APPLICATION OF GEOGRAPHICAL INFORMATION SYSTEM IN SOIL SURVEY AND VEGETATION ASSESSMENT FOR CONSERVATION AND BIODIVERSITY MANAGEMENT OF KAMUKU NATIONAL PARK, KADUNA STATE, NIGERIA

By

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ZARIA, NIGERIA

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TITLE PAGE

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BY

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

DEPARTMENT OF SOIL SCIENCE,

FACULTY OF AGRICULTURE,

AHMADU BELLO UNIVERSITY,

ZARIA, NIGERIA

AUGUST, 2017

DECLARATION

I hereby declare that this research work, "Application of Geographical Information System in Soil Survey and Vegetation Assessment for Conservation and Biodiversity Management of Kamuku National Park" was carried out by me and all information derived from the literature have been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other institution.

Dolapo Abayomi AKANDE _____ _____

Name of student Signature Date

CERTIFICATION

This Dissertation entitled "APPLICATION OF GEOGRAPHICAL INFORMATION SYSTEM IN SOIL SURVEY AND VEGETATION ASSESSMENT FOR CONSERVATION AND BIODIVERSITY MANAGEMENT OF KAMUKU NATIONAL PARK" by DOLAPO ABAYOMI AKANDE satisfies the regulations governing the award of the degree of Master Degree in Soil Science of Ahmadu Bello University, Zaria. It is therefore approved for its contribution to knowledge and literary presentation.

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Dean, School of Postgraduate School	Signature	Date

DEDICATION

This research work is dedicated to

i. Almighty Allah who sustains me despite all the trials I pass through in life.

ii. My late father, Mr. Asheem Aremu Akande.

iii. Staff of Kamuku National Park, who were killed by cattle rustlers inside the park.

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ABSTRACT

National parks are sources of soil and biodiversity conservation, however, in Nigeria, information on national parks' soils as baseline data are grossly lacking. The needs to acquire information on soil status necessitated the use of remote sensing and Geographic Information System for soil survey and vegetation assessment for biodiversity and environmental conservation. Remote Sensing (R.S) and fieldwork were used to carry out soil survey and vegetation assessment of part of Kamuku national park, Birnin-Gwari, in Northern Guinea Savanna zone of Nigeria. Geographic Information System (GIS) was used to integrate the data obtained from both Remote Sensing and fieldwork to develop maps. Four soil mapping units KN1, KN2, KN3, and KN4 were established. Morphological results showed that the soils mapping units ranged from moderately shallow (90cm) to very deep (> 165cm). Physical properties revealed that sand fraction (420-700mgkg^{-1}) dominated the particle size fraction followed by silt (120-420 mgkg^{-1}) and clay (80-460 mgkg^{-1}). The dominant textural class in the study area was sandy clay loam. The bulk densities were high in soil units KN1 (1.65Mg/m^3) and KN3 (1.59Mg/m^3). The bulk densities were moderate both in KN2 (mean 1.49Mg/m^3) and KN4 (1.43Mg/m^3). The Chemical properties of showed that the soils were slightly acidic to neutral (pH 6.2 to 6.8); low to moderate in organic carbon (2.1 to 12g/kg), low in total nitrogen (0.05 to 0.13g/kg) and in exchangeable acidity (0.4 to 1.0cmol/kg). Available phosphorus was rated low to medium (8.6 -18.13g/kg) and cation exchange capacity was rated medium to high (5.7 to 19.6cmol/kg). The soil units KN1, KN2, KN3 and KN4 were classified as Typic Plinthustalf, Eutric Haplustalfs, Typic Plinthustalf and Eutric Haplustepts respectively under USDA soil Taxonomy. These were correlated as Plinthic Lixisols, Rhodic Lixisols, Plinthic Lixisols and Eutric Fluvisol respectively under FAO (WRB).The vegetation analysis of the study area was carried out using Point Centre Quarter Method

(PCQM). There were twenty-two (22) species of trees and shrubs. The highest sampled tree was *Isoberlinia doka* (57 trees) during the survey. The overall estimated population of trees and shrubs in the study area was 102,000 trees and shrubs. The USDA land capability evaluation showed that the study area was capable of sustaining conservation with few limitations. It was recommended that soil survey of the entire national park be undertaken and there was an urgent need for the establishment of soil survey /GIS units in all the existing national parks in the country.

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ABBREVIATIONS

AAS	Atomic adsorption spectrophotometer
P	Available phosphorus
BS	Base saturation
Ca	Extractable calcium
CEC	Cation exchange capacity
DEM	Digital Elevation Models
EA	Exchangeable acidity
EC	Electrical conductivity
ECEC	Effective cation exchange capacity
FAO	Food and agriculture organization
GIS	Geographical Information System
GPS	Global positioning system
IAR	Institute of Agricultural Research
IITA	International Institute for Tropical Agriculture
IUCN	International Union for Conservation of Nature
K	Available potassium
KNP	Kamuku National Park
Mg	Available magnesium
Na	Available sodium
OC	Organic carbon
PCQM	Point Centre Quarter Method
R.S.	Remote Sensing
TN	Total Nitrogen
USGS/NPS	United States Geological Society/National Parks Services
USDA	United State Department of Agriculture
WRB	World Reference Base for Soil Resources

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Soil is the ultimate natural resource that supports virtually all aspects of life processes. It is the meeting point where lithosphere, hydrosphere, biosphere, and atmosphere interact to form pedosphere. Coleman *et al.* (2004) describe the whole of planet's soil ecosystems as pedosphere where a large biomass of the Earth's biodiversity organizes into trophic levels. Soil (pedosphere) is a life supporting system of a country which plays a vital role in the socio-economic development of people (Vinay, 2007). Soils provide food, support houses (shelter), support plants, provides fodder for animals and fuel for meeting basic needs of human beings. The soil's capacity to continuously produce these resources is limited. These limits to production are set by intrinsic characteristics; such as, agro-ecological setting, use and management. This demands systematic appraisal of our soil resources with respect to their extent, distribution, characteristic, behavior and use potential, for developing an effective land use system (FAO, 1993).

Understanding soil is fundamental for proper management of ecosystem as it supplies many of the essential requirements for plant growth, like water, nutrients, anchorage, oxygen for roots, moderate temperature and habitat for millions of organisms (Eni *et al.,* 2012).

The well-being of biodiversity resources found in our protected areas depends on soil found in such places. Very little is known about soil survey and inventory of our protected areas. This poses a serious challenge to effective management of these conservation areas.

Wildlife conservation is a serious global campaign in many countries (Akande, 2002). The conservation of wildlife resources (both fauna and flora) ultimately depends on soil status of the area because soil conservation is the foundation of all ecosystem conservation efforts. It is

the bedrock of vegetation conservation, which in turn, forms the basis of wild animal conservation. Wildlife conservation is the preservation and wise utilization of wildlife resources and their habitat.

Soil and vegetation exhibit a kind of symbiotic relationship, such that soil gives support (moisture, nutrient, and anchorage) to vegetation to grow effectively while on the other hand, vegetation provides protective cover for soil, suppresses soil erosion, and helps to maintain soil nutrient through litter accumulation and subsequent decay (nutrient cycling). Hence, vegetation and soil are interrelated and provide reciprocal effects on each other (Eni *et al*, 2012).

1.2 Statement of the problem

Kamuku National Park was established by the Federal Government of Nigeria for biodiversity protection and preservation of fauna and flora resources of the Northern Guinea Savanna (National First Biodiversity Report, 2001). Soil survey of the area had not been carried out.

The absence of such baseline soil and vegetation information on the current and historical land use in Kamuku National Park made it difficult to determine future improvement interventions in the park. This necessitated the need to provide an up to-date database on soil and vegetation of Kamuku National Park. The absence of various maps such as soil map, land use map, contour map, vegetation map, and land capability map would hinder proper conservation efforts and objectives of establishment.

1.3 Justification

The properties of soils of protected areas, just like those of agricultural land, vary from place to place. Sound knowledge of these variations is required to effectively manage the fauna and flora resources in our conservation areas. The processes of carrying out soil and vegetation surveys of a national park habitat require a multi-disciplinary approach which cut across

different fields; such as soil science, wildlife management, forestry, geology, zoology, botany, and geography. This approach will help in understanding the patterns of soil, vegetation and other environmental factors in the given environment. Since the main focus of a National Park is the protection, management and conservation of natural resources, there was a need for survey to employ ecological approach in assessing the physical, biological, and chemical properties of the soils found within the park. This approach was required to provide soil database for the national park, using Geographical Information System (GIS) and other tools so as to enhance the speed and scope of data gathering in soil and vegetation inventories. In National park or forest reserve, soil investigation is not complete without looking at its relationship with the vegetation found in such a place. The reason is that vegetation found in a place serves as one of the indicators of soil status of the area. A good soil will produce good vegetation and good vegetation attracts many wild animals.

1.4 General Objective

The main objective of this study is to demonstrate the use of satellite imagery in G.I.S environment to develop an integrated soil survey and vegetation assessment for ecological management of Kamuku National Park, Birnin-Gwari, Kaduna State. The specific objectives of the study were to:

i. carry out soil survey and vegetation assessment of parts of Kamuku National Park using satellite imagery in a GIS environment, as well as Fieldwork.

ii. characterize, classify and determine land capability classification of the study area

iii. determine the relationship between soil type and vegetation distribution.

iv. carry out biodiversity assessment of the study area using biodiversity index method

CHAPTER TWO

LITERATURE REVIEW

2.1 Soil and Soil Survey

The United States National Park Service (2009) defines soil as the unconsolidated portion of the earth's crust modified through physical, chemical, and biotic processes into a medium capable of supporting plant growth. According to USDA Soil survey staff (2010), "soils are considered natural bodies covering part of the earth surface and provide support for plant growth, having properties due to the integrated effect climate and living organisms acting on parent material as conditioned by relief over a period of time.

Soil survey on the other hand identifies and describes the characteristics of the soil individual/associations in a given area, plots the boundaries of the soils on a map, classifies the soils according to a standard system of classification, , and makes predictions about the behavior of soil individual to different uses and management (Soil Survey Staff, 2010). It is the investigation of soil landscape or soilscapes and the mapping of the components of soil individuals. The word 'investigation' refers to examination and analysis of the soil and establishment of unit of classification on which soil individual differences are based, of which the mapping units are made (Malgwi, 2007).

2.2 Soil and Vegetation Surveys as Basis for Land Resources Management

Effective management of land resources depends on the availability of information on soil status, topography, vegetation, and climate of a place. This information forms the basis for proper utilization, conservation and ecological management of land resources. It will be difficult and probably impossible to manage effectively natural resources (including agricultural, forestry, wildlife, soil etc.) without having proper information of the soil and vegetation inventory of such ecosystem in terms of the geographical distribution, composition, physical and chemical characteristics of the soil types, and vegetation.

George *et al.* (2011) explains that the results of a habitat survey provide basic ecological information that can be used for biodiversity conservation, park planning and management, including targeting of more detailed soil inventory, botanical or zoological investigations. In essence, soil and vegetation surveys involve wide range of land parameters such as geology, drainage, slope, erosion, deposition, climate, etc. These serve to generate a host of land information necessary in any land use planning.To sum it up, the ultimate goal of any ecological (or habitat) survey is to discover, establish, estimate and analyze the dynamic relationship between population of plants or animals living in an area and their environment over a period of time (Akande, 2002).

2.3 Soil Distribution and Vegetation Zones in Nigeria

The major soil orders according to the USDA Soil Taxonomy (2010) in Nigeria are Oxisols, Alfisols, Ultisols, Vertisols, Entisols and Inceptisol (Ogunkunle, 2009). According to World Reference Base for Soil Resources (F.A.O, 2006), the major soil groups are Lixisols, Luvisols, Fluvisols, Cambisols, Vertisols, Regosols and Gleysols (Chude and Odunze, 2015). The geographical distribution of different soil orders and sub-orders found in Nigeria is shown in Figure 1. The soil orders are further divided into different sub-orders such as udults, usults, fluvents, etc. For instance entisols which are recently formed, weakly developed soil has sub orders such as Psamments (very sandy and droughty soil); Fluvents (recently deposited alluvial soil); Aquents (wet seasonally waterlogged soil); Sulphaquents (coastal marsh wet soil with high sulphide content; and Orthent (very shallow and rocky soil). Ultisol has udults, usults, etc. The distribution and locations of these soils are presented in Table 2.1.

Table 2.1: Distribution of soil orders in Nigeria, locations, and ecological zones

SOIL ORDERS	DESCRIPTION	Locations	Ecological zone	References
ALFISOLS	Soils with a clayey B horizon and exchangeable cation (Ca + Mg + K + Na) saturation greater than 50% calculated from NH_4OAc-CEC at p^H7.	Mokwa, Zaria, Jemaa	Northern Guinea Savanna	Ezenwa (1988) , Shobayo (2010) , Samndi and Jibrin (2011), Aliyu (2016),
ULTISOLS	Soils with a clayey B horizon and base saturation less than 50%. They are acidic, leached soils from humid areas of the tropics and subtropics.	Ondo, Iwo, Ekiti	Derived Savanna Forest zone	Nwachokor and Uzu, (2008) , Ande (2010) Aki et al., (2014)
OXISOLS	Oxisols are strongly weathered soils but have very little variation in texture with depth. Some strongly weathered, red, deep, porous oxisols contain large amounts of clay-sized Fe and Al oxides.	Nsukka, Ikom	Forest land	Uzoho, and Oti, (2005):
VERTISOLS	Dark clay soils containing large amounts of swelling clay minerals (smectite). The soils crack widely during the dry season and become very sticky in the wet season.	Ngala, Numan,	Sahel Savanna	Lombin, and Esu, (1988). Mamman, E. (2002)
INCEPTISOLS	Young soils with limited profile development. They are mostly formed from colluvial and alluvial materials. Soils derived from volcanic ash are considered a special group of Inceptisols, presently classified under the Andept suborder (also known as Andosols).	Sokoto Kubanni Zaria	Sudan / Guinea Savanna	Sharu et al (2013) Jimoh (2015) Aliyu (2016)
ENTISOLS	Soils with little or no horizon development in the profile. They are mostly derived from alluvial materials.	Sokoto	Sudan Savanna	Sharu *et al* (2013)

Nigeria is divided mainly into two zones;

i. The Forest vegetation zone, found in the southern part of the country which includes the mangrove forest, the swampy forest, and rainforest vegetation.
ii. The savanna vegetation zone is found in the northern part and consists of both Guinea and Derived Guinea savanna, Sudan and Sahel savanna.

The soils of the southern forest vegetation are mainly Ultisols, Oxisols, Inceptisol, and Entisol (Nwachokor and Uzu, 2008; Ande, 2010; Aki et al., 2014). The soils of the northern savanna consist mainly of alfisols, vertisols and entisols (Ezenwa, 1988; Shobayo 2010; Samndi and Jibrin, 2011).

2.3.1 Soil distribution in forest vegetation zone

Nwachokor and Uzu (2008) classified the soil of western Nigeria as Ultisols with Itagunmodi, Alagba and Ondo soil series as Oxic Paleustults; Apomu series as Oxic Ustropepts; Odeyinka series as Typic Ustropepts and Iwo series as Oxic Haplustults. The earlier researchers had previously classified the western soils as Alfisols (Harpstead, 1974). These soils were later classified as Ultisols and entisols (Nwachokor and Uzu, 2008).

Ande (2010) studied the morphogenetic and physico-chemical properties of southwest forest soil and classified the soils as Typic Hapludult (Haplic Acrisols), Dystric Hapludult (Dystric Luvisol), Albic plinthudult (Albic plinthosols) and Dystric Haplaquent (Dystric Gleysols). Aki *et al.*, (2014), studied soil of Akamkpa Local Government Area of Cross River State, and classified the soil as Ultisol (loamy skeletal, mixed isohyperthermic typic kandiudults). Ojanuga (1973) reported the dominance of kaolinite in most rain forest series of southern Nigeria. Earlier study by Smyth and Montgomery (1962) showed low CEC and predominance of kaolinitic clay in central western Nigeria. The soil series of southwestern Nigeria were also reported to exhibit low cation exchange capacity (Fasina, and Adeyanju, 2007; Ande 2010).

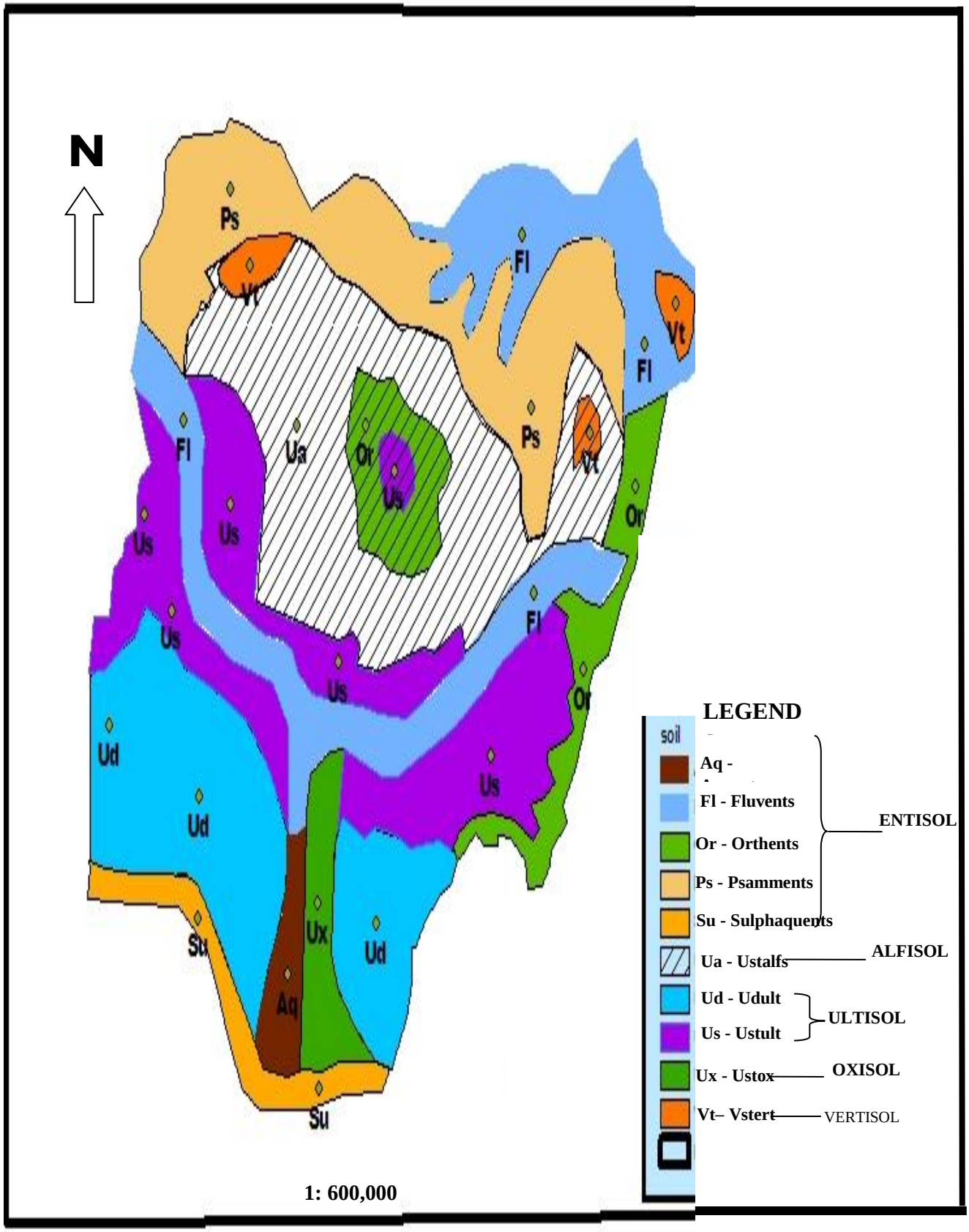


Figure 2.1: Digitized map of Nigeria showing distribution of soils

2.3.2 Soil distribution in savanna vegetation zone

Savannas are one of the world's most extensive biomes (Williams *et al*., 1996), they comprise systems with a continuous herbaceous layer and a discontinuous woody stratum (Sankaran *et al*., 2008). The Nigerian savanna is generally divided into Sahel, Sudan, Guinea and Derived Savanna zones based on moisture and vegetation (Aduayi *et al*., 2002). Ezenwa (1988) classified the soils of Guinea savannah (northern Nigeria) as Ultic Paleustalfs, Plinthusalfs, and Plinthustults. Samndi and Jibrin (2011) classified the soils of teak plantation (*Tectonia grandis*) of Nimbia Forest Reserve located in Jema'a local government area of Kaduna state as Humic Dystrustept, Oxic Dystrustept, Kanhaplic Haplustults, and Typic Haplustults.

Shobayo (2010) classified the soil of Samaru as Typic Haplustult (Dystric Acrisols),Typic Haplustalf (Eutric Lixisols) and Typic Plinthustalf (Eutric Lixisols); Odunze and Kureh (2009) classified some savanna soils as OxyaquicVertic Paleustalfs / GleyicLixisol' and 'Aquic Kandiustalfs / GleyicLixisols'(Alfisols), while Jimoh (2015) classified Kubanni soil as Typic Plinthustalfs (Eutric Lixisols), Typic Haplustepts(Endoeutric Fluvisol), Typic Endoaqualfs and Fluvaquentic Epiaquepts (Terric cambisols) based on the United State Department of Agriculture (USDA) Soil Taxonomy and Food and Agricultural Organisation (FAO system) respectively.

2.4 Influence of Guinea Savanna Soils on Vegetation

The savanna region ranged from humid to semi arid in nature. Distinct soil-vegetation patterns are clearly evident in savanna landscapes. In such environments, the availability of water influences rates of weathering, leaching, and soil formation (Cooke *et al*., 1993). Abdulhameed (2005) stated that vegetation associations within the Guinea savanna and tree species reflect differences in soil texture, structure, and mineral content. Soil factors such as climate, parent materials, topography and time, have important effects on the composition and

distribution of plant communities in Guinea savanna (Menaut *et al*., 1985, Cole 1986). The savanna biome is characterized by heterogeneity in the physiognomy and spatial structure of the vegetation (Ratter *et al*., 1997; Augustine, 2003; Bucini and Hanan, 2007). According to McAuliffe (1994), soil variations in profile characteristics can strongly influence vegetation patterns through effects of pedogenic horizons on spatiotemporal soil-resource dynamics. Distinct vegetation patterns also may result from topographic variations for example, aspect, slope gradient, and slope position).

2.5 Morphological Properties of Guinea Savanna Soil

Generally, the soils of the savanna area tend to have high sand content at surface, as some of the soils are formed on aeolian sand cover (Sombroek and Zonneveld, 1971). Esu and Ojanuga (1985) studied morphological, physical and chemical characteristics of Alfisols occurring in Nigeria Guinea savanna. They observed that soil texture varied from sandy loam to gravelly clay loam in the sub soil with high silt fractions and relatively low in the surface soil. The texture of the soils ranges from sandy loam to sandy clay loam (Oyinlola and Chude, 2010; and Shobayo, 2010), while Odunze and Kureh, (2009) reported loam texture at the surface horizons, and clay loam and clay in the subsoil horizons.

Increase in clay content with increase in depth indicated clay movement into the subsurface horizon, giving rise to pronounced argillic horizons which characterized most of the Nigeria savanna soils (Maniyunda, 1999). Sharu, *et al*, (2013) also observed higher clay content in the subsurface horizons of many soils which were attributed to illuviation and pedoturbation processes. The soils of the savanna region are physically fragile because the surface soil contains large proportion of sand, causing weak aggregation and partly due to low level of organic matter in this layer (Salako, 2003). The physical constraints are further compounded in gravelly soils or soils with shallow depth overlying plinthic or hardpan layers (Adeoye and Mohammed-Saleem, 1990; Salako *et al*., 2002).

Harmattan also plays an important role by contributing silt to soil in the savanna region of Northern Nigeria (Kparmwang, 1993).

2.6 Physico-Chemical Properties of Savanna Soil

Savanna soil is characterized by high bulk density on the soil surface, followed by a decreasing pattern in the sub-soils horizon which later increased in the lowest horizon (Esu, 1988; Raji, 1995; Raji *et al*., 1996) the initial high bulk density was attributed to surface compaction due to animal traction (Sharu *et al.,* 2013) while the later increase in the lowest part of the profiles may be attributed to presence of parent materials (Buol *et al*, 1980). The savannah soils are moderately acidic (Oyinlola and Chude, 2010; Shobayo, 2010). The pH values are low (pH 6.2-6.8), indicating the acidic conditions of the woodland soils. The mean pH values of the soils in the derived savanna zones of western Nigeria indicates that the soils are mildly acidic to neutral in reaction (Gbadegesin and Olabode, 1999). Generally, there is presence of low organic carbon (<10 gkg^{-1}), low available Phosphorus (less than 10 gkg^{-1}) and low total Nitrogen (less than 1.5 gkg^{-1}) in Nigerian savanna soils which is in accordance with the work of Jones and Wild (1975); Esu (1991); Raji and Mohammed (2000); Malgwi et al., (2000).

In savanna region, calcium is the dominant exchangeable base (Raji, 1995, Maniyunda, *et al.,* 2007 and Hussaini, 2011). Hussaini (2011) ranged cation exchange capacity (CEC) from low to medium (1 – 12 $cmolkg^{-1}$). Fasina (2006) also reported that Nigeria soils are characterized by low CEC (< 6 $cmolkg^{-1}$), which indicated presence of some 2:1 clay minerals in the soils.

2.7. Vegetation and Vegetation Survey

Vegetation is a term used to describe the totality of plant species or plant life found on the earth. In its most general term, vegetation refers to the plant cover of the earth (Brocklehurst, 2007) which is the assemblage of plant species and the ground cover they provide (Burrow

1990). The vegetation of a place is the entire plant community found in the place. It refers to the great diversity of plant species which occur in repeating assemblages over the face of the earth. Vegetation survey classifies, describes, and maps plant species and communities that are found in a place. It provides valuable baseline information about vegetation found within an ecosystem (NPS, 2011). Vegetation survey facilitates natural resource management decisions and is useful for the design and implementation of other natural resource projects. It also forms part of the natural resource inventories/survey. Other inventories include soil resource inventory, fauna (wildlife) inventory. Vegetation is characterized by species composition, distribution patterns, structures, and the properties of the environment or landscape where they are found. All these complement one another such that unique relationship is established between the vegetation and soil as well as the environment where both occur. According to the United States National Park Services (2009), some of the applications of vegetation survey are important in the following ways;

i. Used as inputs for habitat evaluation, inventory and monitoring,

ii. For describing ecological processes.

iii. To organize complex natural resource information effectively using spatial displays and analyses, for example, by incorporating basic information about vegetation communities and topography into a spatial analysis, managers can locate potential habitats for endangered species or predict the likely course of wildfire.

2.8 Savanna Vegetation

The term “Savanna” has been borrowed from Latin America and applied in Africa and other countries to a wide range of tropical and subtropical grasslands with or without shrubs or tree growth (Ezenwa 1988). Savanna is seasonal tropical vegetation in which there is a close or nearly closed cover of grasses at least 80cm high and predominantly perennial and where trees and shrubs may or may not be present (Sanford and Isichei, 1980).

2.9 Nigerian Savanna Vegetation

The Nigerian savannas cover northern four-fifth of Nigeria and support about three-quarter of Nigeria's population (Ezenwa, 1988). Keay (1959) classified Nigeria savanna into four main ecological zones namely, southern guinea, northern guinea, Sudan and Sahel savannas. Vegetation distribution in Nigeria is shown in Figure 2.2.

2.10 Vegetation and Soil Relationship

Pedologists have long been interested in the contrasts between soils formed under different vegetation types such as prairie/savannah and forest, and under transitions between them (Jones and Beavers, 1964). Studies have shown that soil properties under grassland ecosystem varied from those under forest ecosystem on uniform parent materials in the north central region of United States (Jones and Beavers, 1964). This is because soil and vegetation exhibit an integral relationship, in that soil gives support (moisture, nutrient, and anchorage) to vegetation to grow effectively while vegetation provides protective cover for soil, suppresses soil erosion, maintain and recycle soil nutrient through litter accumulation and subsequent decay (nutrient cycling) (Eni *et al*., 2012).

Vegetation and soil are interrelated and provide reciprocal effects on each other. Vegetation strongly affects soil characteristics, including its chemistry, and texture, which in turn affect various vegetation characteristics, including productivity, structure, and floristic composition (Brant *et al*, 2006).

Soil is fundamental to ecosystem and agricultural sustainability and production as it supplies many of the essential requirements for plant growth like water, nutrients, anchorage, oxygen for roots, and moderated temperature (Jamieson *et al.*, 2002, Van der Maarel 2004). Marx *et al.*, (1999) stated that soil serves a vital function by providing nutrients for plants growth as well as habitat for millions of micro- and macro-organisms. Healthy soil enables vegetation to flourish, diminishes destructive storm runoff, breaks down waste materials, binds and breaks

down pollutants, and serves as the first course in the larger food chain (Rodriguez-Iturbe, 2000).

2.11 Conservation and Biodiversity

Jordan (1995) defined conservation as being a philosophy of managing the environment in a manner that does not despoil, exhaust or extinguish the environment. Conservation of natural resources includes habitat conservation, soil conservation, wildlife conservation, wildlife management, and wetland conservation. Usually, conservation of natural resources requires sound principle of ecological management to achieve sustainable development in natural ecosystem (IUCN, 1996). The categories of conservation of natural resources are as follows;

a. Energy conservation: This refers to the preservation and management of natural energy resources found in the environment.
b. Habitat conservation: This is the management practices applied to land in order to protect, manage, and restore habitat. It is important in maintaining biodiversity, an essential part of global food security.
c. Marine conservation: It is the protection and management of ocean and sea ecosystems
d. Soil conservation: It refers to the management of soils resources so as to prevent erosion, depletion, and contamination of soil.
e. Water conservation: Management of fresh water at a sustainable level.
f. Wetland conservation: Management, protection and restoration of wetlands.
g. Wildlife conservation: Preservation and protection of endangered species and their habitat.

Wildlife management and conservation: Application of management principles so as to conserve wild species and their habitats

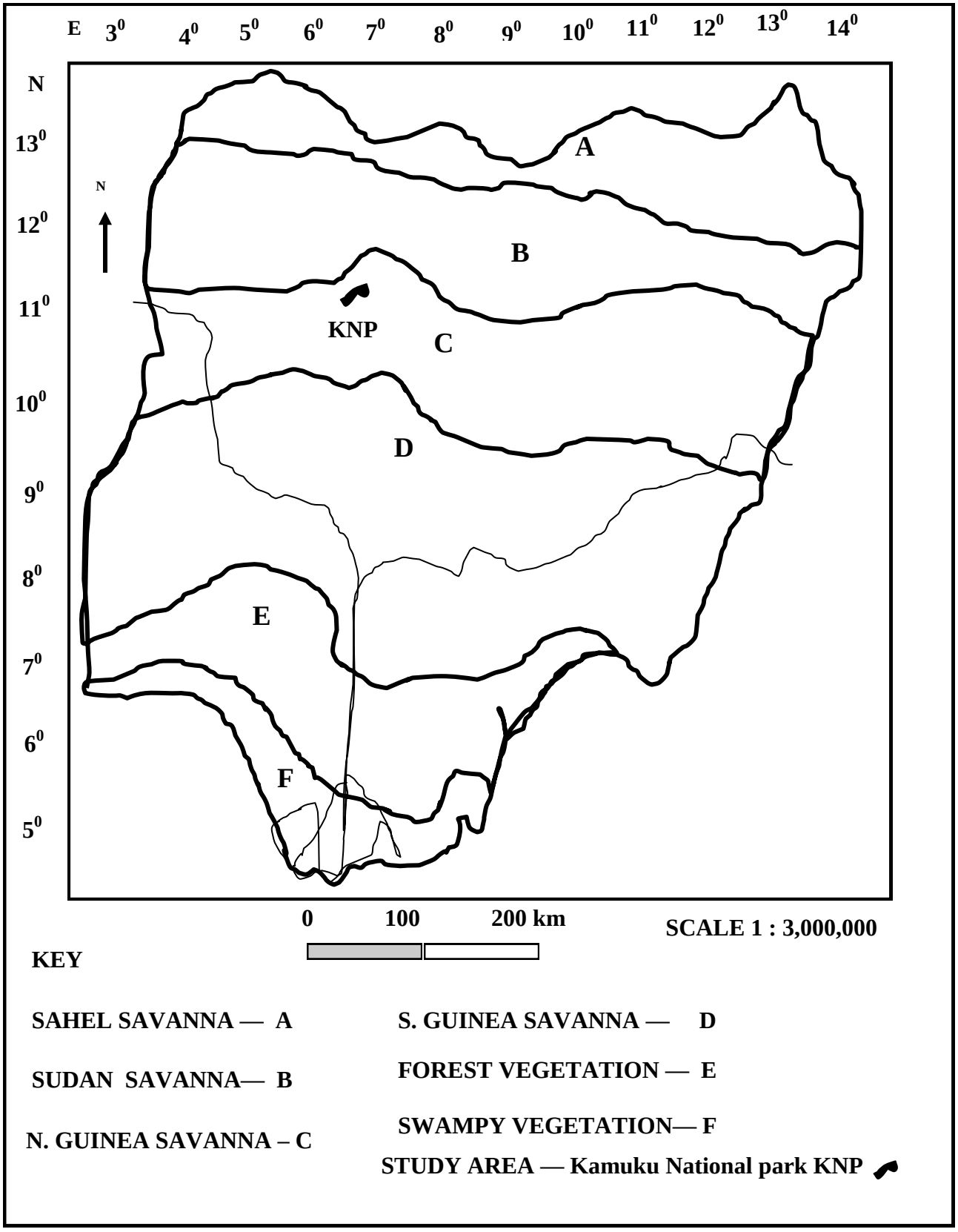


Figure 2.2: Vegetation distribution and location of Kamuku national park

Source: adapted from Maniyunda (2007)

Biodiversity includes species diversity, ecosystem diversity, and genetic diversity and the way such diversity affects the complex ecological processes operating at and among these respective levels (Scholes *et al* 2008; Purvis and Hector 2000) and it plays an important role in ecosystem services which by definition maintain and improve human quality of life (Ostfeld 2009; Cardinale *et al* 2012; Tierney *et al* 2009).

According to Carlton (2001), biodiversity occurs at three levels namely:

i. **Genetic diversity**: Genetic variability among the populations and individuals of the same species.
ii. **Species diversity**: Diversity among species in an ecosystem and
iii. **Ecosystem diversity**: Diversity of habitat in a given unit area, and it embraces variety of ecosystems on earth.

2.12. Biodiversity Conservation in Nigeria

According to the United Nations Commission on Sustainable Development (UNCSD,1997), Nigeria's wildlife is rapidly declining due to habitat loss and increased pressure from hunters, poachers, and bush burning. In Nigeria conservation of diversity of wildlife species are maintained at the optimum level commensurate with other forms of land use in order to ensure the continued existence of wildlife for the purpose of their sustainable utilization for benefit of the people (Mohammed *et al* (2013).

2.13 Protected Areas

Protected areas are conservation sites established by law to protect flora and fauna resources of a country. The globally accepted definition of protected areas as provided by the International Union for Conservation of Nature (IUCN, 1996), is given as "a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve long-term conservation of nature with associated ecosystem services and

cultural values". Protected areas are conservation sites that are protected due to their natural, ecological and cultural values.

According to I.U.C.N. (1996), there are six categories of protected areas in the world namely;

I. **National park:** A large natural or near-natural area protecting large-scale ecological processes with characteristic species and ecosystems, which also have environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities e.g. Kainji National Park, New Bussa, Nigeria.

II. **a). Strict nature reserve**: Strictly protected for biodiversity and also possibly geological/ geomorphological features, where human visitation, use and impacts are controlled and limited to ensure protection of the conservation values e.g. Abi Gorilla Reserve in Cross

b). **Wilderness area**: Large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, protected and managed to preserve their natural condition.

III. **Natural monument or feature**: Areas set aside to protect a specific natural monument, which can be a landform, sea mount, marine cavern, geological feature such as a cave, or a living feature such as an ancient grove.

IV. **Habitat/Species management area**: Areas to protect particular species or habitats, where management reflects this priority.

V. **Protected landscape or seascape**: Where the interaction of people and nature over time has produced a distinct character with significant ecological, biological, cultural and scenic value: and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values

VI. **Protected areas with sustainable use of natural resources**: Areas which conserve ecosystems, together with associated cultural values and traditional natural resource management systems (Dudley 2008).

2.14 National Parks

National parks play major roles in biodiversity conservation. A national park is a large natural or near-natural areas protecting large-scale ecological processes with characteristic species and ecosystems, which also have environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities (IUCN 1996).

According to Mohammed *et al* (2013), the Nigeria National Park Service is to deal with

(a) The conservation of wildlife throughout Nigeria so that the abundance and diversity of species are maintained at the optimum levels commensurate with the other forms of land use in order to ensure the continued existence of wildlife for the purpose of their sustainable utilization for the benefit of the people.

(b) The preservation of outstanding scenic, natural, scientific, recreational and other values in the National Parks.

(c) The protection and maintenance of crucial wetlands and water catchments areas.

(d) The implementation of relevant international treaties, agreements or other arrangements regarding, relating to, or connected with protected areas and wildlife management

(e) The promotion and provision of education about wildlife and nature conservation,

(f) The conservation of biological diversity in Nigeria.

2.15 Importance of Soil Survey in National Parks

National Parks are unique areas where knowledge about our valuable soil resources is acquired and they provide a great opportunity to understand the role soils play within nature (Makarushka, 2012). In advance countries such as United States, soil survey in national parks focuses on scientific discovery and mapping of new soils species. For instance, soil

survey/inventory has identified numerous park endemic soils, including 19 new "species" in Great Smoky Mountains National Park alone—most of those at elevations above 4,600 ft (Makarushka, 2012).

Before soil survey was done the Great Basin National Park in Nevada, United States, it was believed that bristle cone pines (*Pinus longaeva*), the longest-lived trees on earth (over a thousand years old) found in the park, could only grow in calcareous soils—"chalky," alkaline soils, as might be found in an area with a lot of limestone. But the soil survey of the Park later disproved this as some of the trees were also found on non-calcareous soils, this now give more information for scientists to draw on in the future (Makarushka, 2012).

As far back as 1975, the Canadian government executed the soil survey of Elk Island National Park and established the subtle complexity of the soils within the Park which provided data for the identification of their attributes and limitations for various uses.

The soils report showed variation in surface horizonation is in terms of color, thickness and organic matter content. Using the System of Soil Classification of Canada, the survey classified the mineral soils into Luvisolic Order; deep sand deposits into Brunisolic Order; The hummocky and ridged soils of low lying and depression areas into Gleysolic soils; where deep soil accumulations and peats were grouped into Organic Order and the soils with relatively high concentrations of soluble salts were placed in the Solonetzic Order (Crown, 1977).

2.16 Remote Sensing (R.S) and Geographical Information System (G.I.S)

Information on Land use and vegetation is the basis on which the past and present human interactions and its impacts of such interactions with the natural resources and the environment can be understood (Mohammed *et al*, 2013). It is required for rational and sustainable allocation of land resources for future development. Land, soil and vegetation resources have geographical attributes, therefore the need for effective tool for gathering these attributes,

presenting and analyzing them for effective decision making. This is where Remote Sensing (R.S) and Geographical Information System (GIS) become very indispensable.

2.17 Remote Sensing

Remote Sensing simply refers to all activities of recording/observing/perceiving (sensing) objects or events in distant (remote) places. It is the acquisition of information about an object or phenomenon without making physical contact with the object (Schowengerdt, 2007). The term remote sensing generally refers to the use of aerial sensor technologies to detect and classify objects on Earth (both on the surface, and in the atmosphere and oceans) by means of propagated signals (e.g. electromagnetic radiation).

2.17.1 Types of remote sensing

There are two types of remote sensing

i. Active remote sensing: This is remote sensing obtained when a signal is first emitted from aircraft or satellites up in the sky such that the energy emitted scan objects and areas whereupon a sensor then detects and measures the radiation that is reflected or backscattered from the target.

ii. Passive remote sensing: The passive sensors gather radiation that is emitted or reflected by the object or surrounding areas. The most common source of radiation measured by passive sensors is reflected sunlight.

Whichever of the types of remote sensing that is used, the reality is that the technology of remote sensing is gradually gaining ground in soil survey. Soil properties that have been measured using remote or proximal sensing approaches include mineralogy, texture, soil iron, soil moisture, soil organic carbon, soil salinity and carbonate content. In sparsely vegetated areas, successful use of space borne, airborne, and in situ measurements using optical, passive and active microwave instruments has been reported (Mulder *et al*, 2011).

2.18 Geographic Information System

Geographical Information System (G.I.S.) is a system for collecting, processing, manipulating, retrieving, displaying and storing geographical or spatial information (Coulsen, 1991). It deals mainly with the spatial analysis function that provides means of obtaining information based on location. Geographic Information System (GIS) technology is used to process, support and deliver information for environmental management and monitoring (Aronoff, 1991).

