due to shallow to deep nature of the soils (O'Geen *et al.*, 2008).

Factor B: Soil texture (surface texture) Loamy soils receive the highest ratings, and clay-rich and sandy soils receive lower ratings (Storie, 1978). Soils of the upland and flood plain surface texture varied from loam to sandy loam, as such were all rated 100%.

Factor C: Slope, based on steepness of slope. Nearly level to gently sloping conditions (0 to 8% slope) receive high scores, which range from 100 to 85 %. Moderate to strongly sloping conditions (9 to 30%) have scores ranging from 95 to 70%, slops greater than 30% receive lower scores, ranging from 50 to 5 % (Storie, 1978). All the soils of study areas were thus rated 100% with the exception of mapping unit KBII which was rated 60% due to its gentle to steep slope.

Factor X: Characteristics considered are drainage class, alkalinity, degree of acidity, water erosion and microrelief. Scoring for each characteristic in factor X (Drainage, alkalinity (EC and SAR), acidity and erosion) is subjective. Soil pH, EC and SAR of upland and flood plain were rated 100%, based on erosion hazard, KBI on the upland was rated 100% being nearly flat while all the other unit were rated 70 – 90%. The KBI and KBII on upland was rated 100% based on drainage because they are well drain while KBIII, KBIV and KBV were rated 70-80% due to their poorly drain characteristics.

Table 4.17 indicates that land suitability classes of the study area varied from excellent (S1), good (S2) and fair (S3) due to differences in limiting factors (Figure 4.3). The limiting factors are drainage, slope and erosion. Result of Storie index analysis had shown that the limiting factors for maize production according to parametric methods on the upland were slope, drainage and erosion hazard, while limitation for rice production on the flood plain was erosion and drainage hazard.

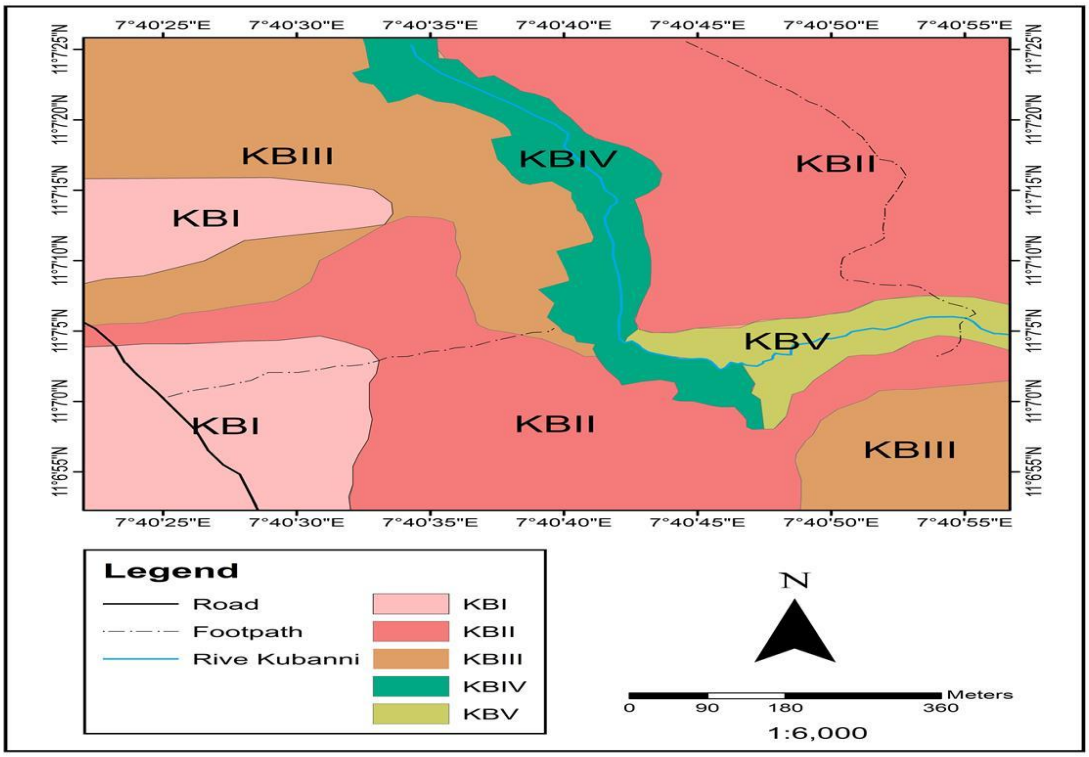
Table 4.17: Land Suitability Index and Corresponding Class according to Storie Index.

Soil Mapping Units	KBI	KBII	KBIII	KBIV	KBV
Factor A (Depth)	100	75	100	100	100
Factor B (Surface Texture)	100	100	100	100	100
Factor C (Slope)	100	60	100	100	100
Factor Xi (pH)	100	100	100	100	100
Factor Xii (SAR)	100	100	100	100	100
Factor Xiii (EC)	100	100	100	100	100
Factor Xiv (Erosion)	100	70	90	90	90
Factor Xv (Drainage)	100	100	80	70	70
Storie Index	100	32	72	63	63
Suitability Class	S1	S3	S2	S2	S2
Soil Grading	Excellent	Poor	Good	Good	Good

4.5.4.5 Overall quantitative suitability evaluation based on storie index

Soil mapping unit KBI on the upland was rated excellent (S1) being suitable for maize without any permanent limitation. KBIII was moderately suitable (S2) as a result of erosion hazard while KBII was marginally suitable (S3) due to depth, slope and erosion hazard which can reduce productivity for maize production on the upland. Soil mapping unit KBIV and KBV on the flood plain were rated good (S2) because they are averagely suitable for rice as a result of erosion and drainage limitation which will require construction of drainage channel and terracing for sustainable crop production.

Generally, there were no significant differences in the suitability of the upland and flood plain based on qualitative land suitability evaluation but there were significant differences in the suitability of the upland and flood plain based on quantitative land suitability (storie index).



Soil Mapping Units	Suitability Class	Sub class	units	Limitation	Recommendation
KBI	S1	S1	S1	Nil	Nil
KBII	S3	S3s	S3s-1	Slope and erosion	Construction of terracing
KBIII	S2	S2ed	S2ed-2	Erosion and drainage	Construction of drainage channels and terracing
KBIV	S2	S2e	S2e-1	Erosion	Construction of terracing
KBV	S2	S2e	S2e-1	Erosion	Construction of terracing

S1 = Highly suitable
S2 = Moderately suitable
S3 = Marginally suitable

S2e-1 = erosion
S3ed-2 = erosion and drainage

Fig. 4.3: Quantitative Suitability Map for Rice and Maize

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary

The study was carried out in Zaria, Kaduna State, Nigeria and located between $11^{0}06\square 50"$- $11^{0}07\square 25"$ N and $7^{0}40\square 22"$ - $7^{0}40\square 58"$E in the lower Kubanni drainage basin, behind Nigeria College of Aviation Technology (NCAT) Zaria. This study aim to characterized and evaluate suitability of soils around River Kubanni for rice and maize production. The soils were classified using USDA Soil Taxonomy (Soil Survey Staff, 2010) and FAO World Reference Base for Soil Resource (FAO, 2014). To achieve the aim of study, satellite imagery and DEM were use to create base map in GIS environment for the field work which was used in creating soil map; morphological and physico-chemical properties of thirty four (34) soil samples were sampled from the identified genetic horizons of ten (10) pedon dug on the study area.

The upland soils were deep to very deep (135 to 170cm) except mapping unit KBII which was shallow to deep (50-120cm), while the flood plains were also deep to very deep (140 to 170cm); depths increased down the slope. The depths reflect influence of parent material, topography and water table. The soils were predominantly medium texture with sub-angular block at the surface and blocky at the subsurface on the upland; and structureless form dominates the flood plain structures. The upland soils were well drained to imperfectly drained while the flood plains were very poorly drained. This was attributed to the influence of topography and increase in clay content with depth. Soil colour varied from dark yellowish brown (10YR4/4) to brown (10YR5/3) over strong brown (7.5YR5/6) on the upland while the flood plain colour varied from yellowish brown (10YR4/6) over dark gray brown (2.5YR4/2).

Horizon differentiation between Ap horizon and the lower B horizon were quite clear. Horizon boundaries in the surface soils were abrupt, smooth to gradual and diffuse on the upland

while, abrupt, smooth and wavy boundary dominate the flood plain. Fine mica flakes in the soils were an indication that the parent materials were derived from Basement Complex rock containing mica. Sand dominated the particle-size fraction of the fine earth portion of the soils with the flood plain significantly ($p<0.05$) higher than the upland. Texturally, the soils were mainly loam to sandy loam at the surface and sub-surface horizons. The bulk density generally increases down the profile with irregular pattern. Total porosity decreased with depth which was attributed to significant illuviation of clay. There were no significant differences in silt, clay, total porosity and bulk density value between the upland and flood plain.

Soil reaction was slightly acidic to neutral (pH 6.3 – 6.9), the pH values decreased down the profile with the upland recording higher value. The exchangeable bases were medium to high indicating moderate basic nutrient status of the soils and occurred in the order Ca^{2+}> Na^{+}> Mg^{2+}> K^{+}. The base saturation was rated medium to high in the soils, which might be a reflection of the intensity of weathering that produced the soils. Organic carbon of the soils was generally low. There were no significant differences in pH, Ca^{2+}, Na^{+}, Mg^{2+} and K^{+} values between the upland and flood plain, but the base saturation on the flood plains were significantly higher.

