BIOMASS AND CARBON STOCK DENSITY OF KPASHIMI FOREST RESERVE AND ADJOINING PARKLAND AREA, NIGER STATE, NIGERIA

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DEPARTMENT OF GEOGRAPHY, FACULTY OF SCIENCE,
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MAY, 2016

DECLARATION

I declare that the work in this thesis entitled 'Biomass and Carbon Stock Density of Kpashimi Forest Reserve and adjoining Parkland Area, Niger State, Nigeria' has been carried out by me in the Department of Geography. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other institution.

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……	……..	……
Name of student	Signature	Date

CERTIFICATION

This thesis entitled 'BIOMASS AND CARBON STOCK DENSITY OF KPASHIMI FOREST RESERVE AND ADJOINING PARKLAND AREA, NIGER STATE, NIGERIA' by Abdullahi JIBRIN meets the regulations governing the award of the degree of PhD Geography of Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.

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Dean, School of Postgraduate Studies Signature Date

DEDICATION

This work is dedicated to my late father- Alhaji Adamu Jibrin, who inspired me, sowed the seed and laboured for my education but did not live to witness the completion of this Ph.D work. May Allah (SWA) reward you with Jannatul Firdaus.

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ABSTRACT

Climate change, during the last decades, has increased the need for information on the amount of forest biomass and carbon stocks. The international concern for carbon emissions and sequestration assessments require adequate coverage of locally quantified carbon stocks. However, the dearth of data on quantitative biomass/carbon stock measurements coupled with the uncertainties associated with extrapolated biome average values, in tropical savannas have resulted in a significant gap in the carbon budget of Kpashimi forest reserve and adjoining parkland area. Current estimates for tropical savannas in Nigeria are based on biome average values plagued by uncertainties associated with inaccurate and incomplete measurement of forest carbon pools. Against this background, the aim of this study was to assess the biomass and carbon stock density of Kpashimi Forest Reserve and adjoining parkland area in Niger State, Nigeria. Biometric forest inventory techniques, direct biomass sampling and laboratory analysis methods were employed for data collection. Eight plant communities inventoried include Savanna Woodland, Riparian Forest, Tree Savanna, Scrubland, Grassland, Agroforestry, Old Fallow Land, and Recent Fallow land. The parameters measured include Tree Density, Species Richness, Shannon Wiener Diversity Index, Species per Plot, Tree Crown Cover, Shrub Cover, Grass Cover, Tree Height, Diameter at Breast Height, Basal Area and Biomass. Carbon stock was measured from six major pools (above ground tree, undergrowth, dead wood, litter, root and soil). Measurement of plant community characteristics was carried out in 45 quadrat sampling plots of 500 m^2. Four fixed size square frames encompassing $1m^2$ was used for the undergrowth (shrubs and grasses) and litter. Composite soil samples (for organic carbon) and undisturbed samples (for bulk density) were taken from each of the $1m^2$ subplot quadrants at two depths (0-15cm and 15-30cm). Descriptive statistics was used to summarize the data

while variation in carbon stock densities among plant communities across study area were tested by use of analysis of variance (ANOVA). The student's *t* –test was used to test for differences in carbon stock and vegetation parameters between pairs of vegetation communities and specifically between the forest reserve and parkland, while stepwise multiple regression analysis was used in identifying key predictors of carbon stock in the study area.

Results obtained revealed that, ecologically dominant tree species in the study area in descending order are *Vitalleria paradoxa*, *Irvingia gabonensis*, *Parkia biglobosa*, *Anogeissus leiocarpus*, *Pterocarpus erinaceous*, *Detarium microcarpum*, *Prosopis africana*, *Danellia oliveri*, and *Afzelia Africana*; which together account for about 65.2 % of total species. The distribution of structural attributes of tree species height, Diameter at Breast Height (DBH), basal area, and biomass produced a reverse "J" shaped curves which shows that the area is dominated by regenerating saplings and seedlings. The Shannon-Wienner index values obtained in this study lie between 2.30 and 2.78; which indicates that the study area is generally characterized by medium biodiversity. The mean tree stand density (stem per hectare) was 244-935 stems/ha. Tree crown cover is in the range of 13- 55 %. The mean tree height in the study area was 17.1 metre. The mean tree diameter at breast height (DBH) recorded in the study area was 25.62 cm. Both ANOVA and *t*-test statistics revealed that there were significant differences in all parameters measured between pairs of plant communities and over the entire study area.

The mean carbon stocks of plant communities, in decreasing order, are Savanna woodland (127.30 Mg ha^{-1}), Riparian Forest (116.31 Mg ha^{-1}), Tree Savanna (114.44 Mg ha^{-1}), Scrubland (111.47 Mg ha^{-1}), Grassland (106.72 Mg ha^{-1}), Agroforestry (78.53 Mg ha^{-1}), Old Fallow Land (72.50 Mg ha^{-1}), and Recent Fallow land (66.31 Mg ha^{-1}).

The ANOVA indicates significant differences in carbon stock across the respective plant communities; where $F(7,37) = 160.69$, $P<0.01$. Similarly, the student *t*–test revealed that there is significant difference in carbon stock density between the forest reserve and parkland study sites where $t\ (43) = 18.34$, $p < 0.001$). The results also revealed that DBH, tree density, and basal area are the best predictors of carbon stock in the study area; with the stepwise multiple regression analysis final model being statistically significant where $F(3,41) = 173.9$, $P <0.05$. The dominance of regenerating saplings implies that there is tremendous capacity for the study area to store carbon and act as carbon sink if properly managed. The study recommends carbon offset trading projects by local communities, which will provide window of opportunities for accessing carbon credits through the Clean Development Mechanism tool of the Kyoto Protocol under the United Nations Framework Convention on Climate Change.