GIS is a powerful software technology that allows a virtually unlimited amount of information to be linked to a geographic location. Coupled with a digital map, GIS allows a user to see locations, events, features, and environmental changes with unprecedented clarity, showing layer upon layer of information such as environmental trends, soil stability, pesticide use, migration corridors, hazardous waste generators, dust source points, lake remediation efforts, and at-risk water wells (ESRI, 2005).

2.19 Land Evaluation

Land evaluation is concerned with the assessment of land performance when used for specified purposes (FAO, 1999). It is the process of predicting land performance over time according to specific types of use (Rossiter, 1996). It involves the execution and interpretation of basic surveys of climate, soils, vegetation and other aspects of land in terms of the requirements of alternative forms of land use. Land comprises all elements of the physical environment, including climate, relief, soil, hydrology and vegetation, as well as includes the results of past and present human activity (FAO 1976).

2.19.1 Types of land evaluation

There are many types of land evaluation but the major ones are

i. Land Capability Evaluation

ii. Land Suitability Evaluation

2.20 Land Capability Classification

The land capability classification was developed by the Soil Conservation Service of USDA (Klingebiel and Montgomery, 1961) and has been widely used throughout the world with numerous adaptations. It is a definite system that uses qualitative criteria and designed for evaluating the potential uses of soils under specified land management (Dent and Young, 1981). The inclusion of a soil within a class is made without directly analysing its capacity, but rather its degree of limitation with respect to a parameter according to a concrete use.

In this system, factors that limit soil potential are used to describe the productive capacity i.e. we have

i. Intrinsic or inherent factors such as soil depth, texture, structure, permeability, rockiness, stoniness, salinity, soil management;
ii. Extrinsic or climatic factors e.g. temperature and rainfall, and
iii. Yield loss e.g. slope of the terrain and degree of erosion.

There are three levels of classification in land capability namely; classes, subclasses and units. The classes are made up of 8 classes from I to VIII and are defined with increasing limitations.

2.20.1Categories of USDA land capability classification

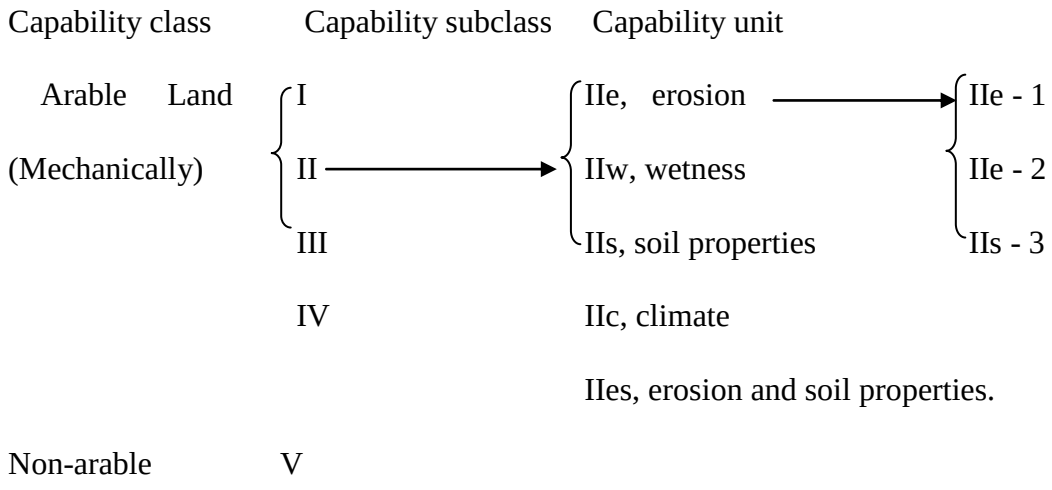
The USDA land capability classification is made up of three categories namely;

i. Capability classes
ii. Capability sub-classes
iii. Capability units

2.20.2 Land capability classification for northern Nigeria

The land capability classes proposed for soil survey in northern Nigeria was modified from the USDA system of land capability classification by many researchers, for instance, Obeng, modified it for land evaluation in Ghana in1962 while Carroll applied it in Nigeria (Carroll, 1974); Sánchez used it in Spain (Sanchez et al 1984). According to Ezenwa (1988), the

difference is that Nigerian classification combines the land classes V – VIII of USDA system together into class V of Nigerian version (FAO, 1971). The structure is shown below;



CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Area

The study area is Kamuku National Park, Birnin-Gwari local government, Kaduna State, Nigeria (Figure 3.1). It is located North-West of Kaduna city, near Birnin-Gwari town, North-western Nigeria, located between latitudes 10° 41` - 11° 01`N and longitude 6° 11`E – 6° 36`E and 450m above sea level (Figure 3.2). It has a total land area of 1,121 square kilometers (112,700 hectares). The study area belongs to Northern Guinea Savanna Zone and the park has two ranges; Doka and Dagara, ranges (Amusa *et al.,* 2013).

3.2 The Study Area Location

The selected site lies 10.55km (6.6 miles) North-East of Birnin-Gwari town on Birnin-Gwari - Doka road. The site is located between latitude10°44'38.35" and 10° 47'27.88" N and longitude 6° 34’17.91’’ and 6° 35’59.41’E with an average elevation of 450 m above sea level (SL) at the south-eastern corner of the park (Figure 3.2).

The choice of location was borne out of the security situation in the area. Previously, centre of the park was proposed but due to the problem of cattle rustlers in the area, a relatively more peaceful site with representative features of the park had to be chosen. The extent of the area is 2 by 1km (200ha) and was situated at the boundary with unprotected area under agricultural land use.

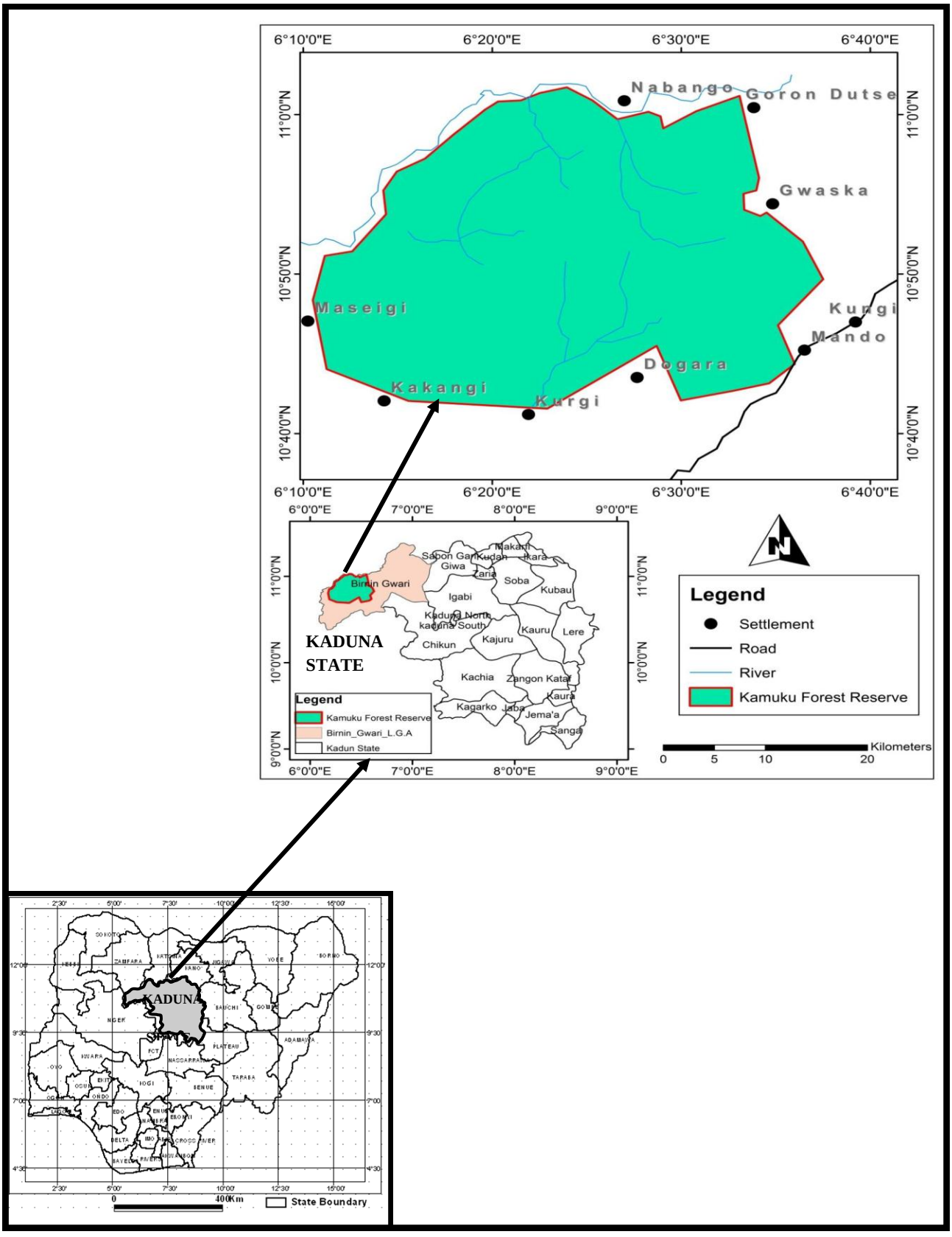


Figure 3.1: Map of Nigeria showing Kaduna state, Birnin-Gwari and Kamuku National Park

Source: Abdulkadir (2005)

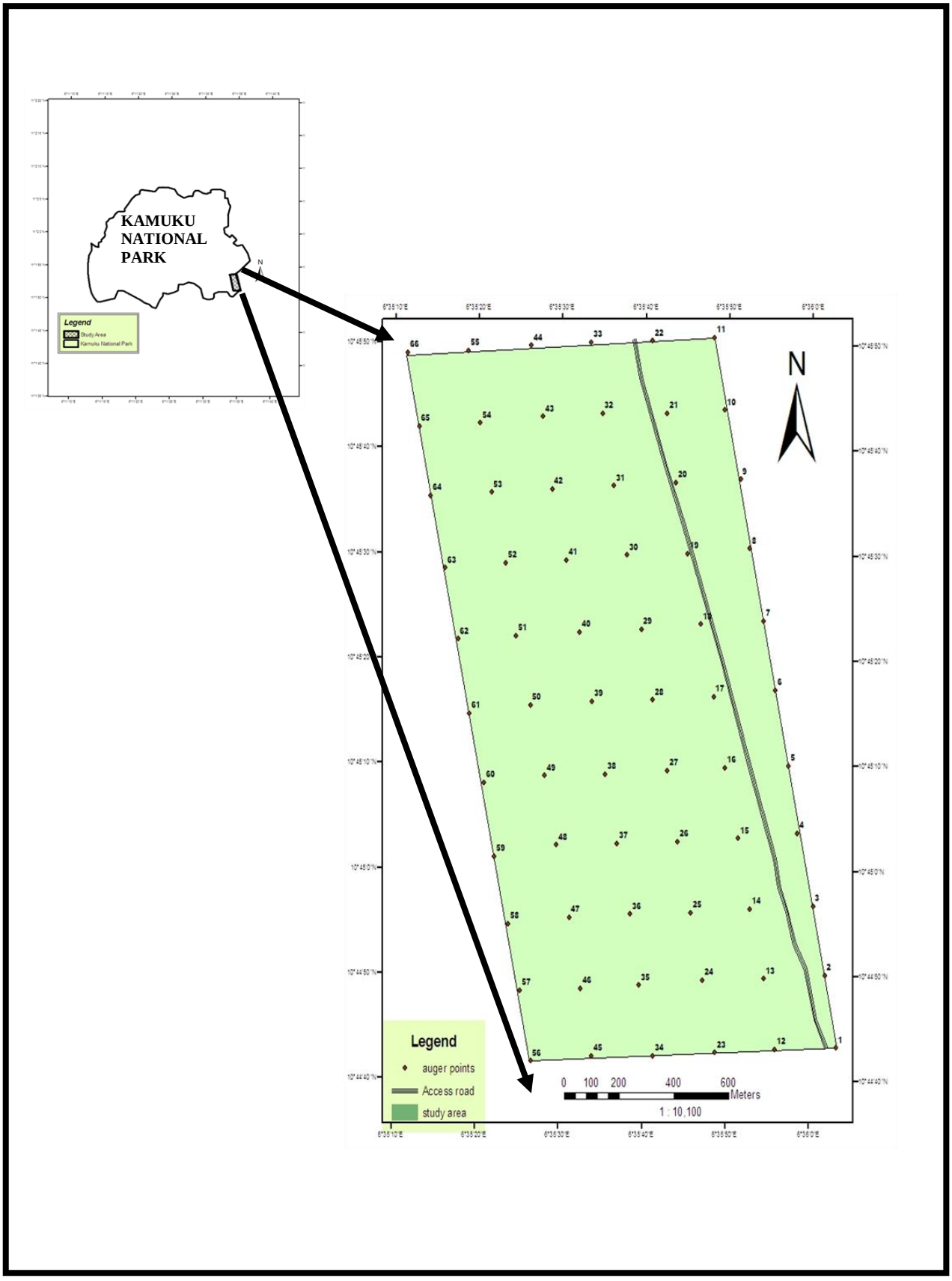


Figure 3.2: Kamuku National Park showing of the Study Area with auger points

3.3 Vegetation

The vegetation is typical savanna woodland, referred to as Northern Guinea Savanna. The dominant tree species in the park are *Isoberlinia doka, Afzelia spp., Daniella spp., Terminalia spp, Detarium macrocarpum, Danellia oliveri, Nauclea latifolia, Lophira lanceolata, Parkia biglobosa, Prosopis Africana, Isoberlinia tomentosa, Pilliostigma reticulate, Tamarindus indica, Entada Africana, Acacia spp, Combretum molle,* etc. Grasses such as *Andropogon spp, Panicum maximum, Pennisetum spp.* are also found in the park. These grasses are quite tall, about 1m high, within the marshy areas. Kamuku national park, together with the forest reserve, represents one of the best remaining blocks of Sudan–Guinea Savanna vegetation in the country's protected-area system (Birdlife, 2014).

National Park Services (2009) categorized Kamuku national park vegetation (Figure 3.3) into the following;

1. Predominantly trees vegetation**.**This is vegetation that contains mainly perennial plants with an elongated stem, or trunk, supporting branches and leaves in most species.
2. Trees and Shrubs vegetation. This consists of a *tree* and shrubs. A shrub is a small to medium-sized woody plant with persistent woody stems above the ground. They are distinguished from trees by their multiple stems and shorter height, and are usually under 6 m (20 ft) tall (Lawrence and Hawthorne, 2006).
3. Grassland vegetation. It refers to vegetation where grasses are dominant. Grasses are family of monocotyledonous flowering plants that belong to family Gramineae.
4. Riparian vegetation : this refers to the vegetation found near wetland, river or stream which is made up of trees, shrubs and grasses that provide cover and stability for banks

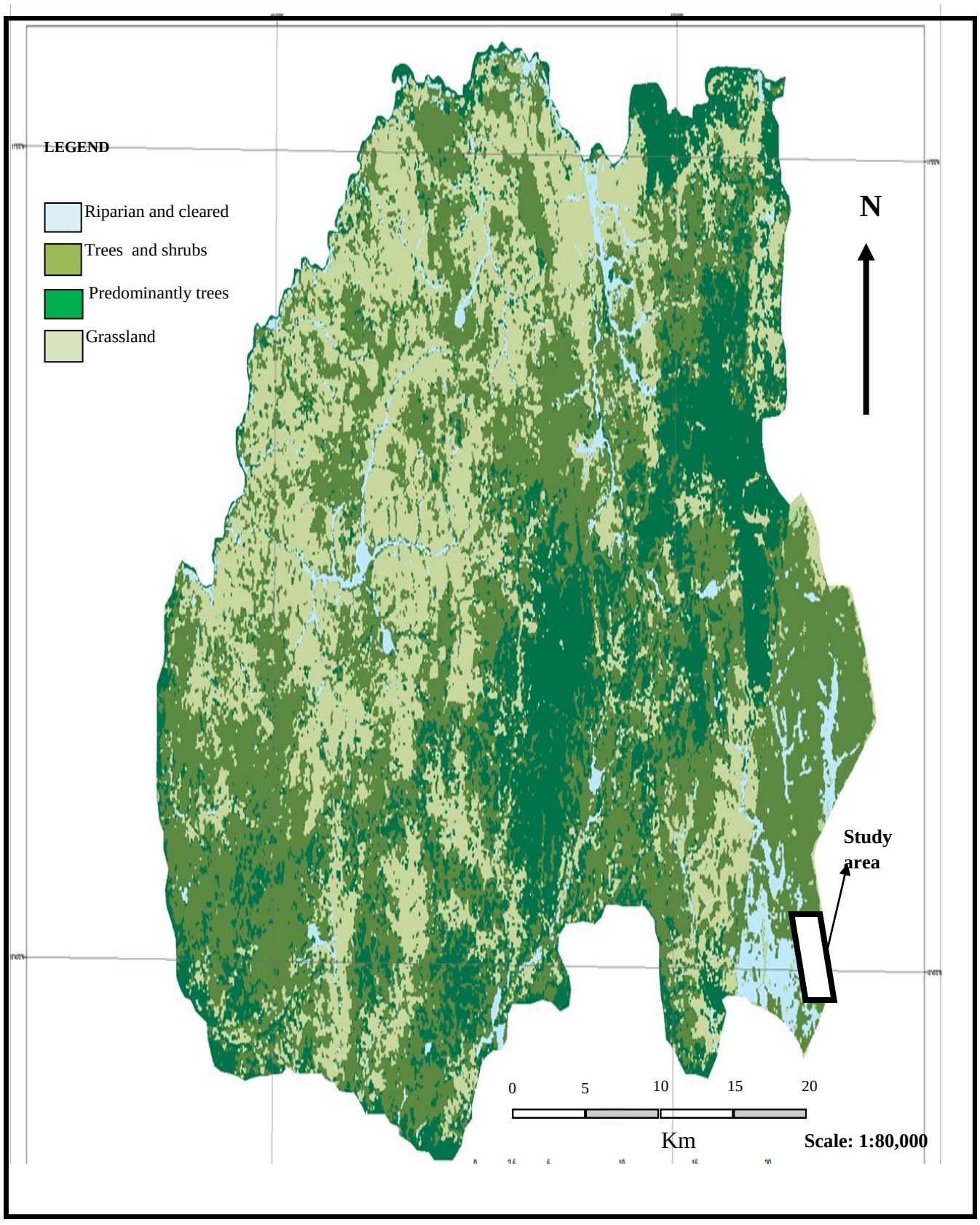


Figure 3.3: Map showing vegetation distribution in Kamuku National Park and study area

3.4 Climate

According to Ahmed (1989) and Jimoh (2015), the climate of Kaduna state is of the Aw type (Tropical savannah or tropical wet and dry climate zone characterized by strong seasonality in rainfall and temperature distributions i.e. distinct wet and dry seasons). The region has a tropical continental climate with distinct wet and dry seasons (Ayuba, 2011). These characteristics are determined by the oscillations of two contrasting air masses namely;

1. The Tropical Maritime and
2. The Tropical Continental Air Masses.

The tropical maritime originates from Gulf of Guinea and brings in rainy season while tropical continental originates from Sahara Deserts and ushers in dry cold and dusty season called the harmattan,which occasionally limits visibility and reduces solar radiation (Oguntoyinbo, *et al.*, 1978). 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. The location of zones is in relation to the surface position of the ITD and this determines weather condition of a place at anytime of the year (Ayuba, 2011).

The ITD influences climatic regime of Kaduna state including that of Birnin-Gwari. The movement of the ITD north and south of Kaduna State is associated with varying attendant temperature changes thus; the region experiences cold and hot weather (Owonubi and Olorunju, 1985). The season changes with movement of Inter tropical Discontinuity (ITD) over the region. By middle of November in most years, the ITD moves south of Birnin-Gwari and the moist south westerly air are replaced by dry continental north easterly air. The wet (rainy) season starts around May and ends around October. On the other hand, dry season lasts between October/November and April/May (Iguisi and Abubakar, 1998).

3.4.1 Rainfall

The Climate of the area is similar to what is obtainable in the central Nigeria, with an annual average rainfall of 1250mm, seven months of rainy season and five months of dry season (Idris-Nda, 2005). Birnin-Gwari has an average annual rainfall of approximately 1,180mm (Figure 3.1) with dry season starting from November to April while wet season begins from May to October

Birnin-Gwari, experiences cool, dry north easterly winds (Harmattan), from November to March. During this period, vegetative growth decreases to a minimum, the soil solum dries out and pedogenetic processes are slowed down. However, from April to May, the seasons change, the moist south-westerly winds bring rains, vegetative activities start again and the processes that develop the soil solum become intensified again (Maniyunda, 2012).

3.4.2 Temperature

The temperature of Birnin-Gwari ranged between 22.7°C and 27.3^0C for the minimum while mean monthly maximum range is between 30.5°C and 37.6°C (Olojugba, and Fatubarin, 2015). This is recorded around April and May (peak of hot period and onset of rainy season). The annual average temperature for the area is 30°C (Idris-Nda, 2005).

From Table 3.1, the maximum temperature of 37.7℃ was recorded in Birnin-Gwari around March and 36.7℃ in April while the minimum temperature of 5.1℃ and 10.2℃ were obtained in January and December respectively (i.e. during Harmattan).The mean maximum monthly temperature was about 33.8℃ while the mean minimum monthly temperature is 16.8℃.

3.4.3 Humidity

In Birnin-Gwari, the relative humidity is directly proportional to rainfall pattern i.e. as the rainfall increases, the relative humidity also increases. Maximum humidity corresponds to the period of maximum rainfall and vice versa. As the dry season sets in, the air become drier and relative humidity falls. This condition heralds harmattan; during which the least relative humidity value is recorded. This happens from November to February.

Table 3.1: Cimatic data for Birnin-Gwari from 1978 to 2004

Month	Rainfall (mm)	Rel. Humidity Max. (-------%----------)	Min.	Temperature (--------℃--------)		Evaporation mm
Jan	0.0	58.7	05.1	34.8	11.3	23.1
Feb	5.7	61.2	07.7	36.3	13.6	25.0
Mar	4.8	77.8	08.8	37.7	15.2	26.5
Apr	54.3	81.6	14.2	36.7	15.4	26.1
May	143.0	89.2	38.0	34.0	20.0	27.0
Jun	177.7	77.4	53.6	31.9	20.8	26.1
Jul	240.4	91.6	51.3	30.4	19.8	25.1
Aug	263.4	91.8	52.7	30.8	19.9	25.4
Sep	221.4	90.7	53.6	31.3	20.0	25.7
Oct	68.3	88.3	49.0	33.1	17.9	25.5
Nov	0.7	72.4	17.0	34.3	12.2	23.3
Dec	0.0	58.3	10.2	34.3	10.1	22.2
Total	1,179.7					
Mean/month		78.3	30.1	33.8	16.8	25.1

Source: Kaduna State Water Board, Birnin Gwari Meteorological Station

3.5 Geology

Kamuku National Park falls within the Nigerian pre-cambian basement complex rock. Russ (1957) described the Basement Complex Rocks of northern Nigeria as rich in high grade metasediments of mainly quartzite's (forming ridges) containing schist and phyllite. Generally, the study area is composed of rocks of Nigerian undifferentiated basement complex; consisting of migmatite-gneiss complex, two low-grade Schist belts and older granite suite (Ajibade *et al.,* 1976). The mylonites are major shear zones which mark the stratigraphic breaks between gneissic basement complex and the cover rocks of the Birnin-Gwari Schist formation (Ajibade *et al.,* 1976).

The Federal Department of Agricultural Land Resources also described the complex as an undifferentiated basement complex, while the area is underlain by undifferentiated older alluvium and younger laterites (Ayuba, 2011). Kamuku national park is located within undifferentiated basement complex as shown in Figure 3.4.

3.6 Relief and Drainage

Terrain of the park is largely flat, rising gradually eastwards to Birnin-Gwari Ridge, which forms part of the eastern boundary (Birdlife International, 2014).The relief comprises of relatively high area at the central and eastern part of the park. The SPOT image analysis of the park shows a gradual rise in elevation from 403m in the southern part to above 460m in the northern part of the national park. The same increase is observed from 423m in the west to above 500m in the eastern part of the park. The relief was low to moderate and the dominant geological formation is undifferentiated basement rock. Some of the relief features in the park include mountains Kaba, Bunsuru and Fakalla. The drainage pattern of the park is of dendritic type. River Mariga flows from the northeastern part of the park, leading to a waterfall at Dogonruwa axis. There are other rivers such as Rivers Beberu, Fasalla, Kuzomani and Tambam.

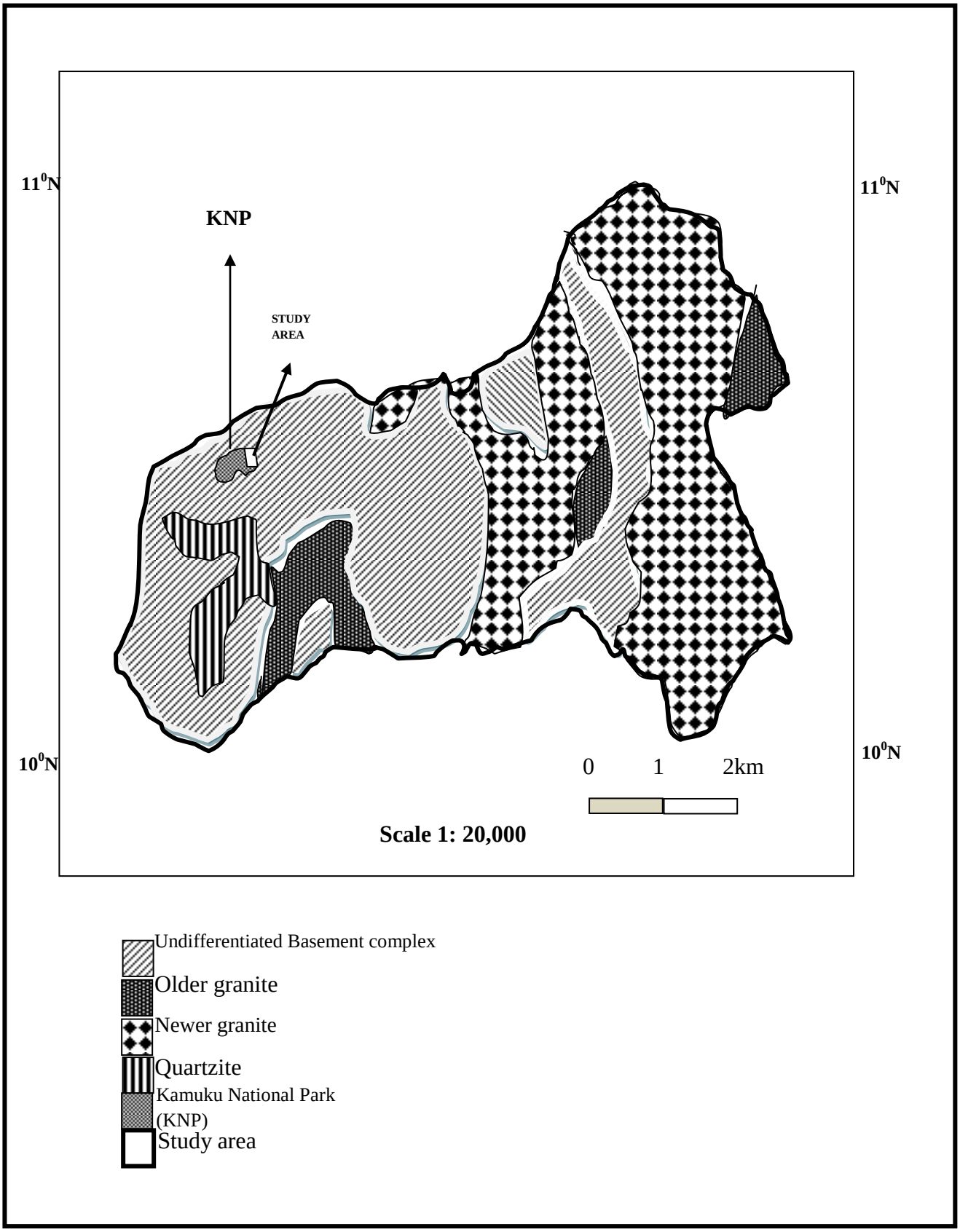


Figure 3.4: The Geological Map of Birnin-Gwari
Source: Kaduna State Ministry of Land and Housing (2009)

3.7 Methodology

The methodology to be employed in this study will be in three major stages as follows;

a. Pre-fieldwork stage
b. Fieldwork stage
c. Post-fieldwork stage

These stages are outlined in the flowchart in Appendix X

3.7.1. Pre-fieldwork stage

The pre-fieldwork stage involved planning and preliminary works. Ancillary data or available records about the park were collected. This included background information of the area, history of the National park, existing maps, books, journals, articles and others. Afterwards, satellite imagery (Figure 3.6) of the study area was acquired and interpreted. The imagery was used to identify vegetation cover, drainage pattern, communication lines, land use and other surface characteristics that were in the study area. The dimension of the area, 2 by 1km was marked out and measured using remote sensing tools. Grid intervals of 200m were created along traverse lines. These points served as soil observation points or auger points. These waypoints were then uploaded into G.P.S. in for reconnaissance survey.

The area was later visited in order to carry out reconnaissance survey of the park. The essence of this was to groundtruth or validate the information obtained from the satellite imagery and compared them with the actual conditions in terms landforms, surface characteristics and accessibility. After these had been done, the next stage was the actual fieldwork.

3.7.2. Field work

i. Soil survey

The study area covered 2 by 1km ($2km^2$) or 200 hectares where rigid grid survey method was employed. Waypoints were uploaded into a GPS and imaginary trasverse lines perpendicular to the baseline were used. The baseline used was along Birnin-Gwari – Funtua road where soil observations were carried out at 200m intervals by auger sampling along each traverse.

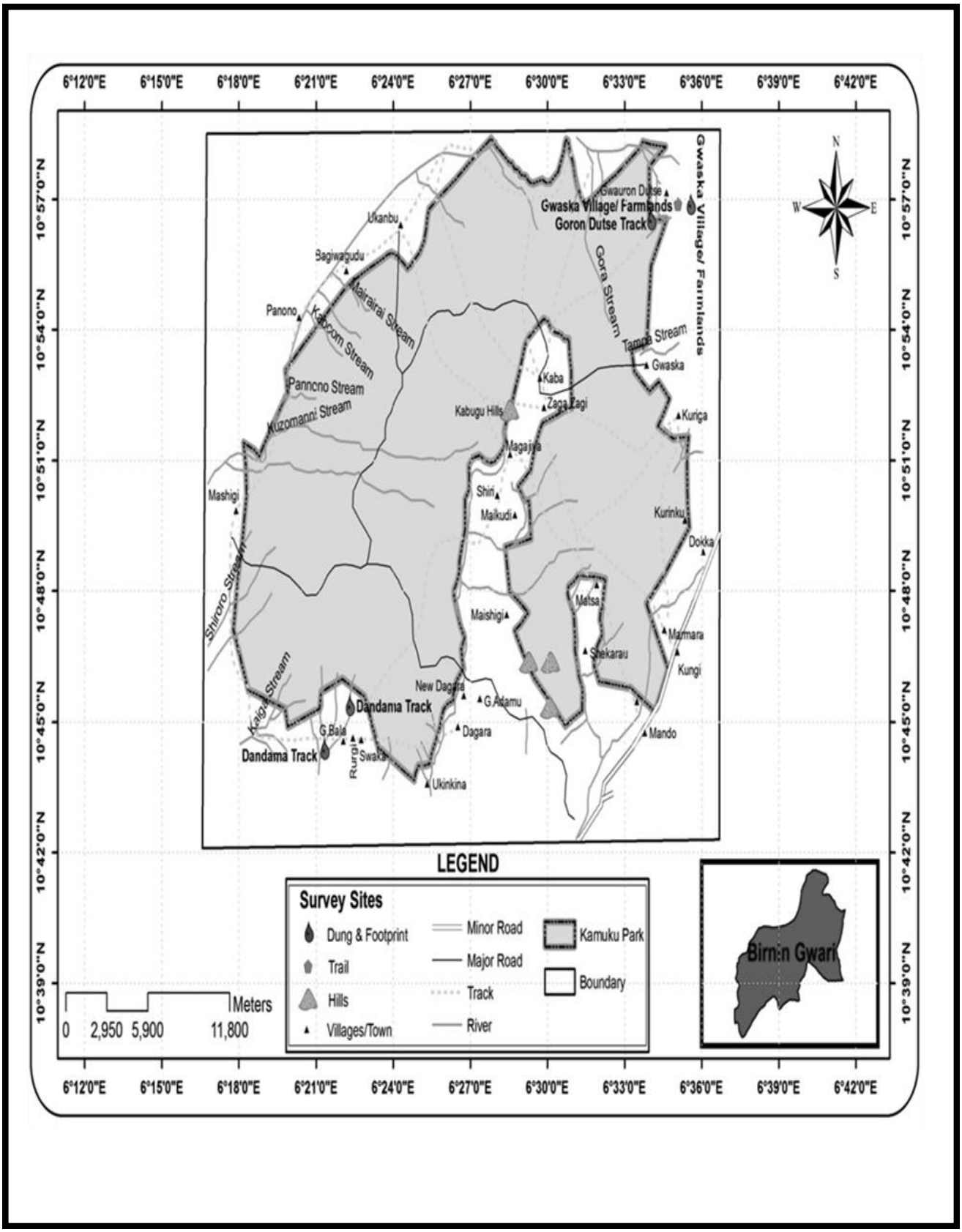


Figure 3.5: Map showing relief and Drainage of Kamuku National Park, Birnin-Gwari.
Source: Amusa *et al.* (2013)

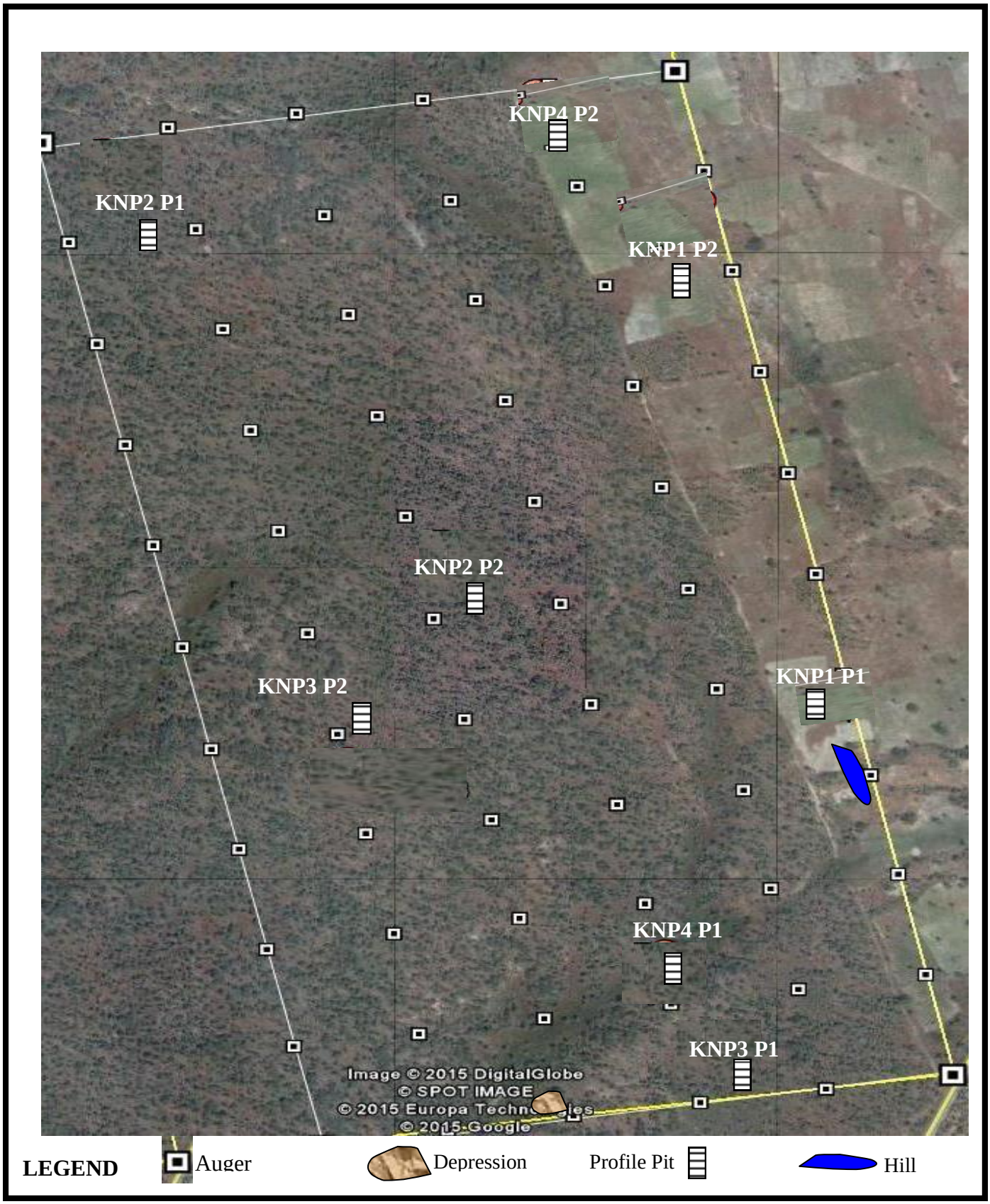


Figure 3.6: Satellite image of the study area showing profile pits, and auger /sampling points

A total of 66 auger points were examined. The major soil properties considered were soil colour, texture, consistence, inclusion, iron concretions,, mottling, physiographic position, slope form and angle, and degree of erosion. Based on theses properties, soils were grouped into mapping units, (i.e. soils having similar or closely related properties were put in the same mapping unit). A total of four mapping units were delineated namely, KN1, KN2, KN3, and KN4. Two soil profile pits were dug per soil mapping unit, making a total of eight soil pits dug in the study area. The profile pits were labeled KN1P1, KN1P2, KN2P1, KN2P2, KN3P1, KN3P2, KN4P1 and KN4P2

Each soil profile pit was described based on parameters like structure, boundary, pores, consistency etc. Each genetic horizon was sampled and all the soil samples were neatly packed in polythene bags and labeled for physical and chemical analyses in the Soil Science Department laboratories, A.B.U, Zaria.

ii. Vegetation Assessment

The vegetation assessment method used was Point-Centered Quarter Method (PCQM). The point-centered quarter method is a plot-less sampling technique more efficient, faster, required less equipment, and fewer workers. The point centered quarter method was used for sampling big trees and shrubs. A cross quadrat was placed on the auger point so as to divide the sampling point into four quarters (Figure 3.10), the nearest tree in each of the quarter was selected and different vegetation parameters were measured. These included tree height, trees specie, distance from the point and diameter at breast height (DBH). In this method, the auger points also served as the sampling points.

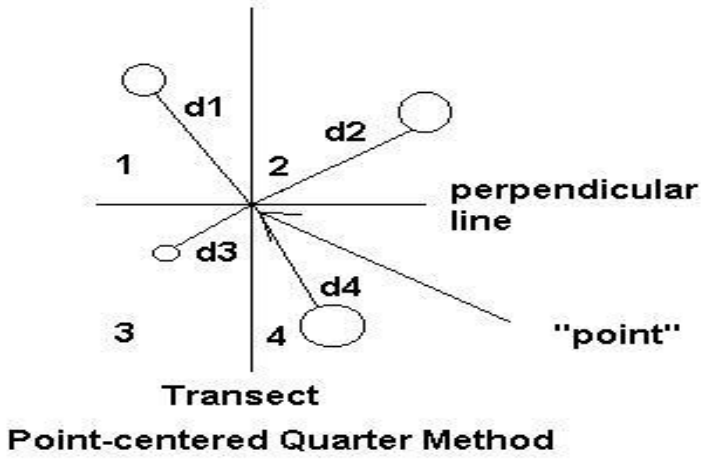


Figure 3.7: Diagram showing point-centered quarter method

3.7.3. Post-fieldwork

Post field work stage activities consisted of all activities carried out after the fieldwork. These included soil analyses, soil mapping, classification and characterization, report writing and interpretation (in form of suitability, or capability evaluation), and others.

a. Soil analyses

The geo-referenced soil samples collected from the respective profiles were air dried,crushed using pestle and mortar and sieved through 2mm sieve. Soil particles retained in the sieve (> 2.0mm) were weighed and percentage recorded to give gravel fractions, while soil fractions less than 2mm portion (fine earth) were used for physical and chemical analyses.

I. Physical Analyses

The physical properties analyses carried out included particle size distribution analysis, bulk density, particle density and total porosity.

1. Particle Size Distribution Analysis

The percentages of soil fractions (sand, silt, and clay) were determined using calgon (sodium hexametaphosphate) solution and sedimentation-hydrometer procedure as outlined by Day (1965), SCS-USDA (1972), and Gee and Bauder,(1986). This involved dispersion of 10g air-dried soil in plastic containers, followed by addition of 5% calgon (Sodium hexametaphosphate) solution. The mixture was thoroughly shaken in a mechanical shaker for 24 hours. The resultant suspension was transferred into 1000 cm^3 graduated measuring cylinder. The volume was made up with distilled water. Hydrometer was introduced into the cylinder and readings were taken at 40 seconds and 3 hours. A blank containing no soil, was analysed through the same procedure to correct the reading taken in the soil suspension. The percentages of Clay, Silt, and Sand were calculated using method described by Day (1965).