Available phosphorus (Ap) and total nitrogen followed similar trend as organic carbon, suggesting that these nutrients could be derived from Organic carbon and they were all low. The Ap was significantly higher on the flood plain, while there were no significant difference in total nitrogen and organic carbon between the upland and flood plain. The extractable micronutrient content was rated high and occurred in the order: Fe > Mn > Zn > Cu > B in the soils and decreased down the profile. The flood plain was significantly higher in Fe, Mn and Zn while there was no significant difference in the Zn and B content. EC and TSS was also rated low, thus the soils were classified as non-saline while unit KBIV on the flood plain had ESP >15 and thus

classified as sodic soils. There was no significant difference in the EC, TSS and ESP of the upland and flood plain soils. Generally there was no significant variation between the upland soils and flood plain.

According to USDA Soil Taxonomy, mapping unit KBI and KBIII on the upland were classified at Great Group as *Plinthustalf*, at the sub group level as *Typic Plinthustalfs*. KBII were classified at the great group as dystrustepts and at the group level, as *torrertic* dystrustepts. Soil unit KBIV and KBV on the flood plain were classified at the great group as *Endoaquepts* and at the group level, they were classified as *Fluvaquentic Epiaquepts*. In the FAO/UNESCO system, mapping unit KBI, KBIII on the upland were classified as *Eutric Lixisols*. KBIV and KBV are classified as *Endoeutric Fluvisol* and KBII was classified *Terric cambisols*.

Using the qualitative land suitability evaluation (simple limitation method), all the soils mapping units in the study were currently not suitable (N1) due to limitation imposed by chemical properties while based on the quantitative land suitability evaluation (storie method), KBI was highly suitable (S1), KBIII was moderately (S2) suitable and KBII was marginally (S3) suitable on the upland for maize, KBIV and KBV on the flood plain were moderately suitable (S2) for rice. Generally, results of socio-economic characteristics of the farmers show that the soils were marginally suitable (S3) as results of low outputs recorded by most of the farmers; which was mainly attributed to inadequate fertilizer since a small percentage of the farmer who used adequate fertilizer recorded high outputs. This result was in line with the qualitative suitability analysis which reveals that the study area was poor in the major macro-nutrient, mainly nitrogen and phosphorus.

5.2 Conclusion

The results from the study showed that the upland and flood plain soils were low in soil fertility, a confirmation of the general characteristic of Savanna soils reported by earlier researchers. There was no significant variation between upland and flood plain soils; although the flood plain soils were significantly higher in base saturation, available phosphorus, iron, manganese and copper. This indicates that the flood plain were more fertile than adjacent upland as the flood plain was significantly higher in BS than the adjacent upland.

The upland and flood plain soils where currently not suitable for maize and rice production respectively as a result of low fertility based on the qualitative land suitability evaluation. The upland was highly to marginally suitable while the flood plain was moderately suitable for maize and rice based on the quantitative method as this method considered permanent factors which are not easily changed. This information has many practical implications for petrologic studies. Catenaries studies and influence of landform on soil properties. Furthermore, it has implication on land productivity of Zaria to meet food and fibre demand of the growing population.

The contributions of this study are as follows; it informs scientists/planners on the sodicity status of the soils and the need for their proper management. It also reveals information on the suitability of soils in Zaria and their limitation for sustainable crop production. Information on micronutrient status of the soils revealed that the soils were not deficient in micronutrients. The study also revealed that low input was responsible for low outputs recorded by farmers.

5.3 Recommendations

Based on findings of this study, the major limitations against sustainable productivity of the soils are low soil fertility, soil depth, steep slope and poor drainage; thus the following recommendations are made:

To improve soil fertility, Farmers should practice mulching by crop residue and manure. These practices have the potential of protecting the soil against direct rain and insulation. It also improves the water and nutrient retention of the soil through the provision of organic matter and improvement of soil structure and porosity. Another practice that has been suggested is zero or minimal tillage, where cultivation is kept to the barest minimum.

Construction of contour ridges and strip cropping in soil mapping units KBII to reduce the rate of suface wash/erosion as a result of steep slope. Intercropping with leguminous crop should also be practice to replenish the soils with nitrogen.

Soil mapping units KBIII on the upland, KBIV and KBV on the flood plain which are imperfectly to poorly drained would require an improvement of aeration conditions in the plow layer, construction of field drainage ditches to conduct excess field and subsoil stagnated water away from the fields which are major limitation of this soils.

For optimum performance and upgrade of the suitability of the area to moderate/highly suitable. Management practices that will encourage return of plants/crop residues into these soils and manure application to improve soils physical and chemical constraints should be practice.

Government and private sector should supply farm inputs (seed and fertilizer) and implement/tractor to farmers at subsidized rate and at appropriate time. Government should provide good roads linking production areas to ease farmers evacuate their produce. Finally, there is need for adequate markets with stable prices for farmers products coupled with storage facilities to further boost crop production on a sustainable bases.

5.4 Study Limitation and Recommendation for Further Studies

This study characterized and evaluates suitability for rice and maize production in Kubanni flood plain and adjoining upland. The study only covered 100ha of land out of the large hectares of land. Soil properties are usually very complex, changing from one place to another in characteristic and suitability, hence the need for the whole area to be surveyed and its suitability is evaluated. There is the need to evaluate other crops grown within Zaria too.

The influence of land use, cultural and management practices on the variation of soil properties could have significant changes in certain soil properties. Therefore, it is suggested that future research should focus on a combination of physical, chemical and mineralogical properties. Further studies should be undertaken to evaluate the cause of sodicity in the study area.

.

REFERENCE

Abdullahi, A.S. (1997). *The Fertility Status of Soils along the Microtopography of the River Galma Flood plains at Zaria.* Unpublished M.Sc. Thesis. Department of Soil Science, ABU, Zaria. pp. 28-41.

Abedi, M.J. and Talibudeen O.J., (1974). The calcareous soils of Azerbaijan. Catena Development Related to the Distribution and Surface Properties Of Soil Carbonate. *Journal of soil science*. 25:357-372 Accessed June, 2005

Adamu, G.K. (2013). An Assessment of Soil Properties of Watari Irrigation Project, Kano State, Nigeria. *Academic Research International.* 4:4:254-266. ISSN: 2223-9944

Adeleye, E.O. (2002) A Review of Soil Management Techniques for Sustainable Crop Production in Nigeria. *Agric. Sci. J.*, 1:91-105.

Adepetu, J.A., Aduagi, E.A. and Alofa, C.A. (1979). A preliminary of fertility status of some soils in Ondo state under traditional cultivation. *Ife Journal of Agriculture* 134:149.

Adetunji, M.T. (1991) An Evaluation of Soil Nutrient Status for Maize Production in Southwestern Nigeria. *Journal of Agricultural Resources,* 8: 101-113.

Adetunji, M. T. and Adepetu, J. A. (1990) Status and distribution of sulphur fractions in soils of South Western Nigeria. *Journal of Soil Science* 24:137 – 140

Aduayi, E.A., Chude, V.O., Adebusuyi, B.A. and Olayiwola, S.O. (2002).Fertilizer Use and Management Practice for Crops in Nigeria. *Journal of Agricultural Resources,* 8:101-133

Agbenin, J.O. (1995) *Laboratory Manual for Soil and Plant Analysis*. Department of Soil Science, Ahmadu Bello University Zaria, Kaduna State.

Ahn, P.M. (1970). *West African Soils*. An Oxford University Press, London

Akinbola, G.E., Anozie, H.I and Obi, J.C (2009).“Classification and Characterization of some Pedons on Basement Complex in the Forest Environment of South-Western Nigeria”. *Nigerian Journal of Soil Science,* vol. 19, no. 1, pp. 109-117.

Akinwunmi A. (2011). *Agricultural Transformation Agenda; We Will Grow Nigerian Agriculture*. A presidential brief at Federal Ministry of Agriculture and Rural

Development. Abuja, Nigeria. Retrieved 9th, September, 2011. http://www.globalbioenergy.org

Akinwunmi A. (2014).*Food Security through Agricultural Transformation Agenda*. Leadership News Paper.www.Leadership.ng. Retrieved May, 29 2014.

Aondoakaa, S.C. and Agbakwuru, P.C. (2012). An Assessment of land Suitability for Rice Cultivation in Dobi, Gwagwalada Area Council, FCT – Nigeria. *Ethiopian Journal of Environmental Studies and Management* Vol. 5 no.4 http://dx.doi.org/10.4314/ejesm.v5i4.S2

Atofarati S.O., Ewulo B.S. and Ojeniyi S.O., (2012).Characterization and classification of soils on two toposequence at Ile-Oluji, Ondo State, Nigeria. *International Journal of Agric Science* Vol. 2(7): 642-650

Audu, M.A., Abdullahi A., Noma S.S. and Abdulaziz S. (2009). Salinity and Sodicity Status of Worno Irrigation project area, Sokoto, Northwest Nigeria. In Fasina A.S., Ayodele, O.J., Salami, A.E; Ojeniyi, S.O. (eds) *Management of Nigerian Soil Resource for enhanced Agricultural Productivity*. Proceeding of the 33rd Annual conference of the Soil Science Society of Nigeria (SSSN*)* 60 -65 pp.

Awanish K., Mishra,V. N., Srivastav, L. K. and Rakesh B. (2014) Evaluations of soil Fertility Status of Available Major Nutrients (N,P & K) and MicroNutrients (Fe, Mn, Cu & Zn) in Vertisol of Kabeerdham District of Chhattisgarh, India.*International Journal of Interdisciplinary and Multidisciplinary Studies (IJIMS)*, Vol 1, No.10, 72-79. Retrieved from http://www.ijims.comISSN: 2348 – 0343

Aweto, A. O. and Enaruvbe, G.O. (2010). Catenary Variation of Soil Properties under Oil Palm Plantation in South Western Nigeria. *Ethopian Journal of Enviromental Studies and Management, Vol 3*.(1)

Ayolagha, G.A. and Opene, G.A. (2012). Characterisation and Classification of Some Selected Soils of Ndoni in the Meander Belt of Niger Delta. *Nigeria Journal of Soil Science* Vol. 22(2) 50-57.