TABLE OF CONTENTS

	Page
Title Page …….	i
Declaration……	ii
Certification……..	iii
Dedication…….	iv
Acknowledgement……	v
Abstract……	viii
Table of Contents……..	xi
List of Figures……...	xv
List of Tables……	xvi
List of Plates…….	xvii
List of Appendices……	xvii
Abbreviations……	xix
**1.0 CHAPTER ONE: INTRODUCTION…….....	1
1.1 Background of the study……..	1
1.2 Statement of the research Problem…….	5
1.3 Aim and Objectives of the study…….	11
1.4 Research Hypothesis…….	11
1.5 Scope of the study…….	11
1.6 Justification for the study……	12
2.0 CHAPTER TWO: CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW	15
2.1 Conceptual Framework……...	15

2.1.1 Ecosystem Primary Productivity…… 15

2.1.2 Structure and Composition of Plant Communities……. 17

2.1.3 The Principles of Ecological Amplitude and Environmental Heterogeneity…….. 18

2.1.4 The Forest Carbon pools……. 21

2.1.5 Forest Carbon Cycle and Climate change…….. 24

2.1.6 Role of forests as carbon sinks……... 26

2.2 Review Of Literature…….. 27

2.2.1 Overview of Global Biomass/Carbon stock estimates……... 27

2.2.2 Carbon stock densities of biomes…….. 32

2.2.3 Carbon stock estimates of Nigeria …… 36

2.2.4 Techniques of monitoring Biomass/Carbon in Forests……. 36

2.2.5 Estimation of carbon stock in specific forest carbon pools…… 40

2.2.6 Summary of Literature Review…….. 43

3.0 CHAPTER THREE: ENVIRONMENT OF STUDY AREA…….. 45

3.1 Location…… 45

3.2 Settlement and Population …… 46

3.3 Climate……. 47

3.4 Geology…… 51

3.5 Relief, Geomorphology and Drainage…….. 52

3.6 Soils ……. 53

3.7 Vegetation……. 56

3.8 Landuse …….. 58

3.9 Land Degradation …….. 61

4.0 CHAPTER FOUR: MATERIALS AND METHODS……..... 63

4.1 Research Design and Methodology …….. 63

4.2 Types and Sources of Data …… 63

4.2.1 Reconnaissance Survey**……..** 66

4.2.2 Major vegetation communities used for sampling frame**……...** 67

4.2.3 Pilot Field Survey**……...** 69

4.2.4 Detailed Field Survey **……** 71

4.2.4.1 *Size of Sample Plots* **……** 71

4.2.4.2 *Determination of Sample size***…….** 72

4.2.4.3 *Location of sample plots***…….** 73

4.2.4.4 *Analysis of satellite imagery data***……** 74

4.2.4.5 *Laying of Sampling Plot***…….** 78

4.2.4.6 *Equipment and Instruments***…….** 79

4.2.4.7 *Measurement of plant community characteristics***……..** 80

4.3 Sampling of Tree Biomass (Phytomass) …….. 83

4.3.1 Selection of Tree Species and DBH range for phytomass sampling**……** 83

4.3.2 Procedures of tree biomass sampling**…….** 85

4.3.3 Laboratory analysis of phytomass samples**……** 87

4.4 Assessment of Carbon Stock…….. 87

4.4.1 Above Ground Tree Phytomass**…….** 89

4.4.2 Undergrowth Phytomass**……** 90

4.4.3 Dead wood Necromass**……...** 90

4.4.4 Litter Necromass**…….** 92

4.4.5 Tree Root Phytomass**……..** 94

4.4.6 Soil Organic Carbon**……...** 94

4.5 Methods of Data Analysis…….. 98

5.0 CHAPTER FIVE: RESULTS AND DISCUSSION……..... 100

5.1 Floristic Composition and Structure of Plant Communities…….. 100

5.1.1 Composition of Woody Species over the study area……..... 100

5.1.2 Species Importance Value……..... 102

5.1.3 Structure of woody species over the study area……..... 104

5.1.4 Biomass of the most dominant tree species……..... 106

5.1.5 Characteristics of Plant communities……..... 108

5.2 Carbon Stock Density……..... 115

5.2.1 Carbon stock density of vegetation communities……..... 115

5.2.2 Carbon stock in pools over the study area……..... 118

5.2.3 Exploration of Carbon stock Predictors……..... 122

5.3 Discussion……..... 125

6.0 CHAPTER SIX: SUMMARY, CONCLUSION AND RECOMMENDATION 131

6.1 Summary……..... 131

6.2 Conclusion……..... 137

6.3 Recommendations……..... 140

REFERENCES……..……..... 142

APPENDICES…… 168

LIST OF FIGURES

Page

Figure 2.1: Terrestrial Global Carbon Balance……..... 16

Figure 2.2: Schematic diagram of the chain of processes that contribute towards vegetation biomass storage. ……..... 17

Figure 2.3: Forest Carbon Pools……..... 22

Figure 2.4: Grouping of the Carbon Pools……..... 22

Figure 2.5: Generalized Carbon Pools and flows of terrestrial ecosystems…… 24

Figure 2.6: The carbon cycle in the forest……..... 25

Figure 3.1: Location of Kpashimi Forest Reserve and Parkland area……. 45

Figure 3.2: Location of settlements and roads in the study area……..... 47

Figure 3.3: Mean monthly rainfall pattern in Minna (1916-2015) ……..... 49

Figure 3.4: Yearly Rainfall trend over Minna (1916 – 2015) ……..... 49

Figure 3.5 :Mean monthly temperature in Minna (1951-2015) ……..... 50

Figure 3.6: Yearly Temperature trend in Minna (1951-2015) ……..... 50

Figure 3.7: Relief and Drainage system Kpashimi forest reserve……..... 52

Figure 4.1: Flow chart of methodology adopted for the study……..... 65

Figure 4.2: Classified Nigeria Sat 1 Image of the Study Area……..... 75

Figure 4.3: Flowchart of procedures for measuring major carbon pools…… 89

Figure 5.1: Distribution of woody species structural classes……..... 105

Figure 5.2: Comparison of biomass of the five most dominant tree species…….. 107

Figure 5.3: Percentage distribution of the mean carbon stock in the respective pools... 120