2. Bulk density

The bulk density was determined using oven drying method as described by Blake and Hartge (1986). It was expressed as ratio of the mass of oven-dried soil to its total volume using gravimetric core method as given below;

$$Bulk\ density = mass\ of \text{ovendried soil} \div \text{volume of core.} \quad \text{B. D} = \frac{mass\ of \text{ovendried soil}}{\text{volume of core}} \text{---------} \ 1$$

This was measured as weight per unit volume of a soil and expressed as megagram per cubic metre ($Mg\ m^{-3}$).

3. Particle density

The particle density was determined by using the pycnometer method as described by Blake and Hartge (1986). This was done after the removal of entrapped air in soils. Ten gram of oven dried soil was weighed into a pycnometer and filled to brim with deaerated water. Note its temperature. Wipe out the surface of the pycnometer and replace the stopper and weight. Empty the pycnometer and fill into it 10g oven-dried soil. Fill the pycnometer to about half with water using the pipette and wash with a jet of water to prevent any soil particles from sticking to the inner side of the neck.

Expel the entrapped air by gently boiling the contents. Allow the contents to cool to room temperature and fill the pycnometer to the brim with boiled and cooled water. Fix the stopper and clean the outerside of pycnometer with water and weight it.

4. Total porosity

Total porosity was obtained through calculation using the results from bulk density and particle density as described by Vomocil (1965) i.e.,

$$T.P\ (\%) = 100\ (1 - \rho b/\rho p) \text{ ---------- } 2$$

Where ρ_b = Bulk density; ρ_p = particle size density.

II. Chemical properties analyses

Soil reaction (Soil pH)

Soil pH was measured in water and calcium chloride solution using electrode pH meter. The pH was determined using 0.01 M calcium chloride solution in a soil to solution ratio of 1:2.5 as described by Agbenin (1995).The pH meter was used to read soil reaction both in water (H_2O) and 0.01M calcium chloride (0.01M $CaCl_2$) in 1:2.5, soil to water suspension ratio using pH 4.00 and pH 7.00 buffer.

Cation exchange capacity (C.E.C)

Cation Exchange Capacity (CEC) of soils was determined using Ammonium saturation displacement method conducted at neutral pH of 7.0 i.e. NH_4OAc saturation method outlined by Rhoades (1982) and Anderson and Ingram (1993).

The CEC of clay fraction will be calculated by the method ofSombroek and Zonneveld (1971) as follows;

$$CEC\ (Clay) = \frac{CEC(Soil) - (3.5\%C) \times 100}{Clay} \text{ ----------3}$$

Organic carbon.

The wet digestion method of Walkey-Black (1935) was used to determine organic carbon. In this method, soil was digested in excess of chromic acid with the titration of unused oxidant using barium diphenylamine sulphate as indicator.

Exchangeable bases (Ca, Mg, K and Na)

Exchangeable bases (Ca, Mg, K and Na) were determined by leaching 10g of soil for two hours with 1N (NH_4OAc) at a pH 7.0 into a volumetric flask (Anderson and Ingram, 1993). Potassium and sodium were read from the undiluted leachate on a Galenkamp Flame Analyser. Before the determination of calcium and magnesium, the leachatess were first diluted 10 times with addition of 2 ml of 6.5% lanthanum chloride solution to prevent ionic interference. Calcium and magnesium were read on a Pye Unicam model Sp 192 Atomic Absorption Spectrophotometer (AAS) at 423 and 285 nm wavelength respectively.

Exchangeable acidity

Exchangeable acidity was determined by leaching 10g of soil with 1ml KCl in a 100ml volumetric flask for two hours. Three drops of phenolphthalein indicator were added to 50ml of the leacheate and titrated with 1.0M NaOH to obtain a pink end-point, and further back titrated with few drops of 0.1M NaF using 0.1MHCl until a colourless end-point persist for about 10s (Anderson and Ingram, 1993).

Total nitrogen

The total nitrogen determination was done using macro-Kjeldahl method as described by Bremner (1965). This involves mixing 10 ml distilled water inside a 500ml Kjeidahl flask, 3gm of Kjeldah catalyst, 15ml of conc. Tetraoxosulphate VI acid and soil sample. This was heated and later mixed with 75ml of 10M NaOH and granular Zinc. The mixture was distilled and titrated against 0.05M H_2SO_4.

Available phosphorus

Available Phosphorus was determined using Bray-1 extraction method (Bray and Kurtz, 1945).

Electrical conductivity

Electrical conductivity of the soil was determined from a soil-water ratio of 1:2.5. Soil samples were soaked for 24 hours to allow for proper setlling of electrolytes, The EC was then measured by an electrical conductivity meter as described by Bower and Wilcox (1965).

b. Vegetation analyses

The vegetation survey was limited to tree vegetation where tree heights, diameter at breast heights (Dbh), basal area, tree population, species abundance, species density, relative density, cover (dominance), relative cover, frequency, relative frequency, and importance value.

Population density

Population density of plant is defined as the number of individuals of a specie or species per unit area (Baxter, 2014). From the vegetation survey;

The number of sampling points, is given as S.

The number of quarters (samples) per sample point, q is 4

A particular transect point, i = 1….n (where n = S)

A particular quarter at a transect point, j = 1, 2, 3, 4.

The point to tree distance at point i and quarter j, = D ij, i.e D_{12} describes distance in transect 1 and quarter 2 which refers to 5m, the distance between *Isoberlina doka* and point center in first sampling point.

The sum of distances, $D = \sum_{i=1}^{n}\sum_{J=1}^{j} D_{ij} = \Sigma D_{1,1} + D_{1,2} + \ldots + D_{S,4}$

(where S = no of all sampling points. The mean distance, d, is the sum of all nearest distances in the quarters surveyed divided by the number of quarters.

i.e.

$$d = \sum_{i=1}^{n} {}_{j=1}^{j} \text{Dij} \div 4S \text{ ----------4}$$

This gives the mean distance per tree, i.e. each tree is assumed to be from each sampling point. If absolute density, **λ**, is defined as number of trees/m^2, the reciprocal of density, 1/λ, then gives the mean area occupied by a single tree (Kelvin, 2007). Thus, the mean distance could be used to calculate tree density. From the works of Cottam *et al* (1953) and Morisita (1954), the relationship between mean distance, d and density, λ, was given as square root of reciprocal of density, i.e.

$$d = \sqrt{\frac{1}{\lambda}} \text{ ----------5 (Cottam } et\ al\text{, 1953); Morisita,1954) ,}$$

where d = mean distance of each tree and λ = density of trees.

This gives tree density, λ. as $\lambda = \frac{1}{d^2}$ ----------6

λ is measured in tree per metre square

Converting this to tree / ha, we multiply by 10000, since 10,000m^2 makes 1hectare

i.e.density λ (trees / ha) = λ X 10000 = 10000 λ trees/ha

Specie density

The species density (absolute density) is the expected number of trees of that species per square meter (or per hectare). It is given by the proportion of quarters in which the species is found by the absolute density of all trees i.e.

$$Spp\ density = \frac{frequency\ of\ individual \times density}{Total\ frequency} \text{ ----------7}$$

Relative density

The relative density of each species is the percentage of the total number observations of that

$$r.d = \frac{Species\ density \times 100}{Total\ density} \text{ ----------8}$$

Population

Population is the number of individual of the same species found in a place.

The total population of trees in the study area was determined by using the equation below;

$. Total\ population = tree\ density\ \times total\ area\ unit$ ----------9

Species population

Equally, the populations of each tree species were calculated using the formula

$Specie\ Population = Specie\ density\ (s.d.)\ x\ size\ of\ the\ study\ area\ (trees)$, ----------10

Dominance of Specie

The absolute cover or dominance of an individual tree is measured by its basal area or cross-sectional area. The basal area is the area covered by cross section of a tree at dbh (diameter at breast height). It is given by $A = \pi r^2 = \left(\frac{\pi}{4}\right) d^2$ (m^2) ---------- 11

Where A= basal area, d= diameter at breast height (dbh), r = radius of the tree

The absolute cover or dominance of each species is expressed as its basal area per hectare and it is given by $\text{Absolute cover or Dominance (m 2)} = \text{Specie density} \times \text{Mean Basal Area} \times 10^{-4}\text{m}$ ----12

Relative cover

This refers to the percentage proportion of specie's dominance (or cover) to the total cover of all species present in a given place. It is calculated as follows;

$Relative\ cover = \frac{the\ specie's\ cover \times 100}{Total\ cover}$ ----------13

$Relative\ cover\ (species) = \frac{\text{Total BA of species along transect x 100}}{Total\ BA\ of\ all\ species\ along\ transect}$ ----------14

The unit is expressed as a percentage.

Absolute frequency

The absolute frequency of a species is the percentage of sample points at which a species occurs.i.e.

$\text{Absolute frequency of a species} = \frac{\text{No.of sample points with a specie x 100}}{\text{Total number of sample points}}$ --------15

Relative frequency

It is defined as the percentage of proportion of absolute frequency to total frequency. It is given by

$\text{Relative frequency} = \frac{\text{Absolute frequency of a species x 100}}{\text{Total frequency of all species}}$ ----------16

The Importance Value (I.V.) of Species

The importance value of a species is defined as the sum of the three relative measures,

$Importance\ value = relative\ density\ + relative\ cover + relative\ frequency$----------17

Biodiversity index

This is a factor or index used to describe the amount of species diversity in a given area and also to compare the biodiversities of different areas. It is a quantitative measurement of the types of species that are found in an area. Shannon diversity index (H) is commonly used to measure diversity in the community.

It is used to describe abundance and evenness of species in a community. It is given as

$H = /- \sum Pi\ logPi\ /$ ----------18 (Magurran, 2004)

$Pi = {}^{ni}/_{N}$----------19

(where ni = no of individual specie, while N = total population)

3.9.4 Soil classification system

The soil classification system adopted for this work was soil USDA land capability classification as adapted to northern Nigeria savanna.

3.9.5 Statistical Analysis

Data collected in this study were subjected to standards Statistical methods usingthe SAS computer package (SAS, 2009). Pearson correlation statistical analysis was used to correlate the chemical and physical properties.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Landscape Units/Topography

The terrain is largely flat, gentle slope, rising towards northern part of the study area. Features of the study area include a hill, a depression, rock outcrops, lowland, and upland. The contour map of the study area generated from digital elevation model (D.E.M.) showed that elevation of the study area decreased from north eastern part towards the south western part as shown in Figure 4.1. The highest elevation in the study area was 480m at the northern part while the least was 450m at south-western part of the study area (Figure 4.1). There was a depression at the southern part of the area, with exposed small granite rocks and a hill at the eastern area. There was waterlogged soil (alluvial soil) found along the lower slope (flood plain) in central eastern part.

This topographical pattern (gentle slope) influenced flow of materials from north-eastern part to southern part of the study area. This might be responsible for the presence of alluvial soil in the area since lower slope would encourage deposition of materials and development of flood plain. Aliyu (2016) reported that this soil type might be formed from mixed alluvial-colluvial deposits on the Basement Complex rock.

4.2 Soil Mapping Units

The study area consists of four mapping units, which were collections of areas with defined properties, mapped and named in terms of soil components. Each mapping unit is made up of auger points with closely related soil characteristics. The four mapping units were designated as KN1, KN2, KN3 and KN4. The soil unit KN2 had the largest area covering 98.6 ha, about 49.3% of the study area. KN1 had the least size, about 30 ha, which was 15% of the study area. The extent of each soil mapping unit is shown in Table 4.1

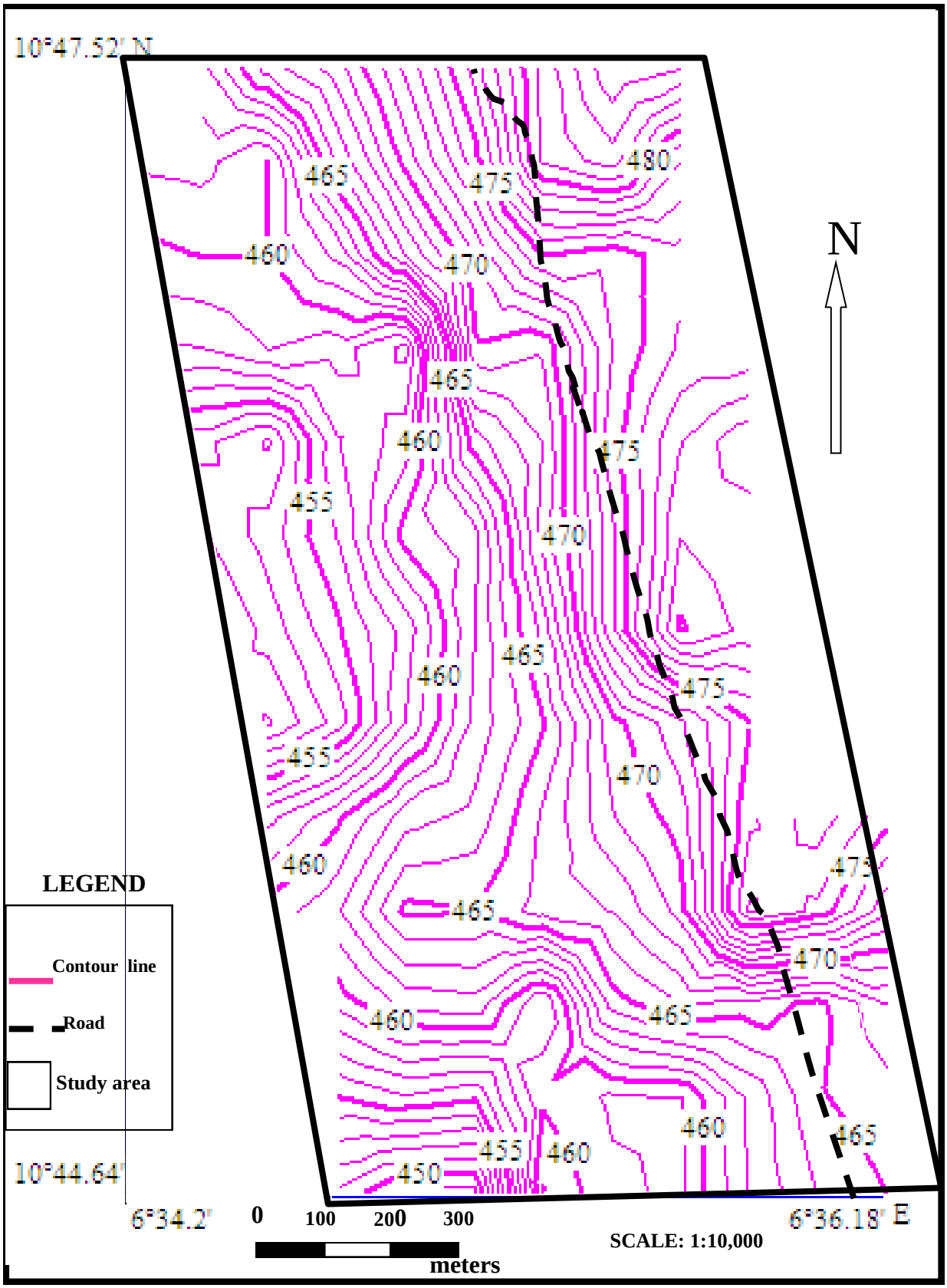


Figure 4.1: Map showing the contour map of the study area

Table 4.1The extent of the soil mapping units, and their characteristics

Soil mapping	Associated landscape	Mapping unit area	Percentage covered (%)	Depth range	Limitation to depth
KN1	Upper slope	30.00	15.00	90 - 110	Plinthite
KN2	Middle slope	98.60	49.30	150 -165	No limitation encountered at 165m
KN3	Middle slope	33.00	16.50	135 – 150	Plinthite
KN4	Lower slope	38.40	19.20	95 - 130	High water table
TOTAL		**200ha**	**100**		

4.3 Morphological properties of soil mapping units

Soil map was generated for the study area as shown in figure 4.2. There were inclusions like hill (western part) and depression (southern part) in the study area. These landforms were small such that they could not form separate soil mapping units. The major characteristics of each soil mapping unit were given in Table 4.2. The morphological properties of soils in the study area are presented in Table 4.3, indicating various soil parameters of each soil profile pit.

4.3.1 Weathering and parent material

The soils of the study area were developed in situ. The parent material was of both alluvial and colluvial origin. The soil mapping units KN1, KN2 and KN3 were colluvial soils developed from loose, unconsolidated sediments that have been deposited along undulating landscapes by either rain-wash, or sheet erosion, composed of a heterogeneous range of rock types and sediments ranging from silt to rock fragments of various sizes. They occupy the upper and middle slope of the study area. This deposition of weathered soil materials resulted in stratification which was more pronounced in soil units KN2 and KN3. This reflects good soil development especially in soil unit KN2 and KN3.The soil unit KN1 has the least horizonation and stratification with presence of plinthites and iron pans. This shows that the soil was poorly weathered, a feature of young or recently formed soil. The stratification of parent material is significant as it can result in soil pan, which may affect infiltration, drainage and root development (Malgwi, 2001).

However, the soil unit KN4 was of alluvial origin. The soil unit was formed from soil brought by water from the upland (or midland) and deposited in lowland (flood plain). A lower slope position encourages development of floodplains (Aliyu, 2016).

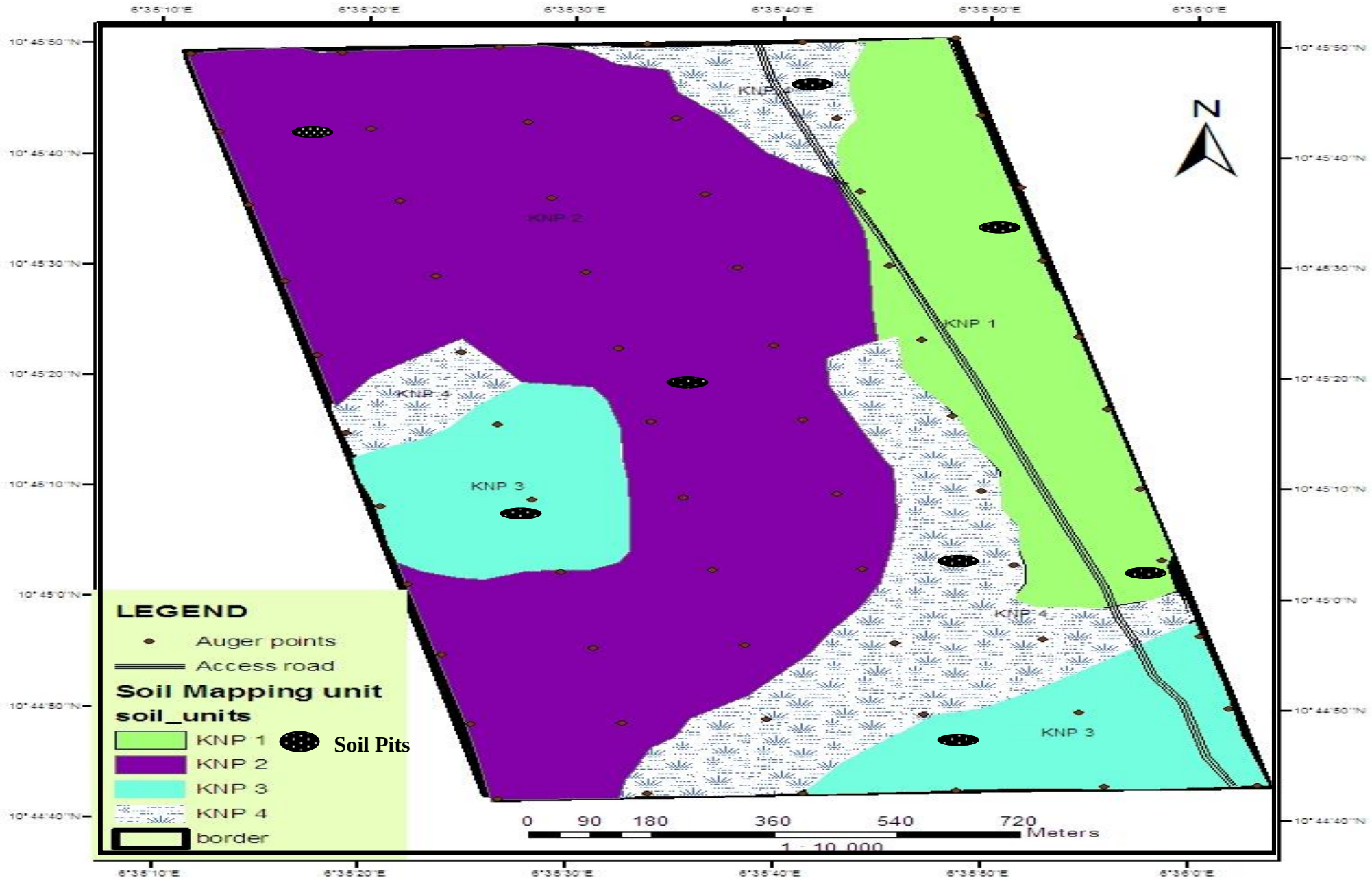


Figure 4.2: Soil map of the study area showing the different mapping units

Table 4.2: Soil mapping units, slope class, size, and their characteristics

Soil Unit	Associated Slope class	Area (Ha)	Major characteristics
KN2	Middle slope	98.60	Very deep soil (150 - > 165cm), well drained, dark brown (7.5YR 3/3) sandy loam underlying by yellowish red (10YR 4/6) sandy clay (10 YR 4/3) loamy sand to reddish yellow (5YR 6/6) clay, with faint few fine mottles to brown. The structure is moderately fine sub- angular blocky type. There is presence of tubular pores, and many fine roots. No limitation to depth encountered at > 165cm.
KN3	Middle slope	33.00	Deep soil (135 -150cm) well drained brown (10YR 5/3) sandy loam underlain by reddish yellow (7.5YR 6/6) sandy clay to brown (7.5YR 4/4) gravelly sand underlain by dark red (2.5YR 3/6) gravelly sandy clay, having moderate coarse sub angular blocky structure. Presence of few fine roots, gravels, and distinct concretions 2-20% depth limited by plinthite.
KN1	Upper slope	30.00	Fairly deep to deep (90cm – 110cm) imperfectly drained, reddish brown (2.5YR 4/3) sandy clay underlain by red (2.5YR 4/6) clay to well drained, very dark grayish brown (10YR 3/2) sandy loam underlain by strong brown (7.5YR 5/8) sandy clay. Presence of sub-angular blocky structure. Inclusions are few fine roots, and gravels. The depth is limited by plinthite.
KN4	Lower slope	38.40	Moderately deep to deep soil (95-130cm), poorly drained very dark gray brown (10YR 3/2) loam underlain by light gray (10YR 6/4) to imperfectly drained light brownish gray (2.5 Y 6/2) underlain by pinkish gray (10YR 6/2) sandy clay the structure is moderate medium sub angular blocky type. Presence of few fine roots, and few mottles. Depth seriously limited by high water table.

Table 4.3 Morphological properties of soil mapping units in part of Kamuku National Park

Soil Mapping Unit	Pedon	Horizon	Depth (cm)	Colour Moist	Mottling	Texture	Structure	Consistency Wet Moist Dry	Boundary	Inclusions
				Typic Plinthustalfs (Plinthic Lixisols)						
	KN1P1	Ap	0-15	5YR 4/3	None	SC	s, m, sb	SP SS, Fm, h	DIB	Many fine roots, few pores,
		Bt	15-90	2.5YR 4/6	none	SC	s, m, sb	VS VP, Fm, h		Few fine roots, micropores, ant holes
				Typic Plinthustalfs (Plinthic Lixisols)						
KN1	**KN1P2**	Ap	0-45	10YR 3/2	None	SL	s, c, sb	NS NP, Fm, h,	CSB	Fine, medium root
		Bt	45-100	7.5YR 5/8	dcc	SC	S, c, sb	VS VP, Fm, h		Common coarse stone,
				Typic Haplustalfs (Rhodic Lixisols)						
		A	0 – 22	10YR 4/3	None	SL	w, m, sb	NS NP, Vfr, s. SS SP, Fm, h	CSB	Few fine to medium roots, pores,
		AB	22 – 65	2.5YR 5/8	None	SC	m , f, sb		CWB	,,
	KN2P1	Bt1	65 – 93	5YR 5/6	none	SiC	m, f, sb	VS VP, Fm, h	CSB	,, Few fine concretions, clay skin, ant hole,
		Bt2	93 - 165	5YR 6/6	none	SC	m, f, sb	VS VP, Fm, h		many micro tubular pores
				Typic Haplustalfs (Rhodic Lixisols)						
										Few fine root,
KN2		A	0 -30	7.5YR 3/3	None	SL	w, m, sb	NS, NP, ls, s	ASB	,,
		B1	30-80	5YR 5/6	F, f, f,	SC	m, m, sb	SS SP, Fm, h,	CSB	,,
	KN2P2	B2	80-150	10YR 4/6	F ff	SC	m, m,sb	VS VP, Fm, h		

Table 4.3 Morphological properties of soil mapping units in part of Kamuku National Park (cont.)

Soil Mapping Unit	Pedon	Horizon	Depth (cm)	Colour Moist	Mottling	Texture	Structure	Consistency Wet Moist Dry	Boundary	Inclusions
				Typic Plinthustalfs (Plinthic Lixisols)						
	KN3P1	**A**	0-25	10YR 5/3	None	SL	w, m, sb	SS SP, V fr, s	CWB	Few, fine root
		B	25-70	7.5YR 6/6	, ,	SC	s , c, sb	SS SP, Fm, h	ASB	Stone, clay film, , many micro pores and tubular pores,medium to coarse mottles, iron concretions
		Bt1	70-105	10YR 6/6	, ,	SiC	s, c, sb	SS SP, Fm, h	CWB	
		Bt2	105- 135	7.5YR 6/6	none	SiC	s, c, sb	SS SP, Fm, h		Fine medium stone
KN3				**Typic Plinthustalfs (Plinthic Lixisols)**						Common, medium stones, Few fine concretions
	KN3P2	**A**	0 - 25	7.5YR 4/4	None	GSL	s, c, sb	NS NP, ls,ls,	CSB	
		Bt1	25-60	2.5YR 4/6	D c c	GS	s, c, sb	NS NP, ls, ls	ASB	Presence of few roots, concretions, many coarse gravels and stones, Few coarse concretions
		Bt2	60-90	2.5YR 3/6	D c c	GSC	s, c, sb	NS NP, ls, ls	ASB	
		Bt3	90-150	2.5YR 3/6	D c c	GSC	s, c, sb	NS NP, ls, ls		
				Aquic Haplustepts (Eutric Fluvisol)						
	KN4P1	**A**	0-25	10YR 3/2	None	SL	w m ms	SS SP, Fm, s	CWB	Common, medium root.
		B	25-95	10YR 6/4	Fff	SCL	w m ms	SS SP, Fm, h		Few fine root, clay skin, , many micro pores
				Aquic Haplustepts (Eutric Fluvisol)						
KN4	**KN4P2**	**O**	0-16	2.5Y 16/2	None	LS	w, f, sb	NS NP, ls, ls,	CSB	
		A	16-65	10YR 6/6	F, f, f	LS	w, f, sb	,NS NP, v.fr, ls	CSB	Few fine roots, medium stones, and pores
		B1	65-120	10YR7/2	F ff	SL	m, m,sb	NS NP, ls, s		

Legend Texture: SiC = Silty clay, SCL = sand clay loam, LS = Loamy Sand, L = Loam, SL = Sandy loam, SC = sandy clay and C= Clay, GSC=Gravelly sandyclay, GS= Gravelly sand, GSL = Gravelly, Sandy loam. **Mottling**: Fff = faint few fine mottling 2%, Dcc = distinct common coarse mottling 2-20%, **Structure**: smsb = Strong, medium, sub angular blocky, wmsb = weak medium sub-angular blocky, mfsb= moderate fine sub-angular, scsb= strong coarse sub-angular, wfsb= weak fine sub angular **Consistence** Dry: ls = Loose, h = hard, s = soft. Moist: fr - friable, vfr = Very friable and Fm= Firm **Consistence** Wet: VS = very sticky, SS = slightly sticky, and NS = non sticky. **Plasticity**: VP = very plastic, SP = slightly plastic, NP = non plastic. **Boundary**: CWB = clear, wavy boundary, CSB = clear, smooth boundary, ASB = abrupt smooth boundary, DIB = diffuse irregular boundary. **Distinctiveness**: A=abrupt, C=clear, and D=diffuse, Topography: S=smooth, W = wavy and I= irregular

4.3.2 Soil depth

The soil depth ranged from moderately shallow (90 cm) in pedon KN1P1 to very deep soil (>165cm) in pedon KN2P1. Pedon KN2P2 recorded the deepest pit with depth of 165cm. The shallowest pedon with depth of 90 cm was observed in KN1PI. The mapping unit with deepest soil depth was observed in soil unit KNP2 as shown in Table 4.3. Soil depth distribution for the study area is shown in Figure 4.3. The very deep soil covered 49.30% (98.60ha) of the study area, deep soil accounted for 36.70% (71.40ha) while moderately deep soil covered 15% (30ha).

The depth of soil unit KN1was limited by the presence of plinthite and iron pan. The deepest profile pits belong to soil mapping unit KN2 (i.e. Profile pit KN2P1 and Profile pit KN2P2 with depth over 165 cm and 150 cm respectively). This is in agreement with the fact that deep soils are well developed, stratified and well horizonated (Maniyunda and Gwari, 2014). There was no limitation encountered even at the depth of below 165cm in profile pit K2P2.

In the soil unit KN4, the soil is also moderately shallow (95cm in Profile pit KN4P1) to deep (120cm in Profile pit KN4P2) due high water table in the soil which is line with Malgwi (2001) that the major limiting to the depth of fadama (flood plain) was the presence of high water table. The soil in the flood plain is associated with high of *Hyperrhenia ruffa* grasses.

From the above, it can be seen that soil unit KN2 was very deep with no limitation to depth; soil unit KN3 was deep, depth limited by iron pan; soil unit KN1 was moderately shallow with depth limited by plinthite; while the soil unit KN4 ranged from moderately shallow soil to deep soil with depth limited by water table.

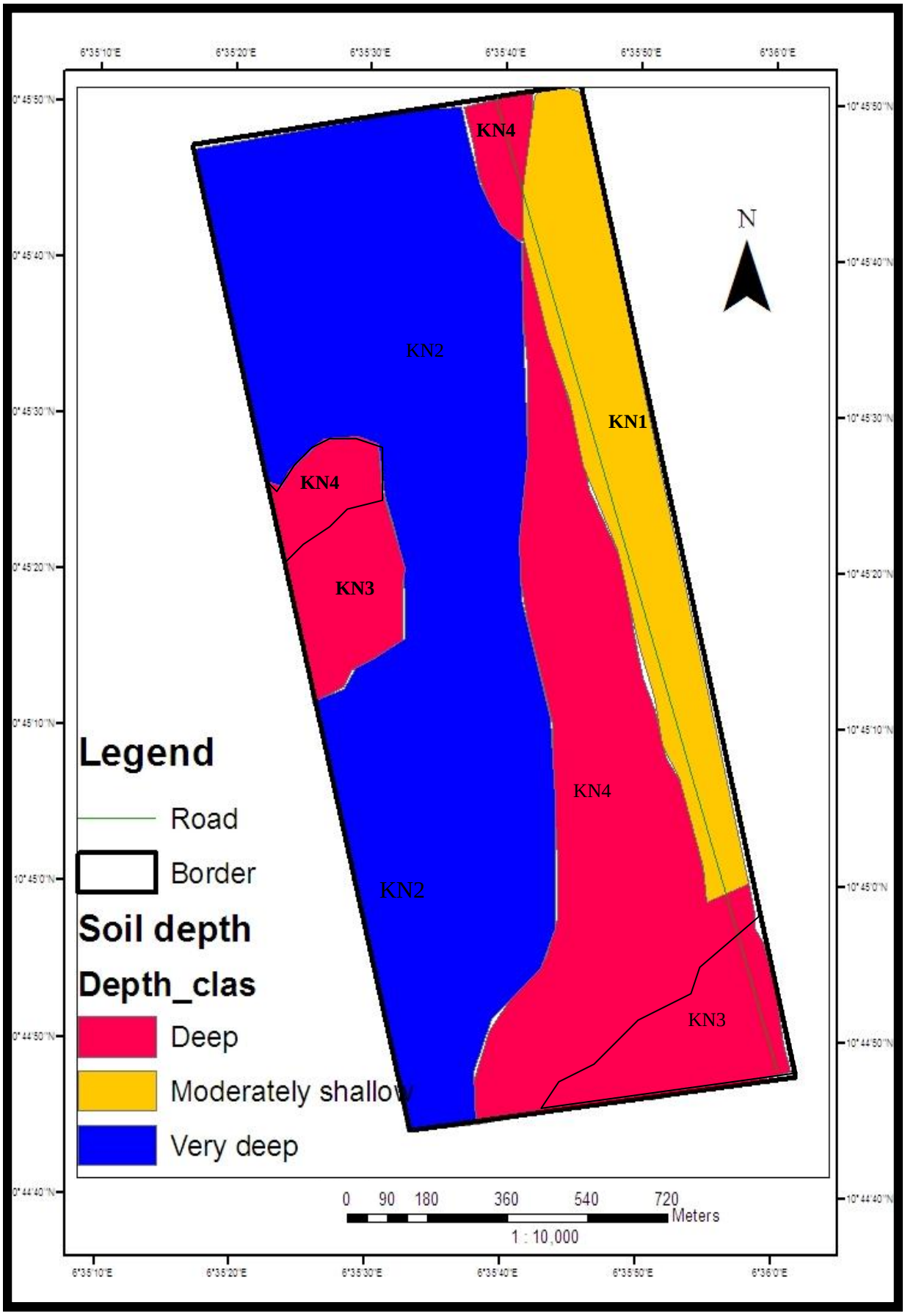


Figure 4.3: Distribution of soil depth in the study area

4.3.3 Soil colour

The soil colour of the surface horizons varied with soil units, reddish brown (2.5YR 4/3) surface colour was observed in soil unit KN1 and was underlain by red (2.5YR 4/6) soil. The mapping unit KN2 has dark brown (7.5YR 3/3) colour at surface horizon with reddish yellow (5YR 6/6) colour within the sub-surface horizon. The surface colour of soil unit KN3 was brown (10YR 5/3) and was underlain by reddish yellow (7.5YR 6/6) colour. KN4 had a very dark gray brown (10YR 3/2) colour topsoil which was underlain by light gray (10YR 6/4) sub soil.

Soil colour is a good pointer to drainage status and mineral composition of a given profile pit. This is because colours of soil are mainly determined by the amount of organic matter and minerals present in the soil. Abu and Malgwi (2012) posited that drainage condition, geology and physiographic position have the major influence on soil colour. Black or dark brown soil indicates accumulation of organic matter (humus), while light brown soil colour shows little organic matter. Ewulo (2012) attributed brown soil colour of upland soils to high haematite content. The brown colour in surface horizons might also be attributed to the effect of high organic matter content (Aliyu, 2016).

Soil unit KN4 had the highest amount of organic matter based on its very dark gray brown colour. The change in colour from dark gray brown surface soil colour to light gray subsoil colour was largely due to poor drainage condition of the study area. The saturated condition of the soil also favoured decomposition and accumulation of organic matter. Mottling observed within the sub-soils of KN3 and KN4 was largely due to their physiographic positions and redox reactions due to fluctuation in ground water table (Malgwi, 2001; Babalola *et al.,* 2011). The grayish colour in the soil matrix was due to oxidation-reduction cycles (Smyth and Montgomery, 1962; Ahn, 1970; Nahusenay et al., 2014).

4.3.4 Drainage

The soil drainage pattern the study area consisted of poorly drained soil, imperfectly drained soil and well-drained soil. Soil mapping units KN1 and KN2 were well drained without any mottling within their solum. Soil unit KN3 was imperfectly drained while unit KN4 was poorly drained. Both units KN3 and KN4 contained mottlings, indicating the poor drainage condition. The map showing the drainage condition is shown in Figure 4.4.

The reason for the presence of well drained soils in mapping units KN1and KN2 could be as a result of slope positions of these mapping units, i.e., they were located on upland and midland positions respectively. This helped to drain excess water down the slope, thus preventing saturation condition of the soil. The reddish and yellowish colours also indicate that the soil is well drained and well aerated. This is supported by the fact that red, yellow and reddish-brown colors in soil are often the result of oxidized iron (Fe^{3+}) and manganese (Mn^{2+}) (Babalola et al 2011; Ewulo, 2012).

The drainage pattern of soil mapping unit KN3 ranged from imperfectly drained (profile pit KN3P1) to well drained (profile pit KN3P2). This mapping unit was a transition from midland to lowland (floodplain). Profile pit KN3P1 was at the toe slope; a position leading to the lowland. This explains the presence of mottles found there which indicated soil wetness brought about by oxidation-reduction cycles due to ground water fluctuation. This could result from cyclic reduction and oxidation reactions during saturation and drainage of the macro-porosity (Ahn, 1970).

Soil mapping unit KN4 was poorly drained with mottling within 50cm depth and had high water table, i.e., Profile pits KN4P1 and KN4P2 had water table within 90cm and 120cm depth respectively. The poor drainage condition of soil mapping unit KN4 was due to saturated condition of the soil. This was facilitated by high clay content, low level topography and high

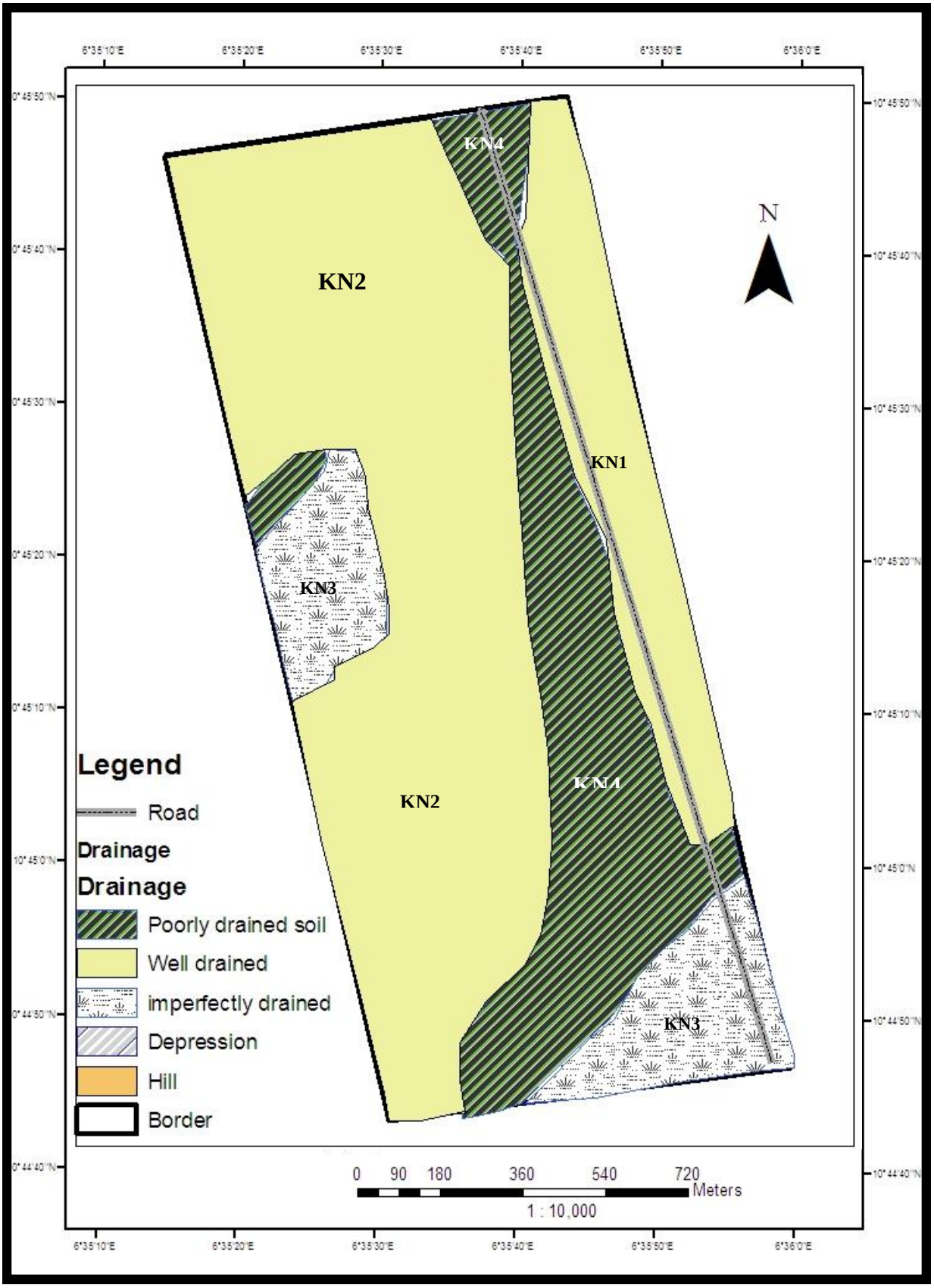


Figure 4.4: Distribution of soil drainage in the study area

water table. The clay offers resistance to movement of water, redox reaction of mineral constituents, mainly iron compounds and stagnant water table cause soils to appear in different colours (Mohammed, 2011; and Nahusenay *et al*., 2014). It could also be noted that vegetation performances were good in well drained soil unit (i.e KN2); average vegetation performance was recorded in imperfectly drained soil (i.e KN3); and poor performance noted in poorly drained soil unit (i.e. KN4). Although, soil unit KN1 had a well drained soil, the vegetation there was still poor largely due to human activities (i.e. farming, grazing, wood gathering etc.) which had negatively impacted on the area.