Babalola T.S., Oso, T., Fasina, A.S. and Godonu, K. (2011).Land Evaluation Studies of two Wetland Soils in Nigeria. *International Research Journal of Agricultural Science and Soil Science* (ISSN: 2251-0044) Vol. 1(6) pp. 193-204Available online http://www.interesjournals.org/IRJAS

Balasubramania, V.L., Singh, L.A. and Mokwunye, A.U. (1984). Fertility Status of Some Upland Savanna soils of Nigeria under Fallowed Cultivation. *Samaru Journal of Agricultural Resource* Vol.2. No 1 and 2.

Balasubramaniyan, P. and Palaniappan, S.P. (2001). *Principles and Practices of Agronomy.* Agro-bios (India), Jodhpur. 596 pp.

Banjoko, V.A. and Ashaye, T.I. (1981). The effect of moisture regime on the extractable Fe content of selected soils of southwestern Nigeria. *Nigerian Journal of Soil Science*, 1, 18-29

Bartelli, L.J. (1978).Technical Classification Systems for Soil Survey Interpretation. *Advance Agronomy*, 30:247-289.

Behzad, M., Albaji, M., Papan, P., Boroomand, S, Nasab, A., Naseri, A. and Bavi, A. (2009). Qualitative Evaluation of land suitability for principal crops in Gargar region, Khuzestan province, southwest Iran. *Asian J. Plant Sci*., 8: 28-34.

Bello, A.L. (1973).*The Morphology of an Erosional Scarp, South of the Ahmadu Bello University, Zaria*". Unpublished B.A. Dissertation. Department of Geography. ABU, Zaria.

Binns J. A., Machonachie, R. A. and Tanko A. I. (2003).*Water, Land and Health in Urban and Peri-urban Food Production*: The case Kano, Nigeria, Retrieved fromwww.cityfarmer.org.

Blake, G.R., and Hartge, K.H., (1986). Bulk density. p. 363-382. In A. Klute (ed.) *Methods of Soil Analysis. Part 1.Physical and Mineralogical Methods*.2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Boul S.W., Southard R.J., Graham R.C., and McDaneil P.A. (2003).*Soil Genesis and Classification*, (5thed.) State Avenue Ames, Lowa, lowa State Press.

Brady, N.C. and Weil, R.C. (2002).*The Nature and Properties of Soils*.13th edition. Pearson Education. India.

Brady, N.C. and Weil, R.C., (2005). The Nature and Properties of soils, Thirteenth Edition, Pearson Printice-Hall Inc., India,

Brady. N.C. and Weil R.R. (1999).*The Nature and Properties of Soils*.12th ed. Prentice Hall, upper Saddle River, New York. 881pp.

Bremmer, J.M., and Mulvaney, C.S., (1982). Nitrogen - Total. p. 595-624. In Page A., L., Miller, R., H. and Keeney, D., R., (eds.) *Methods of Soil Analysis. Part 2.Chemical and Microbiological Properties*.2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

.

Buol, S.W., Sanchez, P.A., Cate, R.B. and Granger, M.A. (1975). Soil Fertility Capability Classification: A Technical Soil Classification System for Fertility Management. In Bornemisza, E. and Alvarado A. (Ed.) *Soil Management in Tropical America*. N.C. State Univ., Raleigh, NC: 126-145

Carroll, D.M. (1974). *The Soils of the Maiduguri-Bama Area*. Soil Survey Bulletin, Samaru 40.

Commercial Agriculture Development Project (CADP) Nigeria (2010). Agriculture Production and Commercialization. Retrieved from www.cadpnigeria.org.

Chude, V.O, Malgwi. W.B, Amapu, I.Y and Ano, O.A (2004). *Manual on soil fertility assessment.* Federal fertilizer department in collaboration with National special programme for food security, Abuja Nigeria.

Daudu, C.K. 1989. *Distribution of total and available forms of B in four soil profiles developed from Loess in Funtua areas of Katsina State*. Unpublished B.Sc. Project, Faculty of Agriculture, ABU, Zaria, 64p

David M. (2003). The *Australian Cotton grower Salinity and sodicity — what's the difference.* 24:1, p. 28

Dent, D. and Young, A. (1981). *Soil Survey and Land Evaluation*. George Allen & Unwin, London.

Donahue, R.L, Raymond, M.W. and Schick Line, J.C. (1990). Soils: *An introduction to soils and plant growth*. Prentice hall of India. 667pp

Dorronsoro, C. (2002). *Soil Evaluation the role of Soil Science in Land Evaluation. Sustainable Use and Management of Soils in Arid and Semiarid Regions*. In Faz, A., Oritz, R. and Mermut, A.R. (eds.). Murcia: 106-128.

Dregne, H.E. (1976).*Development in Soil Science 6: Soils of Arid Regions*. Elsevier Scientific Publishing Company, Amsterdam, Netherland.

Duniya, N.R. (2006). *Effects of Soil Physical Properties on Gully Erosion and its Morphological Development in Zaria, Northern Nigeria*. Unpublished M.Sc., Geography, ABU, Zaria.

Ekwoanya, M.A. and Ojanuga, A.G., (2002) Productivity of Upland and Flood plain Soils in Markurdi, Nigeria. *Geogerma*. vol. 108 (1) pp. 19-29

Esu, I.E. (1982).Evaluation of Soils for Irrigation in the Kaduna Area of Nigeria. An unpublished Ph.D Thesis submitted to Soil Science Department, Ahmadu Bello University, Zaria.

Esu, I.E. (1991).*Detailed Soil Survey of NIHORT Farm at Bunkure, Kano State, Nigeria.* Institute for Agricultural Research, Ahmadu Bello University, Zaria.

Esu, I.E (1999). *Fundamentals of Pedology*. Stirling-Horden, Ibadan Nigeria. 87-98pp

Esu, I.E. (2004) Soil Characterization and Mapping for Food Security and Sustainable Environment in Nigeria. *Proceedings of the 29th Annual Conference of the Soil Science Society of Nigeria*, Dec. 6-10, University of Agriculture, Abeokuta, Nigeria, 20-24.

Food and Agricultural Organization (FAO) (1976). *A Framework for Land Evaluation*. Soils Bulletin 32.Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO (1983).*Guidelines: Land Evaluation for Rain-fed Agriculture*. Soil Bulletin No 52, Food and Agriculture Organization, Rome, 237 pp.

FAO (1985).*Guidelines: Land Evaluation for Irrigated Agriculture*. Soils Bulletin 55.Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO (1989). FAO/UNESCO. *Soil Map of the World, Revised Legend*. World Resources Report 60. Rome; Food and Agriculture Organization. Reprinted as Technical Paper 20, Wageningen, and 138pp.

FAO (2014). World Reference Base for Soil Resources. *A Framework for International Classification, Correlation and Communication.* World Soil Resources Reports 103.128p.

FAOSTAT (2005).FAOSTAT-ON LINE: http://faosts.fao.org.FAOSTAT.http://faostat.fao.org/site/567/DesktopDefault.aspx. Retrieved December 26, 2006.

Fasina, A.S., Awe, G.O. and Aruleba, J.O. (2008). Irrigation Suitability Evaluation and Crop Yield – An Example with Amaranthus Cruentus in Southwestern Nigeria. *African Journal of Plant Science* Vol. 2 (7), pp. 061-066.

Fasina, A.S. (1999). Characteristics, classification and management of soils of Lagos State. *in*: Babalola, O., Omoti, U. and Isenmila, A.E. (eds), *Management of the soil resources of Nigeria for sustainable agricultural production in the 21st century,* pp. 33 - 38. Proc. of the 25th Annual Conference of Soil Science Society of Nigeria, held at Precious Palm Royal Hotel, Benin city, Edo State, Nigeria. 21st – 29th Nov. 1999.

Fasina A.S. (2005). Properties and classification of some selected wetland soils in Ado Ekiti, Southwest Nigeria. *Applied Tropical Agriculture*, 10 (2): 76-82

Fasina, A.S. and A. Adeyanju (2006). Suitability Classification of Some Granitic Soils of Humid Southwest Nigeria for Rain-fed Maize, Cassava and Swamp Rice Production. *Nigeria Journal of Soil Science* 16:1-9.

Fasina A.S and Adeyanju A (2007). Comparison of three Land Evaluation Systems in Evaluating the Predictive Value of some selected soils in Ado-Ekiti, Southwest Nigeria. *Journal of Soil Science* 17:113-119.

Gee, G.W. and Bauder, J.N. (1979). Particle Size Analysis by Hydrometric Method; a Simplified Method for Routine Textural Analysis and Sensitivity Test of Mineral Parameters, *Soil Science Society, American Journal*, 43: 1004-1007.

George, H. (1997). An Overview of Land Evaluation and Land Use Planning. *Land and Plant Nutrition Management Service,* AGLL, FAO.

Ghose. R.L.M., Ghatge.M.B and Subrarnanyan, V. (1960). *Rice in India*. Indian Council of Agricultural Research, New Delhi.471 pp.

Garcia, O. A. (2003). *Physical Properties of Magnesium Affected In Colombia*. Lecture given at College of Soil Physics Treste.LNS0418016, 6pp.

Henry, A. A. (2014). *Developing Priority Agriculture Value Chains in Nigeria's Transformation Agenda.* Tunga Media. Retrieved Feb. 12, 2014.www.tungamediang.com

Hore, P.N. (1970). Weather and Climate of Zaria. In: Mortimore, M.J. (ed), Zaria and its Regions. *Occasional Paper* 4, Department of Geography, A.B.U., Zaria.

Hussaini, G.M. (2011). *Land Suitability Evaluation for Some Selected Land Use Type in the Institute for Agricultural Research Farm, Zaria, Nigeria*. Unpublished M.Sc. Thesis. Department of Soil Science, ABU, Zaria.

Ibrahim, H. Y. and Omotesho, O. A. (2012). Optimal Farm Plan for Vegetable Production under Fadama in North Central Nigeria. Trakia Journal of Sciences, Vol. 9(4) 43-49.