LIST OF TABLES

Page

Table 4.1: Types and sources of data acquired for the study..... 64

Table 4.2: Plot radii for carbon inventory plots……..... 72

Table 4.3: Determination of required sample size for the study……..... 73

Table 4.4: Proportional sample allocation over plant communities in the forest reserve 76

Table 4.5: Distribution of sample plots and their coordinates……..... 77

Table 4.6: Selected species with the highest Species importance value index (S.I.V.) 84

Table 4.7: DBH Class Groups of Tree Biomass Sample……..... 84

Table 4.8: Carbon components and Pools measured……..... 88

Table 5.1: Floristic Composition of Woody Species over the Study Area…… 101

Table 5.2: Species Importance Value Index over the study area……..... 102

Table 5.3: Summary statistics of characteristics of Plant community……..... 109

Table 5.4: Results of student's *t*-test on parameters between pairs of plant communities 114

Table 5.5: Carbon stock density of vegetation communities (Mg ha^{-1}) ……..... 116

Table 5.6: Result of Student's t-test Analysis of carbon stock between pairs of plant communities……..... 117

Table 5.7: Summary of carbon stock density in pools (Mg ha^{-1}) ……..... 119

Table 5.8: Results of multiple regressions with stepwise variable selection…… 123

Table 5.9: Stepwise regression final results……..... 123

LIST OF PLATES

Page

Plate I: Tracking study area boundary using GPS……..... 67

Plate II: Forest Reserve vegetation communities used for sampling frame…….. 68

Plate III: Parkland vegetation communities used for sampling frame……..... 69

Plate IV: Locating a sampling plot with the aid of a GPS receiver..... 78

Plate V: Laying out a 500m^2 Plot……..... 78

Plate VI: Instruments used for measurements……..... 79

Plate VII: Inventory crew with equipments……..... 79

Plate VIII: Measuring Girth at Breast Height……..... 80

Plate IX: (a) Felling (b) cutting and (c) sorting of trees component parts…… 85

Plate X: (a) Trimming into billets and (b) Spring balance bipod system for weighing… 86

Plate XI: (a) Extraction of aliquots and (b) Labelling of the disc aliquots…… 86

Plate XII: (a) Oven drying of dead wood and aliquots and (b) Oven drying of Leaves, undergrowth and litter……..... 87

Plate XIII: (a) Determination of 1m^2 quadrat and (b) fresh weight of undergrowth…… 90

Plate XIV: (a) Measurement of rotten dead wood and (b) intermediate sound deadwood…….. 91

Plate XV: Samples of dead wood collected for oven drying shown in decomposition classes…… 91

Plate XVI: (a) Collection from quadrat and (b) taking fresh weight of litter…… 93

Plate XVII: Collection soil sample for organic carbon analysis……..... 96

Plate XVIII: Collection of soil sample for bulk density……..... 97

LIST OF APPENDICES

Page

Appendix I: Coordinates of Sampling Points……... 168

Appendix II: Summary of Plant Structural Characteristics in Forest Reserve and Parkland…… 169

Appendix III: Summary of Crown cover, Shrub Cover, and Grass Cover in the Forest Reserve and Parkland…….. 170

Appendix IV: Summary of Plant community Composition and Diversity in the Forest Reserve and Parkland……. 171

Appendix V: Summary of data on sampled phytomass of tree components…… 172

Appendix VI: Summary of Data on Parameters of Soil Carbon Stock in the Forest Reserve and Parkland……. 173

Appendix VII: Mean carbon stock in the respective forest carbon pools…… 174

Appendix VIII: Data Sheet for Pilot Survey…… 175

Appendix IX: Data sheet- Tree and Roots…… 176

Appendix X: Data sheet- Undergrowth…… 178

Appendix XI: Data sheet- Dead wood…….. 179

Appendix XII: Data sheet- Litter…….. 180

Appendix XIII: Data sheet- Soil……... 181

Appendix XIV: Data Sheet – Tree Crown, Shrub and Grass Cover……. 182

Appendix XV: Data-Sheet- Laboratory analysis of subsamples…….. 183

Appendix XVI: Data Sheet – Laboratory analysis of Sampled Tree Phytomass……. 184

Appendix XVII: Sample Labelling Codes…… 185

Appendix XVIII: List of Tree Species…….. 186

LIST OF ABBREVIATIONS

AGB	Above Ground Biomass
AGF	Agroforestry
ANOVA	Analysis of Variance
BA	Basal Area
BGB	Below Ground Biomass
C	Carbon
CDM	Clean Development Mechanism
CO_2	Carbon dioxide
DBH	Diameter at Breast Height
FAO	Food and Agriculture Organization
FDF	Federal Department of Forestry
FGN	Federal Government of Nigeria
FPAN	Forest Philanthropy Action Network
GBH	Girth at Breast Height
GC	Grass Cover
GHG	Greenhouse gas
GL	Grassland
GPG	Good Practice Guidance
GPP	Gross Primary Productivity
GPS	Global Positioning System
GtC	Giga tons of Carbon
ha^1	Per hectare
IPCC	Inter-governmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
Kg	Kilogram
Mg	Megagram
MtC	Million tons of Carbon
NPP	Net Primary Production
OFL	Old Fallow Land
ppm	Parts per million
ppmv	Parts per million by volume

RD	Relative Density
RDo	Relative Dominnce
REDD	Reducing Emissions from Deforestation and Degradation
RF	Relative Frequency
RF	Riparian Forest
RFL	Recent Fallow land
SC	Shrub Cover
SEAP	State Environmental Action Plan
SIV	Species Importance Value
SL	Scrubland
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SP	Species per Plot
SR	Species Richness
SW	Savanna Woodland
SWD	Shannon Wiener Diversity Index
TCC	Tree Crown Cover
TD	Tree Density
TH	Tree Height
TS	Tree Savanna
UNFCCC	United Nations Framework Convention on Climate Change
yr	Year

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Carbon (C) is one of the naturally occurring chemical elements on earth. It exists as carbon dioxide (CO_2) in the atmosphere and constitutes about 0.04% of atmospheric gasses (Barry and Chorley, 1971; Strahler, 2003). In the recent past, CO_2 has gained a lot of attention as a greenhouse gas (GHG) that has potential to influence global climate pattern. Forests are terrestrial sink of atmospheric carbon dioxide and play a central role in regulating the exchange of this important greenhouse gas between atmosphere and the biosphere (Houghton, 1999; Malhi, Baldocchi and Jarvis, 1999). Estimating forest carbon stock is thus of paramount importance to assessing the mitigation effects of forests on global warming and climate change.