4.3.5 Soil structure

The structure of the surface horizon for soil unit KN1 was strong fine to medium subangular blocky structure. In the underlying horizon, the soil structures were strong, medium to coarse blocky structure. The mapping unit KN2 had weak fine to medium sub angular blocky structure in the surface horizon while the underlying structure was moderate fine to medium sub angular blocky structure. In soil unit KN3, the structure of the surface soil was weak medium sub angular blocky structure to strong, coarse, sub angular blocky structure in the sub surface horizon. The structure of soil in soil unit KN4 was weak fine massive structure at the surface horizon with underlying strong medium to coarse sub angular structure in the subsurface horizon. The most dominant soil structure in the study area was sub-angular blocky structure which was found across all the soil units except in soil profile pit KN4P1.

The dominant soil structure in the study area was sub-angular blocky soil structure which was observed in soil units KN1, KN2, KN3 and part of KN4. According to Singer and Munns (1999) blocky structure is often found in B horizons on the upland due to higher clay content. Generally, the uplands are well developed than the flood plain which could be attributed to its high clay content. Similar findings in uplands were observed by Shobayo, (2010), Hussaini (2011) and Sharu *et al.* (2013). The soil structure found in KN4P1 could also be described as structureless,

Singers and Munns (1999), refers to structureless soils as either massive or single-grained (Singer and Munns, 1999).

4.3.6 Horizonation

The soil horizonation in the study area varied with soil units. Soil unit KN1 had the least horizonation, only two soil horizons were observed in profile pits KN1P1 and KN1P2. From Table 4.3, soil mapping unit KN1 had the least horizonation i.e., both profiles have only two horizons each. Mapping units KN2 and KN3 were well horizonated or stratified while KN4 had two and three horizons in pedons KN4P1 and KN4P2 respectively. Horizonation reflects the extent of soil development. The soils unit may be considered to be young to matured soil.

The presence of horizonation is caused by processes such as brownification, and mineralization of soil organic matter as well as sedimentation of soil materials in lowland. Clay cutans and mottling also influenced the formation of horizons and boundaries in soil and their presence were helpful in horizon differentiation on the upland soils (Jimoh, 2015). However, the sedimentation in the flood plain may lead to lithological discontinuity; these are not true soil horizons but layers which are referred to as Pseudo-horizons (Malgwi, 2001, Aliyu, 2016)

4.3.7 Inclusions

The inclusions observed were roots, concretions, and stones. The roots were fine to medium roots from soil surface to sub-soil. The roots were few to many, and fine to medium in the surface horizons of all the soil units, while the subsoil horizons had few fine roots. Concretions were also present in profile pit KN1P1 (soil unit KN1) and KN3P1 (soil unit KN3). These concretions were few and ranged from fine to coarse. Quart grains were dominant inclusions in pedons of soil unit KN3. Few clay films were observed in profile pit KN1P2. There were also few to common and medium to coarse stones recorded in some of the soil mapping units (Figure 4.3)

The root abundance decreased with increase in soil depths due to distance from surface soil and soil physical properties. Many roots were found mostly in surface horizons, since they are sites where root derive many of their nutrients. Also, the penetration power of roots decreased due to higher bulk density and nature of sub-soil as depth increased (Hillel, 2004). Soil unit KN1 situated on the upland tends to limit root activities to surface horizons where bulk density is lower and porosity is higher than the subsurface horizon. There were abundance of roots in both surface and sub surface horizons of soil units KN2. This might be connected to the moderate bulk density and other physical properties that encourage root penetration.

Concretions and quartz grains were observed in the subsoil of soil units KN1 and KN3. This could be attributed to presence of plinthite found within the sub-soil. Concretions are formed from precipitation of soil minerals within soil horizons. Sivarajesingham *et al.* (1962) reported that Iron concretions are constituents of plinthite. Gravel content ranged from few to common in abundance. The presence of clay skins (films) and quartz grains in the upper and middle slope positions showed that the soil mapping units are matured soil. The parent material was derived from Basement Complex rock and indicates the age of the soil (Ayolaja and Opene, 2012). Clay cutans or film could also be an indication of the translocation of clays from surface horizon downward by argilluviation process (Akhtaruzzaman, *et al*., 2014). Presence of pores and soil openings were also observed in the soil horizons, indicating the activities of microfauna such as ants, worms, termites and others that were involved in soil mixing and movement (pedoturbation).

4.4.0 Physical Properties

4.4.1 Gravel content

All the profiles in the study area contained gravels (Figure 4.4). The gravel content at the surface horizon across the study area was 43.2 –215.00g/kg. The highest value for surface horizon (215 g/kg) was recorded in KN3P2). The gravel contents for the sub surface horizons ranged from 54.6-460.4 gkg^{-1}. The lowest gravel content (43.2 g/kg) was obtained in pedon KN4P2. The gravel content within the sub-surface horizon ranged from 74.2 g/kg to 460.4 g/kg which represented the lowest and highest values in pedons KN4P2 and KN1P2 respectively. From the result in Table 4.4, mean gravel content value was least in KN2 (mean 92.97 g/kg^{-1}) and highest in KN1 (mean 217.15 g/kg^{-1}).

4.4.2 Particle size distribution

a. Sand fraction

The Sand content of the surface horizons of the entire study area ranged from 660 – 680 g/kg. The highest sand content were obtained in surface horizons of pedons KN2P2, KN3P2, and KN4P1with 720g/kg followed by value in pedons KN2P1 and KN3P1 with small content of 700g/kg. The lowest sand content (600g/kg) was obtained in soil unit KN1, pedon KN1P1 and pedon KN4P2 in soil unit KN4.

For the underlying horizons, the sand contents were slightly lower and varied from 540 to 820g/kg. The highest sand content was observed in soil unit KN4, pedon KN4P2 with a value of 820g/kg. The lowest sand content (540 g/kg) was obtained in soil unit KN2 pedon KN2P1; this was followed by those of pedons KN2P2 and KN3P1 with 560 and 580 g/kg respectively. These results are presented in Table 4.4

Table 4.4: Table showing the Physical properties of the study area

SMU	Horizon	Depth (cm)	Gravel (g/kg)	Clay (g/kg)	Silt (g/kg)	Sand (g/kg)	Silt : clay	Textural class	Bulk density (Mgm^{-3})	Particle density (Mgm^{-3})	Total porosity (%)
	KN1P1										
KN1	**Ap**	0 – 15	94.20	180	160	660	0.89	SL	1.47	2.59	43.24
	Bt	15 - 90	132.00	240	160	600	0.67	SL	1.87	2.75	32.00
	KN1P2										
	Ap	0 - 45	182.00	160	160	680	1.00	SiL	1.45	2.62	44.66
	Bt	4 -110	460.40	180	160	660	0.89	SiL	1.80	2.68	32.84
		Mean	**217.15**	**190**	**160**	**650**	**0.86**		**1.65**	**2.66**	**38.20**
KN2	**KN2P1**										
	A	0 – 22	107.00	160	140	700	0.88	SL	1.40	2.55	45.10
	Bt1	22 – 65	103.00	260	140	540	0.77	SC	1.43	2.57	44.36
	Bt2	65– 93	128.00	280	180	540	0.64	SiC	1.47	2.60	43.46
	Bt3	93-165	54.60	300	200	560	0.47	Cl	1.54	2.64	41.67
	KN2P2										
	A	0 – 30	72.80	280	100	720	0.14	SL	1.45	2.58	43.80
	Bt1	30 – 80	88.80	360	100	560	0.23	SC	1.51	2.62	42.37
	Bt2	80-150	96.60	440	160	640	0.11	SC	1.65	2.66	37.97
		Mean	**92.97**	**297.1**	**145.**	**608.6**	**0.46**		**1.49**	**2.60**	**42.67**
	KN3P1										
	A	0 – 25	192.60	180	60	700	0.67	SL	1.48	2.53	41.50
KN3	Bt1	25 – 70	142.60	240	80	680	0.33	SC	1.52	2.61	41.76
	Bt2	70–105	124.00	260	120	580	0.62	SiC	1.69	2.66	36.47
	Bt3	105-135	388.00	240	160	700	0.25	SiC	1.71	2.69	36.43

Table 4.4: Table showing the Physical properties of the study area (Cont.)

SMU	Horizon	Depth (cm)	Gravel (g/kg)	Clay (g/kg)	Silt (g/kg)	Sand (g/kg)	Silt: clay	Textural class	Bulk density (Mgm^{-3})	Particle density (Mgm^{-3})	Total porosity (%)
KN3	**KN3P2**										
	A	0 – 25	215.00	120	160	720	1.33	GSL	1.53	2.59	40.93
	B	25 – 60	265.60	100	140	760	1.40	GSL	1.55	2.63	41.06
	Bt1	60 - 90	157.00	120	140	740	1.67	GSC	1.59	2.64	39.77
	Bt2	90 - 50	146.00	120	120	760	1.00	GSC	1.65	2.66	37.97
		mean	**203.85**	**172.5**	**122.5**	**705**	**0.91**		**1.59**	**2.63**	**39.49**
	KN4P1										
	A	0 – 25	135.60	160	120	720	0.75	SL	1.30	2.52	48.41
KN4	B	25 - 95	284.00	140	120	740	0.86	SCL	1.55	2.65	41.51
	KN4P2										
	A	0 - 16	43.2	180	220	600	1.22	LS	1.28	2.50	48.80
	B	16 - 65	74.2	100	80	820	0.80	LS	1.48	2.50	40.80
	Bt	65- 120	158.6	120	140	740	1.17	SL	1.53	2.63	41.83
		mean	**139.12**	**140**	**136**	**724**	**0.96**		**1.42**	**2.56**	**44.27**

Sand fraction was the most dominant soil fraction in the study area. The soil unit KN4 had the highest mean sand content in the study area (724 gkg^{-1}) followed by units KN3 and KN1 in that order while the least mean sand content was observed in KN2 (608 gkg^{-1}). Also, it is worthy to state that pedon KN3P2 in unit KN3 had the highest sand content value of 760g/kg. The high sand content of the soils could be attributed to granitic origin of the parent materials 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; Wilson, 2010). The higher sand content in soil units KN3 and KN4 could be partly related to their middle and lower slope positions respectively, these positions enjoy deposition of soil materials from the upland.

According to Brammer (1971), sand is the dominant particle in upland soils. In all the profile pits, it was observed that sand fraction decreased with depth. Sand was significantly higher in the surface horizons than subsurface horizons. This is in consistence with the findings of Ukut *et al*. (2014) who reported high sand content in surface soil. The higher sand fraction in surface soil might be attributed to deposition from upland, due to vertical and lateral clay translocation (Mortimore, 1989; Malgwi, 2001). Higher sand content could also be attributed to clay migration under eluviations and illuviation processes. In table 4.5, sand was positively correlated with silt at $p < 0.05$ ($r=0.63$). Also, there was positive correlation with pH, available P, and Na. This means that if sand content increases, Na and available P will increase.

b. Silt fraction

The Silt fraction in the study area ranged 60 - 220 gkg^{-1} with mean value 138.33 gkg^{-1} for the whole study area (Table 4.4). The silt content of the surface soil horizon ranged from 60 to 220 gkg^{-1}. The highest value was recorded in pedon KN4P2 (220 g/kg) in unit KN4 while the least value (60 g/kg) was obtained from pedon KN3P1 with a value of 60 g/kg. In the

underlying horizons, the silt contents were higher and varied from 80 to 200 g/kg. The highest value of 200 g/kg was recorded in KN3P1and the lowest value (80 g/kg) was obtained in pedons KN3P1 and KN4P2.

Silt content was highest in soil mapping unit KN4 (profile pit KN4P2) as shown in Table 4.4. The silt content did not follow a definite order in all the profile pits studied. Silt deposition might have been influenced by aeolian means of transportation from its origin. Soil Survey Staff (1993) and Schumacher *et al*. (1987) reported that the high silt content in soils might be as a result of small size of silt particles which can be easily transported by wind. Malgwi (2001) attributed high silt content in lowland profile pits to deposition of fine colluvial and alluvial sediments from the upper slope positions through erosion and deposition. This assertion was supported by Maniyunda and Gwari, (2014) who reported high silt content which they attributed to fine sediments eroded from upland to the lower slope

c. The clay fraction

The clay fraction was next dominant size fractions after sand (Table 4.4). The clay fraction in the surface horizons ranged from 120g/kg to 280 g/kg in the study area. The highest value of 280 g/kg was recorded in pedon KN2P2 and the least value (120 g/kg) was obtained in pedon KN3P2. The clay fractions in the sub-surface horizons ranged from 100 g/kg to 440 g/kg. Soil profile KN2P2 in unit KN2 had the highest clay content of 440 g/kg while pedons KN3P2 and KN4P2 contained the lowest value (100 g/kg).

The highest clay content value (440g/kg) was found in mapping unit KN2 while the least (100g/kg) occurred in profile pit KN3P1 (soil unit KN3). It was observed that clay content increased with depth i.e. more clay accumulation occurred in sub soil horizons than in surface horizons. This could be attributed to illuviation and pedoturbation processes (Malgwi, 2001). The lower clay content of surface soils could be ascribed to characteristic of soils formed on Basement Complex in Nigeria as reported by Kparmwang (1993) and Lawal *et al.* (2013).

There was gradual increase in clay content from surface horizon in upland to surface horizons in lowlands, which could be as a result of alluvial deposition process down the slope. Similar result was reported by Maniyunda and Gwari (2014). Another reason for lower clay content in the surface horizon might be due to more intensive chemical weathering taking place within the sub-soil horizons relative to surface horizons (Mosugu, 1989). It may also be an indication of the translocation of clays from surface downward by argilluviation process (Maniyunda, 2014). Boul and Hole (1997) stated that an argillic horizon must contain a minimum clay increase relative to the eluvial horizon or an underlying horizon. Finally, Esu (1982) stated that the dominance of clay loam in subsurface horizons was attributed to illuviation of clay into the sub-soils, giving rise to pronounced argillic horizons which characterize most Nigerian Guinea savanna soils that have undergone some extent of development.

The Pearson's correlation matrix in Table 4.5 shows that clay content had high, positive and significant relationship with silt ($r = 0.63$, $p<0.05$), while it also indicates high, negative and significant relationship with sand ($r = -0.77$, $p<0.05$). This implies that increase in silt significantly increases the amount of clay.

d. Silt/Clay ratio

The silt:clay ratio ranged from 0.11 to 1.67 in the entire study area (Table 4.4). The silt/clay ratio in the surface horizons ranged from 0.14 to 1.33 in the study area. The highest value of 1.33 was recorded in pedon KN3P2 and the lowest value (0.14) was obtained in pedon KN2P2. The silt/clay ratio in the sub-surface horizons ranged from 0.11 to 1.67. Pedon KN3P2 in unit KN3 had the highest silt/clay ratio of 1.67 while pedons KN2P2 had the lowest silt/clay ratio of 0.11.

Silt/clay ratio refers to the relative amount of silt and clay in soils. From the result, Silt/clay ratio ranged between 0.25 and 1.40 with higher values in surface horizons. Mapping unit

KN4 (lowland) has the highest silt: clay mean value of 0.96, while KN2 had the least 0.54. Using silt/clay ratio of 0.15 (Van Wambeke, 1962) or 0.25 (Asamoa, 1973), the mean silt/clay ratios of 0.86 and 0.71 in the surface and subsurface horizons, respectively were greater than 0.15 or 0.25; thereby, indicating that the parent material was in its advanced level of weathering (Akpan-Idiok and Opuwaribo, 1992). Generally, this indicates that parent material of the area is potentially active in weathering (Van Wambeke 1962). From the result, silt/clay ratio decreased down the horizon, indicating more weathered sub-soil horizons than surface horizons. This is in accordance with the findings of Yakubu (2006) and Sharu *et al*., (2013).

4.4.3 Textural classes of the study area

The textural classification of the soils in the study area was done using the USDA soil texture triangle method and the result is shown in Table 4.5. Based on this classification, the most dominant soil in the area was sandy clay loam (49.3%), followed by sandy loam (34.2%), and gravelly sandy loam (16.5%) in that order. The distribution of textural classes in the study area is presented in Table 4.5 while the textural distribution pattern is shown in Figure 4.6. The sandy clay loam occupied the largest part of the study area, about 98.6 ha (49.3%) followed by sandy loam which occupied 68.4 ha (34.2%) and gravelly sandy loam which covered 33 ha (16.5%) respectively. The distribution of soil texture across the study area is shown in Figure 4.5.

4.4.4. Bulk Density

The bulk density of the entire area ranged from 1.28Mgm^{-3} to 1.87gcm^{-3} (Table 4.4). The range in the surface horizon was 1.28 to 1.52 Mgm^{-3}. The maximum value (1.52 Mgm^{-3}) was observed in pedon KN3P2 while the minimum was 1.28 Mgm^{-3} recorded in pedon KN4P1.

Table 4.5: Textural classes of the soil mapping units

Soil unit	Textural class	Extent of each textural class (ha)
KN1	Sandy loam	30.0
KN2	Sandy clay loam	98.6
KN3	Gravelly sandy loam	33.0
KN4	Sandy loam	38.40

Source: Fieldwork 2015

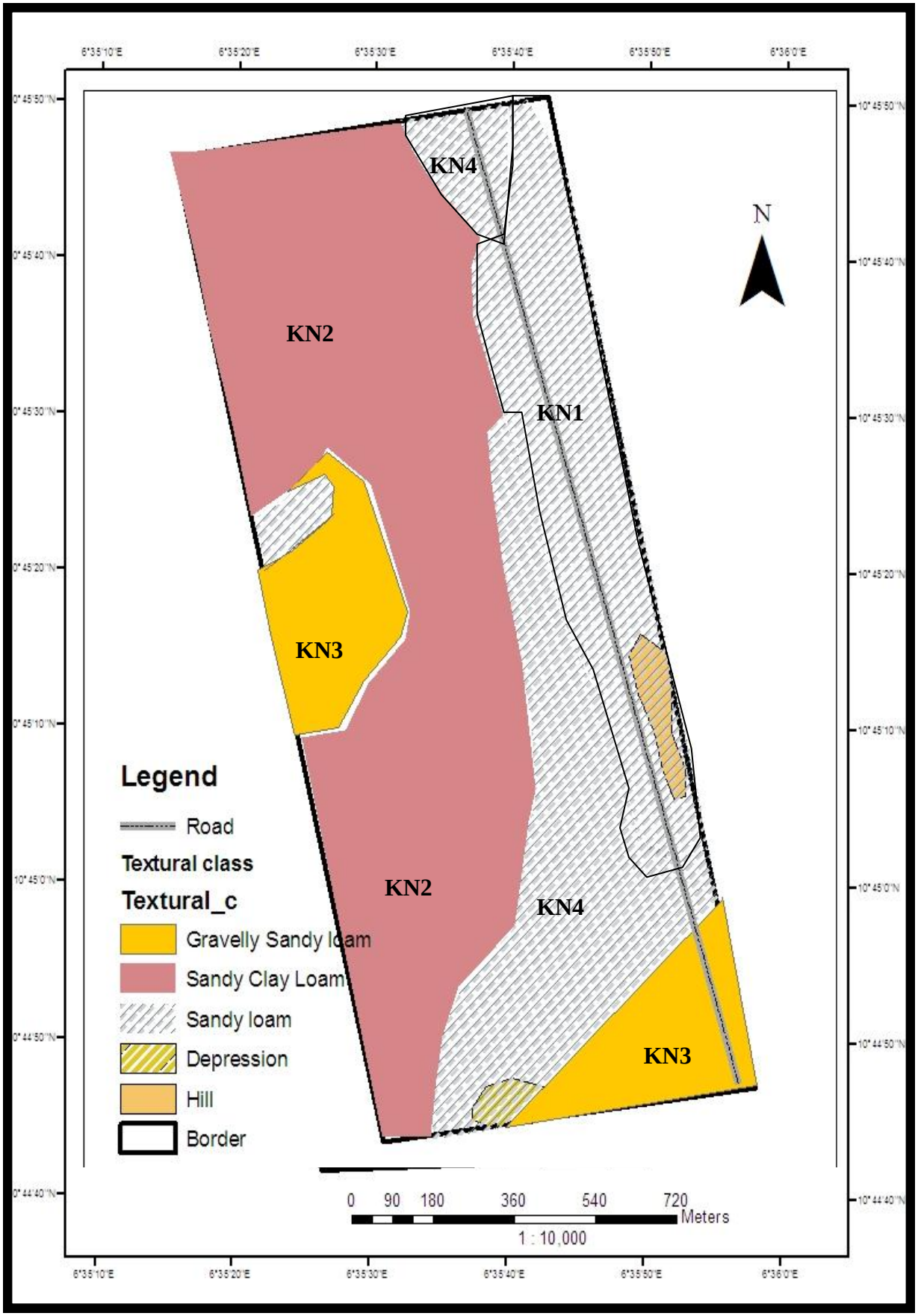


Figure 4.5: Distribution of soil texture in the study area

In sub-surface horizons, bulk density ranged from 1.43 to 1.87 Mgm^{-3}. The highest value (1.87 Mgm^{-3} was recorded in KN1P1 while least value (1.43 Mgm^{-3} was observed in KN2P1.The bulk density in soil unit KN1 ranged from 1.47Mgm^{-3} to 1.87Mgm^{-3} (mean 1.65Mgm^{-3}) while it ranged from 1.40 to 1.65Mgm^{-3} (mean 1.49Mgm^{-3}) in KN2. Soil mapping unit KN3 had bulk density values ranging from 1.48Mgm^{-3} to 1.71Mgm^{-3} with mean 1.59Mgm^{-3} while KN4 had range of values from 1.28Mgm^{-3} to 1.55Mgm^{-3} (mean 1.42Mgm^{-3}). The map showing bulk density distribution was generated and shown in Figure 4.6.

It was observed that soil unit KN1 had the highest mean bulk density (1.65 Mgm^{-3}) followed by density of 1.59 Mgm^{-3} in unit KN3 and 1.49 Mgm^{-3} in unit KN2. The least mean bulk density of 1.42 Mgm^{-3} was recorded in unit KN4. Generally, bulk densities of surface soils were less than that of subsurface horizons in all the studied pedons and bulk density values increased with soil depth. The range 1.28 to 1.52 Mgm^{-3} recorded for the surface horizons fall within the typical range (1.00-1.60 Mgm^{-3}) for mineral soils as reported by Wild (1963) and Akpan-Idiok et al.,(2012). The soils therefore have no mechanical impedance for plant roots and also have adequate aeration since the bulk density values were lower than 1.85Mgm^{-3} (Aki et al., 2014) which is rated medium in the northern guinea savanna of Nigeria. This trend is consistent with the findings of Sharu et al., (2013); Aki et al., (2014), and Akhtaruzzaman (2014), and.The increase in bulk density at the lowest part of profiles may be attributed to concentration of parent materials (Buo et al., 1980), low fauna and root activities. Increase in bulk density with depth might also be ascribed to the high clay content in the sub-soils, filling parts of the pore spaces (Aderson and Ingram, 1993). This was contrary to the findings of Maniyunda (2014), who reported higher values in surface soils than in the subsurface horizons which he attributed to crust formation in the surface horizon.

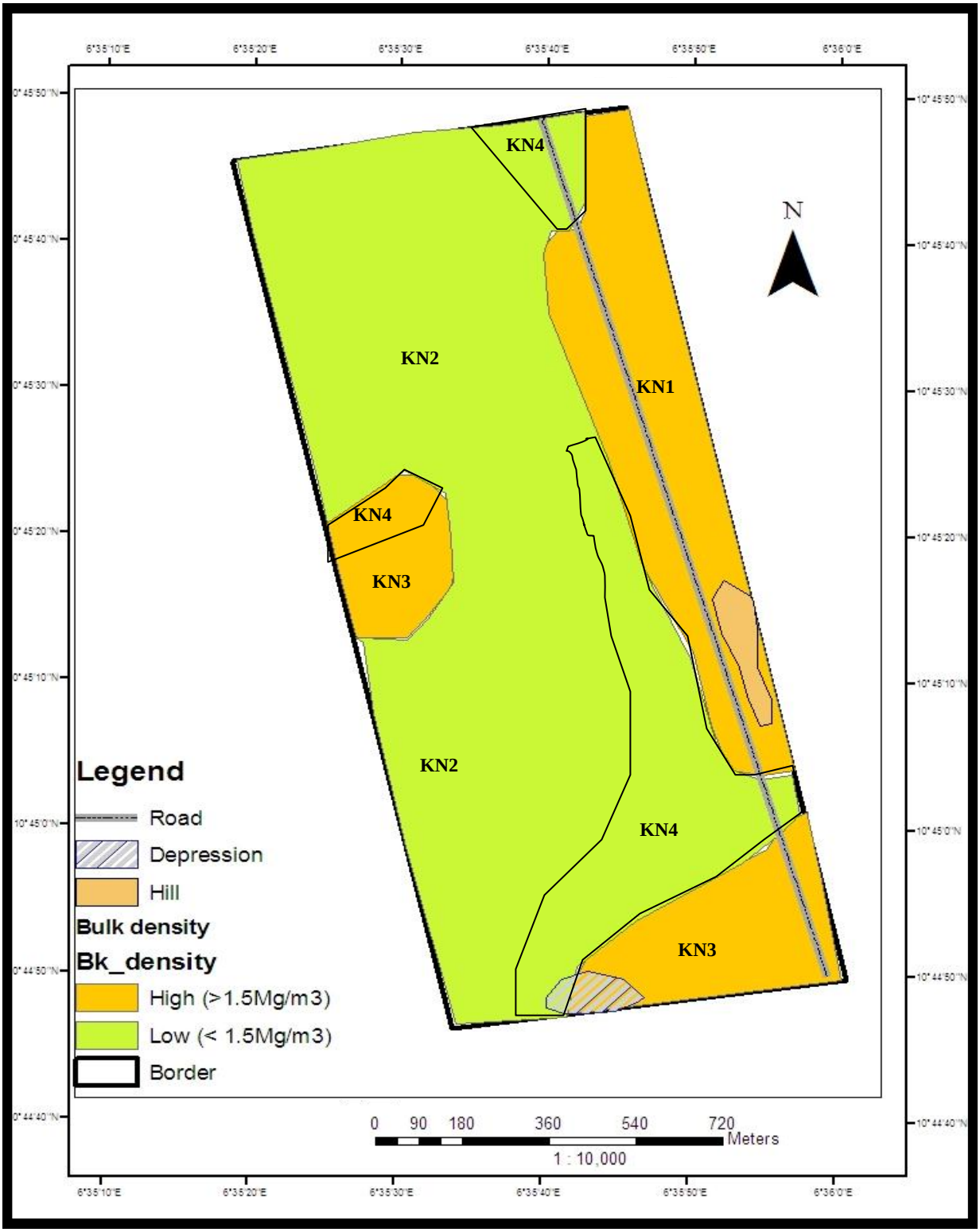


Figure 4.6: Map showing bulk density distribution in the study area

4.4.5 Soil Porosity

The porosity of the study area ranged from 32% to 48.8% (Table 4.4). The mean porosity value of the study area was 40%. The surface soil ranged from 41.5-48.8%. The highest value (48.8 %) was recorded in pedon KN4P2 and the least was recorded in pedon KN1P1. The porosity range of the sub surface horizons was from 32 – 44.36% (mean 39.52%) for all the sub soil horizons. The maximum value (44.36%) was obtained from pedon KN2P1 while the minimum value of 32% was recorded in pedon KN1P1.

Porosity was measured in terms of percentage pores available in the soils. The total porosity of the soils ranged from 32% to 48.80%. This range of values typifies high clay materials which inhibit easy movement of water and air in the soils.

Soils with 50% total porosity are considered high, well granulated and may have high moisture retention which are good for crop plants (Akpan-Idiok *et al*., 2012). Riue and Sposito (1991) also recommended that soils having porosity of 45-50 percent volume are good agricultural soils, thus porosity is a limiting factor presently in the study area, condering the fact that the overall mean porosity for the area was 40% (less than 45-50% recommended range). This could be as a result of significant illuviation of clay in the units thereby reducing the pore spaces (Sharu *et al.,* 2013). Similar pattern of porosity was reported by Maniyunda (1999) in soils of Funtua, Katsina State and Sharu *et al*. (2013) in Sokoto State.

4.4.6. Particle density

The range of particle density of the study area was from 2.50 to 2.69 Mgm^{-3}, with mean value of 2.61 Mgm^{-3} (Table 4.4). The values for surface horizon ranged from . The mean particle density for KN1, KN2, KN3, and KN4 were 2.66, 2.60, 2.63 and 2.56 gm^{-3} respectively. The surface soil ranged from 2.5-2.62 (mean 2.56) g/m^3, with range per soil unit for surface soils

obtained as follows; 2.59-2.62(mean2.61) g/m^3 in KN1, 2.55-2.58 (2.57) g/m^3 in KN2, 2.53-2.59 (2.56) g/m^3 in KN3, and 2.50-2.52(2.51) g/m^3 in KN4.

4.5.0 Chemical Properties

4.5.1 Soil pH

The soil pH values (in water) of the study area (Table 4.6) were observed to range from slightly acidic to neutral. The soil pH (H_2O) values for the study area ranged from 6.20 to 6.80. Soil pH for soil unit KN1varied from 6.4 to 6.5 for the surface horizons while values for soil units KN2, KN3 and KN4 ranged from 6.3 to 6.8. The highest pH value of 6.8 was observed in unit KN3, pedon KN3P2. The lower pH value (6.3) was obtained in pedon KN2P1 in soil unit KN2. The soil pH in the underlying horizons was variable and ranged between 6.2 and 6.8. Most of the underlying horizons in the respective soil units had a pH value that ranged 6.3 to 6.7. The lowest pH value of 6.2 was observed in soil KN3 and in pedon KN3P1. The map showing the distribution of pH across the entire study area is shown in Figure 4.7.

Soil pH of the study area was slightly acidic, 6.1 - 6.5, to neutral, 6.6 -7.3, (Soil Survey Staff, 1993). There was progressive decrease in pH values from surface to subsurface (except in pedon KN2P2), indicating an increase in acidification from surface horizon to sub surface horizon. This might be as a result of nutrient cycling, primarily through root uptake of bases from lower horizons and their returns to the soil surfaces through litter fall (biogenetic cycling of bases), (Jones and Wild, 1975; Mosugu, 1989; Maniyunda, 1999; and Shobayo, 2010).

Audu, *et al.* (2009), Lawal *et al.* (2012) and Jimoh (2015) also reported increase in pH with soil depth in Northern Guinea Savanna. Ojanuga and Awujoola (1981) attributed the higher pH values of surface soil layers to the addition of bases as loess during harmattan.

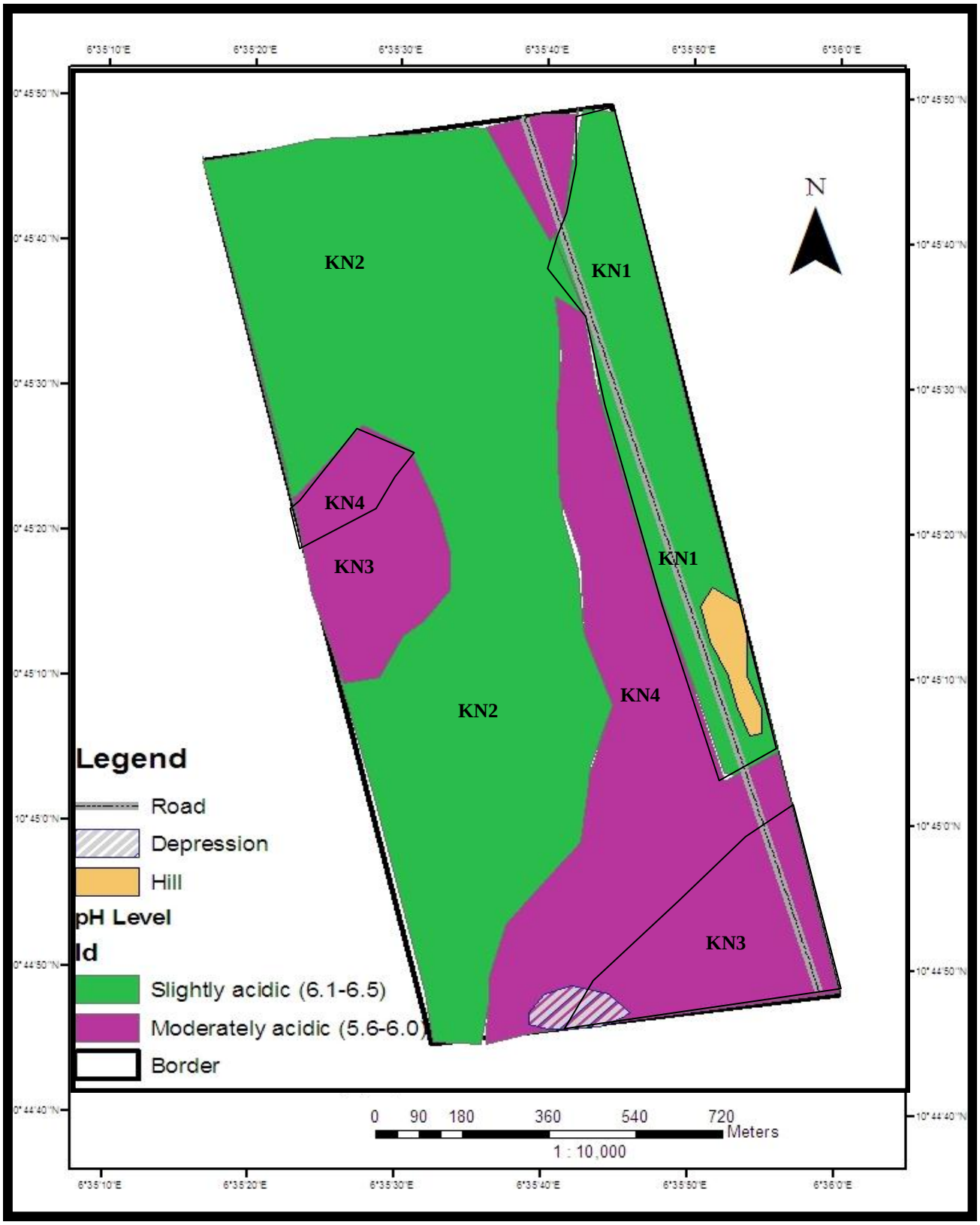


Figure 4.7: Distribution of soil reaction (soil pH) in the study area

Table 4.6: Chemical properties of soils in the study area

Soil Mapping Units	Horizon	Depth (cm)	pH		E.C ds/m	O C g/kg	T N g/kg	C/N	A. P. mg/kg	Ca	Mg	K	Na	TEB	E.A (H^+Al)	CEC (cmol/kg)		BASE SATN (%)
			H_2O	$CaCl_2$						cmol/kg						CEC	ECEC	ECEC
				l														
	KN1P1																	
	Ap	0 – 15	6.4	5.6	0.65	6.80	0.10	68.00	10.48	5.08	0.69	0.27	0.45	6.49	0.50	8.90	6.99	92.85
KN1	Bt	15– 90	6.3	5.3	0.70	4.30	0.08	53.75	8.60	5.33	0.75	0.29	0.70	7.07	0.40	13.70	7.47	94.65
	KN1P2																	
	Ap	0 – 45	6.5	5.8	0.80	6.50	0.07	92.85	13.00	7.10	0.76	0.27	0.80	8.93	0.60	14.90	9.53	93.70
	Bt	45-110	6.3	5.5	0.90	4.20	0.06	70.00	14.00	4.20	0.71	0.24	0.70	5.85	0.50	12.90	6.35	92.13
		Mean	**6.38**	**5.55**	**0.76**	**5.45**	**0.08**	**68.13**	**11.52**	**5.68**	**0.73**	**0.27**	**0.66**	**7.09**	**0.50**	**12.60**	**7.59**	**93.33**
KN2	**KN2P1**																	
	A	0 – 22	6.3	5.5	0.80	10.94	0.10	109.4	11.00	4.80	0.64	0.18	1.13	6.75	1.00	16.20	7.75	87.10
	Bt1	22– 65	6.4	5.6	0.90	8.26	0.07	118	10.00	4.75	0.78	0.27	0.80	6.60	0.80	15.40	7.40	89.19
	Bt2	65– 93	6.6	5.8	0.65	5.82	0.06	97	8.80	4.33	0.78	0.32	0.61	6.04	0.70	14.30	6.74	89.61
	Bt3	93-165	6.8	5.8	0.80	4.34	0.05	86.80	8.60	4.42	0.77	0.34	0.45	5.98	0.60	12.50	6.58	90.88
	KN2P2																	
	A	0 – 30	6.7	5.6	0.80	9.10	0.11	82.73	14.00	4.83	0.71	0.21	0.61	6.36	0.70	19.60	7.06	90.09
	Bt1	30 – 80	6.6	5.4	0.78	7.40	0.08	92.50	11.03	7.17	0.80	0.30	0.58	8.85	0.50	14.90	9.35	94.65
	Bt2	80 – 150	6.5	5.3	0.80	4.34	0.06	72.33	10.33	7.42	0.82	0.31	0.53	9.08	0.50	13.43	9.58	94.78
		Mean	**6.6**	**5.57**	**0.79**	**7.17**	**0.08**	**89.60**	**10.54**	**5.35**	**0.76**	**0.27**	**0.70**	**7.05**	**0.69**	**15.20**	**7.73**	**90.82**

Table 4.6: Chemical properties of soils in the study area (cont.)

Soil Mapping Units	Horizon	Depth (cm)	pH		E.C ds/m	O C	T N	C/N	A. P.	Ca	Mg	K	Na	TEB	E.A	CEC (cmol/kg)		BASE SATN (%)
			H_2O	$CaCl_2$		g/kg	g/kg		mg/kg	← cmol/kg →					(H^+Al)	CEC	ECEC	ECEC
KN3	**KN3P1**																	
	A	0– 25	6.5	5.4	0.65	9.00	0.11	81.81	17.00	5.42	0.64	0.21	0.35	6.62	0.80	11.80	7.42	89.21
	Bt1	25– 70	6.4	5.2	0.90	4.29	0.10	42.91	10.85	5.08	0.66	0.31	0.61	6.66	0.60	11.60	7.26	91.74
	Bt2	70– 105	6.3	5.0	0.75	4.17	0.06	69.50	10.15	4.92	0.73	0.45	0.74	6.84	0.40	10.40	7.24	94.47
	Bt3	105-135	6.2	5.0	0.70	4.00	0.04	100.00	10.33	4.33	0.69	0.47	0.86	6.35	0.50	8.30	6.85	92.70
	KN3P2																	
	A	0 – 25	6.8	6.1	0.90	4.86	0.06	81.00	13.65	4.25	0.71	0.41	0.52	5.89	0.60	8.00	6.49	90.76
	B	25 – 60	6.7	5.9	0.80	3.47	0.05	69.40	12.78	4.20	0.72	0.43	0.80	6.15	0.40	12.60	6.55	93.89
	Bt1	60 – 90	6.5	5.6	0.83	2.26	0.04	56.50	12.55	4.10	0.72	0.43	3.10	8.35	0.50	12.60	8.85	94.35
	Bt2	90 – 150	6.4	5.5	0.78	2.10	0.04	52.50	11.78	4.10	0.72	1.02	0.52	6.36	0.40	12.80	6.76	94.08
	Mean		**6.5**	**5.5**	**0.79**	**4.27**	**0.063**	**67.77**	**12.39**	**4.36**	**0.70**	**0.44**	**0.88**	**6.83**	**0.51**	**11.01**	**6.90**	**92.27**
KN4	**KN4P1**																	
	A	0 – 25	6.7	5.9	0.60	12.00	0.13	92.31	11.68	5.20	0.68	0.40	0.45	6.73	0.60	10.20	7.33	91.82
	Bt	25– 95	6.4	5.3	0.80	10.94	0.11	99.45	10.03	3.70	0.62	0.31	0.80	5.43	0.60	8.30	6.03	90.05
	KN4P2																	
	A	0 – 16	6.6	6.1	0.80	7.50	0.12	62.50	13.48	1.50	0.54	0.11	0.52	2.67	0.80	7.90	3.47	76.95
	B	16– 65	6.4	5.6	0.92	6.77	0.06	112.83	13.13	2.20	0.54	0.12	0.70	3.56	0.60	7.60	4.16	85.58
	Bt	65-120	6.3	5.4	0.93	6.25	0.05	125.00	18.13	4.00	0.70	0.14	0.75	5.59	0.40	5.70	5.99	93.32
	Mean		**6.48**	**5.66**	**0.81**	**8.69**	**0.062**	**140.20**	**13.29**	**3.32**	**0.62**	**0.21**	**0.58**	**4.73**	**0.60**	**7.94**	**5.33**	**87.47**

Vegetation of a place may also influence soil pH because of the difference in base content of the litter. Conifer leaves and litters have lower base content than that of hardwood (Ezenwa, 1988). Therefore, leaves and litters from hardwood tend to add basic materials to soil, thereby, increasing the pH at the soil surface.