Ibrahim A. K. and Abubakar B. (2013).Extractable Micronutrients Status in Relation to other Soil Properties in Jangargari, Yamaltu-Deba Local Government Area, Gombe State. Asian Journal of Agriculture and Food Science (ISSN: 2321 - 1571) Volume 01 (www.ajouronline.com)

International Institute of Tropical Agriculture (IITA), (1979).*Selected Methods for Soil and Plant Analysis.*2nd edn., International Institute of Tropical Agriculture, Ibadan, Oyo State, Nigeria, Pages: 70.

IITA, (2009).Research to Nourish Africa; *Maize*. Retrievedwww.iita.org/maize

Isirimah, N.O., Dickson, A.A. and Igwe, G. (2003). *Introductory Soil Chemistry and Biology for Agriculture and Biotechnology.* Osia, Int'l publishers Ltd. Nigeria, pp. 31.

Ita, E.R. and Esu, I.E. (2012). Morphological And Physic-Chemical Properties Of Saprolite Derived Coastal Plain Sands In Se Nigeria. *Nigerian Journal of Soil Science.*22 (2) pp316-326

Jackson, G. (1970). Vegetation of Zaria In: Mortimore, M.J. (ed), Zaria and its Regions.*Occasional Paper* 4, Department of Geography, A.B.U., Zaria.

Jagdish, P., Ray, S.K., Gajbhiye, K.S. and Singh S.R. (2009). Soil of Selsura Research farm in Wardha District, Maharashtra and their suitability for crops. *Agropedology* 19:84-91.

Jha. K. P., Moorthy B.T. and Rao. K.S. (1999). Rice. In P.S. Rathore (Ed.). *Techniques and Management of Field Crop Production. Agrobios* (India), Jodhpur. pp.6-40.

Jones, M.J. and Wild, A. (1975).*Soils of West Africa Savanna soils*. Commonwealth Agricultural Bureaux, pp. 241.

Joseph K., Njoroge J. B. and Hunja M. (2013). Suitability Analysis for Rice Growing Sites Using A Multicriteria Evaluation And Gis Approach In Great Mwea Region, Kenya. *Springer* 2: 265. doi: 10.1186/2193-1801-2-265

Katyal, J.C., (1985).Research Achievements of all India coordinated Scheme of micronutrient in soil and plants. *Fert*. New 30:67-80

Klingebiel, A.A. and Montgomery, P.H. (1961). *Land Capability Classification.* USDA Agricultural Handbook 210.US Government Printing Office, Washington, DC.

Klinkenberg, K. (1970). A Nigerian Savannah City and its Environs. *Occasional Paper No. 4* Department of Geography, Ahmadu Bello University, Zaria. Pp. 5-10.

Kparmwang, T. (1993).*Characterization and Classification of Basaltic Soils in the Northern Guinea Savanna Zone of Nigigeria*.Unpublished Ph.D Thesis. Department of Soil Science, ABU, Zaria. pp. 176.

Kparmwang, T. and Esu, I.E. (1990). Characteristics and Agricultural land use of Flood plains soil in the savanna region of Nigeria: A review. *Savanna* 11:116-131.

Kyari, D.J. (1995): Use of Airphotos in the Identification of Land Degradation in Kubanni River Basin. Unpublished M.Sc DI ABU, Zaria.

Lombin, G. (1985). Micronutrient soil tests for the semi-arid savanna of Nigeria. Boron and Molybdenum. *Soil Science Plant Nutrition*. 13:1-11.

Lawal, B.A., Ojanuga A.G., Noma, S.S., Adeboye, M.K.A., Dikko, A.U and Singh, A. (2012). Suitability Evaluation of Soils of Lower River Oshin Flood plain, Kwara State, Nigeria for Rain-Fed Arable Crop Cultivation. *Nigerian Journal of Soil and Environmental Research.* Vol. 10:71 - 78

Lawal, B.A, Ojanuga, A.G., Tsado, P.A. and Mohammed, A. (2013) Characterization, Classification and Agricultural Potentials of Soils on a Toposequence in Southern Guinea Savanna of Nigeria, *International Journal of Biological, Veterinary, Agricultural and Food Engineering* Vol:7, No:5.

Malgwi W.B. (2007). *Soil Survey: Soil Analytical Data Interpretation for Land Management*. Paper presented at Training Workshop in Soil Survey and Land Evaluation Methodology for Federal Department of Agriculture and Land Resource Staff in Kaduna.

Malgwi, W.B. (2001). *Characterization of salt affected soils in some selected location in the North Western Zone of Nigeria*. An unpublished PhD Thesis submitted to Soil Science Department, Ahmadu Bello University, Zaria.

Malgwi, W.B. Ojanuga, A.G., Chude, V.O., Kparmwang, T. and Raji, B.A. (2000). Morphological and Physical Properties of Some Soil at Samaru, Zaria, Nigeria. *Nigerian Journal of Soil Research*, vol. 1, pp. 58–64.

Maniyunda, L.M. (1999). *Pedogenesis on Loess and Basement Complex rocks in a subhumid environment of Nigeria and the suitability of the lands for rainfed cultivation.* Unpublished M.Sc. Thesis. Department of Soil Science, ABU, Zaria. pp. 49-67.

Maniyunda, L.M., Kparmwang, T., Raji, B.A., and Yaro, D.T. (2007). Land Suitability Evaluation of Haplustults for Rainfed Crop Production in a Sub- Humid Environment of Nigeria. In Uyovbisere, E.O, Raji, B.A, Yusuf, A.A, Ogunwale, J.O, Aliyu, L. and Ojeniyi, S.O (Eds).*Soil and water management for poverty alleviation and sustainable Envtironment.* Proceedings of the 31st annual conf. of SSSN/ABU Zaria Nig. Nov. 13th to 17th, 2006.

Maniyunda L.M. and Gwari M.G. (2014). Soils Development on a Toposequence on Loessial Deposit in Northern Guinea Savanna, Nigeria. *Journal of Agricultural and Biological Science.* VOL. 9(3) ISSN 1990-614. Retrieved fromwww.arpnjournals.com

Matsuo, T. (1955). *Rice Culture in Japan*. Yokendo Japan.

Martin, J.H. and Leonard, W.H. (1967).*Principle of Crop Production*. The Macmillan Company: pp 291-345

McRae, S.G. and Burnham, C.P. (1981). *Land Evaluation*, Monograph Soil Survey. Clarendon Press.

Moberg, J.P. and Esu, I.E. (1991). Characteristic and Composition of Some Savanna Soils in Nigeria. *Geoderman* 48:113-129

Mokwunye, A.U. and Batiano, B. (2002).Meeting the Phosphorus Need of Soils and Crops pf West Africa. The Role Of Indigenous Phosphate Rocks, in. *Integrated Plant Nutrient Management in Sub-Sahara Africa*. Pp209-224

Mosugu, M.E. (1989). *A Bio-Climosequence Study Of Upland Soils Developed On Older Granites In Nigeria.* M.Sc. Thesis (unpublished). Department of Soil Science, ABU, Zaria. pp. 132.

Nahusenya, A., Kibebew, K., Heluf, G. and Abayneh, E. (2014) Characterization and classification of soil along the toposequence at the Wadla Delanta Massif, North Central Highlands of Ethiopia. *Journal of Ecology and the Natural Environment*. Vol. 6(9):304-320

Naidu L.G.K., Ramamurthy V., Challa O., Rajendra H and Krishnan, P. (2006). *Manual Soil-Site Suitability Criteria for Major Crops.* National Bureau of Soil Survey and Land Use Planning (ICAR) No. 129, NBSS & LUP, Nagpur 1) 8 pp.

Nelson, M.J and Sommers, L.E (1982). Total Carbon, Organic Carbon and Organic Matter. In: Page, L.A., Miller, R.H. and Keeney, D.R. (eds), *Methods of Soil Analysis*, pp. 539-579. Part 2.Chemical and Microbiological Methods (2nded).American Society of Agronomy. Madison, W.I

Njar, G.N, Iwara, A.I, Egbe, M, Offiong, R.A. and Essoka, P.A. (2012). An Evaluation of Soil Suitability for Maize Production In Obiaruku Community In Nigeria. *British Journal of Advance Academic Research.*1:1 pp.16-27.

Noma, S.S., Tanko, I.I, Yakubu, M. Dikko, A.U., Abdullahi. A.A and Audu, M. (2011).Variability in the physico-chemical properties of the soils of Dundaye District, Sokoto State, Nigeria. In Hassan, W.A. Kyiogom, U.B. Tukur, H.M. Ipinjolu, J.K. Maigandi, S.A. Singh, A., Ibrahim, N.D., Dikko, A.U., Bashir, Y.A. and Muhammad, N. (Eds). Mobilizing Agricultural Research Towards Attaining Food Security And Industrial Growth in Nigeria. *Proceedings of the 45th annual conferences of the Agricultural Society of Nigeria* held at the Faculty of Agriculture, Usmanu Danfodiyo University Sokoto, Nigeria, 24th to 28th Oct.

Nwaka, G.I.C. and Kwari, J.J. (2000).The Nature and Properties of the Soils of Jere Bowl near Maiduguri in Borno State. *Samaru Journal of Agricultural Resource* 16:25-40.

Odunze, A.C. (2006). Soil properties and management strategies for some sub humid savanna zone Alfisols in Kaduna State, Nigeria. *Samaru Journal of Agricultural Resource*. 22:3-14.

Odunze A.C. and Kureh, I. (2009).Land Use limitations and management option for a Savanna Zone Alfisol. *Journal of Agriculture and Environment for International Development*.103 (4): 321-335.