Biomass and carbon result from the synthesis of organic matter. Through photosynthesis, plants convert CO_2 from atmosphere into vegetal tissues by trapping the carbon into their biomass. Therefore, an accurate measurement of forest carbon is difficult to obtain without precise measurements of biomass (Malhi *et al.*, 1999; Inter-governmental Panel On Climate Change- IPCC, 2007). Consequently, estimation of the magnitude of forests as carbon sinks or sources requires accurate and reliable estimate of biomass density of the forests (Houghton, 1999; Brown, 2002; Cairns, Olmsted, Granados and Argaez, 2003). Since carbon stocks estimations are generally determined by estimation of forest biomass, more attention is being received by forest biomass estimation in recent years; as the change in biomass of a region is associated with vital components of climate change (Houghton, 1999, 2006; Malhi *et al.*, 1999).

Quantification and monitoring of carbon stock has also gained major attention in international climate change mitigation and adaptation negotiations (Houghton, 2005a; IPCC, 2006), because verification and accounting of carbon stock in forest ecosystems have been recognised as potential strategies to reduce and stabilize atmospheric greenhouse gas concentrations (IPCC, 2001; IPCC, 2007; UNFCCC, 2009, 2010). Strategically, the role of tropical forests in global carbon cycle and its potential to reduce increasing carbon dioxide by photosynthesis has made it crucial to estimate the carbon stock of these forests (Brown, 1997; IPCC, 2006). In the context of Kyoto protocol, forests are considered important for their unique role as carbon sinks (FAO, 2005a). Specifically, Article 3.3 and 3.4 of the Kyoto protocol pointed out forests as potential carbon storage (United Nations, 1998; Brown, 2002). Furthermore, Article 2 of the Kyoto protocol advocates for inventory of carbon sinks and quantification of carbon stocks in different ecosystems (IPCC, 2003; Houghton, 2005a, 2006). As a result, the ability to accurately and precisely measure the carbon sequestered and stored in forests is increasingly gaining global recognition (Brown, 2002; Kauppi, 2003).

Globally, forests have the largest carbon stock in terrestrial ecosystems; accounting for about 80% of all above ground terrestrial carbon, and about 40% of below ground carbon (Kirschbaum, Fischlin, Cannell, Cruz, Galinski, and Cramer, 1996, 1998; IPCC, 2000; 2007; Bonan, 2008). Tropical forests hold large stores of carbon, yet uncertainty remains regarding their quantitative contribution to the global carbon cycle (Houghton, 1999; Malhi, *et al*., 1999; Houghton, 2005a, 2007; IPCC, 2007). Most information on the role of forests in carbon stock and flux processes amongst plants, soil and atmosphere generally comes from boreal and temperate regions, and tropical America and Asia, while less attention has been given to Africa (Cao, Zhang, and Shugart, 2001).

Owing to the small number of such studies in tropical Africa, this could produce large errors in estimates of the global carbon balance (Houghton, 2005b, 2006).

According to FAO (2005b), 'forest' is technically defined as land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 per cent or trees able to reach these thresholds *in situ*. Based on this definition, most of the ecosystems generally referred to as 'savanna woodlands' in West Africa are considered as forest (Lykke, Barfod, Tinggaard, Svendsen, Greve and Svenning, 2009). The savanna biome is characterised by co-dominance of trees and grasses, but ranges from grasslands where trees are virtually absent to more forest-like woodland ecosystems where trees are dominant (Pullan, 1974). Woodlands are therefore, characterised by a mixture of grasses, shrubs and trees. Parklands are defined as landscapes in which mature trees occur scattered in cultivated or recently fallowed fields (Pullan, 1974; Raison, 1988).

Savannas are one of the world's major terrestrial ecosystems, comprising between 10% and 15% of the world's land surface, depending upon definition (Scholes and Hall, 1996). Distributed across nearly all the continents, they occur in broad bands between the equatorial forests and mid-latitude deserts. Approximately 50% of African continent is savannas; inhabited by over 30% of the world's population (Solbrig *et al*., 1991; 1992), and consequently experience marked impacts from human activities resulting in deforestation and degradation (FAO, 1981, 1995). Further, Veenendaal, Kolle, Lloyd (2004) pointed out that much carbon cycle research has focused on temperate and tropical forests while savannas have been less frequently studied. In addition, savanna ecosystems have been identified to cover a larger area than any forest biome (Prentice *et al.*, 2001) and are a potential carbon sink (Scholes and Hall, 1996; Scurlock and Hall,

1998) due to losses of vegetation and soil organic carbon during the last century (Kurz and Apps, 1999; Grace, San Jose, Meir, Miranda, and Montes, 2006).

Carbon absorbed from the atmosphere is stored as carbon-rich organic compounds; such as cellulose and hemicelluloses, lignin, starch, lipid and waxes, mostly in secondary woody tissues in tree boles and in large roots, as well as in foliage, branches and fine roots. As the forest biomass experiences growth, the carbon held captive in the forest stock increases. Simultaneously, plants grow on the forest floor and add to this carbon store. Over time, branches, leaves and other materials fall to the forest floor and contain carbon until they decompose. Additionally, forest soils sequester some carbon after the decomposition of plant litter and through root / soil interactions (Kirschbaum, 1998; Brown, 2002).