However, there was increase in pH with depth in profile pit KN2P1 of soil unit KN2 i.e., pH increases from surface to sub-surface horizons soil. This might be due to leaching of bases due from the top soil to subsoil due to high rainfall (Sivashankaran *et al,* 1993).

There were no significant ($p>0.05$) differences in the soil pH of all the profile pits. From the correlation analysis, the pH positively correlated with organic carbon (O.C.), Ca, Mg, TEB, and B.S. Also, the soil pH values in 0.01*M* $CaCl_2$ were less than pH values measured in water i.e. pH values in water > pH values in $CaCl_2$. i.e. $\Delta pH = [pH\ (CaCl_2) - pH\ (H_2O)]$ = minus ΔpH

In all cases, ΔpH values were negative, indicating that the soils had net negative charge on their colloids (Uehara and Gillman, 1981; and Kparmwang, 1993) and that some plant nutrients may be more readily available in water than in $CaCl_2$. Finally, the pH values of all the profile pits fall within the normal range i.e. 6.20 - 6.80, Thus, A-horizons are less acidic than B-horizons and in some instances tend toward neutrality. High mobility of H^+ ions contributes to the acidic nature of soils (Udom, 2006). This range was reported to be optimum for the release of plant nutrients (Lawal *et al.,* 2012 and Sharu *et al.,* 2013)

4.5.2 Electrical conductivity (E.C.)

Electrical conductivity varied across the soil mapping units, indicating differences in the amount of soluble salt present in the soils. The electrical conductivity in the entire area ranged from o.65 to 0.93 dS/m. the surface horizons for electrical conductivity ranged from 0.6 to 0.90 dS/m. The highest electrical conductivity value (0.90dS/m) in the surface horizon was observed in soil unit KN3, pedon KN3P2 while the least value (0.60 dS/m) was recorded in KN4P1.The electrical conductivity in the underlying sub surface horizons ranged from 0.65 to 0.93 dS/m. the highest value (0.93dS/m) was recorded in K4P2 while the least value (0.65dS/m) was observed in KN2P1. Soil unit KN4 had the highest mean value electrical conductivity of 0.81dS/m while KN1 had the least mean value of 0.76 dS/m.

This shows the amount of soluble salt (solute concentration) present in soils. The soluble salt content was low as indicated by electrical conductivity (EC) values of the study area. The electrical conductivity ranged from 0.6 to 0.90dS/m while the mean value for the area was 0.79dS/m. Based on critical limit of $4dSm^{-1}$ for saline soil as defined by FAO (1993), and limit set by Schoeneberger *et al.* (2002), the electrical conductivity (EC) of all the soil mapping units were very low, thus indicating the non-saline nature of the soils. The lower value of EC in the study area might be due to the combined effect of pH and parent material as well as leaching due to high rainfall in the study area.

4.5.3. Organic carbon

The organic matter contents of the soil were generally low. It ranged from 2.10 to12.00 gkg^{-1} for the study area. The organic carbon content of the surface soil ranged from 4.86 to 12.00 gkg^{-1} with pedon KN4P1 having the highest value of organic carbon content (12.00 gkg^{-1}). The least value was observed in pedon KN3P2 (4.86gkg^{-1}).

In the sub surface horizon, the organic carbon content ranged from 2.10 to 10.94 gkg^{-1} with pedon K4P1 having the highest organic carbon value (10.94 gkg^{-1}) and pedon KNP2 had the

lowest value of 2.1 $gkg^{-1.}$ The mean value for all the profiles was 5.68gkg^{-1}, while the mean organic carbon (OC) content of surface and sub-surface soils were 6.9gkg^{-1} and 5.1gkg^{-1} respectively.

The organic carbon content ranged from low (i.e.<10gkg^{-1}) to moderate (10-15gkg^{-1}) in the study area. The low to moderate rate of organic carbon content could be attributed to occasional destruction of leaf litters by wildfire (Ezenwa,1988). Another reason for moderate organic carbon was due to high temperature and sparse vegetation in the hot semi arid climate which favours rapid rate of decomposition and mineralization of organic matter (Fasina, 1999; Sharu *et al.*,2013). Organic carbon decreased down the profile pits; this might be attributed to immobilization of organic matter by clay in the A horizon in forms of organo-clay-complexes (Kparmwang, 1993; Maniyunda, 1999; Shobayo, 2010). Generally, low organic carbon values have been reported for soils in the northern Guinea savanna zone of Nigeria (Ojanuga, 1971; Ezenwa 1988; and Jimoh, 2015). The pearson correlation analysis (at significant level $P < 0.05$), showed that organic carbon correlated positively with B.S (r = + 0.72), TEB (r - + 0.75), Ca (r = + 0.68), and total Nitrogen (r = + 0.65).

4.5.4 Exchangeable acidity (H^+ Al^{+3})

The exchangeable hydrogen and aluminum content of the soil were recorded. The result showed that exchangeable acidity of the whole area ranged from 0.4 -1.0 cmol/kg. the range within the surface horizon was from 0.5 to 1.0 cmol/kg. the highest value (1.0 cmol/kg) was recorded in KN2P1 and the least value (0.5 cmol/kg) was recorded in KN1P1. The result in Table 4.5 showed that the exchangeable acidity within the sub surface horizon ranged from 0.4 to 0.8 cmol/kg). The highest value (0.8 cmol/kg) was recorded in KN2P1 and the least value (0.4 cmol/kg) was recorded in pedon KN1P1. The mean values of 0.50 cmol/kg, 0.69 cmol/kg, 0.53 cmol/kg, and 0.60 cmol/kg were obtained for soil units KN1, KN2, KN3, and KN4 respectively.

Exchangeable acidity refers to the exchangeable hydrogen and exchangeable aluminum content of the soil. The exchangeable acidity (H^+ and Al^{+3}) was low (less than or equal 1cmol/kg) in the study area, indicating that there is negligible or no acidity problem in the study area.

The exchangeable acidity values were higher in the surface horizons and decreased in sub surface horizons. There was no Aluminium toxicity. The E.A. decreased down the depth in a similar pattern as obtained in organic carbon. This showed a direct relationship between organic carbon and exchangeable acidity. Esu (1992) attributed exchangeable acidity to the dissociation of weak organic acid's functional groups and oxyhydrates of iron and Aluminium complexes of organic matter. Similar results were reported by Raji and Mohammed (2000), Shobayo (2010) and Hussaini, (2011).

4.5.5. Total nitrogen

Total nitrogen content of the study area, as shown in Table 4.5 was very low. The total Nitrogen ranged from 0.04 to 0.13gkg^{-1} for the study area. The total Nitrogen content of the surface horizons ranged from 0.06 to 0.13 gkg^{-1}, with pedon KN4P1 having the highest value (0.13 gkg^{-1}) while the least value was observed in pedon KN3P2 (0.06 gkg^{-1}).

In the underlying sub surface horizons, the total Nitrogen ranged from 0.04 to 0.11 gkg^{-1} Pedon KN4P1 had the highest value (0.11 gkg^{-1}) and pedons KN3P1 and KN3P2 had the lowest value (0.04 gkg^{-1})

The values of total nitrogen content of the soil were generally low in all the soils studied. The average nitrogen content in sub-soils was lower (0.063 gkg^{-1}) than that of the topsoil (0.081 gkg^{-1}). The lower nitrogen values of the subsoil were normal because total nitrogen levels are directly correlated with organic matter and have high positive correlation coefficient with

organic carbon (Shreiner and Brown 1938; Ezenwa 1988; Konnovora *et al.,* 1966; Samndi *et al*, 2006).

The low nitrogen values of the study area were supported by the findings of Jones (1973) who reported low nitrogen values (0.008 – 0.029% and mean 0.05%) in 295 savanna soils of West Africa. Seasonal burning has also been indicated as another important factor responsible for low nitrogen content. Other mechanisms that result in poor residual/available Nitrogen in soils include Ammonia volatilization, succeeding denitrification, chemical and microbial fixation, leaching and runoff (Awanish *et al*, 2014). Low total nitrogen values have been reported by Ibrahim (2010) and Sharu *et al.*, (2013) for soils in the Northern Guinea Savanna Zone of Nigeria. Nitrogen decreased with increasing depth in most of the profile pits and had a correlation with organic carbon.

4.5.6. Available phosphorus

The values of available phosphorus content of the study area were low (as shown in Table 4.6). The available Phosphorus content result showed that phosphorus content of the whole study area ranged from 8.60 to 18.13 $mgkg^{-1}$. The range within the surface horizon is from 10.48 to 17.00 $mgkg^{-1}$. The highest value (17.0$mgkg^{-1}$) was recorded in KN3P1 and the least value (10.48 $mgkg^{-1}$) was recorded in KN1P1. The results also show that available phosphorus within the sub surface horizon ranged from 8.6 to 18.13 $mgkg^{-1}$). The highest value (18.13 $mgkg^{-1}$) was recorded in KN4P2 and the least value (8.6 $mgkg^{-1}$) was recorded in pedon KN4P2. The means of the mapping units were 11.52 mg/kg, 10.54 mg/kg, 12.39 mg/kg and 13.29 mg/kg for KN1, KN2, KN3, and KN4 respectively.

The available phosphorus decreased with increase in soil depth (except in pedon KN4P2) and was low in all the profile pits studied. Maniyunda (1999) reported the same trend in the Basement Complex soils in the northern Guinea Savanna of Nigeria. It was also observed that

available Phosphorus decreased with depth and followed similar pattern as found in organic carbon (Zarafi, 1993; Abdullahi, 1997; Yaro, 2005 and Maniyunda and Gwari, 2014).

The surface horizons had more available phosphorus than sub-surface horizons. This could be associated with the presence of more organic carbon in surface horizons because available phosphorus was organic based (Yaro, 2005; and Jimoh, 2015) Similar results were obtained by Kparmwang (1993), and Mohammed (2011).

Soil mapping unit KN4 (flood plain) has the highest mean available phosphorus while the least was obtained in KN2. This could be attributed to lateral movement from upper slope position to lower slope by erosion.

The least values of available phosphorus were recorded on soils with plinthite at shallower depth (i.e. pedon KN1P1). This could be as a result of low organic matter in the plinthic soil and the area was observed to have scanty trees. Since the area was slightly acidic, there was also possibility of phosphorus fixation by iron in the soil. There was positive correlation between available phosphorus and organic carbon which indicated that organic matter is the main source of available phosphorus..

4.5.7 Cation exchange capacity

The cation exchange capacity (CEC) ranged from5.7 to 19.6 cmol/kg for the study area. The CEC values in surface horizon ranged from 8.0 to19.6 cmol/kg with pedon KN2P2 having the highest value of 19.6 cmol/kg. The least value was observed in pedon KN3P2. In the sub surface horizon, the values ranged from 5.7 to 15.4 cmol/kg. Pedon KN2P1had the highest value (15.4 cmol/kg) and pedon KN4P4 had the lowest value of 5.7 cmol/kg.

The CEC values were rated 0 < 6, 6 - 12 and > 12 cmol/kg as low, medium and high respectively based on ratings of FAO (1993;and Adepetu *et al.*,(1979). The CEC values of the study area were rated medium to high, The CEC by NH_4OAc method for horizons ranged from 5.7 to 19.60 $cmolkg^{-1}$ (mean 11.86 $cmolkg^{-1}$) for all pedogenic horizons in the study area. The mean values for each soil mapping units were 12.60 cmol/kg, 15.19 cmol/kg, 11.01cmol/kg and 7.94mg kg^{-1} in KN1, KN2, KN3, and KN4 respectively. All the surface horizons range from 7.9 to 19.60cmol/kg (mean 12.18) cmol/kg. The CEC of the sub surface soils ranged from 5.7-15.4cmol/kg (11.69cmol/kg).

The CEC of the study site was however rated medium to high. The increasing values of C.E.C as depth increased could be attributed to increase in clay content down the horizons. Similar trend was reported by Vinay (2007), and Mohan (2008). There was high correlation between clay content and CEC (r = + 0.40).

Sharma and Anilkumar, (2003) and Vinay (2007) obtained closely related results between clay content on the CEC values of soils. Also, the occurrence of appreciable amount of kaolinite (clay minerals) has been reported in soils in various parts of Nigeria (Ojanuga, 1971) and this might be an indication of the intensity of weathering that produced the soil and the dominance of Kaolinitic clays in the fine earth fractions (Ojanuga and Awujoola, 1981).

Regarding the decreasing CEC as soil depth increased, Egbuchua and Enujek (2013) submitted that it could be as a result of high contents of basic cations on the surface soil. Wessel and Treteman (1995) attributed the decrease in ECEC as depth increased to replacement of basic cations by hydrogen ion (H^+) while Ashenafi *et al.* (2010) ascribed it to the strong association between organic carbon and CEC. From the result,(Table 4.4) ECEC values were all lower than CEC (NH_4OAc) values, Balasubramanian *et al.* (1980) attributed this to the fact that CEC of tropical soils are highly pH dependent and that ECEC measures charge at the soil pH, whereas, CEC-NH_4OAc measures charge in the soil colloids at pH 7.

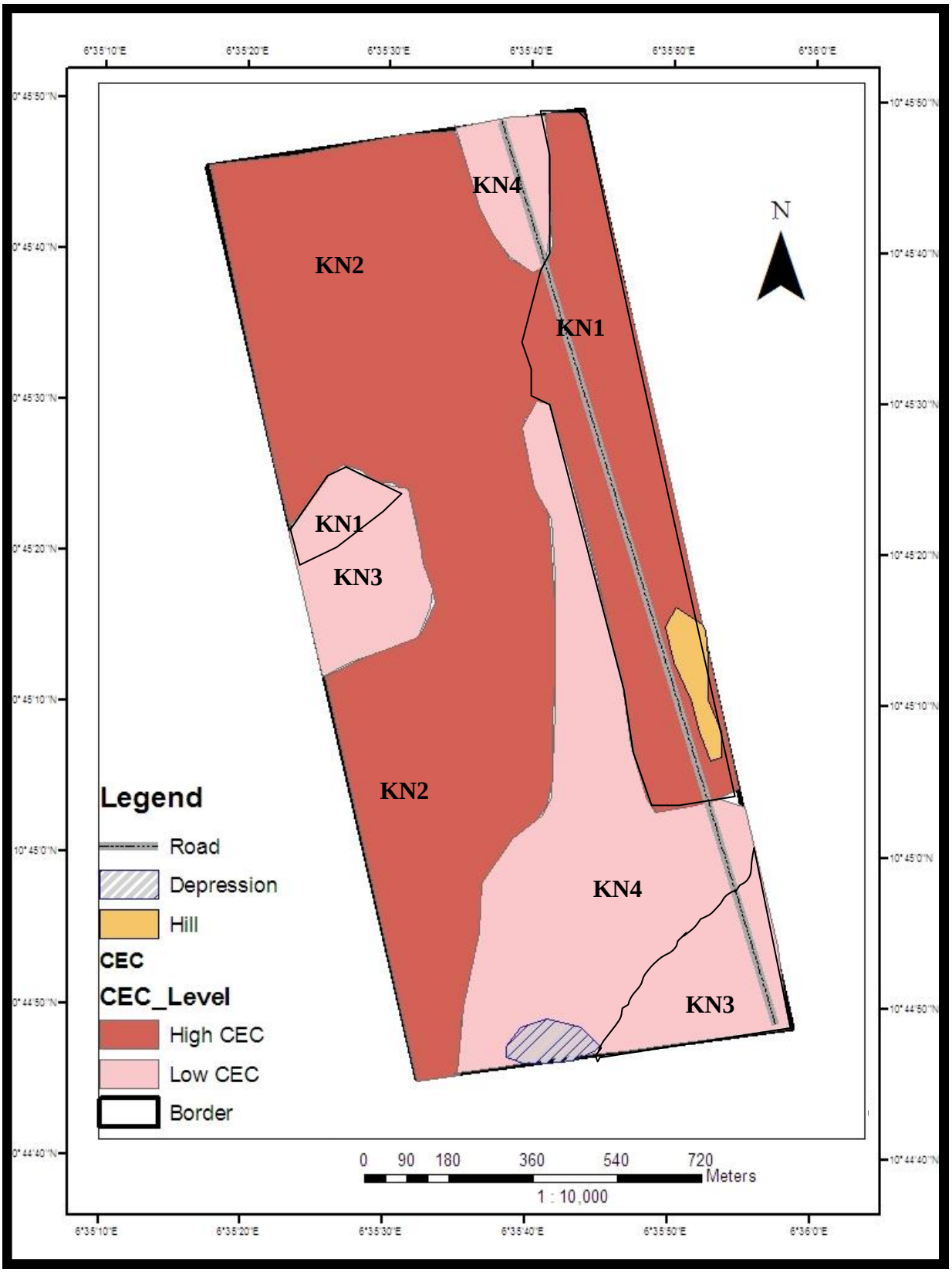


Figure 4.8: Map showing CEC distribution in the study area

4.5.8 Base Saturation (BS)

The result showed that the base saturation value (by ECEC method) of the study area ranged from 76.95 to 94.82%. The base saturation of surface horizon ranged from 76.95 to 93.70% The highest value (93.7%) was recorded in KN1P2 and the least value (76.95%) was recorded in KN4P2. The results in Table 4.5 shows that base saturation of sub-surface horizons ranged from 85.58 % to 94.78%). The highest value (94.78%) was recorded in KN2P2 and the least value (85.58%) was recorded in pedon KN4P2. The mean values of base saturation (ECEC) by summation for soil units KN1, KN2, KN3 and KN4 were 93.33%, 90.82%, 92.27%, and 87.47% respectively. Base saturations were rated high (B.S. > 90%) for all the mapping units except in KN4 (87.47%).

The base saturation was determined by using ECEC method, since it gives a more realistic picture of the acidity level of variable charged soils than base saturation (NH_4OAc method) which tendsto overestimate (Sanchez (1976). The base saturation of the study area was rated very high (mean > 90%) . Malgwi (2001) reported that the incidence of high base saturation could be linked to accumulation of bases leached from upper horizons and through lateral movement of water. Base saturation correlated positively with clay (r=0.72), and total nitrogen (r = 0.46). Based on FAO report (1999), fertile soils are those considered to have more than 50% base saturation while soils with less than 50% BS are considered infertile. Therefore, soils in the study are very fertile.

4.5.9 Exchangeable bases

The exchangeable bases include exchangeable calcium, magnesium, potassium and sodium. The results are shown in Table 5.3

a) Exchangeable calcium (Ca)

The range for exchangeable Ca in the study area was 1.5 – 7.10 cmol/kg. In the surface horizons, the calcium ranged from 1.5 to 7.10 cmol/kg (mean, 4.61 cmol/kg). The highest

was recorded in pedon KN1P2 (7.10 cmol/kg) while the lowest value (1.5 cmol/kg) was observed in pedon KN4P2. The subsurface horizons values ranged from 2.2 to 7.42 cmol/kg, (mean 4.61 cmol/kg). The maximum value (7.42 cmol/kg) in subsurface horizon was observed in pedon KN2P2 while the minimum value (2.2 cmol/kg) was recorded in KN4P2. The mean values for calcium in soil mapping units KN1, KN2, KN3 and KN4 were 5.68cmol/kg, 5.35cmol/kg, 4.36 cmol/kg and 3.32 cmol/kg respectively.

The exchangeable calcium ranged from medium to high (FAO, 1993) and decreased down the horizons; except in profile KN4P2 (KN4), where it increased with depth. The least value for the site (2.20 cmol (+) kg^{-1} in Profile pit KN4P2) was rated medium. The reason for high calcium content could be ascribed to presence of exchange sites in the soil with specific affinity for Calcium (Esu, 1982). The protected status (forested conditions) of soil also allowed accumulation of calcium in the soil over along period of time. Nahusenay *et al*. (2014) attributed the high calcium content in some soils to parent material from which such soils were formed. These higher values in surface horizons suggested that there was minimal leaching in those profile pits partly due to litter contribution; except in profile pit KN4P2 where lower values were recorded in the surface horizons. This pattern of decrease of calcium content with increase in depth and calcium dominance had been reported in the Nigerian savanna (Ezenwa, 1988; Kparmwang, 1993; Yaro, 2005; Mohammad, 2011; Singh*et al*., 2013; Aliyu, 2016). However, in profile pit KN4P2, there was increase in exchangeable calcium as depth increased, this could be attributed to leaching. This result is consistent with that of Shobayo, (2010) who reported that the calcium content of surface horizon is less than sub-soils

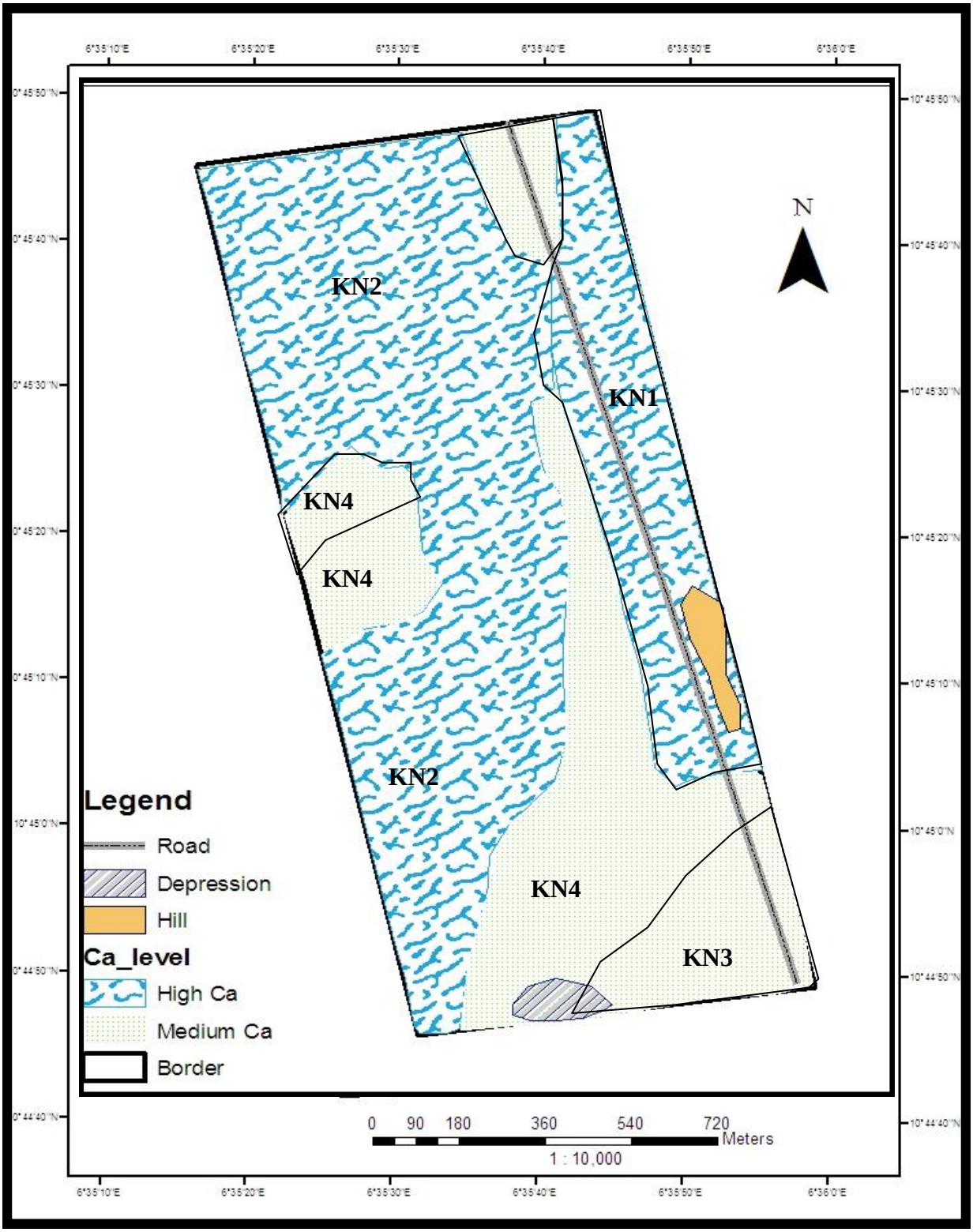


Figure 4.9: Map showing Calcium distribution in the study area

b) Exchangeable magnesium (Mg)

The range of values of exchangeable magnesium in the study area was 0.54 to 0.82cmol/kg. the range in surface horizons was from 0.54 cmol/kg in pedon KN4P2, to 0.76 cmol/kg in pedon KN1P2. The values of exchangeable magnesium in underlying soil horizons ranged from 0.54 cmol/kg to 0.82cmol/kg. Pedon KN2P2 had the highest value of 0.82 cmol/kg while pedon KN4P2 had the least value of 0.54 cmol/kg.

Exchangeable Magnesium (Mg) was the second most dominant cation after calcium on the exchange site. The exchangeable magnesium values in all the profiles, were greater than 0.3 cmol/kg (low) and less than 1.0 cmol/kg (rated high FAO, 1993). Magnesium rating of the site was moderate, that is, medium. Similar medium values of Magnesium were reported by Odunze and Kureh (2009) for Zaria soils**.** The trend of distribution was not orderly in all the mapping units; except in KN2, where it decreased with increase in depth in both profile pits. For instance, it increased down the horizons in profile pit KN2P1(soil unit KN2) and profile pit KN3P1 (KN3), while it decreased down the subsoil in profile pits KN1P1 (KN1), and profile pit KN4P1 (KN4), and no definite order in profile pits KN3P2 (KN3) and profile pit KN4P2 (KN4). The decrease in magnesium from surface horizons to sub-soil could be due to plant uptake and litters decomposition. This decrease in value of Mg with increasing depth may also be associated with organic matter trend in the soil (Aliyu, 2016). However, the increase in exchangeable magnesium with depths could be attributed to leaching of basic cations down the profile (Ashenafi *et al*, 2010; Jimoh, 2015).

c) Exchangeable sodium (Na)

The values of exchangeable sodium content ranged from 0.35 to 3.10 cmol/kg for all the horizons in the study area. The range of values in surface horizons was from 0.35 to 1.13 cmol/kg. The maximum value (1.13 cmol/kg) was recorded in pedon KN2P1 while the minimum value (0.35 cmol/kg) was recorded in pedon KN3P1.

The range of exchangeable sodium in the underlying sub-soil horizon was from 0.45 to 3.10 cmol/kg. The highest value was observed in pedon KN3P2 (3.10 cmol/kg) while the least value was recorded in KN2P1. The mean values of exchangeable sodium per mapping unit were 0.66 cmol/kg (KN1), 0.7 cmol/kg (KN2), 0.88 cmol/kg (KN3), and 0.58 cmol/kg (KN4).

Exchangeable sodium (Na) was next to magnesium. Sodium content of all the pedogenic horizons in the study area was higher than 0.3 cmol/kg rating of FAO (1993). The soils were rated high in sodium for both surface and subsoil horizons. The values in surface horizons were generally lower than the underlying subsoil horizon values in the upland. Generally, sodium contents were irregularly distributed within the soils(they did not follow a specific trend in the soil studied.)

There was decrease in sodium content with depth in Profiles KN1P1, KN2P1and KN2P2. However, it increased down the horizons in KN4P1 KN4P2, KN3P1. AND KN1P2 but there was no marked trend in profile pit KN3P2 (KN3). The decrease in exchangeable Na values as depth increased could be ascribed to capillary movement of water from the water table to the surface (Malgwi, 2001). Jimoh (2015) attributed the increase in values with depth to leaching of basic cation down the profile. This could also be as a result of the nature of parent material (Malgwi, 2001; Babalola *et al.*,2011).

d) Exchangeable potassium (K)

The values of exchangeable potassium across the study area ranged from 0.11 to 1.02 cmol/kg. The values in surface horizons ranged from 0.11 to 0.41cmol/kg with pedon KN3P2 having the highest value of (0.41cmol/kg). The least value of 0.11 cmol/kg was observed in pedon KN4P2. In the underlying sub surface horizon, the values ranged from 0.12 to 1.02cmol/kg with pedon KN3P2 having the highest value (1.02cmol/kg), while the lowest value (0.12 cmol/kg) was recorded in pedon KN4P2

The exchangeable potassium value was rated high across the study area. It increased down the depth in all the pedons except in pedon KN1P1 where it decreased down the sub surface horizon surface. This could be attributed to leaching and uptake by plants. Hussaini (2011), and Maniyunda and Gwari (2014) reported increase in exchangeable potassium down the soil. Conversely, the decrease of potassium down the depth in pedon KN1P1, was in line with the findings of Shobayo, (2010) who explained that higher potassium values at the surface soil than subsoils was influenced by the organic matter in the surface horizon.

Chemical properties with respect to soil units

The mean pH of soil unit KN1was slightly acidic (pH 6.38). The electrical conductivity (0.76 dS/m), organic carbon content (5.43 gkg^{-1}) as well as total nitrogen (0.08) were also rated low in the study area. However, high values were recorded for exchangeable calcium (5.2 $cmolkg^{-1}$), exchangeable sodium (0.66 cmolkg-1) and CEC (12.6 $cmolkg^{-1}$).

In soil unit KN2, the pH was neutral (6.6). The electrical conductivity, organic carbon and total nitrogen values were low (0.79 dS/m, 7.17 gkg^{-1}, and 0.08 gkg^{-1} respectively) in the study area while the values of available phosphorus (10.54 $mgkg^{-3}$) and exchangeable magnesium (0.76 $cmolkg^{-3}$) were moderate. The values of exchangeable calcium (5.35 cmol kg^{-1}), potassium (0.27$cmolkg^{-1}$), and sodium (0.58$cmolkg^{-1}$) were high.

The mean pH of soil unit KN3 was 6.5 (slightly acidic), while low values were recorded for total nitrogen (0.063 gkg^{-1}), organic carbon content (4.27 gkg^{-1}), exchangeable acidity (0.51 $cmolkg^{-1}$) and electrical conductivity (0.79 dS/m). The values recorded for calcium 4.36 $cmolkg^{-1}$), available phosphorus (12.36 gkg^{-1}) and magnesium (0.70 $cmolkg^{-1}$) were moderate. Meanwhile, the values of exchangeable potassium, sodium and CEC were rated high with values 0.44 $cmolkg^{-1}$, 0.88 $cmolkg^{-1}$, and 11.0 $cmolkg^{-1}$) respectively.

Lastly, the soil unit KN4 was slightly acidic with mean pH of 6.48. The mean values of total nitrogen content (0.062 gkg^{-1}), organic carbon content (8.69 gkg^{-1}), electrical conductivity 0.81 dS/m and exchangeable acidity (0.6 $cmolkg^{-1}$). The medium mean values were recorded for CEC (7.91 $cmolkg^{-1}$), exchangeable magnesium (0.62$cmolkg^{-1}$) and available phosphorus (13.29 gkg^{-1}). High mean value of 0.58 $cmolkg^{-1}$ was recorded for exchangeable sodium.

Comparisons of chemical properties of soil units in the study area

The results obtained across the study area revealed that soil unit KN2 had the highest mean pH value of 6.6 (neutral), while the least pH value was recorded in KN1 (slightly acidic). The maximum organic carbon content was observed in KN4 (8.69 gkg^{-1}), followed by KN2 (7.17 gkg^{-1}) and KN1 (5.43 gkg^{-1}), with KN3 having the least value of 4.27 gkg^{-1}). The results of available phosphorus showed that KN4 had the highest value (13.29 gkg-1) and the least value (10.54 gkg-1) was obtained in soil unit KN2. The available phosphorus was moderate across the study area. Exchangeable sodium was rated high across the study area, the minimum value recorded (0.58 $cmolkg^{-1}$ in KN4) was greater than sodium content value of 0.3 $cmolkg^{-1}$ rated high by USDA rating (1993).

Exchangeable acidity and electrical conductivity were rated low in the entire study area. All the values obtained for exchangeable acidity and electrical conductivity were less than 1.0 $cmolkg^{-1}$ and 1.0 dS/m respectively in USDA ratings (1993).

However, CEC values of soil units KN1, KN2, and KN3 were above 10 $cmolkg^{-1}$ (USDA, 1993) and were therefore rated high while the CEC of soil unit KN4 was moderate (7.9$cmolkg^{-1}$). The base saturation in the entire study area was very high, indicating high fertility status of the soil. The mean value obtained for the study area was 91.02 %.

Table: 4.7 Pearson Correlation Matrix for Physico-Chemical properties of the study area.

	Gravel	Sand	Silt	Clay	pH	OC	TN	AP	Ca	Mg	Na	K	TEB	BS	CEC
Gravel	1.00														
sand	-0.32	1.00													
Silt	-0.21	0.63**	1.00												
Clay	-0.43	-0.77	0.35*	1.00											
pH	0.23	0.37*	0.31	-0.54	1.00										
OC	-0.52	-0.39	0.32*	0.41*	0.37	1.00									
TN	-0.27	0.07	-0.41	0.23	-0.07	0.65**	1.00								
AP	-0.15	0.37*	0.35*	-0.67	0.13	0.76**	-0.42	1.00							
Ca	0.21	-0.41	-0.32	0.85**	0.61**	0.68**	0.31	-0.78	1.00						
Mg	0.43*	-0.63	-0.26	0.72**	0.52**	0.47	-0.43	-0.58	0.64*	1.00					
Na	-0.85	0.16	-0.31	0.15	0.73**	-0.31	0.51**	0.31	-0.21	-0.26	1.00				
K	0.71**	-0.72	-0.35	0.74**	-0.25	0.42	-0.38	-0.74	0.74**	0.86**	-0.36	1.00			
TEB	-0.15	-0.19	-0.76	0.54*	0.52*	0.75**	0.96**	-0.52	0.43**	-0.16	0.41*	-0.12	1.00		
BS	-0.53	-0.73	-0.52	0.72**	-0.16	0.72**	0.46	-0.86	0.93**	0.61**	-0.39	0.67**	0.34	1.00	
CEC	-0.15	-0.59	-0.21	0.83**	-0.87	0.53	-0.14	-0.21	0.41	0.64**	0.42*	0.48**	0.24	0.41	1.00

Level of Significance **= Highly significant * = Significant

TEB –Total echangble base B.S- Base Saturation **CEC** – cation exchange capacity

4.6 Vegetation Analysis

Vegetation parameters analyzed are species composition, heights, diameter at breast height (DBH), basal area (BA), density, dominance, and importance value.

4.6.1. Analysis of Point-Centered Quarter Method

All trees and shrubs parameters measured from the sampling points are presented in Table 4.8. These include the specie, height, dimeter at breast height, and distance from the point center (quadrant). This layout was used to derive other calculated parameters. These parameters were used to derive the data shown in Table 4.9

Some of the data calculated included species composition; sampling population, population estimate, species density, relative density, cover, relative cover, frequency, relative frequency, importance value and others.These data were used to calculate the importance value of each woody species and their significance were ranked as shown in Table 4.10.

4.6.2 Species composition

Twenty two (22) species of trees and shrubs were observed during the sampling. The names of the species observed are as the followings; *Anona senegalensis, Azanza azanza, Cochlospermum planchoni, Combretum kerstingii, Cussonia barteri, Daniellia oliveiri, Detarium macrocarpum, Entada Africana, Ficus glumosa, Gardenia aqualla, Gardenia sokotomiensis, Isoberlin doka, Isoberlina tormentosa, Lannea acida, Nuclea latifolia, Parkia biglobosa, Piliostigma thunningii, Prosopis africana, Terminalia glicocen, Upaca togolensis, Vitellaria paradoxa, and Vitex doniana*

Table 4.8: Layout of point-centered quarter analysis

Sampling point	Quarters	TREE / Shrub spp	HEIGHT (m)	Distance (m)	Dbh (cm)	Basal Area(cm^2)
1	1	*Isoberlina doka*	5.60	4.50	39.15	30.76
	2	*Isoberlina doka*	6.80	5.00	42.01	33.01
	3	*Gardenia sokotomiensis*	2.70	6.30	12.09	9.50
	4	*Vitex doniana*	6.80	4.20	41.06	32.26
2	1	*Piliostigma thunningii*	2.10	1.40	10.82	8.50
	2	*Isoberlina doka*	6.70	7.00	40.74	32.01
	3	*Azanza azanza*	2.10	2.30	11.14	8.75
	4	*Cussonia barteri*	6.80	4.20	38.19	30.01
3	1	*Piliostigma thunningii*	3.10	6.00	9.87	7.75
	2	*Anona senegalensis*	2.80	5.20	11.46	9.00
	3	*Isoberlina doka*	7.80	7.30	42.33	33.26
	4	*Piliostigma thunningii*	1.80	4.00	9.23	7.25
4	1	*Cochlospermum planchoni*	3.00	1.60	10.82	8.50
	2	*Upaca togoensis*	4.60	4.90	27.05	21.26
	3	*Prosopis africana*	8.60	8.30	41.69	32.76
	4	*Gardenia aqualla*	3.10	2.20	13.37	10.50
5	1	*Isoberlina doka*	6.40	4.30	32.15	25.26
	2	*Terminalia glicocen*	6.10	2.60	28.64	22.51
	3	*Piliostigma thunningii*	2.20	5.00	10.50	8.25
	4	*Piliostigma thunningii*	2.30	7.00	12.41	9.75
6	1	*Piliostigma thunningii*	3.40	8.40	9.87	7.75
	2	*Piliostigma thunningii*	3.60	7.30	11.78	9.25
	3	*Isoberlina tormentosa*	6.40	5.20	38.19	30.01
	4	*Entada africana*	5.70	4.70	33.10	26.01

Table 4.8:Layout of point-centered quarter analysis (cont.)

Sampling point	Quarters	TREE / Shrub spp	HEIGHT (m)	Distance (m)	Dbh (cm)	Basal Area(cm^2)
7 -30	.	.	.	.	.	.
31-54	.	.	.	.	.	.
55	1	*Vitex doniana*	7.80	4.20	104.00	33.10
	2	*Piliostigma thunningii*	2.00	2.40	16.00	5.09
	3	*Parkia biglobosa*	13.80	3.30	168.00	53.47
	4	*Vitex doniana*	9.90	3.20	137.00	43.60
56	1	*Entada africana*	6.60	5.20	91.00	28.96
	2	*Detarium microcarpum*	5.40	2.80	73.00	23.23
	3	*Isoberlina doka*	10.20	5.40	167.00	53.15
	4	*Combretum kerstingii*	7.30	5.20	85.00	27.05
57	1	*Cochlospermum planchoni*	2.70	6.40	32.00	10.18
	2	*Isoberlina doka*	11.50	5.00	146.00	46.47
	3	*Daniellia oliveiri*	12.70	2.50	175.00	55.70
	4	*Prosopis africana*	10.50	4.30	125.00	39.78
TOTAL	**228**	**228**	**1423.40**	**1014.0**	**18696.0**	**5950.35**
Mean	**4**		**6.24**	**4.45**	**82.00**	**26.10**

4.6.3 Sampling population

The total of 228 woody species.were sampled out of which, *Isoberlina doka* had the highest number of individuals sampled (57), representing 25% of the sampled population, followed by *Piliostigma thuningii (25 treees, 11%), Isoberlina tormentosa (20trees, representing 8.77%) and Gardenia aqualla* (17trees 7.5%) in that order. *Daniella oliveiri*, and *Gardenia sokotomiensis*, had only two (2) individuals, representing 0.88% of the population. Table 4.9 showed that *Isoberlina doka* had highest estimated population (25,500 trees), largest population density (128 trees/ha), and highest importance value (80.87) due to its presence in almost all the sampling points, we can refer to the study area as Isoberlina woodland.

Distribution of sampled population in the study area

The analysis of sampled population distribution (Table 4.12 and Figure 4.13) showed that soil unit KN2 had the highest sampled population of 128 with Isoberlinia doka having the highest number of trees (34). Soil unit KN3 had population of 40 plants followed by soil unit KN4 with 32 woody plants. The least sampled population was found in KN1 (28 plants). Six plant species that had at least a representative in each soil unit were *Anona senegalensis, Cussonia barteri, Gardenia aqualla, Isoberlina doka, Isoberlina tormentosa, and Piliostigma thuningii.*All these were sampled in all the soil units (Figure 4.12).

4.6.4. Total Population

The estimated total population of the study area was 102,000 trees and shrubs using population density of 510tree/ha for the whole area (Table 4.11). The specie with highest population size was *Isoberlinia doka (25,500trees),* followed by *piliostigma thunningi (11184shrubs),* and *Isoberlina tormentosa (8947)* while *Gardenia sokotomensis (894)* had the least estimated population size in the study area.