Ogban, P.I., Akwue, I.P. and Maduako, O. (1999).Properties and Management of Catenary Soils on coastal plain sands in South-Eastern Nigeria. *In:* Babalola, O., Omoti, U. and Isenmila, A.E. (eds), *Management Of The Soil Resources Of Nigeria For Sustainable Agricultural Production in the 21st century*, pp. 45-61.Proceeding of the 25th Annual Conference of Soil Science Society of Nigeria, held at Precious Palm Royal Hotel, Benin city, Edo State, Nigeria. 21st – 29th Nov. 1999.

O'Geen, A.T., Southard, S.B and Randal, J.S (2008). *Revised Storie Index with Digital Soil Information.* Division of Agriculture and Natural Science. Special Publication 8335.Retrieved from www.ancatalog.ucdavis.edu.

Ogbodo, E.N. (2011). Assessment of Fertility Characteristic of Abakaliki Urban Flood plain of South-East Nigeria, for sustainable Crop Production. *World Journal of Agricultural Sciences*. 7 (4): 489-495.

Ogunwole, J.A. (2008). Soil Aggregate Characteristic and Organic Carbon after 45 Annual Application of Manual and Organic Fertilizer. *Biology, Agriculture and Horticulture*, Vol. 25:223-233

Ojanuga, A.G. and Awujoola, A.L. (1981). Characteristics and Classification of the Soils of the Jos Plateau, Nigeria. *Journal of Soil Science.* 2:101-119.

Olaleye A.O (1998). Characterization, Evaluation, Nutrient dynamics and Rice Yields of Selected Wetland soils in Nigeria. PhD Tesis in the Department of Agronomy, University of Ibadan. 202 pp

Olaleye, A.O., Ogunkunle, A.O., Sahrawat, K.L, Osiname, O.A. and Ayanlaja, S.A. (2002). Suitability Evaluation of Selected Wetland Soils in Nigeria for Rainfed Rice Cultivation. *Tropicultura*, 20(3): 97-103

Loge, K.O. (1971): *Gully Development in the Zaria Area Northern Nigeria (with Particular Reference to Kubanni Basin).* Unpublished Ph.D. Thesis, University of Liverpool, London.

Oluwatosin, G.A. (2005) Land Suitability Assessment in Continental Grits of Northwestern Nigeria for Rainfed Crop Production. *West African Journal of Applied Ecology*, 7: 53 – 67.

Omar, G. (2011). Assessment of the Fertility Status of some Irrigated Fluvisols in Northern Guinea Savannah of Nigeria. *Savannah Journal of Agriculture,* 6(1):19-31.

Oyinlola, E.Y. and Chude, V.O. (2010). Status of Available Micronutrients of The Basement Complex Rock – Derived Alfisols In Northern Nigeria Savanna. *Tropical and Subtropical Agroecosystems,* 12: 229 - 237

Raji, A. (2013) Making Agricultural Transformation Agenda Reality. *47th Annual Conference of the Agricultural Society of Nigeria (ASN).* Daily Independent News. Retrieved July 09, 2014, from www.dailyindependentnig.com.

Raji, B.A. (1995). *Pedogenesis of ancient dune soils in the Sokoto sedimentary basin, NW Nigeria*. Unpublished Ph.D. Thesis. Dept. of Soil Science, ABU, Zaria.

Raji, B.A. and Mohammed, K. (2000), "The Nature of Acidity in Nigerian Savanna Soils", *Samaru Journal of* Agricultural *Research,* Vol. 16, pp. 15-24.

Raji, B.A., Esu, I.E., Chude, V.O., Owonubi, J.J. and Kparmwang, T. (1996). Profiles, Classification and Management Implication of Soils of Illela Sand Dunes, NW Nigeria. *Journal of Science Food Agriculture,* 71:425-432.

Ray S.K., Gajbhiye K.S., Challa O., Jagdish S.N., Singh S.R., Anantwar G., Gaikawad M.S. and Padihar S.K. (2000). Systematic soil survey to identify potential soil sodicity areas in parts of Tawa command, Madhya Pradesh. *Journal of Indian Society of Soil Sci*ence. 48:346-351

Reshmidevi, T.V., Eldho, T.I., and Jana, R., (2009). A Gis-Integrated Fuzzy Rule-Based Inference System for Land Suitability Evaluation In Agricultural Watersheds. *Agr. Syst*. 101 (1–2), 101–109.

Rhoades, J.D. (1982). Cation Exchange Capacity. In Miller, R.H., Page, A.L., and Keeney, D.R. (eds). *Methods of Soil Analysis*. Part 2 Agron 9.Madison WI.149-157.

Rieu, S. and Sposito, T. (1991). Fractal Fragmentation, soil porosity and soil water properties. Theory. Soil *Science Society of American Journal*, 55:12311238.

Riquier, J., Bramao, L. and Cornet, S.P. (1970) *A New System Or Soil Appraisal In Terms Of Actual And Potential Productivity*: FAO Soil Resources No 38. Rome. Italy.

Ritung, S.W., Agus F. and Hidayat H., (2007).*Land Suitability Evaluation with a case map of Aceh Barat District,* Indonesian Soil Research Institute and World Agroforestry Centre, Bogor, Indonesia.

Rossiter, D.G. (1994) *Land Evaluation*. Cornell University, College of Agriculture and Life Sciences, Department of Soil, Crop and Atmospheric Sciences.

Rossiter, D.G., (1994). *Lecture Notes*: "Land Evaluation.

Rossiter, D.G., (1996). *A Theoretical Framework for Land Evaluation (with discussion)*. Elsevier Scientific, Geoderma, (72): 165-202.

Sanchez, P.A. (1976). *Properties and Management of Soils in the Tropics*.Wiley-Interscience publications. John Wiley and Sons, NY, London, Sydney, Toronto.

Sánchez, P.A., Couto, W. and Buol, S.W. (1982). *The Fertility Capability Soil Classification System: Interpretation, Applicability and Modification*. Geoderma 27(4): 283-309.

Sanda, A.R., Ogunwale, J.O., Oluwasemire, K.O. and Raji, B.A. (2007).Effects of Drainage Water Recycles and Irrigation Scheduling on Soil Properties and yield of tomato under a high water table in Northern Nigeria. In Uyovbisere, E.O., Raji, B.A., Yusuf, A.A, Ogunwale, J.O, Aliyu, L.and Ojeniyi, S.O (Eds).*Soil and water management for poverty alleviation and sustainable environment. Proceeding of the 31st annual conference of SSSN/ABU, Zaria, Nigeria.* Nov. 11th to 17th, 2006

Sayed, A.S.A., (2006)" *Pedological Studies on Soils of Esh-Milahah Depression, Red Sea Region, Egypt.*". M.Sc., Thesis, Faculty of Agriculture, Al_Azhar University, Cairo, 1-190 pp.

Schoeneberger, P.J., Wysocki, D.A., Benham, E.C. and Broderson, W.D. (Eds) (2002).*Field Book for Describing and Sampling Soils*, version 2.0 Nat. Soil survey center. NRCS, USDA, Lincolns, NE.

Sharu, M., Yakubu, M. and Tsafe, A.I. (2013). Characterization and Classification of Soils on an Agricultural landscape in Dingyadi District, Sokoto State, Nigeria. *Nigerian Journal of Basic and Applied Sciences*, 21 (2), 137 -147.

Shobayo, A.B. (2010). *A Lithosequence Of Soils Developed On Basement Complex Rocks Of Zaria, The Northern Guinea Savanna, Nigeria*. Unpublished M.Sc., Thesis. Department of Soil Science, ABU, Zaria.

Sillanpaa, M. (1982).*Micronutrients and the Nutrient Status of Soils*: A Global Study. Soils Bull. No. 48 FAO Rome.

Sims, J.T. and Johnson.G.V. (1991).*Micronutrient soil test*. In: J.J. Mortvedt, F.R., Cox, L.M. Shuman and R.M. Welch (editors), Micronutrients in Agriculture. (2nd ed.), Soil Science Society of America. Book series: 4 Madison, Wisconsin, USA

Singer, M.J. and Munns, D.N. (1999).*Soils: An Introduction*. 4th Ed. Prentice-Hall, Inc. Upper Saddle River, New Jersey. pp. 27-29, 48-49.

Singh, B. T., Nandini D. K., Bijen K. Y., Bishworjit N., Nongdren K. S. L. and Herojit S. A., (2013) Characterization, and Evaluation for Crop Suitability in Lateritic Soils. *African Journal of Agricultural Research* vol. 8(37) pp 4628-4636. doi:10.5897/AJAR12013.7309. Retrieve from http://www.academicjournals.org/AJAR

Sivarajasinham, S., Alexander, L.T., Cady, J. and Cline, M.G. (1962).Laterite. In: A.G. Norman 9 (ed). *Advances in Agronomy* 14:1-60

Smith, B. D. (1998).*The Emergence of Agriculture*. Scientific American Library, A Division of HPHLP, New York. ISBN 0-7167-6030-4.

Soil Survey Staff, (2010). *Keys to Soil Taxonomy*.11thEdition.USDA/NRCS, Washington, DC.

Sombroek, W.G. and Zonneveld, I.S. (1971). *Ancient Dune fields and Fluviatile Deposits in Rima-Sokoto River Basin NW. Nigeria.* Soil Survey Paper No. 5. Soil Survey Inst. Wageningen, The Netherlands, pp. 109.

Storie, R.E. (1933). *An Index for Rating the Agricultural Value of Soils.* Bulletin - California Agricultural Experiment Station.Vol.556, University of California Agricultural Experiment Station, Berkley, CA.

Storie, R.E., (1978). *Storie Index Soil Rating (Revised).*Special Publication 3203., Division of Agricultural Science ,University of California, Berkeley, CA. 214

Switzer R.E. and Pettry D.E. (1992). Phosphorus Distribution in Loessial Soil Parent Material in North West Oregon. *Soil Science Society of America Journal*. 56: 849856.

Sys, C., (1979).*Evaluation of the Physical Environment for Irrigation In Terms Of Land Characteristics and Land Qualities*. 201929. Rome.