Carbon stock implies the quantity of carbon in a given pool or pools per unit area (Pearson, *et al.*, 2005). Carbon inventory involves the estimation of stocks and fluxes of carbon from different land use systems in a given area over a given period (Ravindranath and Ostwald, 2008). Carbon stock in a given land area is attributed to biomass while biomass is defined as the total amount of live and inert organic matter above and below ground expressed in Megagrams (tonne) of dry matter per unit area (FAO, 2008). Above-ground biomass consists of all biomass life forms including stem, branches, and foliage, shrubs and herbs, dead wood and litter. Below-ground biomass consists of all living plant roots excluding fine roots (less than 2mm in diameter), and soil organic carbon content (IPCC, 2006).

Carbon storage estimates for African forests have been primarily based on extrapolations from a few forest surveys and inventory data from the United Nations Food and Agricultural Organization (FAO) (Brown and Galton, 1995; Cao *et al*., 2001).

Such studies have typically focused on commercially valuable trees, and are often biased towards plots with large diameter trees; which can underestimate carbon storage by ignoring high densities of small trees and/or non-commercial species (Cao *et al*., 2001). Therefore, there is the need for refined estimates of carbon storage in specific sites such as the Kpashimi Forest reserve and adjoining parkland area, in Niger state.

The development and application of allometric equations is the standard methodology for aboveground tree biomass estimation (Brown *et al.*, 1989; Chavé *et al*., 2003). However, measurement methods for carbon storage in tropical forests are still evolving (Cao *et al*., 2001). At regional scales, current allometric data for complex, diverse tropical forests are almost entirely based on Southeast Asian and South American measurements (Brown, 1997; Ketterings *et al*., 2001). For instance, Brown (1997) and Chave *et al.* (2005), reported a set of allometric equations for tropical world forests; however, several sites were not well typified in this dataset (Cao *et al*., 2001; Ketterings *et al*, 2001). In view of the highlighted gaps in knowledge, this study is also an attempt to provide site specific predictor variables that could be used in assessing biomass and carbon stock in the study area; because the site specific allometric equations would be more reliable in predicting forest biomass stocks at the local level as it takes into account the site effects.

1.2 Statement of the Research Problem

Climate change is perhaps the greatest environmental challenge in the twenty-first century that has become a source of major global threat to humanity. It has energized such threats as hunger, poverty, forced migration, soil degradation and desertification (UNFCCC, 2009). Carbon dioxide (CO_2) is one of the more abundant greenhouse gases and a primary agent of global warming. It constitutes 72% of the total anthropogenic

greenhouse gases, causing between 9-26% of the greenhouse effect (Kiehl and Trenberth, 1997). IPCC (2007) reported that the amount of carbon dioxide in the atmosphere has increased from 280 ppm in the pre-industrial era (1750) to 379 ppm in 2005 and continues to rise by 1.5 ppmv per year, contributing 63% of the radiative forcing of climate change.The rapid increase in atmospheric concentration of CO_2 and other greenhouse gases has raised questions on the role of tropical ecosystems as sources or sinks for atmospheric CO_2 (Houghton *et al.,* 2001). Increased levels of carbon dioxide have implications for climate change and consequently there has been much research on carbon 'sinks' or the processes which take up atmospheric carbon. Knowing where these sinks are, their area and their stage or condition in ecological terms is of great importance in helping to mitigate human impact on the carbon cycle.

Understanding the role of forests in greenhouse effect requires a better understanding of biomass and carbon stock at the forest level (Houghton and Hackler, 2001). Organic matter contains carbon susceptible to be oxidized and returned to the atmosphere in form of CO_2. Hence, estimating forest carbon stock is of paramount importance in designing measures for mitigating the effects of forest removal on global warming and climate change. However, poor knowledge of the quantity of biomass in a given ecosystem is one most uncertain factor involved in estimating carbon stock in developing countries (Brown *et al.*, 1989). The spatial distribution of carbon stock in ecosystems is controlled by variation in a number of environmental factors, including tree community composition, disturbance history, successional stage, climate, and soil fertility (Wright, 2005; Malhi *et al.*, 2011; Min *et al.*, 2013). Thus, estimating emissions of carbon dioxide resulting from changes in land cover, use, and management of tropical forests require the quantification of total biomass per unit area. However, lack

of sufficient and reliable inventory data is a significant factor limiting biomass estimates for the tropical forests and savannas.

The international concern for carbon emissions and sequestration assessments require adequate coverage of locally quantified carbon stocks (IPCC, 2006). However, several authors (Brown *et al*., 1989; Kauppi *et al*., 1992; Brown and Lugo, 1992; Chidumayo, 2002; Salis *et al*., 2006; Williams *et al*., 2008; Lewis, 2009) have commented on the relative dearth of quantitative estimates for dry forests and savannah biome relative to moist tropical forests biome. According to Brown and Lugo (1992), forest inventories are valuable sources of data for estimating biomass density, but inventories for the tropics are few in number and their quality is poor. Lewis (2009) noted that very few information on carbon stock are available for tropical forests and savannah woodlands. Similarly, Williams *et al*. (2008), posited that inventories in the tropics are generally inadequate, particularly in view of the high rates of land-use change, fire disturbance, and land degradation which could result in heterogeneous carbon density in such ecosystems.

The role of tropical forests/savannas in the global carbon cycle, and therefore in climate change, is increasingly recognized (Houghton and Hackler, 2006; Williams *et al*., 2007). Evidence from official reports (UNFCCC, 2005a; UNFCCC, 2005b; FAO, 2006) suggest that only a very small number of developing countries currently reports data on carbon stock, though emissions from deforestation and forest degradation are likely to be significant in many cases (Grassi, *et al*., 2008). Deforestation and other land-cover changes typically release carbon from the forests to the atmosphere (by respiration, decomposition and combustion) as CO_2, while regenerating vegetation in abandoned agricultural or logged land removes CO_2 from the atmosphere and sequesters

it in vegetation biomass and in the soil (Saatchi, *et al*., 2007). Emissions from land-use and land-cover change are perhaps the most uncertain component of global carbon cycle, with enormous implications for balancing the present-day carbon budget and predicting future evolution of climate change (Ramankutty, *et al.*, 2007).