4.6.5. Importance value

Importance Value of specie measures the dominance or significance of plant specie in a particular ecosystem. It forms a vital inventory in forestry as it gives how well represented a species is in forest vegetation since we can not count all the trees present. It implies ranking of plants species from the most important to the least important. The importance value (I.V) was calculated by addition of relative frequency, relative density and relative cover (Table 4.8). Each of these relative values is expressed as a percent, and ranges from 0 to 100. This means I.V. ranges from 0 to 300 in values. *Isoberlinia doka* has the highest I.V. (80.87) as shown in Figure 4.10. This high importance value of *Isoberlinia doka* indicated that *Isoberlinia doka* was well represented in the study because of its large number compared to other species. The plant specie with least I.V was *Gardenia sokotomensis* (2.35). This showed that *Gardenia sokotomensis* was not well represented in the study area.

Table 4.9: Species composition, number of individuals, species density, relative density, cover, relative cover, frequency, relative frequency, importance value and population of woody plants in the study area

	Spp Composition	No of individual species.	No of ind. / Total plants	Spp density Trees/ha	Spp. population (trees)	Relative density	Mean Basal Area (cm^2)	Sp. Cover (m^z/h	Relative Cover	Absolute Frequency	Relative Frequency	Importance value
1	*Anona senegalensis*	8.00	0.04	18.00	3579.00	3.51	7.85	0.014	1.34	14.04	3.96	8.81
2	*Azanza azanza*	6.00	0.03	13.00	2684.00	2.63	8.10	0.011	1.00	10.53	2.97	6.60
3	*Cochlospermum planchoni*	8.00	0.04	18.00	3579.00	3.51	8.22	0.015	1.41	12.28	3.47	8.38
4	*Combretum kerstingii*	6.00	0.03	13.00	2684.00	2.63	16.63	0.022	2.06	10.53	2.97	7.66
5	*Cussonia barteri*	7.00	0.03	16.00	3132.00	3.07	32.15	0.051	4.89	12.28	3.47	11.42
6	*Daniellia oliveiri*	2.00	0.01	5.00	895.00	0.88	36.26	0.018	1.72	3.51	0.99	3.59
7	*Detarium microcarpum*	8.00	0.04	18.00	3579.00	3.51	14.88	0.027	2.55	14.04	3.96	10.02
8	*Entada africana*	8.00	0.04	18.00	3579.00	3.51	21.32	0.038	3.65	14.04	3.96	11.12
9	*Ficus glumosa/capensis*	2.00	0.01	5.00	895.00	0.88	21.88	0.011	1.04	3.51	0.99	2.91
10	*Gardenia aqualla*	17.00	0.07	38.00	7605.00	7.46	7.60	0.029	2.75	24.56	6.93	17.14
11	*Gardenia sokotomiensis*	2.00	0.01	5.00	894.00	0.88	10.13	0.005	0.48	3.51	0.99	2.35
12	***Isoberlina doka***	**57.00**	**0.25**	**128.00**	**25500.00**	**25.00**	**28.83**	**0.369**	**35.08**	**73.68**	**20.79**	**80.87**
13	*Isoberlina tormentosa*	20.00	0.09	45.00	8947.00	8.77	26.91	0.121	11.51	33.33	9.41	29.69

Table 4.9: Specie composition, number of species, specie density, population, importance value etc. (cont)

	Spp Composition	No of individual species.	No of ind. / Total plants	Spp density Trees/ha	Spp. population (trees)	Relative density	Mean Basal Area (cm^2)	Sp. Cover (m^2/ha)	Relative Cover	Absolute Frequency	Relative Frequency	Importance value
14	*Lannea acida*	5.00	0.02	11.00	2237.00	2.19	23.36	0.026	2.44	8.77	2.48	7.11
15	*Nuclea latifolia*	5.00	0.02	11.00	2237.00	2.19	29.71	0.033	3.11	8.77	2.48	7.77
16	*Parkia biglobosa*	7.00	0.03	16.00	3132.00	3.07	27.00	0.043	4.11	12.28	3.47	10.64
17	*Piliostigma thunningii*	25.00	0.11	56.00	11184.00	10.96	7.35	0.041	3.91	36.84	10.40	25.27
18	*Prosopis africana*	8.00	0.04	18.00	3579.00	3.51	19.48	0.035	3.33	14.04	3.96	10.80
19	*Terminalia glicocen*	11.00	0.05	25.00	4921.00	4.82	23.58	0.059	5.60	17.54	4.95	15.37
20	*Upaca togoensis*	3.00	0.01	7.00	1342.00	1.32	19.42	0.014	1.29	5.26	1.49	4.10
21	*Vitellaria paradoxa*	5.00	0.02	11.00	2237.00	2.19	25.00	0.028	2.61	8.77	2.48	7.28
22	*Vitex doniana*	8.00	0.04	18.00	3579.00	3.51	24.04	0.043	4.11	12.28	3.47	11.09

Table 4.10: Ranking of importance value in the study area

Woody species	Importance value
Isoberlina doka	80.87
Isoberlina tormentosa	29.69
Piliostigma thunningii	25.27
Gardenia aqualla	17.14
Terminalia glicocen	15.37
Cussonia barteri	11.42
Entada africana	11.12
Vitex doniana	11.09
Prosopis africana	10.80
Parkia biglobosa	10.64
Detarium microcarpum	10.02
Anona senegalensis	8.81
Cochlospermum planchoni	8.38
Nuclea latifolia	7.77
Combretum kerstingii	7.66
Vitellaria paradoxa	7.28
Lannea acida	7.11
Azanza azanza	6.60
Upaca togoensis	4.10
Daniellia oliveiri	3.59
Ficus glumosa/capensis	2.91
Gardenia sokotomiensis	2.35
Total	300

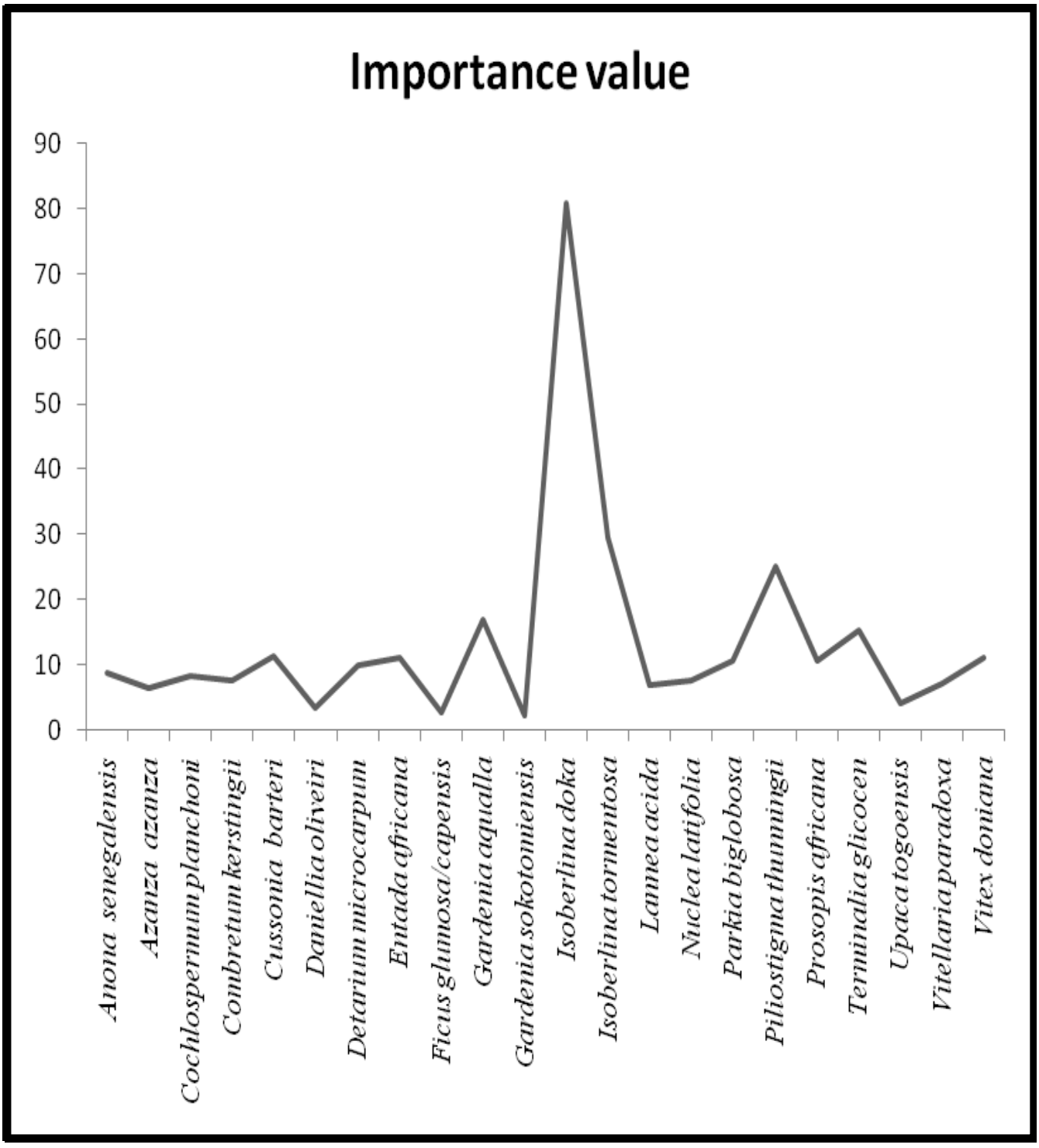


Figure 4.10: Graph showing importance values of woody species in the study area

Table 4.11 Relationship between soil units and vegetation

SMU	No of Sampling	No of samples	No Spp	Area (ha)	Depth range (cm)	Limitation to depth	Plant density	Actual population	*Popn Estimate	Av. Height(m)	B.A (cm^2/ha)
KN1	14	28	11	30.00	90 - 110	Plinthite	458	13740	15,300	5.34	8578.80
KN2	21	128	22	98.60	> 150	No limitation	522	51469	50,286	6.61	12969.95
KN3	11	40	15	33.00	135 – 150	Plinthite	482	15906	16830	5.07	8376.29
KN4	11	32	13	38.40	95 - 130	High water	515	19776	19584	5.86	9597.07
TOTAL	**57**	**228**	**22**	**200ha**				**100,891**	***102,000**		

SMU- Soil Mapping Unit. B.A. – Basal Area.*Popn Estimate – population obtained by using similar tree density for the whole study area.

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Table 4.12: Distribution of sampled woody species in the study area

SPECIES	KN1	KN2	KN3	KN4	TOTAL
Anona senegalensis	2	3	2	1	**8**
Azanza azanza	0	3	2	1	**6**
Cochlospermum planchoni	1	4	0	3	**8**
Combretum kerstingii	0	4	2	0	**6**
cussonia barteri	1	3	2	1	**7**
Daniellia oliveiri	0	2	0	0	**2**
Detarium microcarpum	0	4	0	4	**8**
Entada africana	0	5	2	1	**8**
ficus glumosa	0	2	0	0	**2**
Gardenia aqualla	5	6	2	4	**17**
Gardenia sokotomiensis	0	1	1	0	**2**
Isoberlina doka	4	34	11	8	**57**
Isoberlina tormentosa	2	11	3	4	**20**
Lannea acida	0	5	0	0	**5**
Nuclea latifola	0	3	1	1	**5**
Parkia biglobosa	1	5	1	0	**7**
Piliostigma thunningii	7	11	5	2	**25**
Prosopis africana	1	6	0	1	**8**
Terminalia glicocen	3	6	2	0	**11**
Upaca togoensis	1	1	1	0	**3**
Vitellaria paradoxa	0	4	0	1	**5**
Vitex doniana	0	5	3	0	**8**
TOTAL	**28**	**128**	**40**	**32**	**228**

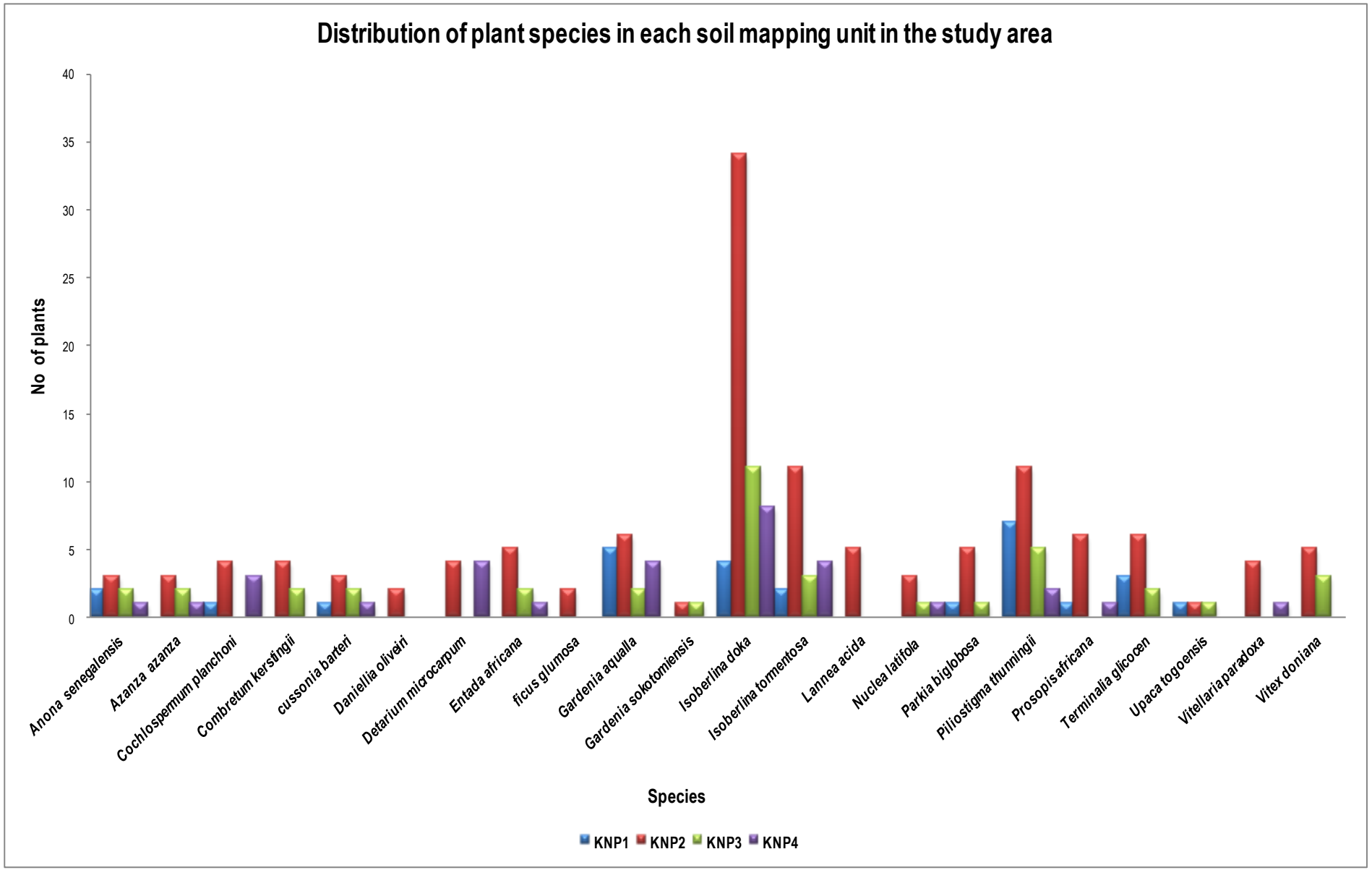


Figure 4.11: Chart showing sampled species in each soil mapping unit in the study

4.6.6 Biodiversity index

The biodiversity index shows the level of degradation of an habitat or degree of human interference in the ecosystem. Table 4.13 shows the calculated values of biodiversity abundance in the study area while Figure 4.12 shows the map generated for the biodiversity distribution in the area. Soil unit KN2 had the highest biodiversity index (2.702), followed by KN3 and KN4 which had 2.42 and 2.28 respectively. The least index of 2.143 was observed in KN1.

The biodiversity index shows the degree of specie abundance and level of degradation in an ecosystem due to human interference. According to Magurran (2004), the midpoint value of 2.5 determines the biodiversity status of a place. A value greater than the midpoint (>2.5) shows good biodiversity, while lower value (< 2.5) indicates poor biodiversity (low diversity). The Shannon diversity index calculated for the study area was 2.69 indicating that the study area is rich in biodiversity and the ecosystem has not been much degraded.

The diversity indices vary across the soil mapping units that made up the study area. The diversity index value of soil unit KN2 (2.702) was greater than 2.50 (Figure 4.12), this showed that KN2 was rich in biodiversity and had not been subjected to much human interference. The reason for high index in soil units KN2 could be as a result of its physiographic position, moderate bulk density, good porosity, and more importantly due to the active protection of the area (frequent patrols carried out by the National Park staff).

Soil unit KN3 had biodiversity index of 2.42 which, though less than 2.5, it is still fairly okay in terms of biodiversity conservation. The reasons could be attributed to the nature of the land (slope) and texture of the soil (gravelly).

Soil mapping units KN1 had the least diversity index of 2.143, while unit KN4 had second least value (2.278). Both soil units were not rich in biodiversity compared to soil units KN2 and KN3. The reasons for this low diversity are;

i. Soil mapping unit KN1 fell within unprotected area, where farming, grazing, wood gathering and logging were practised. All these activities affected the soil quality and in turn affected vegetation performances in the soil unit.

ii. Soil mapping unit KN4 is mainly grassland, with few trees and shrubs growth. The waterlogged condition of the soil is also an important factor that affected tree growth and development. Part of the soil unit was under farming, which exposed it to human interference and degradation.

4.6.7 Species abundance

The species abundance showed that soil unit KN2 had the highest composition of species (22 plant species) followed unit KN3 which had 15 plant species and soil unit KN4 with 13 woody species. The lowest number of species, 11, was found in unit KN1 (Figure 4.14).

This implied that there were many species in unit KN2 more than any of the other units. It also showed that soil unit KN2 was the most bio-diversed mapping unit. The number of species present in a soil unit was directly proportional to diversity index, the higher the species abundance, the higher the diversity index. Therefore, we can conclude that the same factors were responsible for both specie abundance and biodiversity index.

Table 4.13: Species composition, Biodiversity index, and Evenness

Mapping unit	Species composition	Diversity Index (H)	Hmax	Evenness	Sampled Population
KN1	11	2.143	2.397	0.894	**28**
KN2	22	2.702	3.091	0.874	**128**
KN3	15	2.421	2.708	0.894	**40**
KN4	13	2.278	2.565	0.889	**32**

Source: Fieldwork 2015

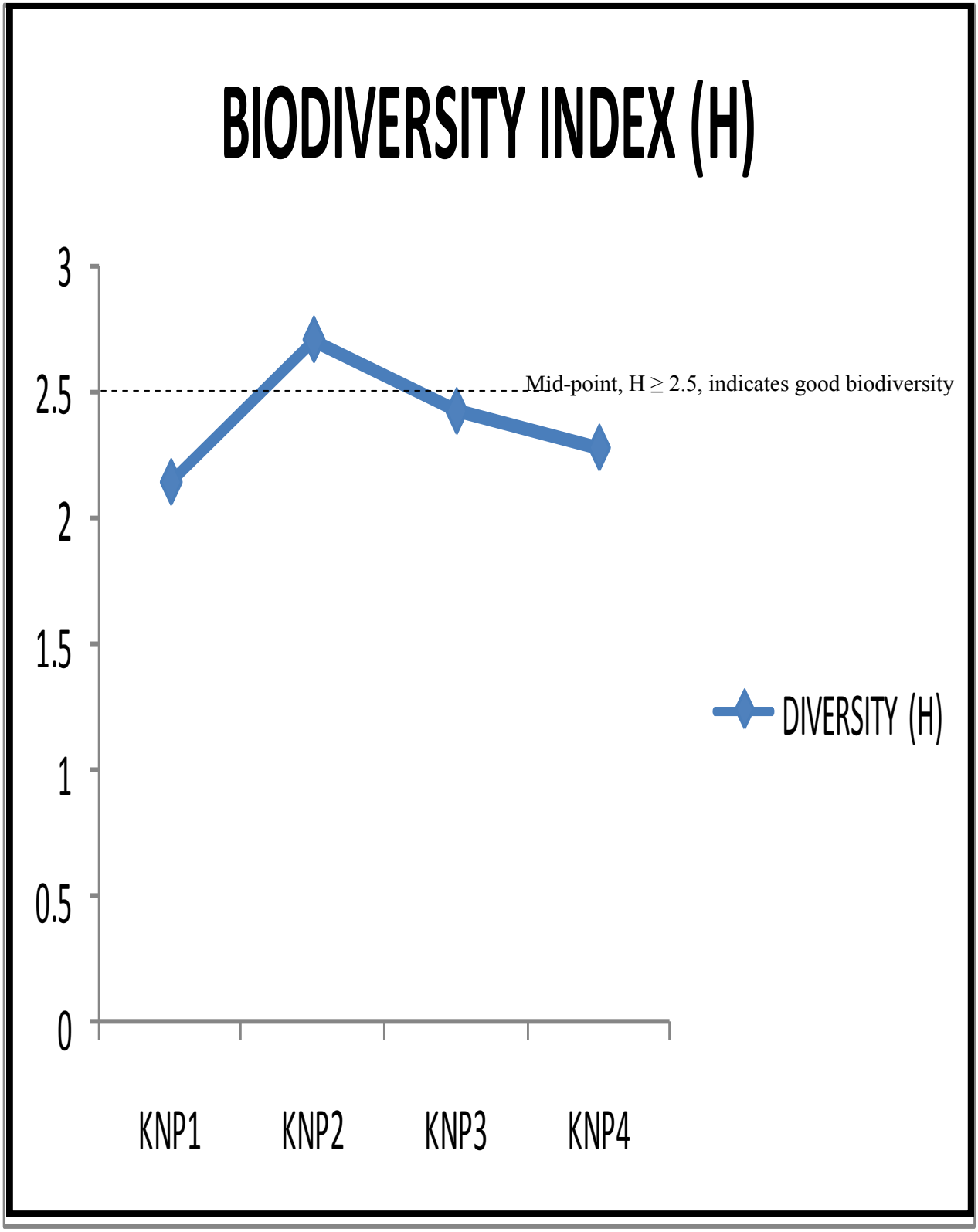


Figure 4.12: Chart showing biodiversity index of the study area

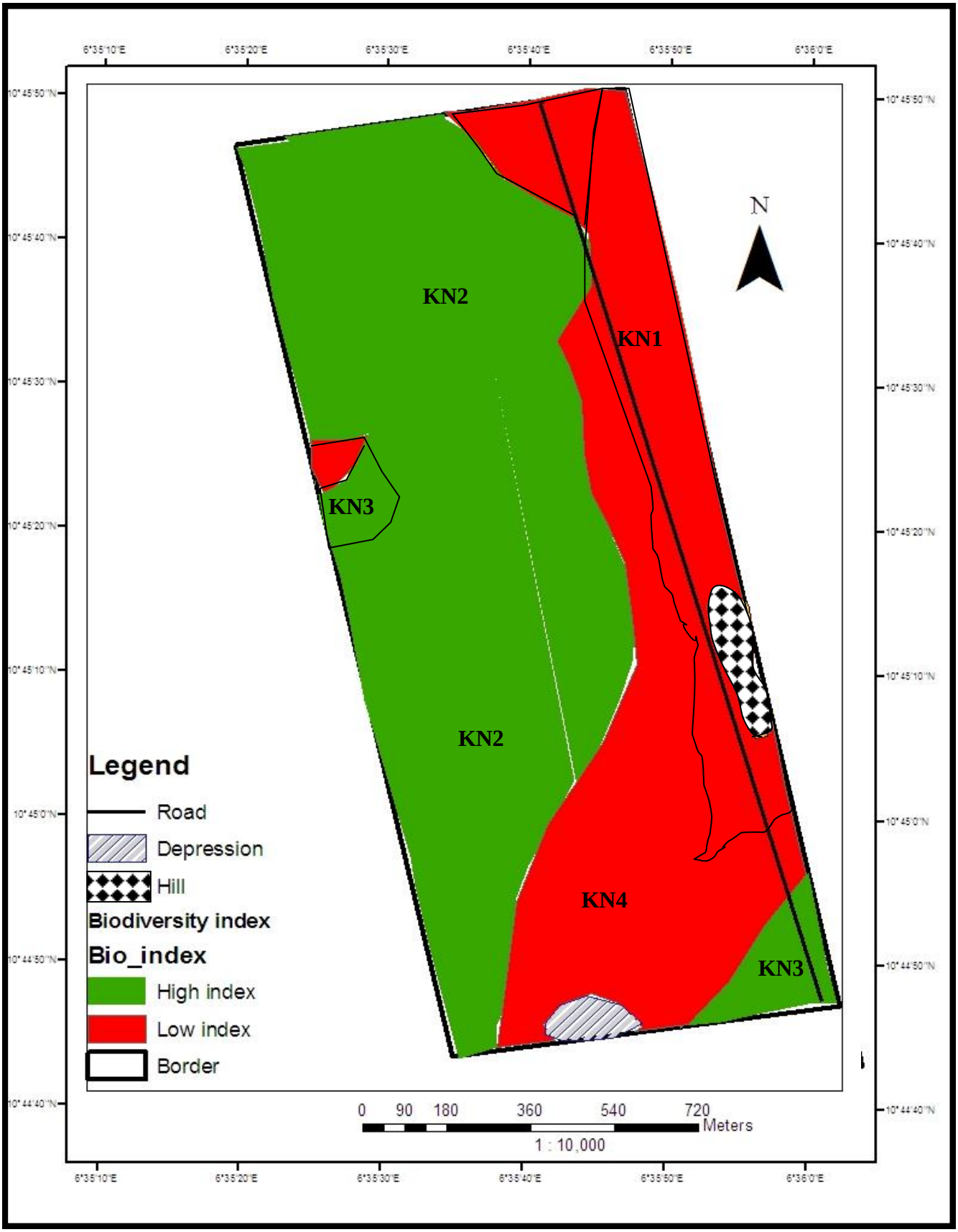


Figure 4.13: Map showing biodiversity index of the study area

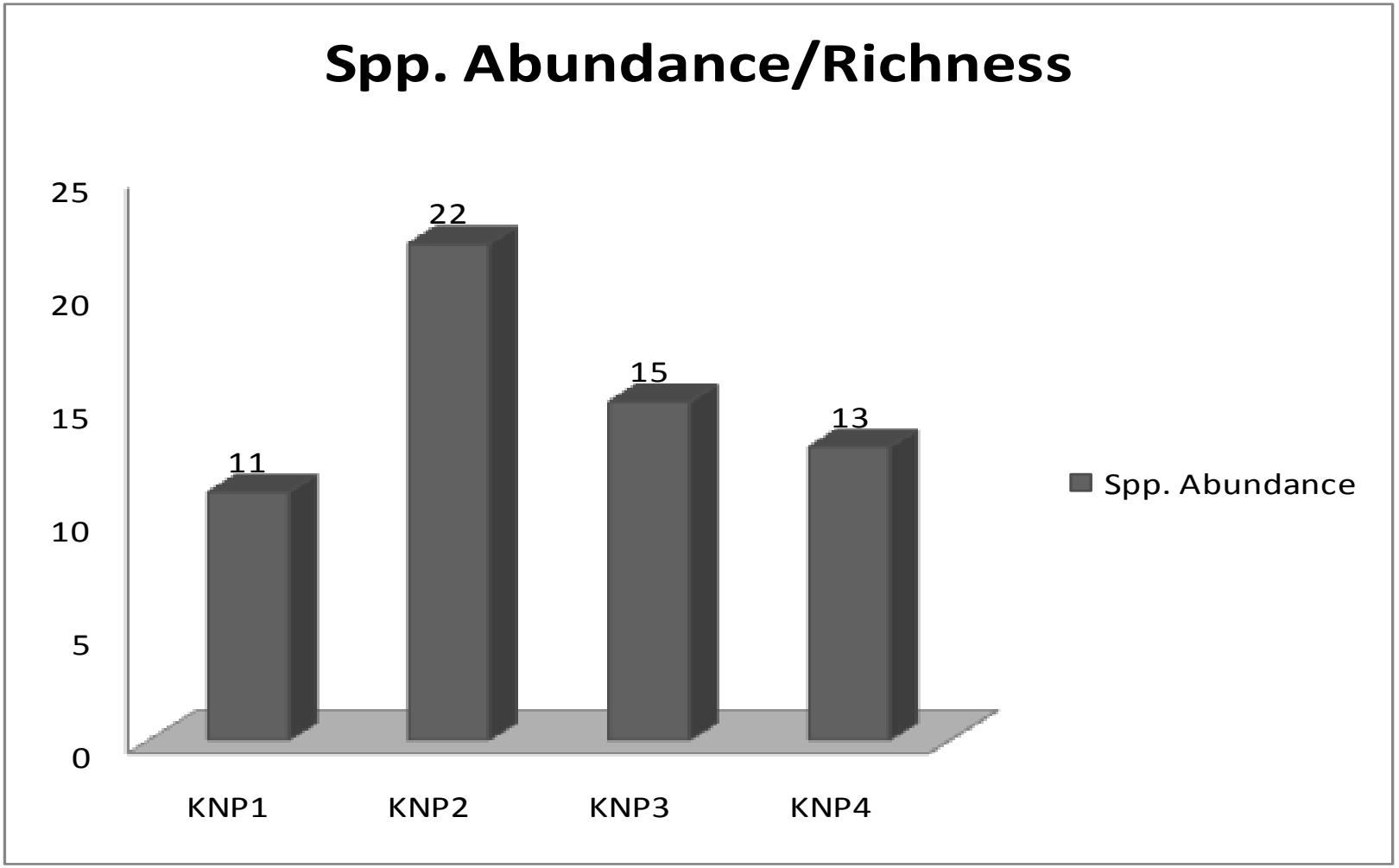


Figure 4.14: Chart of Specie abundance (richness) of the study area

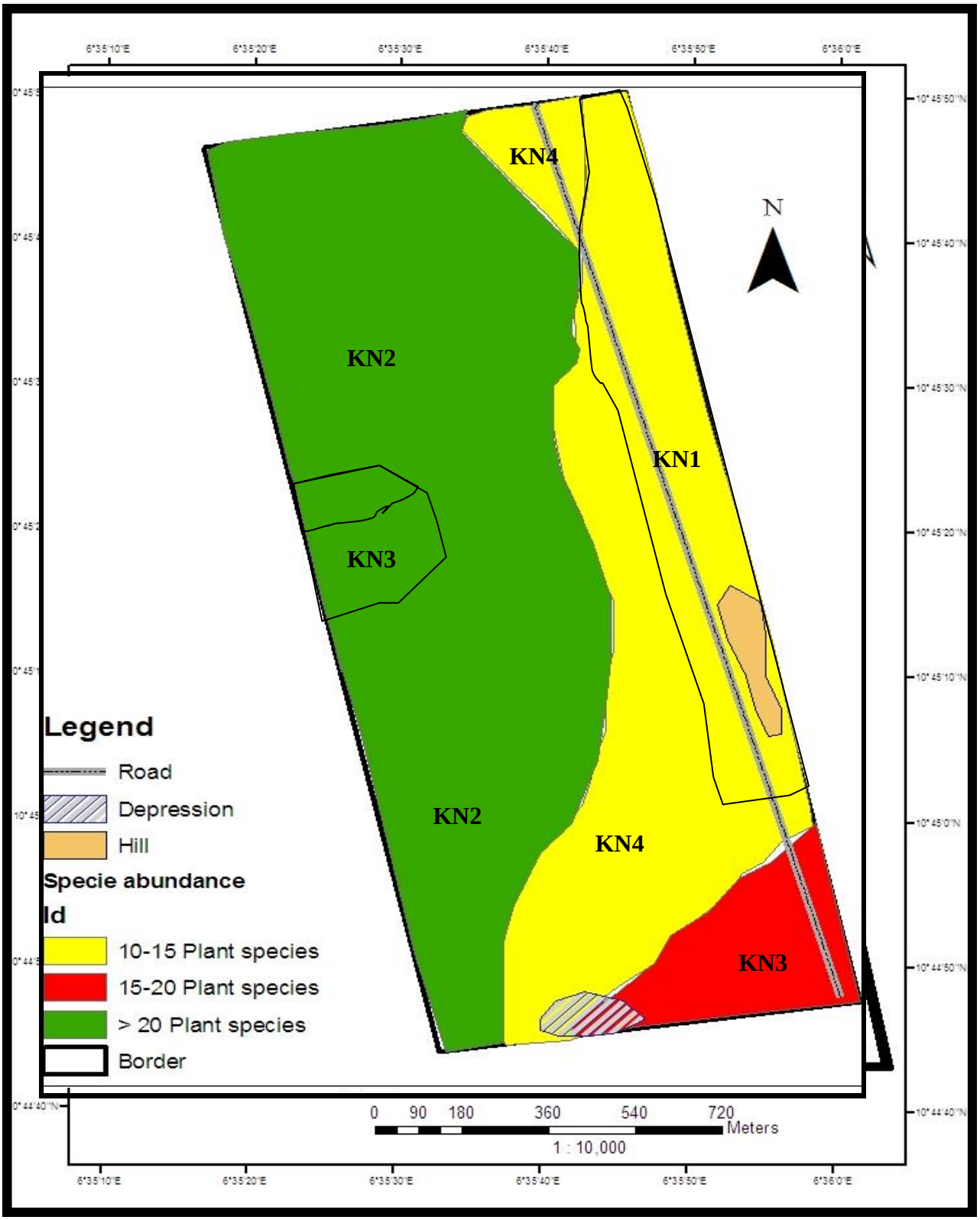


Figure 4.15: Map showing distribution of species abundance in the study area

4.7 Soil Classification

Two soil classification systems were employed in classifying the soils of the study area. The USDA soil classification system (2014) and World Reference Based Soil Legends (FAO/UNESCO) Classification System (2014).

4.7.1 Soil Classification using USDA Soil Taxonomy, Soil Survey Staff, 2014

The taxonomic criteria used by USDA (Soil Survey Staff, 2014) include temperature regime, moisture regimes, morphological, physical and chemical properties.

(a) Soil temperature regime

From Table 3.1, mean maximum and minimum annual air temperature of the study area is greater than 22^0C while there is difference of less than 5°C at the depth of 50cm between the mean maximum and minimum annual soil temperature (Table: 3.1). This temperature regime of the study area is classified as iso-hyperthermic (Soil Survey Staff, 2010).

(b) Soil Moisture regime

The study area experiences mean annual rainfall of about 1,100mm which spans from April to October. The area has dry season which extends over 5 months, with more than 90 cumulative days of dryness in the soil moisture control section (upper 50cm), but less than 180days. Based on this, the moisture regime of soil mapping unit KN1, KN2, and KN3 were *Ustic*. The mapping soil unit KN4 (floodplain) was classified as having Aquic moisture regime, since the soil is saturated and with less than 90 days of dry soil moisture in control section (Soil Survey Staff, 2010).

(c) Diagnostic Surface Horizons (Epipedons)

All surface horizons in the soil mapping units under study were low in phosphorus, with poor and thin humus layer. They had moderately low organic carbon content and high values/chromas greater than 2. This facilitated their classification under Ochric epipedons since they did not fit into histic, folistic mollic, umbric or anthropic epipedons.

(d) Diagnostic Sub-Surface Horizons (Endopedons)

Soil mapping units KN1, KN2 and KN3 had considerable amount of clay, which was formed from argillation; thus, they contained argillic horizons. This was established by the presence of clay bulge in the illuvial horizons which had more clay content than the overlying layer (eluvial horizon). The high clay content of argillic horizons was further confirmed by the presence of the clay ratio of the illuvial to the elluvial horizons of more than 1.2 times. It contained between 15-40% total clay in the fine earth fraction as well as a total thickness of more than 15cm in all the pedons. There was also pronounced textural change as the transition from elluvial to illuvial horizons.Plinthite horizons were more pronounced in soil units KN1 and KN3. The soil mapping unit KN4 contained weakly developed B-horizon with little evidence of clay and iron illiuviation. It had an Aquic condition within 50cm of the soil surface, absence of rock structure, a colour value of 4 or more and chroma of 2 or less and significant amount of weathered materials; thus it was described as Cambic horizon (Soil Survey Staff, 2014).

4.8. Classification of the Soil Mapping Units Based on the USDA soil taxonomy

According to the USDA Soil Taxonomy, soil mapping units KN1, KN2, and KN3 had argillic horizons which increased in clay content with depth. The organic matter content however decreased as depth increased. The soils had high base saturation (>50% by NH_4OAc) and the cation exchange capacity was also high as well as presence of Ochric epipedons, hence, the soils belonged to the order Alfisol. The soils units KN1, KN2, and KN3 were placed into sub-order Ustalfs because they have Ustic moisture regime; high chroma value; they do not have Aquic conditions within 50 cm of the mineral soil surface, and lack redoximorphic features. At great group, soil units KN1 and KN3 were grouped as Plinthustalfs due to presence of plinthic layers and at the sub-group level, they (KN1 and KN3) were grouped as Typic Plinthustalfs because they do not have the characteristic of other Plinthustalf.

The KN2 at great-group was classified as Haplustalfs due to presence of an argillic horizon and absence of plinthite, and it was sub-grouped into Eutric Hapustalfs due to presence of high base saturation (Soil Survey Staff, 2010). KN4 soil unit had Aquic conditions within 50cm depth of the soil surface for some time in a normal year (or artificial drainage) and presence of histic epipedon. The epipedon was characterized by saturation (for 30 days or more, cumulative). This satisfied grouping of the soil into Inceptisols. The presence of annual soil temperature of above 22° C and moisture for more than 180 cumulative days per year satisfied grouping them into ustepts. They belong to great group Haplustepts, and sub great group Aquic Haplustepts due to water saturation in one or more layers within 100 cm of the mineral soil surface for more than 20 consecutive days.

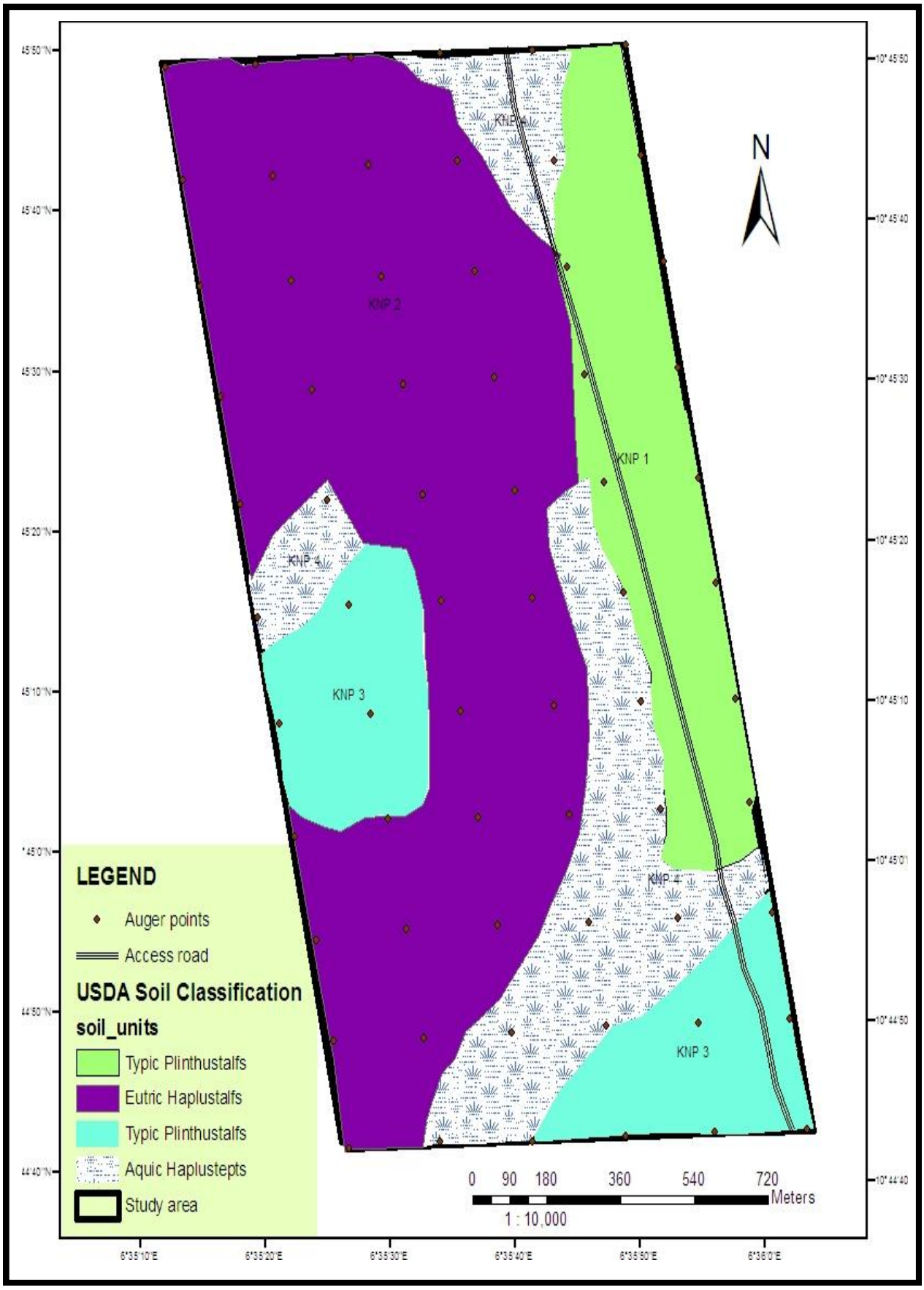


Figure 4.16: Map showing USDA soil classification of the study area

4.9 Classification Based on FAO (World Reference Base)

The soil mapping units KN1, KN2, and KN3 contained strongly weathered soils, having more clay content (Low activity clay) at the subsoil horizons than at the surface horizons due to clay accumulation. This led to the formation of argic horizons within the subsoil (subsurface layer with distinctly higher clay content than the overlying layer starting ≤ 100 cm from the soil surface; and a CEC (by 1 M NH_4OAc, pH 7) of < 24 cmol kg^{-1} clay in some part of the the argic horizon within ≤ 50 cm below its upper limit.). They also contained high base saturation; all these conditions qualified them into Lixisols (Low-activity clays, high base status in the first level classification).