Sys C, Vanranst E. and Debvay J. (1991) *Land Evaluation*. Part: III. General Administration for Development Cooperation Agriculture, Brussels, Belgium. pp: 199.

Szabolcs, I. (1989).*Salt affected soils*, Boca Raton, CRC Press.

Tan K.H., (2000). *Environmental Soil Science*.2nd edition. Marcel Dekker Inc. New York. p. 452.the Nigerian Semi-Arid Savannah, *Soil Use and Management*, 11, pp. 84-89.

Thomas, G.W. (1982). Exchangeable Cations. p. 159-165. In Page, A.L., Miller, R.H. and Keeney, D.R. (eds.) *Methods of Soil Analysis*. Part 2.Chemical and microbiological properties.2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Thorp, M.B. (1970). "Landforms" In Mortimore, M.J. (ed) Zaria and its Region: A Nigerian Savanna City and Environs. *Occasional Paper*. No. 4. Pp. 13-32.

Uehara, G. and Gillman, G. (1981).*The Mineralogy, Chemistry and Physics of Tropical Soils with Variable Charge Clays*. West view Press, Boulder, Colorado.

USDA (2003).*Soil Survey Manual*. Hawaii: University Press of Pacific, Honolulu.

USDA FAS, (2014).*Nigeria Grain and feed update*. GAIN report. USDA FAS: Washington.

USDA-NRCS., (2010) *Field Book for Describing and Sampling Soils*, Eleventh Edition (National Natural Resource Conservation Service and USDA. Soil Survey Centre).

Van Diepen, C.A., Van Keulen, H., Wolf, J. And Berkhout, J.A. (1991).*Land Evaluation: From Intuition to Quantification.* In: Advances in Soil Science (ed. B.A. Stewart). Springer, New York, pp. 139-204

Van Wambeke, R.G. (1962). *Criteria for Classifying Tropical Soils by Age*. John Wiley and Sons Inc. New York.

Wilson J.R. (2010). "*Minerals and Rocks*". J. Richard Wilson and Ventus Publishing Aps. An e-Book available online at www.bookboon.com (Accessed 6th October 2012), pp. 14–20.

Wislow, M.O. and John, V.T. (1989).*Rice Production in Nigeria*. I.I.T.A. Research Brief Vol. 9.No. 8.

Wolf, B. (1971). The determination of boron in soil extracts, plant materials, compost, water and nutrient solutions. *Communication Soil Science Plant Analysis*. 2: 263-274.

Wolf, B. (1974). Improvements in the Azomethine-H method for the determination of B. *Communication Soil Science Plant Analysis.* 5: 39-44

World Reference Base for Soil Resources (2014). *International Soil Classification System for Naming Soils and Creating Legends for Soil Maps*. World Soil Resources Reports.FAO, Rome. Retrieved from www.fao.org/publications.

World Bank (1998). *Human Development Report*. The World Bank, Washington D C.

Wright, J.B. and McCurry, P (1970). Geology of Zaria. In: Mortimore, M.J. (ed), Zaria and its Regions.*Occasional Paper* 4, Department of Geography, A.B.U., Zaria.

Yakubu Samuel (2004). *Assessment of soil changes under different land uses in Zaria area, Northern Nigeria*. Unpublished M.Sc., thesis Department of Geography, ABU Zaria

Yakubu M. (2001). *Survey, Classification and Genesis of soils of Kalambaina area, Sokoto State, Nigeria*. Unpublished M.Sc. Thesis, Department of Soil Science and Agricultural Engineering, University of Agriculture, Abeokuta, Nigeria.

Yakubu, M. (2006).*Genesis and classification of soils over different geological formations and surfaces in the Sokoto plains Nigeria.* Unpublished PhD Thesis. Department of Soil Science and Agricultural Engineering, Usmanu Danfodiyo University Sokoto, Nigeria.

Yakubu, M., Baraya, S. and Noma, S.S. (2011).Assessment of Soil and Water Quality along River Kadarko in Sanyinna District, Sokoto State. In Hassan, W.A. Kyiogom, U.B. Tukur, H.M. Ipinjolu, J.K. Maigandi, S.A. Singh, A., Ibrahim, N.D., Dikko, A.U., Bashir, Y.A. and Muhammad, N.(Eds).*Mobilizing Agricultural Research towards Attaining Food Security and Industrial Growth In Nigeria*. Proceedings of the 45th annual conferences of the ASN held at the Faculty of Agriculture, UDUS, Nigeria, 24th to 28th Oct.

Yaro, D.T. (2005). *The Position of Plinthite in a Landscape and its Effects on Soil Properties.* Unpublished Ph.D Thesis. Department of Soil Science, ABU, Zaria, Nigeria.

Yaro, D.T., Kparmwang, T., Raji, B.A. and Chude, V.O. (2006). The extent and properties of plinthite in a landscape at Zaria, Nigeria, *International Journal of Soil Science*, 1(3), pp. 171-183.York. 603 pp.

Young, A. (1976). *Tropical Soils and Soil Survey*. Cambridge University Press, Cambridge. 468

Younes D. Ezlit, Rod J.Smith and Steven R. Raine (2010). *A review of salinity and sodicity in irrigation*. Cooperative research centre for irrigation futures. Irrigation matter series N0 01/10

Yusuf, Y.O. (2006). "*An Analysis of the Magnitude of Suspended Sediment Production by the Northernmost Tributary of the Kubanni River, Zaria, Kaduna State*." Unpublished M.Sc. Thesis, Department of Geography, A. B. U. Zaria

Zarafi, G.S. (1993). *Morphological, physicochemical and mineralogical properties of hydromophic soils in the Zaria region*. Unpublished M.Sc. Thesis. Department of Soil Science, ABU, Zaria. pp 8-24.

APPENDIX A: SOIL PROFILE DESCRIPTIONS

Soil Unit KBI (Upland)

Pedon KBI P1

General Site Information

Location	Kubanni Basin
Date of examination	14/07/2014
Weather prior to Description	Sunny
Taxonomic Classification	Typic Plinthustalf / Eutric Lixisols
Parent Material	Basement Complex
Local Relief	Upland
Slope	0-2%
Coordinate	N11º6" 57' E7º 40'28"
Soil Erosion/Description	None
Rock outcrop	No bedrock exposed
Drainage	Well Drained
Surface Characteristic	None, gravelly, Stony and Bouldery
Depth to Water table	Not encountered
Depth to impenetrable layer	Not encountered
landuse/ Vegetation	Maize farm
Human Influence	Arable farming
Described by	Jimoh A. I.

Horizon Descriptions

Horizon	Depth (cm)	Description
Ap	0-21	Dark yellowish brown (10YR4/4 wet) loam, weak fine sub angular blocky, slightly sticky and slightly plastic, very friable moist, hard dry, common medium roots, channel void, few fine mica flakes, clear smooth boundary.
Bt1	21 -114	Strong brown (7.5YR 5/6) loam few medium distinct reddish brown mottles, weak medium sub angular blocky, slightly sticky, slightly plastic, firm moist, hard dry, few coarse roots, channel void, few fine mica flakes, gradual smooth boundary
Bt2cv	114 -140	Brownish yellow (10YR 6/6) loam many coarse prominent reddish brown mottles, moderate medium angular blocky, very sticky, very plastic, firm moist, very hard dry, few fine roots, channel voids some iron and magnesium concretion, some termites holes limited by plinthite

Soil Unit KBI (Upland)

Pedon KBI P2

General Site Information

Location	Kubanni Basin
Date of examination	14/07/2014
Weather prior to Description	Sunny
Taxonomic Classification	Typic Plinthustalf / Eutric Lixisols
Parent Material	Basement Complex
Local Relief	Upland
Slope	0-2%
Coordinate	N11º07'' 07' E7º40''30'
Soil Erosion/Description	None
Rock outcrop	No bedrock exposed
Drainage	Well Drained
Surface Characteristic	None, gravelly, Stony and Bouldery
Depth to Water table	not encountered
Depth to impenetrable layer	not encountered
Land use/ Vegetation	Maize farm
Human Influence	Arable farming
Described by	Jimoh A. I.

Horizon Description

Horizon	Depth (cm)	Description
Ap	0-40	Dark yellowish (10YR 4/4) Sandy loam, moderate medium sub angular blocky, very friable moist, hard dry, common medium roots, few mica flakes, clear smooth boundary.
Bt 1	40 – 70	Yellowish brown (10YR 5/6) loam, few fine faint reddish brown mottles, moderate medium sub angular blocky, slightly sticky, slightly plastic, firm moist, dry hard, few fine roots, gradual smooth to diffuse boundary.
Bt 2	70- 140	Pale brown (10YR 6/3) Sandy clay loam structureless (massive), very sticky, very plastic, firm moist, few fine roots, channels voids, termites holes, few fine mica flakes.

Soil Unit KBII (Upland)

Pedon KBII P1

General Site Information

Location	Kubanni Basin
Date of examination	14/07/2014
Weather prior to Description	Sunny
Taxonomic Classification	Torrertic Dystrustepts / Terric cambisols
Parent Material	Basement Complex
Local Relief	Upland
Slope	>30 %
Coordinate	N11º07'' 07' E7º40''40'
Soil Erosion/Description	Gully

Rock outcrop	No bedrock exposed
Drainage	Well Drained
Surface Characteristic	None, gravelly, Stony and Bouldery
Depth to Water table	Not encountered
Depth to impenetrable layer	Not encountered
landuse/ Vegetation	Maize farm
Human Influence	Arable farming
Described by	Jimoh A. I.

Horizon Description

Horizon	Depth (cm)	Description
Ap	0- 130	Strong brown (10YR 5/8) to very pale brown (10YR 7/4) loam, strong coarse angular blocky, non sticky,non plastic, very hard dry, few fine roots, manycoarse gravels, many channel voids, few fine mica flakes, smooth wavy boundary
2Btcg	130 – 170	Dark gray (10YR 4/1) clay loam structureless (massive), very sticky, very plastic, very firm moist, very hard dry, many coarse magnesium concretion.