Land use practices are closely linked with carbon stock (Hairiah, *et al*., 2001). However, lack of adequate data on spatial variation in carbon stocks in different types of land-uses, and the actual stocks of carbon in ecosystems affected by land-use change are two major sources of uncertainties in carbon estimates; particularly in developing countries (Chambers *et al*., 2001; Houghton *et al*., 2001; Keller *et al*., 2001). That may seriously undermine the credibility of estimates; and therefore, of reduced deforestation as mitigation option (Grassi *et al.*, 2008). It is likely that the most typical and important example of incomplete estimates will arise from the lack of reliable data for carbon stock.

The distribution of forest biomass over tropical forests/savannas vary widely (Fearnside, 1996; Brown, 1997; Houghton, 1997, 2003), and contribute more than any other factor to the uncertainty in estimates of carbon flux from land-cover and land-use change (Houghton *et al*., 2000; Houghton, 2005b). Further, estimates of biomass for tropical forests suffer from uncertainties associated with measurements at individual plots and uncertainties in extrapolating data from individual plots to the entire region; because measurements at individual plots are often incomplete. For instance, the biomass of litter and or understorey vegetation is considered to be small and is sometimes dismissed as negligible (Houghton *et al*., 2001). Full accounting requires measurement of live and dead biomass, above- and belowground biomass, covering all major carbon pools (above ground tree, undergrowth, dead wood, litter, root and soil) which are

sometimes incomplete (Brown and Lugo, 1992; Fearnside, 1996). Measurements at individual plots also suffer from other problems; such as the possible bias of data toward low (accessible) biomass; when samples are restricted to outer perimeter of forests (Brown *et al*., 1995), the possible bias of small plots toward large biomass; by ignoring low diameter trees (Fearnside, 1996) and use of different allometric equations to calculate biomass (Brown and Lugo, 1984, 1992; Chave *et al*., 2005).

Ravilious *et al.* (2010), combined estimates of above - and below- ground biomass and soil organic carbon to 1 metre depth. According to this analysis, a total of 7.5 Gt of carbon is stored in biomass and soils of Nigeria's terrestrial ecosystems. The largest areas of high carbon density were found in the southern parts of the country, mostly along the Niger Delta and in rainforest regions. The highest carbon density class, which holds 20% of the country's carbon, covers 7% of the country's land area. In contrast, Federal Government of Nigeria – FGN (2003), revealed that total carbon stored in the forest formation in Nigeria is estimated to be 2.84 GtC. Of this figure, the moist deciduous forest contributed the most. In terms of carbon stock per hectare, tropical rainforest has the highest value of 197.35 Mg C ha^{-1}, while dry deciduous forest has the least of 125.32 Mg C ha^{-1}. These analysis of carbon stock in Nigeria do not provide the precise quantity of carbon stock in specific plant communities in Nigeria. This is a gap in knowledge which can be filled by quantifying biomass/carbon stock in specific plant communities; which will go a long way in providing a more accurate data on carbon stock in specific plant communities.

According to Federal Department of Forestry, Nigeria FDF (1996), Kio *et al*. (1989), and Food and Agriculture Organization FAO (2010), Nigeria has no reliable data on forest extent, physiognomic characteristics, growth yield, biomass, and carbon stock,

due to limited capacity in terms of number of staff, low level technology and finance to implement regular national forest inventory services. The effect of inadequate forest data is lack of information for making informed management decisions and hence poor forest management. This has deprived the country of ample window of opportunities to access carbon credits under the United Nations Framework Convention on Climate Change- UNFCCC's Clean Development Mechanism of Kyoto protocol (FGN, 2003). Moreover, most quoted biomass/carbon data on vegetation formations are at variance with local realities (Daniel and Ayobami, 2007). Due to the shortfall in biomass and carbon stock research for Nigeria, it is logical that this gap in knowledge be bridged particularly for the savanna ecological areas characterised by heterogenous plant communities. From the foregoing background, this research attempted to provide answers to the following research questions:

a. What are the characteristics of plant communities in the study area?
b. What is the estimate of carbon stock density of respective plant communities in the study area?
c. What is the quantity of carbon stock in the respective major carbon pools in the forest reserve and adjoining parkland area?
d. To what extent is the difference in carbon stock density between the Forest Reserve and adjoining parkland area?
e. What are the best sets of predictors for estimating carbon stock in the study area?

1.3 Aim and Objectives of the Study

The aim of the study was to assess the biomass and carbon stock density of Kpashimi Forest Reserve and adjoining parkland area in Niger State, Nigeria. The specific objectives were to:

i. characterize the various plant communities of the study area,
ii. estimate and compare carbon stock density of plant communities in the study area,
iii. quantify carbon stock in the respective major carbon pools (above ground tree, undergrowth, dead wood, litter, root and soil) in the study area,
iv. compare carbon stock density of Kpashimi Forest Reserve and adjoining parkland area,
v. establish the relationship among key parameters of plant species and carbon stock for the study area.

1.4 Research Hypotheses

This research is guided by the following hypotheses:

i. There is no significant difference in carbon stock density within and between the Forest Reserve and Parkland in the study area.
ii. There is no significant relationship between carbon stock and parameters of plant species in the study area.

The hypotheses were tested at 0.05, 0.01, and 0.001 statistical levels of significance.