The soil unit KN2 had red coloured subsoil horizons thicker than 30cm with a Munsell hue redder than 5 YR., within the 150cm of the soil from surface. These fitted them into lower level classification as Rhodic Lixisol; while soil units KN1and KN3 were classified as Plinthic Lixisols because they had plinthic horizons starting ≤ 100 cm from the soil surface.

The soil unit KN4 was a recently developed alluvial soil of the flood plain with temporary saturated condition. It has a low bulk density and contains highly humified organic matter.The soil was shallow due to limitation by high water table. Fluvic horizon was present with fluvic material within 25 cm of the soil surface. These conditions satisfied first level classification of Fluvisol. The soil had high base saturation (NH_4OAc) of more than 50 percent in depth between 20 and 100 cm from the soil surface, the lower level of classification was grouped as Eutric Fluvisol. The two systems of soil classification were correlated, and the summary of soil classification of the study area is presented in table 5.2.

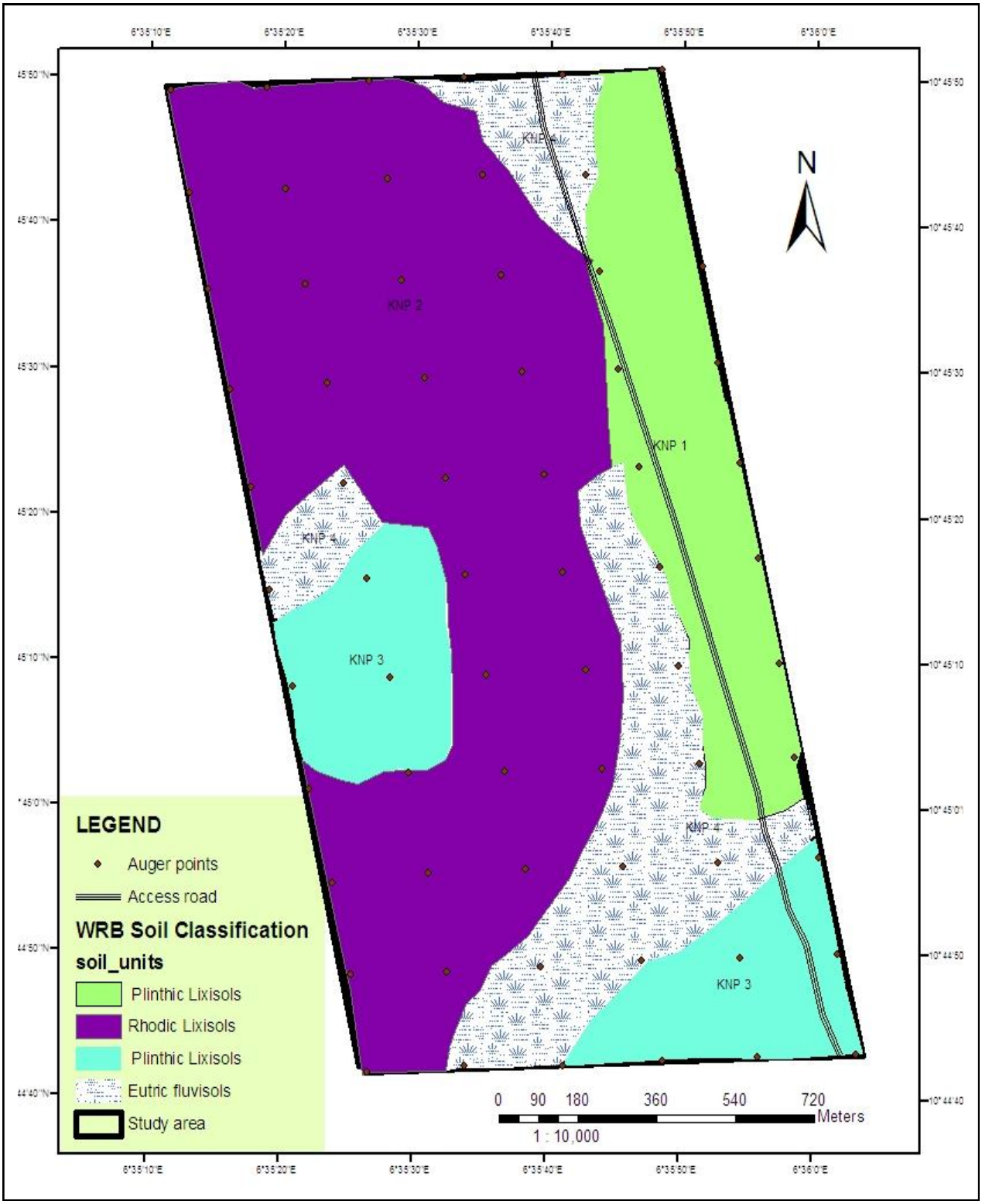


Figure 4.17: Map showing FAO/WRB soil classification of the study area

Table 4.14: Summary of soil classification of Kamuku National Park, Birnin-Gwari.

SMU	Order	Sub-order	Great group level	Sub-group level	USDA Soil taxonomy	FAO/WRB (Soil legend)
KN1	Alfisols	Ustalfs	Plinthustalfs	Typic Plinthustalfs	Typic, Plinthustalfs, isohyperthermic	Plinthic Lixisols
KN2	Alfisols	Ustalfs	Haplustalfs	Typic Haplustalfs	Typic, Haplustalf , isohyperthermic	Rhodic Lixisols
KN3	Alfisols	Ustalfs	Plinthustalfs	Typic Plinthustalfs	Typic, Plinthustalf, Isohyperthermic	Plinthic Lixisols
KN4	Inceptisols	Ustepts	Haplustepts,	Aquic Haplustepts	Aquic Haplustepts, isohyperthermic	Eutric Fluvisol

4.10. Land Capability Evaluation for National Park

Land capability classification is the grouping of soils that are nearly alike in characteristics, suitability for plant growth and response to the same kinds of soil management (Dent and Young, 1981). The land capability classification for forest reserves and national parks in northern Nigeria was adapted from the capability classification system of the United States Department of agriculture (Klingebiel and Montgomery, 1961) which was modified from the systems of Obeng (1968), Young (1976), and FAO (1976). Table 5.2 shows the parameters for land capability classification for forestry purposes in Nigerian Savanna.

4.10.1 Land capability classes of the soil mapping units of the study area.

The land capability classification for each soil is based on assessment of the degree of limitation to land use (or land potential) imposed by land characteristics on the basis of permanent characteristics. The ratings for land capability classification in Nigerian savanna are presented in Table 4.15. Table 4.16 presents soil characteristics of the study area, while classification into capability classes and subclasses are presented in Table 4.17 and Table 4.18 respectively.

From Table 4.18, soil mapping unit KN2 belongs to capability class I (good soils without or with little limitation). Some of the properties that made it to be classified were absence of erosion hazard, presence of good soil depth, ground water below 150cm, and presence of sandy loam texture. This means that the soil is capable of meeting the management objectives without or with little correction.

Table 4.15: Land characteristics for land capability classification for forestry in the Nigeria savannas

Land characteristics	Class I (Plantable Without limitations)	Class II (Plantable with minor limitations)	Class III (Plantable subject to major limitations)	Class IV (Marginally plantable)	Class V (Unplantable Lands)
1. Soil effective depth (cm)	100cm of good free working soil	75 cm of good free working soil	50cm of good soil	Shallow depth to bedrock, iron pan or clay pan,	Very shallow depth
2. Texture	Sandy loam to friable clay loam	Loamy sand to very permeable clay	Loamy sand to permeable clay	Very poorly drained clay to excessively drained sand	Very stony land, solid iron pans out crop
3. Soil erosion	None to slight	Slight to moderate	Moderate to high	Moderate to high	High and severe
4.Inherent soil fertility					
CEC(by NH_4OAc,pH 7)	> 10 meq/100g soil	6-10 meq/100g soil	< 6 meq/100g	Very low inherent soil fertility	Very low inherent soil fertility parameters.
Base saturation (%)	60 – 100	50 -59			
Total Nitrogen (%)	0.1 - 1.0	0.05 – 0.09	0.01 -0.05	Low CEC, water holding capacity,	
Available P. (ppm)	10	5.0 - 9.0	0.05 – 5.0		
Exchangeable K	0.5	0.1 – 0.5	< 0.1		
6. Exchangeable Cation ($cmolkg^-$)					
5. Slope	0 - 2	2 - 4	4 -5	Sloping to hilly topography	Steep slopes
6. Wetness	Ground or perched water below 150cm	Ground or perched water below 100cm	Ground or perched water below 75cm	Poorly to very poorly or excessively drained soil	Permanent water-logging

Source: Adapted from Ezenwa (1988)

The soil mapping unit KN1 was classified into capability class II, this means it had good soils but with some limitations due to soil properties such as shallowness, drought risk, stoniness, or salinity. Some characteristics that facilitated its classification were, presence of 75cm good free working soil, loamy sand texture, presence of slight to moderate soil erosion, 2 – 4% slope, and so on. It was classified into subclass,'s' which showed presence of plinthite and coarse fragment. Therefore, the land capability classification was denoted as CIIs.

Soil mapping unit KN3 was classified under CIIIes which indicated that soils were fairly good but with severe limitations. These limitations were indicated by sub-classes 'e' and 's' which represented erosion and soil properties (plinthites/coarse fragment) respectively. The properties that placed it in this class were presence of moderate to high soil erosion, 4 -5% slope angle, 50 cm of good soil, etc. Mapping unit KN4 was classified as Class IIIw. The reasons for this were due to moderate erosion, presence of ground water below 75 cm, and good soil with effective depth of 50 cm. Its capability subclass 'w' showed limitation due to presence of water i.e. drainage problem.

Table 4.16: Land characteristics of the study area

Land characteristics	KN1	KN2	KN3	KN4
1. Depth (cm)	90 - 110	150 - 165	135-150	95 - 120
2. Texture	Sandy clay	Sandy loam	Gravelly sandy clay	Sandy loam
3. Slope	2 - 4	0 – 2	4 – 8	2- 4
4. Soil fertility				
i. CEC	12.60	15.20	11.00	7.94
ii. Base saturation (%)	93.00	90.80	92.30	87.40
iii. Total N (g/kg)	0.08	0.08	0.063	0.06
iv. Av. Phosphorus (mg/kg)	11.52	10.54	12.39	13.29
v. Exch. Bases (cmol/kg)				
a. Calcium	5.68	5.35	4.36	3.32
b. Magnesium	0.73	0.76	0.70	0.62
c. Sodium	0.66	0.70	0.88	0.58
d. Potassium	0.27	0.27	0.44	0.21
5. Soil erosion	Slight to moderate	None to slight	Moderate to high	Slight to moderate
6. Wetness /Drainage	Ground water below 150cm	Ground water below 150cm	Groundwater below 150cm	Groundwater below 100cm
7. Organic carbon (g/kg)	9.01	4.74	4.14	6.80
8. pH	6.38	6.54	6.48	6.48

Table 4.17: Land capability classes of the study area

Land characteristics	KN1	KN2	KN3	KN4
1. Depth (cm)	I	I	I	II
2. Texture	IIIs	II	IIIs	IV
3. Slope	II	I	IIIe	II
4. Soil fertility				
i. CEC (mol/kg)	I	I	I	II
ii. Base saturation (%)	I	I	I	I
iii. Total N (g/kg)	II	II	II	II
iv. Av. Phosphorus (mg/kg)	I	I	I	I
v. Exch. Bases (cmol/kg)				
Potassium	II	II	II	II
5. Soil erosion	II	I	IIIe	II
6. Wetness /Drainage	I	I	I	IIIw

KEY:

I contain good soils without or with little limitation.

II has good soils but with some limitations.

III soils are fairly good but with severe limitation.

IV has very severe limitation and is recommended for pastures, grazing and wildlife.

e- limitations due to erosion risks.

w- limitations due to wetness and drainage.

s- limitations due to soil properties like shallowness, drought risk, stoniness, or salinity.

Table 4.18: Summary of land capability classification of the study area

Soil Mapping Unit	Topography			Soil physical Characteristics			Fertility		Land capability Classification
	Slope	Erosion	Drainage	Texture	Coarse fragment	Soil depth	C.E.C	B.S	
KN1	II	II	I	IIIs	II	I	I	I	IIs
KN2	I	I	I	II	I	I	I	I	I
KN3	III	IIIe	I	IIIs	III	I	I	I	IIIes
KN4	II	II	IIw	IV	I	I	II	I	IIIw

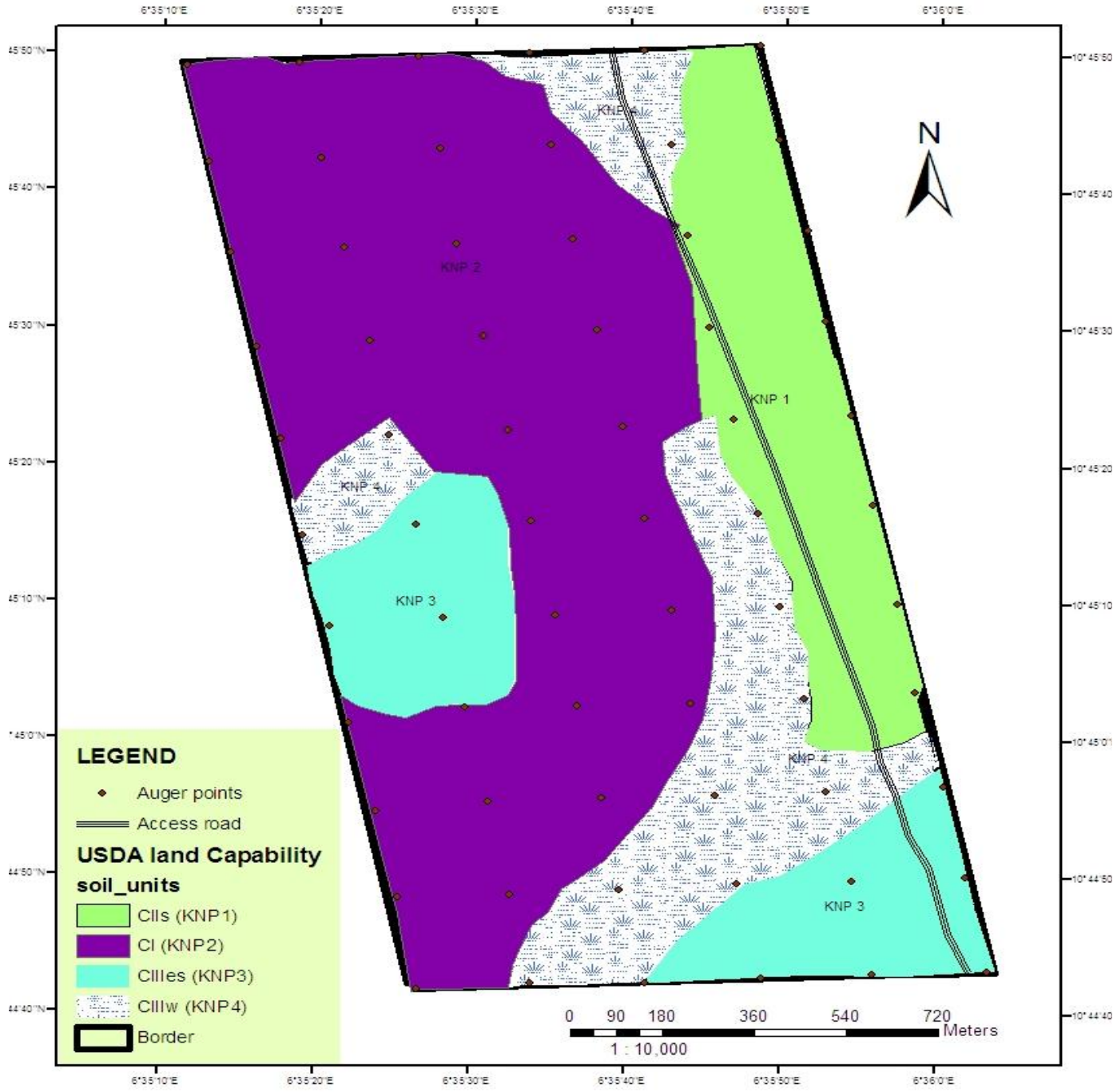
KEYS:

I contains good soils without or with little limitation. **II** has good soils but with some limitations.

III soils are fairly good but with severe limitation. **IV** has very severe limitation and is recommended for grazing and wildlife.

e- limitations due to erosion risks. **w-** limitations due to wetness and drainage,

s-limitations due to soil properties like shallowness, drought risk, stoniness, or plinthites.



Capability classes	Capabilty. Sub-classes	Limitations	Remarks
I	**I**	No or little limitation	Capable
II	**IIs**	Limitations due to soil properties i.e. plinthites	Capable
III	**IIIes**	Limitations due to erosion and soil properties	Capable
III	**IIIw**	Limitations due to drainage and wetness	Capable

Figure 4.18: Map showing land capability classes, subclasses, and limitations of the study area

4.10.2 Land capability and soil mapping units

The land capability classification of the study area showed that soil unit KN2 had the best capability class (class I), this could be seen in the performances of the vegetation in the unit with highest estimated population of 50,286 plants, highest population density of 522 plants/ha, highest species composition (22 species), and second specie cover (dominance) value. Major contributing factors to this could be attributed to soil depth (it had the deepest soil >150cm), moderate bulk density and other physical properties that favoured vegetation growth.

Soil mapping unit KN1 had the second best capability class in the study area. It was categorized into capability class II, with least parameters such as population size, population density, species composition, biodiversity index and so on. The reasons for low parameters in this soil unit KN1 were mainly due to agricultural land use, fuelwood gathering, grazing and other human activities within mapping unit. The tall trees there had been felled to pave way for farming, resulting in few tree species present and low biodiversity. The shallowness of the soil, its stoniness and the resultant high bulk density also contributed to limitations in the soil capability.

The soil mapping units KN3 and KN4 were both classified into capability class III with different sub-classes groupings. They had moderate population sizes, population densities, biodiversity indices, species compositions, and so on. The soil unit KN3 faced limitations due to erosion risk and stoniness, while limitation in soil unit KN4 was largely due to waterlogging.

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary

This study was undertaken to develop an integrated soil survey and vegetation assessment for biodiversity management of Kamuku National Park, Birnin-Gwari, Kaduna state. The park was set up solely for the protection and preservation of eco-biodiversity of Nigerian Northern Guinea Savanna. Remote Sensing (R.S.) and Geographic Information System (GIS) were used to evaluate the soil and vegetation resources of the park, as well as to produce thematic maps of the investigated areas. Such maps included soil map, vegetation map, and land capability map.

The study covers an area of 200 hectares, thereby necessitating the use of semi-detailed soil survey involving satellite image and field work. The slope classes were grouped into the following upper slope (upland), middle slope (mid-land), and lower slope (lowland).

Soil survey and vegetation assessment were carried out at 200m intervals along the traverse, four soil mapping units were identified in the study area and were denoted as KN1, KN2, KN3, and KN4. The vegetation of the study area was grouped into trees; trees, shrubs and grasses; and grassland vegetation.

The soil unit KN2 covered the largest area 98.60 ha (49.30%), while KN1 has the lowest area 30 ha (15%) with KN3, while mapping unit KN4 had 33.00ha (16.5%) and 38.40ha (19.2%) respectively. All the soils mapping units were moderately deep to very deep (90cm to > 165cm). Soil mapping units KN1, and KN2 were well drained, unit KN3 was imperfectly drained, while soil unit KN4 was poorly drained. The soil colour ranged from reddish brown (2.5YR 4/3) to dark brown (7.5YR 3/3) and light brownish gray (2.5 Y 6/2). The drainage was well drained soil in KN1 and KN2 to imperfectly drained in KN3 and poorly drained in KN4. The most dominant soil structure in the study area was sub-angular blocky structure found in soil units KN1, KN2, and

KN3, while soil unit KN4 had weak massive structure. This could be ascribed to the alluvial nature of the soil found in KN4. This soil promotes grassland vegetation as found in KN4. The consistency and plasticity of the soil varied from non sticky to very sticky and non plastic to very plastic respectively.

Sand was the most dominant soil particle content of the soils, with more than 45% of the size fraction. The gravels were negligible. Sand fraction (420-700mgkg^{-1}) dominated the particle size fraction followed by silt (120-420 mgkg^{-1}) and clay (80-460 mgkg^{-1}). Sandy loam to sandy clay loam were dominant within the study area. The bulk densities were high in soil units KN1 (1.65Mg/m^3) and KN3 (1.59Mg/m^3). The bulk densities were moderate both in KN2 (mean 1.49Mg/m^3) and KN4 (1.43Mg/m^3).

The Chemical properties of soils of the study area show that the soils were slightly acidic to neutral (pH 6.2 to 6.8); low to moderate in organic carbon (2.1 to 12g/kg), low in total nitrogen (0.05 to 0.13g/kg) and low in exchangeable acidity (0.4 to 1.0cmol/kg). Available phosphorus was rated low to medium (8.6 -18.13g/kg) and cation exchange capacity was rated medium to high (5.7 to 19.6cmol/kg). In all the pedons, calcium was most dominant cation (rate medium to high, 1.5 to 7.42cmol/kg) followed by magnesium (rated medium, 0.54 to 0.82 cmol/kg), sodium (rated high 0.35 to 3.10cmol/kg) and potassium (rated low to high, 0.11 to 1.02 cmol/kg). These exchangeable bases occurred in the order Ca>Mg>Na>K.

Based on USDA Soil Taxonomy system, the soils in mapping units KN1, KN2, and KN3were grouped in the order *Alfisol* due to presence of Ustic moisture regime, Ochric epipedon, Argillic endopedons, and high base saturation. The soil unit KN4 was grouped as Inceptisols because it had aquic conditions within 50cm depth of the soil surface and presence of histic epipedon. At the sub-order levels, mapping units KN1,KN2, and KN3 were classified as Ustalfs because they have ustic moisture regime; high chroma value; no Aquic conditions within 50 cm of the mineral soil

surface and lack redoximorphic features while KN4 was grouped as ustepts due to presence of annual soil temperature of above 22° C and moisture for more than 180 cumulative days per year. At great group level, KN1 and KN3 were classified as Plinthustalfs because due to presence of considerable amount of plinthites, KN2 was grouped as Haplustalfs due to presence of an Argillic horizon and absence of plinthite at any subhorizon, KN4 was classified as Haplusteps because due to presence of histic layer with high base saturation

Using USDA soil classifications, soil unit KN1 belonged to Typic plinthustalf isohyperthemic; KN2 belonged to Eutric haplustalfsisohyperthemic; KN3belonged to Typic plinthustalf isohyperthemic while soil unit KN4 was Aquic haplustepts isohyperthermic.

Based on FAO/UNESCO Soil Legend (World Reference Base 2014), the soils of the study area were classified into the following;

i. Plinthic Lixisols (KN1)
ii. RhodicLixisols (KN2)
iii. Plinthic Lixisols (KN3)
iv. Eutric Fluvisol (KN4,)

The land capability classification was carried out based on the inherent soil characteristics, external land features and environmental factors. Four land capability classes including three subclasses were obtained in the study area, namely;

i. Soil mapping unit KN2 was classified as land capability class I because it contained good soil with little or no limitation. The extent of this capability class was 49.3%.
ii. Soil mapping unit KN1 was classified as capability class IIs due to presence of good soil with some limitations due to soil properties. Class II covered 15% of the area.

iii. Soil mapping unit KN3 was classified as land capability class IIIes, it had limitations due to erosion risks and soil properties such as plinthites and stoniness. This covered 16.5% of the study area.

iv. Soil mapping unit KN4 was grouped into land capability class IIIw, it had limitation due to waterlogging and wetness and covered 19.2% of the study area.

Point Centre Quarter Method (PCQM) was used for vegetation analysis in the study area. Fifty-seven (57) sampling points, consisting of twenty-two (22) species of trees and shrubs. The highest sampled tree species was *Isoberlina doka* (57 trees) out of the 228 trees and shrubs sampled during the survey. The tree specie density for the area was 510 trees/ha with *Isoberlina doka* having the highest specie density of 128 trees/ha while *Daniellia oliviera*, *Gardenia sokotomiensis,* and *Ficus glumosa* have the least species density of 2 trees/ha. The overall population of trees and shrubs in the study area was 102,000 trees and shrubs. *Isoberlina doka* had 25,500 trees while *Danialla oliveiri*, *Gardenia sokotomiensis*, and *Ficus glumosa* had 894 trees each. Importance Value (I.V) of 300 was calculated for the whole area, with *Isoberlina doka* having 80.87 importance value while *Gardenia sokotomiensis* had the least importance value of 2.35.

5.2 Conclusion

The application of D.E.M, G.P.S, R.S, and G.I.S greatly enhanced the speed and accuracy of the soil and vegetation surveys of the study area vis a vis creation of base map of the study area; delineation of soil mapping units, and calculation of their extents; and more importantly generation of contour maps and other thematic maps for that part of Kamuku National Park that was studied. The soil survey and vegetation assessment of Kamuku national park revealed that the soils of the study area belonged to Alfisols and Inceptisols.The morphological, physical, and chemical characteristics of the soils are capable of sustaining the conservation of fauna and floral resources found in the park.

5.3 Recommendations

To have a comprehensive baseline data for successful national park management, the following recommendations are made

1. The National Park Service Headquarters, should as a matter of importance, establish soil survey (soil information/GIS desk) units in all the existing national parks in the country.
2. The soil survey of the whole Kamuku National Park should be undertaken to know the extent of soils distribution there. This should also be extended to all national parks in the country so as to add to the soil database of our protected areas.
3. There should be synergy between universities and national park on biodiversity management especially on soil research.

5.4 Recommendations for further studies

1. Net Difference Vegetation Index (NDVI) investigation of vegetation distribution with respect to soils in Kamuku National park.
2. The effects wildlife resources on properties of soil in Kamuku national park.
3. The impact of terrorism and cattle rustling on tourism potential and development of Kamuku National Park.

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APPENDICES

Appendix I: SOIL PROFILE DESCRIPTIONS

Mapping Soil Unit KN1

1. Profile pit KN1P1

General Site Information

Location	Doka range (Dogonruwa axis)
Date of examination	2/10/2015
Weather prior to Description	Sunny
Taxonomic Classification	Typic plinthustalf isohyperthemic
Parent Material	Basement Complex
Local Relief	Crest
Slope	4-7%
Coordinate	$N10^0$ 45 07.9, E 6^0 35 15.47 E. Elev: 471m
Soil Erosion/Description	Moderate
Rock outcrop	No bedrock exposed
Drainage	well drained
Surface Characteristic	Not gravelly,
Depth to Water table	Not encountered
Depth to impenetrable layer	90cm
land use/ Vegetation	Farming (fallowed)
Human Influence	Arable farming/wood gathering
Described by	Akande Dolapo and Leko Victor

Horizon Description

Horizon	Depth (cm)	Description
Ap	0-15	Reddish Brown (5YR4/3), sandy clay, strong medium sub angular blocky, slightly sticky and slightly plastic when wet, with few fine roots, diffuse irregular boundary.
Bt	15-90	Red (5YR4/6), clay, sub angular blocky, very sticky and very plastic (wet), presence of tubular pores, and few fine roots, clear wavy boundary.

Mapping Soil Unit KN1

2. Profile pit KN1P2

General Site Information

Location	Dogonruwa axis, Doka range
Date of examination	2/10/2015
Weather prior to Description	Sunny
Taxonomic Classification	**Typic plinthustalf isohyperthemic**
Parent Material	Basement Complex
Local Relief	Crest
Slope	4-7% (class C)
Coordinate	10^0 45 47.2 N; 06^0 35 43.7 E; Elev. 473m
Soil Erosion/Description	Moderate
Rock outcrop	No bedrock exposed
Drainage	well drained
Surface Characteristic	Not gravelly,
Depth to Water table	Not encountered
Depth to impenetrable layer	110cm
Land use/ Vegetation	Fallowed area with shrubs
Human Influence	Arable farming,
Described by	Akande Dolapo and Leko Victor

Horizon Description

Horizon	Depth (cm)	Description
Ap	0-45	Very dark gray brown (10YR3/2), sandy loam, strong coarse sub -angular blocky, non sticky and non plastic (wet), Fine, medium root, clear smooth boundary.
Bt	45-110	Strong Brown (7.5YR 5/8), Sandy clay, strong coarse sub-angular blocky, very sticky, very plastic (wet), firm (moist), common coarse stone, clear smooth boundary.

3. Mapping Soil Unit KN2Profile pit KN2P1

General Site Information

Location	Dogonruwa axis, Doka range
Date of examination	3/10/2015
Weather prior to Description	Sunny
Taxonomic Classification	**Eutric haplustalfsisohyperthemic;**
Parent Material	Basement Complex
Local Relief	Middle land
Slope	0-2% (class A)
Coordinate	10^0 45 18.3 N; 06^0 35 34.1 E, Elev: 467m
Soil Erosion/Description	None
Rock outcrop	No bedrock exposed
Drainage	well drained
Surface Characteristic	Normal soil (Not gravelly)
Depth to Water table	Not encountered
Depth to impenetrable layer	Not encountered (>165cm)
Land use/ Vegetation	Conservation and tourism (Trees, shrubs, & grasses)
Human Influence	Protection,
Described by	Akande Dolapo and Leko Victor

Horizon Description

Horizon	Depth (cm)	Description
A	0-22	Very dark gray brown (10YR3/2), Sandy loam, strong coarse sub -angular blocky, non sticky and non plastic (wet), Fine, medium root, clear smooth boundary.
AB	22-65	Strong Brown (7.5YR 5/8), Sandy clay, strong coarse sub-angular blocky, very sticky, very plastic (wet), firm (moist), common coarse stone, clear smooth boundary.
Bt1	65-93	Yellowish Red (5YR 5/6) Siltyclay, moderate fine sub-angular blocky, very sticky very plastic (wet), firm (moist), hard (dry), fewfine concretions
Bt2	93-165	Reddish Yellow(5YR 6/6) Clay, few fine mottles, moderate-fine sub angular blocky, very sticky very plastic (wet), firm, (moist), hard (dry), common fine concretions.

4. Mapping Soil Unit KN2

Profile pit KN2P2

General Site Information

Location	Dogonruwa axis, Doka range
Date of examination	3/10/2015
Weather prior to Description	Sunny
Taxonomic Classification	Eutric haplustalfsisohyperthemic;
Parent Material	Basement Complex
Local Relief	Middle land
Slope	0-2% (class A)
Coordinate	10^0 $45^0$44.27 N; 6^0 35 15.47 E; Elev. 465m
Soil Erosion/Description	None
Rock outcrop	No bedrock exposed
Drainage	well drained
Surface Characteristic	Normal soil (Not gravelly)
Depth to Water table	Not encountered
Depth to impenetrable layer	150cm
Land use/ Vegetation grasses)	Conservation and tourism (Trees, shrubs, &
Human Influence	Protection,
Described by	Akande Dolapo and Leko Victor

Horizon Description

Horizon	Depth (cm)	Description
A	0-30	Dark Brown (7.5YR 3/3), Sandy loam, moderate medium sub-angular blocky, non sticky and non plastic (wet), loose (moist), few fine root, abrupt smooth boundary boundary.
B1	30-80	Yellowish Red (5YR 5/6), Sandy clay, moderate medium sub-angular blocky, very sticky, very plastic (wet), firm (moist), few fine roots clear smooth boundary
B2	80-150	Dark Yellowish Brown (10YR 4/6) Sandy clay, moderate medium sub-angular-blocky, very sticky very plastic (wet), firm (moist), hard (dry), few fine roots, clear smooth boundary

5. Mapping Soil Unit KN3

Profile pit KN3P1

General Site Information

Location	Dogonruwa axis, Doka range
Date of examination	5/10/2015
Weather prior to Description	Sunny
Taxonomic Classification	Typic plinthustalf isohyperthemic
Parent Material	Basement Complex
Local Relief	Middle land
Slope	2-4% (class B-undulating)
Coordinate	10^0 45 05.7 N; 06^0 35 28.0 E; Elev.: 464m
Soil Erosion/Description	Moderate
Rock outcrop	No bedrock exposed
Drainage	well drained
Surface Characteristic	Gravelly
Depth to Water table	Not encountered
Depth to impenetrable layer	150cm
Land use/ Vegetation	Conservation and tourism (Forest vegetation)
Human Influence	Protection,
Described by	Akande Dolapo and Leko Victor

Horizon Description

Horizon	Depth (cm)	Description
A	0-25	Brown (10YR5/3), Sandy loam, weak moderate sub -angular blocky, slightly sticky and slightly plastic (wet), Friable, few fine root, stones, clay films, clear wavy boundary.
AB	25-70	ReddishYellow (7.5YR 6/6), Sandy clay, strong coarse sub angular blocky, slightly sticky, slightly plastic (wet), firm (moist), common medium stones, abrupt smooth boundary.
Bt1	70-105	Yellowish Red (10YR 6/6) Silty clay, strong coarse subangular blocky, slightly sticky, slightly plastic (wet), firm (moist), common medium stones, wavy smooth boundary.
Bt2	105-135	Reddish Yellow(7.5YR 6/6) Silty clay, strong coarse Subangularblocky, slightly sticky, slightly plastic (wet), firm (moist), common medium stones, wavy smooth boundary.

6. Mapping Soil Unit KN3

Profile pit KN3P2

General Site Information

Location	Dogonruwa axis, Doka range
Date of examination	5/10/2015
Weather prior to Description	Sunny
Taxonomic Classification	**Typic plinthustalf isohyperthemic**
Parent Material	Basement Complex
Local Relief	Middle land
Slope	2-4% (class B-undulating)
Coordinate	10^0 44 47.4 N; 06^0 35 48.07 E; Elev.: 463m
Soil Erosion/Description	Moderate
Rock outcrop	No bedrock exposed
Drainage	well drained
Surface Characteristic	Gravelly
Depth to Water table	Not encountered
Depth to impenetrable layer	150cm
Land use/ Vegetation	Conservation and tourism (Forest vegetation)
Human Influence	Protection,
Described by	Akande Dolapo and Leko Victor

Horizon Description

Horizon	Depth (cm)	Description
A	0-25	Brown (7.5YR4/4), Gravelly Sandy loam, coarse, subangular blocky, non- sticky and non-plastic (wet), loose, few roots, concretions, stones, clear smooth boundary.
Bt1	25-60	Red (2.5YR 4/6), Gravelly Sand, structureless coarse Crumbs, non- sticky and non-plastic (wet), loose, few roots, Concretions, many stones, abrupt smooth boundary.
Bt2	60-90	Dark Red (2.5YR 3/6), Gravelly Sandy clay, structureless coarse Crumbs, non- sticky and non-plastic (wet), loose, few root, Concretions, gravels, abrupt smooth boundary.
Bt3	90-150	Dark Red (2.5YR 3/6), Gravelly Sandy Clay, coarse non- sticky and non-plastic (wet), loose, few roots, Concretions, many stones, clear wavy boundary.

Mapping Soil Unit KN4

7. Profile pit KN4P1

General Site Information	
Location	Doka range (Dogonruwa axis)
Date of examination	9/10/2015
Weather prior to Description	Sunny
Taxonomic Classification	**Aquic haplustepts isohyperthermic**
Parent Material	Basement Complex
Local Relief	Crest
Slope	0-2% (class A)
Coordinate	$N10^0$ 44 52.9, E 6^0 35 42.1 E. Elev: 456m
Soil Erosion/Description	None
Rock outcrop	No bedrock exposed
Drainage	poorly drained
Surface Characteristic	wet soil
Depth to Water table	95cm
Depth to impenetrable layer	water encountered at 95cm
land use/ Vegetation	Conservation (grassland vegetation)
Human Influence	Protection
Described by	Akande Dolapo

Horizon Description

Horizon	Depth (cm)	Description
A	0-25	Very dark grayish brown (10YR3/2), Loam, weak medium sub-angular blocky, slightly sticky and slightly plastic when wet, with common medium roots, clear wavy boundary.
B	25-95	Light Yellowish Brown (10YR3/2), Sandy Clay Loam, presence of mottling (2% fine and faint) weak medium sub- angular blocky, slightly sticky and slightly plastic when wet, with common medium roots, stones, clearwavy boundary.

Mapping Soil Unit KN4

8. Profile pit KN4P2

General Site Information

Location	Doka range (Dogonruwa axis)
Date of examination	9/10/2015
Weather prior to Description	Sunny
Taxonomic Classification	**Aquic haplustepts isohyperthermic**
Parent Material	Basement Complex
Local Relief	Crest
Slope	0-2% (class A)
Coordinate	N10^0 45 17.9, E 6^0 35 49.1 E. Elev: 468m
Soil Erosion/Description	None
Rock outcrop	No bedrock exposed
Drainage	poorly drained soil
Surface Characteristic	
Depth to Water table	120cm
Depth to impenetrable layer	water encountered at 120cm
land use/ Vegetation	Farming (rice and pepper)
Human Influence	cultivation/Arable cropping
Described by	Akande Dolapo

Horizon Description

Horizon	Depth (cm)	Description
O	0-16	Light Brownish Gray (2.5Y 6/2), Loamy Sand, weak fine crumbs, non-sticky and non-plastic (wet), with few fine roots, clear smooth boundary.
A	16-65	Brownish Yellow (10YR6/6), Loamy Sand, weak fine crumbs, non-sticky and non-plastic (wet), very friable, few fine roots, medium stones, and pores, clear smooth boundary.
B1	65-120	Light Gray (10YR 7/2), Sandy Loam moderate medium crumbs, non-plastic, non-sticky, few fine roots, medium stones, and pores, clear smooth boundary.