Soil Unit KBII (Upland)

Pedon KBII P2

General Site Information

Location	Kubanni Basin
Date of examination	14/07/2014
Weather prior to Description	Sunny
Taxonomic Classification	Torrertic Dystrustepts / Terric cambisols
Parent Material	Basement Complex
Local Relief	Upland
Slope	>30 %
Coordinate	N11º07" 05' E7º40"32'
Soil Erosion/Description	Moderate
Rock outcrop	No bedrock exposed
Drainage	Well Drained
Surface Characteristic	None, gravelly, Stony and Bouldery
Depth to Water table	Not encountered
Depth to impenetrable layer	Not encountered
Land use/ Vegetation	Maize farm
Human Influence	Arable farming
Described by	Jimoh A. I.

Horizon Description

Horizon	Depth (cm)	Description
Ap	0- 40	Yellowish brown (10YR 5/4) loam structureless (massive), non sticky, non plastic, common medium roots, channel voids, few fine roots, many fine mica flakes, smooth wavy boundary.

2Bt	40-12	Light gray brown (10YR6/2) sandy clay loam, structureless (massive), slightly sticky, slightly plastic, firm moist, hard dry, few fine roots.

Soil Unit KBIII (Upland)

Pedon KBIII P1

General Site Information

Location	Kubanni Basin
Date of examination	13/07/2014
Weather prior to Description	Sunny
Taxonomic Classification	Typic Plinthustalf / Eutric Lixisols
Parent Material	Basement Complex
Local Relief	Upland
Slope	0- 2%
Coordinate	N11º07" 19' E7º40"30'
Soil Erosion/Description	Moderate
Rock outcrop	No bedrock exposed
Drainage	Imperfectly Drained
Surface Characteristic	None, gravelly, Stony and Bouldery
Depth to Water table	Not encountered
Depth to impenetrable layer	Not encountered
Land use/ Vegetation	Rice and Maize farm
Human Influence	Arable farming
Described by	Jimoh, A. I. and Victor, T.

Horizon Description

Horizon	Depth (cm)	Description
Ap	0-27	Brown (10YR 5/3) loam, weak fine sub angualr blocky, slightly sticky, slightly plastic, friable moist, common coarse roots, channel voids, many termites holes, abrupt smooth boundary.
Bt1	127 – 75	Brown (10YR 4/3) loam, moderate medium angular blocky, slightly sticky, slightly plastic, very friable moist, common fine roots, termites holes, gradual smooth boundary.
Bt 2	75-148	Yellowish brown (10YR 5/4) silt loam common medium distinct reddish brown mottles, structureless (massive) slightly sticky, slightly plastic, very friable moist few fine riots many termites holes gradual wavy boundary.
Btc 3	148 - 165	Light gray brown (10YR 6/2) loam structureless (massive) very sticky, very plastic, firm moist, common coarse roots, many termites holes, many magnesium concretion

Soil Unit KBIII (Upland)

Pedon KBIII P2

General Site Information

Location	Kubanni Basin
Date of examination	13/07/2014

Weather prior to Description	Sunny
Taxonomic Classification	Typic Plinthustalf / Eutric Lixisols
Parent Material	Basement Complex
Local Relief	Upland
Slope	0- 2%
Coordinate	N11º07" 19' E7º40"39'
Soil Erosion/Description	Moderate
Rock outcrop	No bedrock exposed
Drainage	Imperfectly Drained
Surface Characteristic	None, gravelly, Stony and Bouldery
Depth to Water table	Not encountered
Depth to impenetrable layer	Not encountered
land use/ Vegetation	Rice and Maize farm
Human Influence	Arable farming
Described by	Jimoh A. I.

Horizon Description

Horizon	Depth (cm)	Description
Ap	0 – 42	Dark yellowish brown (10YR 4/4) loam, moderate fine sub angular blocky, non sticky, non plastic, very friable moist, soft dry, common medium roots, channel voids, many mica flakes, abrupt smooth boundary.
Bt1	42 -70	Yellowish brown (10YR 5/6) loam, moderate medium sub angular blocky, non sticky, non plastic, few fine roots, channel voids many termite holes few fine mica flakes, clear wavy boundary
Bt2	70- 120	Brown (10YR 4/3) loam, strong medium angular blocky, slightly sticky, slightly plastic, very friable moist, hard dry, few fine roots channels voids, few fine mica flakes, gradual wavy boundary.
BC	120- 170	Brown (10YR 3/4) loam, many medium prominent reddish brown mottles, strong coarse angular blocky, very friable moist, very hard dry, few fine roots, tubular voids, few fine mica flakes

Soil Unit KBIV (Flood plain)

Pedon KBIV P1

General Site Information

Location	Kubanni Flood plain
Date of examination	11/07/2014
Weather prior to Description	Sunny
Taxonomic Classification	Fluvaquentic Epiaquepts / Endoeutric Fluvisol
Parent Material	Basement Complex
Local Relief	Flood plains
Slope	0- 2%
Coordinate	N11º 07' 03" E7º40'42"
Soil Erosion/Description	Moderate
Rocky outcrop	No bedrock exposed
Drainage	Very poorly Drained
Surface Characteristic	None, gravelly, Stony and Bouldery
Depth to Water table	125cm

Depth to impenetrable layer	Not encountered
land use/ Vegetation	Rice farm
Human Influence	Arable farming
Described by	Aliyu, J. and Jimoh A. I.

Horizon Description

Horizon Depth (cm) Description

Ap 0 -25 yellowish brown (10YR 5/4) sandy loam, structureless (single grain), non sticky, non plastic, very friable moist, common medium roots, common fine mica flakes, abrupt wavy boundary.

Bc 25 – 36 Dark yellowish brown (10YR 4/4) sandy loam, structureless, (single grain) non sticky, non plastic, loose moist, few fine roots, many fine mica flakes, smooth wavy boundary.

2Bt1 36 -58 Dark yellowish brown (10YR4/6) sandy loam, structureless (single grain), non sticky, non plastic, very friable moist, few medium roots, many fine mica flakes, smooth wavy boundary.

2Bt258 – 90 Dark yellowish brown (10YR 4/6) loam structureless (massive) slightly sticky slightly plastic, firm moist, few five roots common coarse gravel, smooth wavy boundary.

2Bt 390 -135 Brown (10YR 5/3) sandy loam structureless (massive) very sticky, very plastic, very firm moist, few fine roots, tubular voids, smooth wavy boundary.

2Cr 135 – 145 Dark yellowish brown 910YR 4/6) gravelly loam, structureless (single grain) non sticky, non plastic, loose moist, many coarse gravel and stones

Soil Unit KBIV (Flood plain)

Pedon KBIV P2

General Site Information

Location	Kubanni Flood plain
Date of examination	11/07/2014
Weather prior to Description	Sunny
Taxonomic Classification	Fluvaquentic Epiaquepts / Endoeutric Fluvisol
Parent Material	Basement Complex
Local Relief	Flood plains
Slope	0- 2%
Coordinate	N11º 07' 16" E7º40'39.3"
Soil Erosion/Description	Moderate
Rock outcrop	No bedrock exposed
Drainage	Very poorly Drained
Surface Characteristic	None, gravelly, Stony and Bouldery
Depth to Water table	130cm
Depth to impenetrable layer	Not encountered
land use/ Vegetation	Rice farm
Human Influence	Arable farming

Described by Aliyu, J. and Jimoh A. I.

Horizon Description

Horizon Depth (cm) Description

Ap0 -54		Yellowish brown (10YR 5/4) loam, structureless (single grain) non sticky, non plastic, very friable moist, common medium roots, channel voids, few fine mica flakes, few medium charcoal, abrupt smooth boundary.
Bt 154 -78		Dark yellowish brown (10YR 4/4) loam structureless (massive), slightly sticky, slightly plastic, very friable moist, few medium roots channels voids clear – smooth gradual boundary.
Bt2	78 – 122	Yellowish brown (10YR 5/4) loam, structureless (massive) slightly sticky, slightly plastic, very friable moist, few medium roots, tubular voids, few fine mica flakes, gradual wavy boundary
Bt 3 122 -160		Brown (10YR 5/3) sandy loam structureless (massive) slightly stick, slightly plastic firm moist few five root, few medium gravels

Soil Unit KBV (Flood plain)

Pedon KBV P2

General Site Information

Location	Kubanni Flood plain
Date of examination	11/07/2014
Weather prior to Description	Sunny
Taxonomic Classification	Fluvaquentic Epiaquepts / Endoeutric Fluvisol
Parent Material	Basement Complex
Local Relief	Flood plains
Slope	0- 2%
Coordinate	N11º 07' 16" E7º40'39.3"
Soil Erosion/Description	Moderate
Rock outcrop	No bedrock exposed
Drainage	Very poorly Drained
Surface Characteristic	None, gravelly, Stony and Bouldery
Depth to Water table	135cm
Depth to impenetrable layer	Not encountered
land use/ Vegetation	Rice farm
Human Influence	Arable farming
Described by	Jimoh, A. I. and Aliyu, J.

Horizon Description

Horizon Depth (cm) Description

Ap	0 -20	Dark yellowish brown (10YR 4/6) loam, structureless (massive) non sticky, non plastic, very friable moist, many fine roots, many fine tubular voids, many fine mica flakes, abrupt wavy boundary.
Bt 1	20- 80	Pale brown (10YR 6/3) loam structureless (massive) non sticky, non plastic, very friable moist, many fine tubular voids, many fine mica flakes, clear wavy boundary.

Cr 80- 135	Strong brown (7.5YR 3/8) gravelly sandy loam structureless (single grain) non sticky non plastic, loose moist, common medium gravels.