1.5 Scope of the Study

The spatial scope of the study is the Kpashimi Forest Reserve and adjoining parkland. The forest reserve covers an area of 213.101 square kilometres while the parkland covers an area of 58.361 square kilometres which consists of fallow and cultivated

fields dotted with solitary trees. Conceptually, the scope of the study is restricted to characterising the plant community characteristics and quantifying carbon stock in six major carbon pools of the vegetation communities viz: above ground tree; undergrowth; dead wood, Litter; roots; and soil. The relationships between plant community biophysical parameters (tree density, species diversity, species richness, diameter at breast height (DBH), basal area, tree height, crown cover, shrub cover, and grass cover) and carbon stock in the study area were also explored. Research fieldwork and data collection process took place between 2011 and 2013.

1.6 Justification for the Study

Forest carbon estimates are of scientific importance in view of the significant role of forest carbon sequestration in earth's carbon cycle. Whilst biomass per unit area in savannas is less than tropical forests, the high rates of disturbance through fire and land clearing and their significant global extent, makes it imperative that the carbon stocks of savannas are adequately quantified and reported (Bombelli *et al.*, 2009). Estimation of the magnitude of forests as carbon stocks requires accurate and reliable measurements to quantify the biomass density of the forests (Cairns *et al.*, 2003). This will then provide the basis for more accurate global estimates.

According to UNFCCC (2006), developing countries are required to produce robust estimates of forest carbon stocks for successful implementation of climate change mitigation policies related to reducing emissions from deforestation and degradation (REDD). Such quantification would allow income generation through carbon offset trading by local communities (Jibrin *et al.*, 2013a; Jibrin, Jaiyeoba and Abdulkadir, 2015). However, lack of empirical data limit the feasibility of initiating carbon offset projects in most developing countries where forests are threatened (FAO, 2008).

Therefore, it is imperative to enhance Nigeria's window opportunities for participating in carbon offset projects. Forest Philanthropy Action Network -FPAN (2010) noted that out of the 52 carbon offset projects currently going on in Africa, East Africa has 31 (59%); Central Africa has 5 (10%); North Africa has 1 (2%); and West Africa has 15 (29%), but only 1 is based in Nigeria. It is high time Nigeria explore its carbon sequestration potentials; which would go a long way to avail Nigeria some window opportunities of accessing carbon credits through the Clean Development Mechanism (CDM) tool of the Kyoto Protocol under the United Nations Framework Convention on Climate Change (UNFCCC).

To improve our understanding of the role of vegetation formation in carbon cycle, there is the need for reliable estimation of biomass and carbon pools in forest ecosystems (Brown, 2002; Wirth *et al*., 2003; Joosten *et al*., 2004). Reliable information on the amount of forest biomass/carbon stock is useful for implementing Reducing Emissions from Deforestation and Forest Degradation (REDD) policy recently introduced in the Kyoto Protocol (UNFCCC, 2006, 2010). These estimates can also help to assess forest productivity, carbon pools, and carbon sequestration in biomass components including roots, trunk, branches and leaves (Návar, 2009). Estimation of the accumulated biomass in forest ecosystem is important for assessing ecological sustainability of the forest (Brown, 2002; Wirth *et al*., 2003; Joosten *et al*., 2004). It also gives an idea of the potential amount of carbon that can be emitted in the form of carbon dioxide when forests are being cleared or burned (Houghton *et al*., 2001). Biomass estimation of forest ecosystem enables us to estimate the amount of carbon dioxide that can be sequestered from atmosphere by the forest (Návar, 2009). The accurate assessment of biomass estimates of a forest is also important for tracking changes in the carbon stocks of forest and global carbon cycle (Aboal *et al*., 2005). Thus, the importance of studying

carbon stock density in the savannah area of Niger state, Nigeria can not be over emphasized.

CHAPTER TWO

CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

2.1 Conceptual Framework

2.1.1 Ecosystem Primary Productivity

The basic framework for carbon stock assessment in a forest is the Ecosystem Primary Productivity; because the key ecosystem variable that determines carbon stock in a forest is the Net Primary Production (**NPP**) (Brown, 2002; Chave *et al*., 2003; Wirth *et al.,* 2003; Aboal *et al*., 2005; Malhi *et al.,* 2011). NPP is defined as the rate of concurrent accumulation of organic matter by vegetation and equals the difference between total carbon assimilated by plants through photosynthesis (**GPP** -Gross Primary Productivity) and the carbon consumed by plant autotrophic respiration $\boldsymbol{R_a}$ (Chapin *et al*., 2002). **NPP** represents the net new carbon stored as biomass in stems, leaves or roots of plants and defines a balance between **GPP** and autotrophic respiration $\boldsymbol{R_a}$ (Sannier *et a.,l* 1998; Gower *et al.,* 1999). The classic model for the net primary production of ecosystem is given by:

$$\boldsymbol{GPP\ (g\ C/m^2/yr) = NPP\ (g\ C/m^2/yr) + R_a(g\ C/m^2/yr)} \quad \text{……(2.1)}$$

Thus, the quantity of carbon stock can be estimated as

$$\boldsymbol{NPP\ (g\ C/m^2/yr) = GPP\ (g\ C/m^2/yr) - R_a(g\ C/m^2/yr)} \quad \text{……(2.2)}$$

The biomass of forests provide estimates of carbon pools in forest vegetation (Brown, 1997). The range most cited of carbon proportion content in dry biomass is 0.43 to 0.58, hence it is often suggested that 0.50 is the average value for biomass carbon fraction (Brown, 1997; MacDicken, 1997; Cairns, *et al.*, 2003; IPCC, 2003; and FAO, 2008). However, IPCC (2006) recommended a default value of 0.47 biomass carbon fraction for live above ground tree, roots, shrubs grasses and dead wood, but 0.40 default biomass carbon fraction for litter. Therefore, converting from dry biomass to carbon

stock is achieved by multiplying dry biomass by appropriate conversion factor accordingly.