Appendix II: USDA 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

Source: Soil Survey Manual, U.S. Department of Agriculture. 1993

Appendix III: Land capability classification – quantification of the criteria

Characteristics	Class-I	Class-II	Class-III	Class-IV	Class-V	Class-VI	Class-	Class-VIII
Topography (t)								
Slope (%)	0-1	1-3	3-8	8-15	Up to 30	15-35	35-50	>50
Erosion	Nil	Slight	Moderate	Severe	Nil	Severe	Severe	
Wetness (w)								
Flooding	nil (F0))	nil (F0)	nil to slight	slight to mod.	mod. to	nil to severe	nil to	
Drainage	Well	Moderately	Imperfect	Poor	V. poor	Excessive	Excessiv	Excessive
Permeability	Moderate	Mod. rapid	Raid slow	V. rapid, v				
Infiltration (cm/hr)	2 - 3.5	1-2.0, 3.0-	0.5-1.0, 5.0-	<0.5, >10.0	2.0			
Physical								
Surface texture	Loam	Silt &clay	SL & C	scl	S,c(m)	Ls-cl	Ls, s,c	Ls, s, c(m)
Surface coarse	1-3	3-15	15-40	40-75	15-75	75+		
Surface stoniness	<1	1-3	3-5	5-8	8-15	15-40	40-75	>75
Subsurface coarse	< 15	< 15	15-35	35-50	50-75	50-75	50-75	>75
Soil depth (cm)	>150	150-100	100-50	50-25		25-10	25-10	<10
Profile	Cambic/	A-B-C	Stratified	Salic	Az-C, A-	Gypsic (y)	A-C	A-C
Development	Argillic hor. A-(B)-		A-C; A-B-C	Z)/Calcic(K) hor. A-Bz-	B,C	hor A- cy	(stony)	(bouldery)
Fertility (f)								
CEC (cmol (p+) kg-	40-16	16 - 12	16-12				-	
Base saturation (%)	80 +	80 +	80 - 50	50.35	50-35	35-15	< 15	
OC (0-15 cm) (%)	> 1.0	0.75 -1.0	0.5 – 0.75	<0.5	< 0.5	-	-	
Salinity EC (dS m-	< 10	1-2	2-4	4-8	8 -15	15 -35	35-50	> 50
Gypsum	0.3-2.0 - -	2-5	5-10	10-15	15-25	>25		

Source: Mohan, 2008

Appendix IV: Vegetation sampling showing species, height, and other parameters in PCQM layout,

Plants	Sample points	Plant species	Height	SMU	Girth(m)	Dist(m)	Dbh(cm)
1	1	*Hyparrhenia ruffa grasses*	0	KN3	0	0	0
2	2	*Isoberlina doka*	5.6	KN3	1.23	4.5	39.13458
3		*Isoberlina doka*	6.8	KN3	1.32	5	41.99809
4		*Gardenia sokotomiensis*	2.7	KN3	0.38	6.3	12.09036
5		*Vitex doniana*	6.8	KN3	1.29	4.2	41.04359
6	3	*Piliostigma thunningii*	2.1	KN3	0.34	1.4	10.81769
7		*Isoberlina doka*	6.7	KN3	1.28	7	40.72542
8		*Azanza azanza/Azanza garckeana*	2.1	KN3	0.35	2.3	11.13586
9		*Cussonia barteri*	6.8	KN3	1.2	4.2	38.18008
10	4	*Piliostigma thunningii*	3.1	KN1	0.31	6	9.863188
11		*Anona senegalensis*	2.8	KN1	0.36	5.2	11.45402
12		*Isoberlina doka*	7.8	KN1	1.33	7.3	42.31626
13		*Piliostigma thunningii*	1.8	KN1	0.29	4	9.226853
14	5	*Cochlospermum planchoni*	3	KN1	0.34	1.6	10.81769
15		*Uapaca togoensis*	4.6	KN1	0.85	4.9	27.04423
16		*Prosopis africana*	8.6	KN1	1.31	8.3	41.67992
17		*Gardenia aqualla*	3.1	KN1	0.42	2.2	13.36303
18	6	*farm*	0	KN1	0	0	0
19	7	*farm*	0	KN1	0	0	0
23	8	*farm*	0	KN1	0	0	0
24	9	*Isoberlina doka*	6.40	KN1	0.31	8.4	9.86
25		*Terminalia glicocen*	6.10	KN1	0.37	7.3	11.77
26		*Piliostigma thunningii*	2.40	KN1	1.2	5.2	38.18
27		*Piliostigma thunningii*	2.30	KN1	1.04	4.7	33.08
28	10	*farm*	0	KN1	0	0	0
29	11	*farm*	0	KN1	0	0	0
30	12	*Piliostigma thunningii*	2.10	KN3	31.00	8.40	9.87
31		*Piliostigma thunningii*	1.60	KN3	37.00	7.30	11.78
32		*Isoberlina tormentosa*	6.40	KN3	120.00	5.20	38.19
33		*Entada africana*	5.70	KN3	104.00	4.70	33.10
34	13	*Isoberlina doka*	7.50	KN3	117.00	7.40	37.24

35		*Parkia biglobosa*	6.90	KN3	120.00	6.70	38.19
36		*Gardenia aqualla*	3.50	KN3	38.00	5.40	12.09
37		*Anona senegalensis*	3.20	KN3	35.00	2.10	11.14
38	17	*Terminalia glicocen*	6.30	KN1	95.00	4.60	30.24
39		*Piliostigma thunningii*	3.40	KN1	31.00	5.60	9.87
40		*Piliostigma thunningii*	2.90	KN1	28.00	2.40	8.91
41		*Gardenia aqualla*	3.70	KN1	31.00	3.50	9.87
42	18	*Isoberlina doka*	6.30	KN1	113.00	5.00	35.96
43		*Isoberlina doka*	7.10	KN1	130.00	3.60	41.37
44		*Cussonia barteri*	7.50	KN1	135.00	7.30	42.97
45		*Isoberlina tormentosa*	6.40	KN1	123.00	4.70	39.15
46	19	*Anona senegalensis*	3.10	KN1	28.00	5.70	8.91
47		*Parkia biglobosa*	6.70	KN1	130.00	8.50	41.37
48		*Gardenia aqualla*	3.40	KN1	30.00	5.20	9.55
49		*Isoberlina tormentosa*	6.80	KN1	132.00	2.70	42.01
50	20	*Gardenia aqualla*	3.50	KN1	31.00	1.60	9.87
51		*Terminalia glicocen*	5.80	KN1	116.00	3.10	36.92
52		*Gardenia aqualla*	2.50	KN1	29.00	4.00	9.23
53		*Piliostigma thunningii*	2.10	KN1	30.00	5.00	9.55
54	21	*Isoberlina tormentosa*	7.40	KN4	143.00	4.00	45.51
55		*Isoberlina doka*	6.30	KN4	156.00	7.00	49.65
56		*Isoberlina tormentosa*	5.70	KN4	167.00	5.50	53.15
57		*Isoberlina doka*	9.10	KN4	187.00	7.30	59.52
58	22	*Piliostigma thunningii*	2.30	KN4	34.00	7.00	10.82
59		*Cochlospermum planchoni*	1.90	KN4	34.00	3.80	10.82
60		*Isoberlina doka*	9.70	KN4	115.00	5.20	36.60
61		*Detarium microcarpum*	4.90	KN4	98.00	3.50	31.19
62	14	*grasses*	0	KN4	0		0
63	15	*grasses*	0	KN4	0		0
64	16	*grasses*	0	KN4	0		0
65	23	*Gardenia aqualla*	3.00	KN3	34.00	5.90	10.82
66		*Isoberlina doka*	6.10	KN3	142.00	7.50	45.19
67		*Terminalia glicocen*	5.40	KN3	115.00	5.80	36.60
68		*Terminalia glicocen*	5.90	KN3	135.00	4.00	42.97

69	24	*Isoberlina doka*	6.20	KN3	121.00	6.30	38.51
70		*Isoberlina tormentosa*	5.70	KN3	96.00	8.20	30.55
71		*Isoberlina doka*	6.80	KN3	134.00	3.60	42.65
72		*Isoberlina doka*	5.20	KN3	115.00	2.10	36.60
73	25	*Cochlospermum planchoni*	3.10	KN4	29.00	3.00	9.23
74		*Isoberlina doka*	5.90	KN4	98.00	4.10	31.19
75		*Entada africana*	6.30	KN4	107.00	4.60	34.05
76		*Nuclea latifolia*	9.60	KN4	157.00	4.00	49.97
77	26	*Prosopis africana*	7.20	KN2	74.00	3.00	23.55
78		*Isoberlina doka*	12.40	KN2	145.00	3.80	46.15
79		*Isoberlina doka*	8.30	KN2	114.00	2.00	36.28
80		*Piliostigma thunningii*	2.15	KN2	28.00	1.70	8.91
81	27	*Gardenia aqualla*	3.20	KN2	29.00	3.20	9.23
82		*Terminalia glicocen*	8.60	KN2	95.00	5.00	30.24
83		*Isoberlina tormentosa*	12.40	KN2	168.00	3.50	53.47
84		*Cussonia barteri*	11.30	KN2	174.00	6.00	55.38
85	28	*Isoberlina doka*	9.80	KN2	157.00	4.00	49.97
86		*Isoberlina doka*	9.30	KN2	113.00	2.30	35.96
87		*Anona senegalensis*	3.40	KN2	28.00	3.00	8.91
88		*Nuclea latifolia*	9.20	KN2	125.00	4.30	39.78
89	29	*Parkia biglobosa*	6.70	KN2	95.00	3.50	30.24
90		*Detarium microcarpum*	4.80	KN2	54.00	1.60	17.19
91		*Isoberlina doka*	7.30	KN2	98.00	5.80	31.19
92		*Isoberlina doka*	7.80	KN2	87.00	3.00	27.69
93	30	*Cochlospermum planchoni*	2.90	KN2	35.00	1.30	11.14
94		*Isoberlina doka*	10.40	KN2	186.00	3.90	59.20
95		*Piliostigma thunningii*	2.30	KN2	28.00	2.70	8.91
96		*Gardenia aqualla*	2.76	KN2	30.00	5.00	9.55
97	31	*Isoberlina tormentosa*	9.80	KN2	167.00	4.90	53.15
98		*Isoberlina doka*	9.50	KN2	121.00	5.20	38.51
99		*Gardenia sokotomiensis*	3.20	KN2	43.00	2.60	13.69
100		*Isoberlina doka*	6.30	KN2	99.00	2.40	31.51
101	32	*Upaca togolensis*	6.30	KN2	64.00	3.20	20.37
102		*Entada africana*	7.80	KN2	106.00	3.20	33.74
103		*Isoberlina doka*	9.60	KN2	97.00	1.80	30.87
104		*Isoberlina doka*	7.90	KN2	103.00	1.40	32.78
105	33	*Gardenia aqualla*	3.15	KN4	28.00	5.10	8.91

106		*Isoberlina doka*	11.20	KN4	176.00	1.60	56.02
107		*Isoberlina tormentosa*	9.40	KN4	103.00	2.50	32.78
108		*Gardenia aqualla*	2.30	KN4	30.00	6.00	9.55
109	34	*Upaca togolensis*	5.30	KN3	84.00	3.60	26.73
110		*Combretum kerstingii*	5.70	KN3	75.00	3.20	23.87
111		*Isoberlina doka*	12.90	KN3	185.00	6.40	58.88
112		*Isoberlina doka*	7.40	KN3	104.00	2.10	33.10
113	35	*Isoberlina tormentosa*	6.20	KN4	106.00	6.20	33.74
114		*Vitellaria paradoxa*	6.70	KN4	91.00	3.50	28.96
115		*Isoberlina doka*	6.50	KN4	87.00	5.70	27.69
116		*Azanza azanza*	4.30	KN4	34.00	4.70	10.82
117	36	*Vitellaria paradoxa*	9.60	KN2	132.00	9.00	42.01
118		*Piliostigma thunningii*	2.30	KN2	27.00	6.40	8.59
119		*Isoberlina doka*	10.40	KN2	138.00	3.00	43.92
120		*Lannea acida*	6.80	KN2	96.00	8.60	30.55
121	37	*Prosopis africana*	5.70	KN2	53.00	4.80	16.87
122		*Terminalia glicocen*	5.90	KN2	76.00	2.60	24.19
123		*Isoberlina tormentosa*	6.20	KN2	87.00	3.50	27.69
124		*Detarium microcarpum*	4.70	KN2	36.00	3.70	11.46
125	38	*Entada africana*	5.50	KN2	71.00	13.00	22.60
126		*Gardenia aqualla*	2.70	KN2	29.00	2.70	9.23
127		*Isoberlina doka*	6.90	KN2	87.00	4.00	27.69
128		*Isoberlina doka*	7.50	KN2	73.00	7.00	23.23
129	39	*Azanza azanza*	3.20	KN2	19.00	3.00	6.05
130		*Isoberlina doka*	7.80	KN2	79.00	7.00	25.14
131		*Isoberlina tormentosa*	7.10	KN2	56.00	4.60	17.82
132		*Piliostigma thunningii*	2.10	KN2	23.00	1.60	7.32
133	40	*Terminalia glicocen*	6.70	KN2	86.00	4.70	27.37
134		*Entada africana*	5.60	KN2	95.00	7.10	30.24
135		*Vitex doniana*	7.90	KN2	87.00	3.70	27.69
136		*Lannea acida*	6.30	KN2	77.00	3.90	24.51
137	41	*Isoberlina doka*	6.10	KN2	56.00	13.00	17.82
138		*Isoberlina doka*	9.40	KN2	106.00	5.40	33.74
139		*Vitellaria paradoxa*	9.60	KN2	104.00	4.80	33.10
140		*Isoberlina tormentosa*	7.90	KN2	94.00	3.30	29.92
141	42	*Anona senegalensis*	2.50	KN2	28.00	5.60	8.91
142		*Isoberlina*	8.10	KN2	113.00	4.60	35.96

		tormentosa					
143		*Isoberlina doka*	10.70	KN2	173.00	7.40	55.06
144		*Piliostigma thunningii*	2.30	KN2	27.00	4.00	8.59
145	43	*Isoberlina doka*	11.10	KN2	174.00	3.00	55.38
146		*Parkia biglobosa*	9.80	KN2	112.00	5.00	35.65
147		*Gardenia aqualla*	3.20	KN2	36.00	4.50	11.46
148		*Nuclea latifolia*	9.40	KN2	125.00	4.60	39.78
149	44	*Isoberlina doka*	10.80	KN2	148.00	6.50	47.10
150		*Cussonia barteri*	9.30	KN2	143.00	3.60	45.51
151		*Piliostigma thunningii*	3.10	KN2	28.00	4.50	8.91
152		*Isoberlina doka*	10.60	KN2	131.00	4.60	41.69
153	45	*Detarium microcarpum*	4.70	KN4	64.00	3.00	20.37
154		*Anona senegalensis*	3.50	KN4	31.00	2.70	9.87
155		*Isoberlina doka*	8.70	KN4	75.00	3.00	23.87
156		*Prosopis africana*	6.80	KN4	71.00	6.00	22.60
157	46	*Vitex doniana*	7.10	KN2	97.00	2.40	30.87
158		*Prosopis africana*	5.10	KN2	68.00	1.50	21.64
159		*Piliostigma thunningii*	2.00	KN2	27.00	3.20	8.59
160		*Isoberlina tormentosa*	10.30	KN2	142.00	6.00	45.19
161	47	*Cochlospermum planchoni*	2.20	KN2	31.00	4.00	9.87
162		*Isoberlina doka*	6.30	KN2	81.00	3.10	25.78
163		*Ficus glumosa/capensis*	9.70	KN2	86.00	5.30	27.37
164		*Cochlospermum planchoni*	1.80	KN2	37.00	6.30	11.78
165	48	*Daniellia oliveiri*	9.60	KN2	115.00	2.50	36.60
166		*Terminalia glicocen*	7.30	KN2	89.00	4.80	28.33
167		*Gardenia aqualla*	2.90	KN2	30.00	5.00	9.55
168		*Cussonia barteri*	8.70	KN2	82.00	2.10	26.10
169	49	*Isoberlina tormentosa*	5.10	KN3	68.00	1.40	21.64
170		*Combretum kerstingii*	4.70	KN3	38.00	3.50	12.09
171		*Entada africana*	4.30	KN3	36.00	4.30	11.46
172		*Piliostigma thunningii*	2.60	KN3	35.00	3.60	11.14
173	50	*Isoberlina doka*	6.70	KN3	65.00	4.20	20.69
174		*Vitex doniana*	7.40	KN3	63.00	6.10	20.05
175		*Cussonia barteri*	8.30	KN3	79.00	4.30	25.14
176		*Anona senegalensis*	2.20	KN3	33.00	2.70	10.50
177	51	*Gardenia aqualla*	3.00	KN4	32.00	4.10	10.18

178		*Detarium microcarpum*	4.60	KN4	35.00	3.40	11.14
179		*Cussonia barteri*	10.90	KN4	167.00	5.30	53.15
180		*Isoberlina doka*	7.40	KN4	58.00	2.80	18.46
181	52	*Isoberlina tormentosa*	5.10	KN2	51.00	5.30	16.23
182		*Isoberlina doka*	9.10	KN2	85.00	3.10	27.05
183		*Isoberlina doka*	8.30	KN2	53.00	4.00	16.87
184		*Entada africana*	5.70	KN2	72.00	7.00	22.92
185	53	*Isoberlina tormentosa*	6.90	KN2	45.00	8.20	14.32
186		*Prosopis africana*	5.40	KN2	49.00	4.20	15.60
187		*Isoberlina doka*	6.90	KN2	47.00	4.80	14.96
188		*Piliostigma thunningii*	2.40	KN2	31.00	3.80	9.87
189	54	*Vitellaria paradoxa*	7.50	KN2	67.00	5.30	21.32
190		*Combretum kerstingii*	5.80	KN2	45.00	2.80	14.32
191		*Terminalia glicocen*	6.20	KN2	75.00	6.00	23.87
192		*Prosopis africana*	6.70	KN2	52.00	4.00	16.55
193	55	*Lannea acida*	7.20	KN2	87.00	3.00	27.69
194		*Isoberlina doka*	4.90	KN2	45.00	7.00	14.32
195		*Azanza azanza*	3.20	KN2	37.00	5.00	11.78
196		*Parkia biglobosa*	8.70	KN2	79.00	3.00	25.14
197	56	*Ficus glumosa/capensis*	11.20	KN2	89.00	4.50	28.33
198		*Lannea acida*	7.50	KN2	126.00	6.40	40.10
199		*Isoberlina doka*	6.90	KN2	118.00	2.40	37.56
200		*Isoberlina tormentosa*	5.80	KN2	92.00	3.70	29.28
201	57	*Vitellaria paradoxa*	9.50	KN2	106.00	4.90	33.74
202		*Azanza azanza*	3.50	KN2	37.00	6.30	11.78
203		*Anona senegalensis*	2.70	KN2	32.00	2.00	10.18
204		*Nuclea latifolia*	9.70	KN2	102.00	5.90	32.46
205	58	*Lannea acida*	7.20	KN2	81.00	5.30	25.78
206		*Isoberlina tormentosa*	6.80	KN2	79.00	3.00	25.14
207		*Piliostigma thunningii*	2.10	KN2	17.00	7.00	5.41
208		*Isoberlina doka*	9.40	KN2	118.00	4.00	37.56
209	59	*Isoberlina doka*	10.80	KN2	154.00	6.40	49.01
210		*Combretum kerstingii*	6.40	KN2	69.00	4.10	21.96
211		*Piliostigma thunningii*	2.24	KN2	31.00	2.20	9.87
212		*Terminalia glicocen*	5.20	KN2	65.00	1.30	20.69

213	60	*Azanza azanza*	4.20	KN3	32.00	0.90	10.18
214		*Vitex doniana*	7.60	KN3	83.00	3.70	26.42
215		*Nuclea latifolia*	6.50	KN3	85.00	2.50	27.05
216		*Piliostigma thunningii*	2.10	KN3	32.00	4.10	10.18
217	61	*Gardenia aqualla*	3.30	KN4	35.00	5.30	11.14
218		*Piliostigma thunningii*	1.50	KN4	29.00	3.20	9.23
219		*Detarium microcarpum*	6.50	KN4	53.00	5.40	16.87
220		*Cochlospermum planchoni*	3.40	KN4	31.00	2.50	9.87
221	62	*Parkia biglobosa*	6.20	KN2	52.00	2.10	16.55
222		*Isoberlina doka*	14.30	KN2	67.00	4.20	21.32
223		*Isoberlina doka*	8.60	KN2	85.00	4.60	27.05
224		*Vitex doniana*	6.10	KN2	69.00	6.30	21.96
225	63	*Combretum kerstingii*	6.40	KN2	87.00	3.60	27.69
226		*Isoberlina doka*	9.70	KN2	125.00	5.30	39.78
227		*Detarium microcarpum*	6.30	KN2	63.00	4.60	20.05
228		*Gardenia aqualla*	2.20	KN2	33.00	5.70	10.50
229	64	*Vitex doniana*	7.80	KN2	104.00	4.20	33.10
230		*Piliostigma thunningii*	2.00	KN2	16.00	2.40	5.09
231		*Parkia biglobosa*	13.80	KN2	168.00	3.30	53.47
232		*Vitex doniana*	9.90	KN2	137.00	3.20	43.60
233	65	*Entada africana*	6.60	KN2	91.00	5.20	28.96
234		*Detarium microcarpum*	5.40	KN2	73.00	2.80	23.23
235		*Isoberlina doka*	10.20	KN2	167.00	5.40	53.15
236		*Combretum kerstingii*	7.30	KN2	85.00	5.20	27.05
237	66	*Cochlospermum planchoni*	2.70	KN2	32.00	6.40	10.18
238		*Isoberlina doka*	11.50	KN2	146.00	5.00	46.47
239		*Daniellia oliveiri*	12.70	KN2	175.00	2.50	55.70
240		*Prosopis africana*	10.50	KN2	125.00	4.30	39.78

Source: Fieldwork (2015)

Appendix V: Calculation of Shannon Biodiversity index (H) for the study area

Species	Population	Pi=n/N	lnPi	PiLnPi
Anona senegalensis	8	0.04	-3.35	-0.12
Azanza azanza	6	0.03	-3.64	-0.10
Cochlospermum planchoni	8	0.04	-3.35	-0.12
Combretum kerstingii	6	0.03	-3.64	-0.10
Cussonia barteri	7	0.03	-3.48	-0.11
Daniellia oliveiri	2	0.01	-4.74	-0.04
Detarium microcarpum	8	0.04	-3.35	-0.12
Entada africana	8	0.04	-3.35	-0.12
Ficus glumosa/capensis	2	0.01	-4.74	-0.04
Gardenia aqualla	17	0.07	-2.60	-0.19
Gardenia sokotomiensis	2	0.01	-4.74	-0.04
Isoberlina doka	57	0.25	-1.39	-0.35
Isoberlina tormentosa	20	0.09	-2.43	-0.21
Lannea acida	5	0.02	-3.82	-0.08
Nuclea latifolia	5	0.02	-3.82	-0.08
Parkia biglobosa	7	0.03	-3.48	-0.11
Piliostigma thunningii	25	0.11	-2.21	-0.24
Prosopis africana	8	0.04	-3.35	-0.12
Terminalia glicocen	11	0.05	-3.03	-0.15
Upaca togoensis	3	0.01	-4.33	-0.06
Vitellaria paradoxa	5	0.02	-3.82	-0.08
Vitex doniana	8	0.04	-3.35	-0.12
TOTAL	**228**			-2.69

Biodiversity index ,H, = H = /-2.69/H=2.69

Hmax = Ln (S) = ln (22) = 3.091

Evenness = H / Hmax = 2.69 / 3.901= 0.87

Appendix VII: Calculation of Biodiversity index (H) for KN1, KN2, KN3, and KN4

A.) Calculation of Shannon Biodiversity index (H) for KN1

SPECIES	**No of plants**	**Pi =n/N**	**LN Pi**	**Pi LNPi**
Anona senegalensis	2	0.07	-2.64	-0.19
Azanza azanza	0	0.00	0.00	0.00
Cochlospermum planchoni	1	0.04	-3.33	-0.12
Combretum kerstingii	0	0.00	0.00	0.00
cussonia barteri	1	0.04	-3.33	-0.12
Daniellia oliveiri	0	0.00	0.00	0.00
Detarium microcarpum	0	0.00	0.00	0.00
Entada africana	0	0.00	0.00	0.00
ficus glumosa	0	0.00	0.00	0.00
Gardenia aqualla	5	0.18	-1.72	-0.31
Gardenia sokotomiensis	0	0.00	0.00	0.00
Isoberlina doka	4	0.14	-1.95	-0.28
Isoberlina tormentosa	2	0.07	-2.64	-0.19
Lannea acida	0	0.00	0.00	0.00
Nuclea latifola	0	0.00	0.00	0.00
Parkia biglobosa	1	0.04	-3.33	-0.12
Piliostigma thunningii	7	0.25	-1.39	-0.35
Prosopis africana	1	0.04	-3.33	-0.12
Terminalia glicocen	3	0.11	-2.23	-0.24
Upaca togoensis	1	0.04	-3.33	-0.12
Vitellaria paradoxa	0	0.00	0.00	0.00
Vitex doniana	0	0.00	0.00	0.00
TOTAL	28	1.00	-29.23	-2.14
D = Σ(PiLNPi)		D=H=/-2.143/		2.143
		Hmax = Ln (S=11)		2.397895
		E = H/Hmax	=2.143/2.399	0.893702

B). Calculation of Shannon Biodiversity index (H) for KN2

	SPECIES	No	Pi = n/N	LN Pi	Pi LN(Pi)
1	*Anona senegalensis*	3	0.02	-3.75	-0.09
2	*Azanza azanza*	3	0.02	-3.75	-0.09
3	*Cochlospermum planchoni*	4	0.03	-3.47	-0.11
4	*Combretum kerstingii*	4	0.03	-3.47	-0.11
5	*cussonia barteri*	3	0.02	-3.75	-0.09
6	*Daniellia oliveiri*	2	0.02	-4.16	-0.06
7	*Detarium microcarpum*	4	0.03	-3.47	-0.11
8	*Entada africana*	5	0.04	-3.24	-0.13
9	*Ficus glumosa*	2	0.02	-4.16	-0.06
10	*Gardenia aqualla*	6	0.05	-3.06	-0.14
11	*Gardenia sokotomiensis*	1	0.01	-4.85	-0.04
12	*Isoberlina doka*	34	0.27	-1.33	-0.35
13	*Isoberlina tormentosa*	11	0.09	-2.45	-0.21
14	*Lannea acida*	5	0.04	-3.24	-0.13
15	*Nuclea latifola*	3	0.02	-3.75	-0.09
16	*Parkia biglobosa*	5	0.04	-3.24	-0.13
17	*Piliostigma thunningii*	11	0.09	-2.45	-0.21
18	*Prosopis africana*	6	0.05	-3.06	-0.14
19	*Terminalia glicocen*	6	0.05	-3.06	-0.14
20	*Upaca togoensis*	1	0.01	-4.85	-0.04
21	*Vitellaria paradoxa*	4	0.03	-3.47	-0.11
22	*Vitex doniana*	5	0.04	-3.24	-0.13
	S = 22	128	1.00	-75.28	-2.70

D=H=/-2.702/	2.702
Hmax = Ln (S)	3.09104
Evenness, E =H/Hmax	0.87415

C. Calculation of Shannon Biodiversity index (H) for KN3

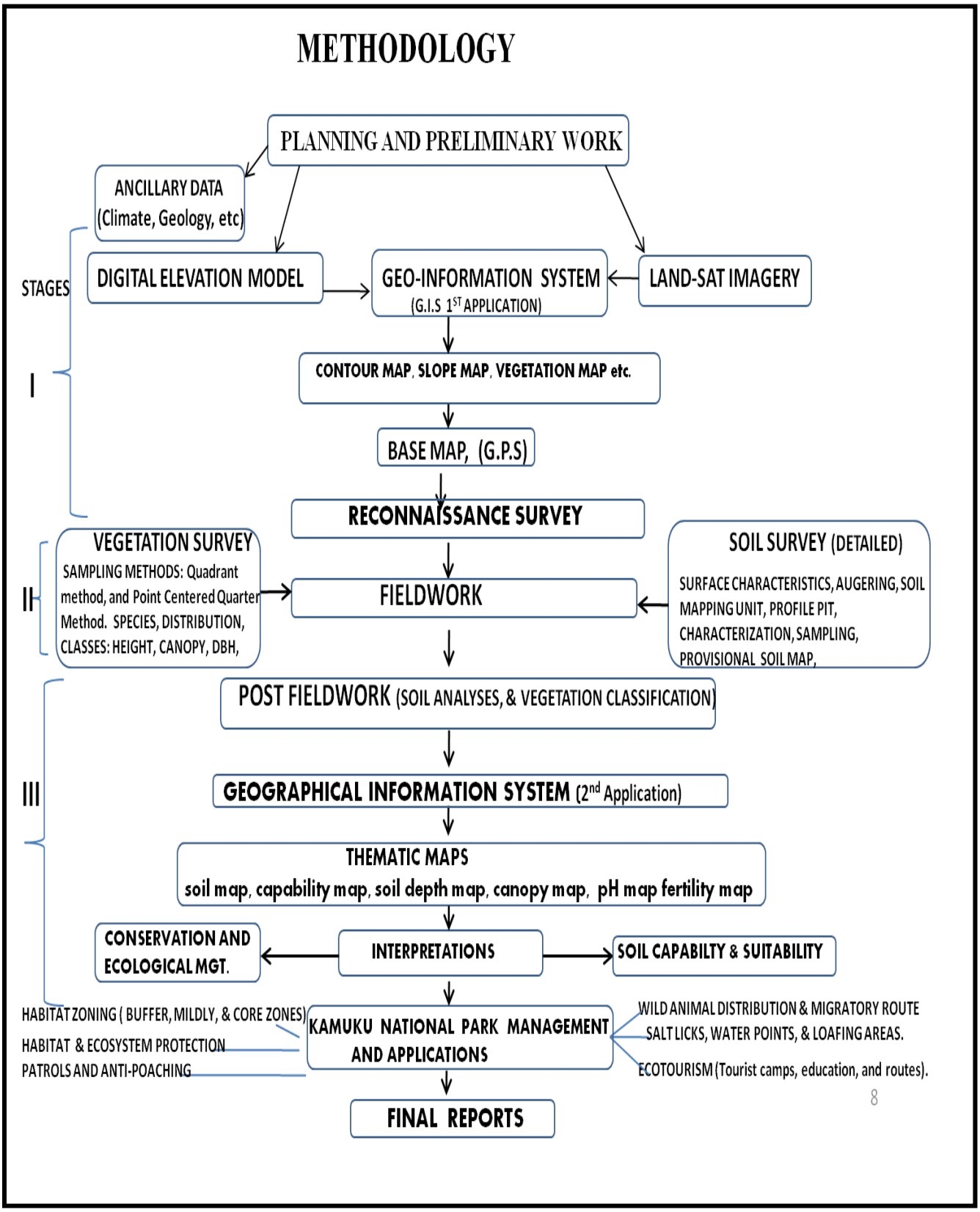
SPECIES	NO	Pi = n/N	LN Pi	Pi LNPi
Anona senegalensis	2	0.05	-3.00	-0.15
Azanza azanza	2	0.05	-3.00	-0.15
Cochlospermum planchoni	0	0	0	0
Combretum kerstingii	2	0.05	-3.00	-0.15
cussonia barteri	2	0.05	-3.00	-0.15
Daniellia oliveiri	0	0	0	0
Detarium microcarpum	0	0	0	0
Entada africana	2	0.05	-3.00	-0.15
ficus glumosa	0	0	0	0
Gardenia aqualla	2	0.05	-3.00	-0.15
Gardenia sokotomiensis	1	0.03	-3.69	-0.09
Isoberlina doka	11	0.28	-1.29	-0.36
Isoberlina tormentosa	3	0.08	-2.59	-0.19
Lannea acida	0	0.00	0.00	0.00
Nuclea latifola	1	0.03	-3.69	-0.09
Parkia biglobosa	1	0.03	-3.69	-0.09
Piliostigma thunningii	5	0.13	-2.08	-0.26
Prosopis africana	0	0	0	0
Terminalia glicocen	2	0.05	-3.00	-0.15
Upaca togoensis	1	0.03	-3.69	-0.09
Vitellaria paradoxa	0	0	0	0
Vitex doniana	3	0.08	-2.59	-0.19
TOTAL	40	1.00	-44.28	-2.42
S=15				
		D=H=/-2.42/		2.421
		Hmax = Ln (S)		2.70805
		E = H/Hmax		0.89348

D. Calculation of Shannon Biodiversity index (H) for KN4

SPECIES	No	Pi = n/N	LN Pi	Pi LNPi
Anona senegalensis	1	0.03	-3.47	-0.11
Azanza azanza	1	0.03	-3.47	-0.11
Cochlospermum planchoni	3	0.09	-2.37	-0.22
Combretum kerstingii	0	0.00	0.00	0.00
cussonia barteri	1	0.03	-3.47	-0.11
Daniellia oliveiri	0	0.00	0.00	0.00
Detarium microcarpum	4	0.13	-2.08	-0.26
Entada africana	1	0.03	-3.47	-0.11
ficus glumosa	0	0.00	0.00	0.00
Gardenia aqualla	4	0.13	-2.08	-0.26
Gardenia sokotomiensis	0	0.00	0.00	0.00
Isoberlina doka	8	0.25	-1.39	-0.35
Isoberlina tormentosa	4	0.13	-2.08	-0.26
Lannea acida	0	0.00	0.00	0.00
Nuclea latifola	1	0.03	-3.47	-0.11
Parkia biglobosa	0	0.00	0.00	0.00
Piliostigma thunningii	2	0.06	-2.77	-0.17
Prosopis africana	1	0.03	-3.47	-0.11
Terminalia glicocen	0	0.00	0.00	0.00
Upaca togoensis	0	0.00	0.00	0.00
Vitellaria paradoxa	1	0.03	-3.47	-0.11
Vitex doniana	0	0.00	0.00	0.00
TOTAL	32	1.00	-37.02	-2.28

D=H=/-2.28/	2.28
Hmax = Ln (S)	2.56495
E = H/Hmax	0.88877

Appendix VI : Flowchart showing research methodology



Appendix VII: Vegetation parameters of various soil units in the study area

Vegetation parameters of soil mapping unit KN1

Species	No of plants	Height	DBH (cm)	Basal Area (cm^2/ha)	Rel. freq	Spp density	Rel. density	Spp popn	Spp cover	Rel. Cover	I.V
Anona senegalensis	2	2.95	10.19	82.765	8.70	32.69	7.14	980.57	0.27	1.01	16.85
Cochlospermum planchoni	1	3.00	10.82	92.01	4.35	16.34	3.57	490.29	0.15	0.56	8.48
Cussonia barteri	1	7.50	42.97	1450.83	4.35	16.34	3.57	490.29	2.37	8.83	16.75
Gardenia aqualla	5	3.24	10.38	86.42	17.39	81.71	17.86	2451.43	0.71	2.63	37.88
Isoberlina doka	4	6.90	39.94	1258.09	13.04	65.37	14.29	1961.14	8.22	30.63	57.96
Isoberlina tormentosa	2	6.60	40.58	1295.53	8.70	32.69	7.14	980.57	4.23	15.77	31.61
Parkia biglobosa	1	6.70	41.37	1344.79	4.35	16.34	3.57	490.29	2.20	8.19	16.10
Piliostigma thunningii	7	2.57	9.69	73.88	17.39	114.40	25.00	3432.00	0.85	3.15	45.54
Prosopis africana	1	8.60	41.69	1365.89	4.35	16.34	3.57	490.29	2.23	8.31	16.23
Terminalia glicocen	3	6.07	34.69	953.53	13.04	49.03	10.71	1470.86	4.68	17.41	41.17
.Upaca togoensis	1	4.60	27.05	575.06	4.35	16.34	3.57	490.29	0.94	3.50	11.42
TOTAL	**28.00**		**309.36**	**8578.80**	**100.00**	**457.60**	**100.00**	**13728.00**	**26.85**	**100.00**	**300.00**

Vegetation parameters of soil mapping unit KN2

Species	Height (m)	Dbh (cm)	Basal Area(cm2)	No of plant	Rel freq	Spp density	Rel. density	Spp popn	Spp cover	Rel. Cover	I.V
Anona senegalensis	2.87	9.33	68.77	3.00	2.63	12.23	2.34	1206.31	0.08	0.23	5.21
Azanza azanza	3.30	9.87	82.22	3.00	2.63	12.23	2.34	1206.31	0.10	0.28	5.25
Cochlospermum planchoni	2.40	10.74	91.11	4.00	2.63	16.31	3.13	1608.41	0.15	0.41	6.16
Combretum kerstingii	6.48	22.76	429.40	4.00	3.51	16.31	3.13	1608.41	0.70	1.92	8.56
Cussonia barteri	9.77	42.33	1524.17	3.00	2.63	12.23	2.34	1206.31	1.86	5.12	10.10
Daniellia oliveiri	11.15	46.15	1533.99	2.00	1.75	8.16	1.56	804.21	1.25	3.44	6.75
Detarium microcarpum	5.30	17.98	268.82	4.00	3.51	16.31	3.13	1608.41	0.44	1.20	7.84
Entada africana	6.24	27.69	617.11	5.00	4.39	20.39	3.91	2010.52	1.26	3.46	11.75
Ficus glumosa	10.45	27.85	609.56	2.00	1.75	8.16	1.56	804.21	0.50	1.37	4.68
Gardenia aqualla	2.83	9.92	77.83	6.00	5.26	24.47	4.69	2412.62	0.19	0.52	10.47
Gardenia sokotomiensis	3.20	13.69	147.17	1.00	0.88	4.08	0.78	402.10	0.06	0.16	1.82
Isoberlinia doka	9.02	35.35	1096.57	34.00	19.30	138.66	26.56	13671.51	15.20	41.76	87.62
Isoberlina tormentosa	8.05	31.65	925.57	11.00	9.65	44.86	8.59	4423.13	4.15	11.40	29.65
Lannea acida	7.00	29.73	718.74	5.00	4.39	20.39	3.91	2010.52	1.47	4.03	12.32
Nuclea latifolia	9.43	37.34	1105.11	3.00	2.63	12.23	2.34	1206.31	1.35	3.71	8.69
Parkia biglobosa	9.04	32.21	935.02	5.00	4.39	20.39	3.91	2010.52	1.91	5.24	13.53
Piliostigma thunningii	2.27	8.19	54.52	11.00	9.65	44.86	8.59	4423.13	0.24	0.67	18.91
Prosopis africana	6.77	22.33	446.24	6.00	5.26	24.47	4.69	2412.62	1.09	3.00	12.95
Terminalia glicocen	6.65	25.78	530.19	6.00	5.26	24.47	4.69	2412.62	1.30	3.56	13.51
Upaca togolensis	6.30	20.37	16.01	1.00	0.88	4.08	0.78	402.10	0.01	0.02	1.68
Vitellaria paradoxa	9.05	32.54	874.82	4.00	3.51	16.31	3.13	1608.41	1.43	3.92	10.55

Vitex doniana	7.76	31.44	817.00	5.00	3.51	20.39	3.91	2010.52	1.67	4.58	11.99
Total				**128.00**		**522.00**		**51469.20**			

Vegetation parameters of soil mapping unit KN3

Species	**Height**	**Dbh**	**B.A (cm sq/ha)**	**No of plant**	**Rel freq**	**spp density**	**rel. density**	**spp popn**	**Spp cover**	**Rel. Cover**	**I.V**
Anona senegalensis	2.70	10.82	92.09	2.00	5.88	24.10	5.00	795.30	0.22	0.67	11.55
Azanza azanza	3.15	10.66	89.50	2.00	5.88	24.10	5.00	795.30	0.22	0.65	11.53
Combretum kerstingii	5.20	17.98	281.32	2.00	5.88	24.10	5.00	795.30	0.68	2.03	12.91
Cussonia barteri	7.55	31.67	821.44	2.00	5.88	24.10	5.00	795.30	1.98	5.93	16.82
Entada Africana	5.00	22.28	482.01	2.00	5.88	24.10	5.00	795.30	1.16	3.48	14.36
Gardenia aqualla	3.25	11.46	103.47	2.00	5.88	24.10	5.00	795.30	0.25	0.75	11.63
Gardenia Sokotomiensis	2.70	12.09	114.93	1.00	2.94	12.05	2.50	397.65	0.14	0.42	5.86
Isoberlina doka	7.08	39.52	1287.07	11.00	20.59	132.55	27.50	4374.15	17.06	51.13	99.22
Isoberlina tormentosa	5.73	30.13	749.23	3.00	8.82	36.15	7.50	1192.95	2.71	8.12	24.44
Nuclea latifolia	6.50	27.05	575.06	1.00	2.94	12.05	2.50	397.65	0.69	2.08	7.52
Parkia biglobosa	6.90	38.19	1146.13	1.00	2.94	12.05	2.50	397.65	1.38	4.14	9.58
Piliostigma thunningii	2.10	10.76	91.29	5.00	11.76	60.25	12.50	1988.25	0.55	1.65	25.91
Terminalia glicocen	5.65	39.79	1251.59	2.00	2.94	24.10	5.00	795.30	3.02	9.04	16.98

Upaca togolensis	5.30	26.73	561.60	1.00	2.94	12.05	2.50	397.65	0.68	2.03	7.47
Vitex doniana	7.27	29.18	729.57	3.00	8.82	36.15	7.50	1192.95	2.64	7.90	24.23
				40.0		**482.00**		**15906.0**			

Vegetation parameters of soil mapping unit KN4

Species	**Height**	**Dist. (m)**	**Dbh**	**B.A**	**No of plant**	**Rel. freq**	**spp density**	**Rel. density**	**Spp popn**	**Spp cover**	**Rel. Cover**	**I.V**
Anona senegalensis	3.50	2.70	9.87	76.49	1.00	3.45	16.09	3.13	618.00	0.12	0.31	6.89
Azanza azanza	4.30	4.70	10.82	91.97	1.00	3.45	16.09	3.13	618.00	0.15	0.38	6.95
Cochlospermum planchoni	2.80	3.10	9.97	78.46	3.00	10.34	48.28	9.38	1854.00	0.38	0.97	20.69
Cussonia barteri	10.90	5.30	53.15	2219.5	1.00	3.45	16.09	3.13	618.00	3.57	9.12	15.69
Detarium microcarpum	5.18	3.83	19.89	352.90	4.00	13.79	64.38	12.50	2472.00	2.27	5.80	32.09
Entada africana	6.30	4.60	34.05	911.18	1.00	3.45	16.09	3.13	618.00	1.47	3.74	10.32
Gardenia aqualla	2.94	5.13	9.95	78.23	4.00	10.34	64.38	12.50	2472.00	0.50	1.29	24.13
Isoberlina doka	8.10	4.59	37.88	1290.0	8.00	24.14	128.75	25.00	4944.00	16.61	42.39	91.53
Isoberlina tormentosa	7.18	4.55	41.30	1396.4	4.00	10.34	64.38	12.50	2472.00	8.99	22.94	45.79
Nuclea latifolia	9.60	4.00	49.97	1961.8	1.00	3.45	16.09	3.13	618.00	3.16	8.06	14.63
Piliostigma	1.90	5.10	10.03	79.44	2.00	6.90	32.19	6.25	1236.00	0.26	0.65	13.80

thunningii												
Prosopis africana	6.80	6.00	22.60	401.38	1.00	3.45	16.09	3.13	618.00	0.65	1.65	8.22
Vitellaria paradoxa	6.70	3.50	28.96	659.13	1.00	3.45	16.09	3.13	618.00	1.06	2.71	9.28
TOTAL					**32.00**		**515.00**		**19776.0**			