Soil Unit KBV (Flood plain)

Pedon KBV P2

General Site Information

Location	Kubanni Flood plain
Date of examination	11/07/2014
Weather prior to Description	Sunny
Taxonomic Classification	Typic Haplustalf / Haplic Lixisols
Parent Material	Basement Complex
Local Relief	Flood plains
Slope	0- 2%
Coordinate	N11º 07' 50.3" E7º40'50.3"
Soil Erosion/Description	Moderate
Rock outcrop	No bedrock exposed
Drainage	Very poorly Drained
Surface Characteristic	None, gravelly, Stony and Bouldery
Depth to Water table	Not encountered
Depth to impenetrable layer	Not encountered
land use/ Vegetation	Rice farm
Human Influence	Arable farming
Described by	Jimoh A. I. and Aliyu, J.

Horizon Description

Horizon Depth (cm)	Description
Ap0 – 40	brownish yellow (10YR 6/6) loam structureless (single grain) non sticky, non-plastic, loose moist, common coarse roots, many tubular voids, many fines mica flakes, abrupt smooth boundary.
Bt1 40- 135	Dark yellowish brown (10YR 4/6) loam structureless (massive) slightly sticky, slightly plastic, very friable moist, common medium roots many tubular voids, gradual wavy boundary.
Btg 2135 -170	Dark gray brown (2.5YR 4/2) loam, structureless (massive) very sticky, very plastic, many coarse roots, many tubular voids many fine mica flakes

APPENDIX B: LEGEND FOR SYMBOLS USED IN SOIL MORPHOLOGICAL DESCRIPTIONS

Texture

FSL - fine sandy loam
Sl - sandy loam
GSCL - gravelly sandy clay loam
SCL - sandy clay loam
LS - loamy sand
VGSL - very gravelly sandy loam
VGSC - very gravelly sandy loam
C - clay
Cl - clay loam

Structure

Wfcrsbk - weak, fine, crumb, sub angular blocky
Msmsbk – moderately strong medium sub angular blocky
Scsbk – strong, coarse sub angular blocky.
Wfcrbk – weak, fine, crumb, sub angular blocky
Scabk – strong coarse angular blocky
Wfcr – weak fine crumb
Wmcrsbk – weak, moderate, crumb angular block

Consistence

Wet (Stickiness):	ns	- Non sticky
	ss	- Slightly sticky
	s	- Sticky
	vs	-Very sticky
Wet (plasticity):	np	- Non plastic
	sp	- Slightly plastic
	p	- Plastic
	vp	- very plastic
Moist:	fr	– friable
	vfr	– very friable
	fm	– firm
	vfm	– very firm
	l	– loose
Dry:	s	– soft
	sh	– slightly
	h	– hard

vh – very hard

Boundary: Distinctness (thickness): a – abrupt (< 2 cm)
c – clear (2-5 cm)
g – gradual (5-15 cm)
d – diffuse (>15 cm)
topography: s – smooth
w – wavy
i – irregular
b - broken

APPENDIX C: RATING FOR SOIL DATA INTERPRETATION

1. Soil Depth (cm)

Very shallow	< 25
Shallow	25 – 50
Moderately shallow	50 – 100
Deep	100 – 150
Very deep	> 150

2. Soil Reaction

Extremely acid	< 4.5
Very strongly acid	4.5 - 5.0
Strongly acid	5.1 - 5.5
Moderately acid	5.6 - 6.0
Slightly acid	6.1 - 6.5
Neutral	6.6 - 7.3
Slightly alkaline	7.4 - 7.8
Moderately alkaline	7.9 - 8.4
Strongly alkaline	8.5 - 9.0
Very strongly alkaline	> 9.0

3. Organic Carbon (gkg^{-1})

Low	< 10
Medium	10 – 15
High	> 15

4. Total Nitrogen (gkg^{-1})

Low	< 1.5
Medium	1.5 – 2.0
High	> 2.0

5. Available Phosphorus (Bray 1) ($mgkg^{-1}$)

Low	0 – 10
Medium	10 – 20
High	> 20

6. Exchangeable Cation [cmol(+)kg^{-1}]

		Ca	Mg	K	Na
Low	0 – 2		0 – 0.3	0 – 0.15	0 – 0.1
Medium	2 – 5		0.3 – 1.0	0.15 - 0.30	0.1 – 0.3
High	> 5		> 1.0	> 0.30	> 0.3

7. Cation Exchange Capacity [cmol(+)kg^{-1}]	**NH_4OAc**	**ECEC**
Low	< 6	< 4
Medium	6 – 12	4 – 10
High	> 12	> 10

APPENDIX D: RATING FOR SOIL DATA INTERPRETATIONCont'd.

8. Base Saturation (%)	**NH_4OAc**	**ECEC**
Low	< 50	<70
Medium	50 – 80	70-90
High	> 80	>90

9. Micronutrients (mgkg^{-1})	**Zn**	**Cu**	**Mn**	**Fe**
Low	< 1	< 0.2	< 1	< 4.5
Medium	1 – 2	0.2 – 1.0	1 – 5	-
High	> 2	>1.0	2 – 5	> 4.5

10. Electrical Conductivity (Ece) (dSm^{-1})		
None saline	<4	
Saline	>4	
11. Sodicity	ESP (%)	SAR (%)
Low level sodicity	<15	<13
High level sodicity	>15	>13
12. Chloride (mgkg^{-1})		
Low	<2	
Moderate	2 - 8	
High	> 8	
13. Boron (mgkg^{-1})		
Low	< 0.5	
Medium	0.5 – 2.5	
High	> 2.5	
14. Sulphate (mgkg^{-1})		
Low	<5	
High	>5	
15. Bulk Density (Mgm^{-3})		
Low	< 1.85	

High > 1.85

Source: Malgwi (2007) Soil survey manual.

Appendix E

Tables for calculating pHc

Ion Concentration meq/L	(pK^1_2-pKc^1)	p[Ca+Mg]	p[HCO_3]
0.5	2.11	3.60	3.30
1.0	2.13	3.30	3.00
4.0	2.20	2.70	2.40
8.0	2.25	2.40	2.10
10	2.27	2.30	2.00
20	2.35	2.00	1.70
30	2.40	1.82	1.52
40	2.44	1.70	1.40
50	2.47	1.60	1.30
80	2.5	1.40	1.10

Appendix F; t-Test: Paired Two Sample for Means

	UPLAND	*FLOOD PLAIN*
Mean	13.43017	17.61354
Variance	451.9422	969.6789
Observations	35	35
Pearson Correlation	0.847199	
Df	34	
t Stat	-1.42904	
P(T<=t) one-tail	0.081058	
t Critical one-tail	1.690924	
P(T<=t) two-tail	0.162115	
t Critical two-tail	2.032245	

Appendix G: Summary Result of t-test between Fadama and adjacent upland.

Parameters	Upland/Fadama	Level of Significance
Effective Cation Exchange Capacity (ECEC)	0.368	NS
Base Saturation (BS)	0.034	S
BS ECEC	0.595	NS
Exchangeable Sodium Percentage	0.856	NS
Sodium Absorption Ratio (SAR)	0.835	NS
Adjusted SAR	0.675	NS
Carbonate (HCO_3)	0.012	S
Electrical Conductivity	0.198	NS
Iron (Fe)	0	S
Manganese (Mn)	0.002	S
Copper (Cu)	0.023	S
Zinc (Zn)	0.209	NS
Organic Carbon (OC)	0.959	NS
Total Nitrogen (TN)	0.538	NS
Available P.	0.001	S
Residual Sodium Carbonate (RSC)	0.129	NS
Total Soluble Salt (TSS)	0.171	NS
Total Porosity (TP)	0.812	NS
Soil Density	0.026	S
Silt	0.879	NS
Clay	0.077	NS
Particle Density	0.011	NS
pH	0.783	NS
Calcium (Ca)	0.197	NS
Magnesium (Mg)	0.138	NS

Potassium (K)	0.397	NS
Sodium (Na)	0.848	NS
Total Exchangeable Bases (TEB)	0.347	NS
Exchangeable Acidity (H^+Al^{3+})	0.741	NS
Cation Exchange Capacity (CEC)	0.094	NS
Boron	0.915	NS
Chloride (Cl^-)	0.991	NS
Sulphate (SO_4)	0.576	NS

S = Significance, NT = Not Significant

Appendix H

DEPARTMENT OF GEOGRAPHY
FACULTY OF SCIENCE
AHMADU BELLO UNIVERAITY, ZARIA

Dear Respondent,

The researcher is carrying out a study on characterization and suitability evaluation of kubanni flood plain (Flood plains) and adjoining upland soils for rice and maize production in Zaria, Nigeria. I wish to request you to kindly assist in filling this questionnaire as accurate as possible.

INSTRUCTION: Please tick or fill in the spaces provided where necessary

Date..... Questionnaire NO.....

DEMOGRAPHIC CHARACTERISTICS;

1. Name.....
2. Sex: Male [ ] Female [ ]
3. Age a) 0 – 14 b) 15 – 29 c) 30 – 44 d) 45 and above
4. Marital Status (a) Single [ ] (b) Married [ ] (c) Widow/ Widower [ ]
5. Household size (a) 1 - 4 (b) 5 - 9 (c) 10 -14 (d) 15 - 20

6. Education qualification a) Primary ( ) b) Secondary ( ) c) College ( )

d) University ( ) e) None ( )

LANDUSE CHARACTERISTICS

7) What is the size of your farmland in hectare: .....

8) Land tenure system a) Rent ( ) b) Inherited ( ) c) Purchase ( )

9) What type of fertilizer do you use on your farm? .....

10) What quantity of fertilizer do you use for production and its cost?

11) How many bags of rice/maize do you realized from your farm?.....

12) What is your net profit for rice/maize?……

13) What are your challenges in the production and marketing of these crops? .....

14) What do you think could be the possible solutions to these problems? .....

THANK YOU.