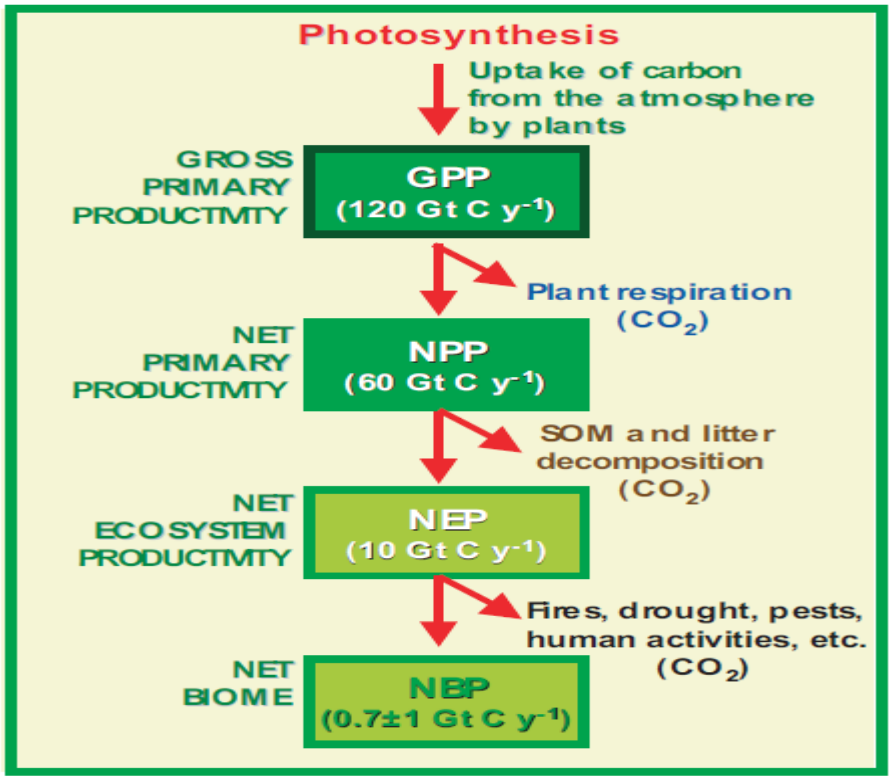


Figure 2.1: Terrestrial global Carbon balance
Source: Adapted from IPCC (2000)

Figure 2.1 presents a simplified diagram of the carbon balance of terrestrial ecosystems. The main entry of C into the biosphere is through the process of photosynthesis or gross primary productivity (GPP), which is the uptake of C from the atmosphere by plants. Part of this C is lost in several processes: through plant respiration (autotrophic respiration) and metabolic activities; as a result of litter and soil organic matter (SOM) decomposition (heterotrophic respiration) and as a consequence of further losses caused by fires, drought, human activities etc.

Standing biomass stocks represent a balance between a number of processes that lead to biomass accumulation or to biomass loss. These include the total net primary productivity (*N*PP); itself a function of gross primary productivity (*G*PP) and the carbon

use efficiency (*N*PP/*G*PP), as well as the allocation of *N*PP into different plant organs and the mean residence time of carbon stored in different plant organs (Lloyd and Farquhar, 1996). Figure 2.2 illustrates the processes that contribute towards vegetation biomass storage (Malhi *et al*., 2011).

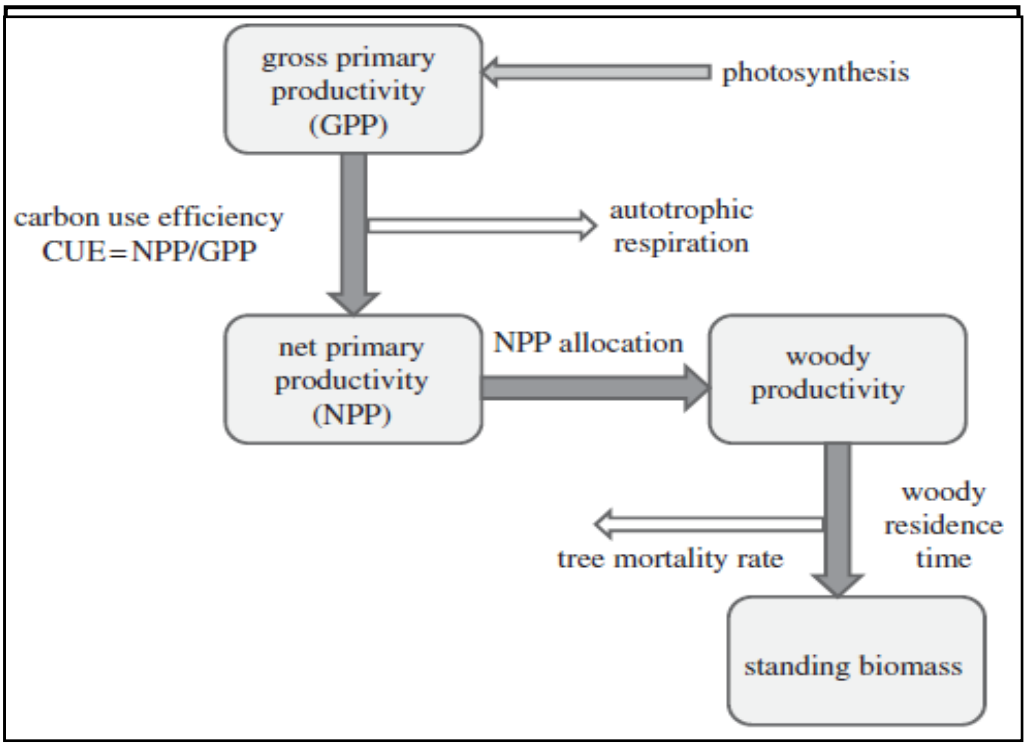


Figure 2.2: Schematic diagram of the chain of processes that contribute towards vegetation biomass storage.
Source: Adapted from Malhi *et al.* (2011).

2.1.2 Structure and Composition of Plant Communities

Assessment and prediction forest carbon stocks require an understanding of the factors; such as plant species composition, structure and diversity that control the potential biomass at a site. Stand structure can be described as the distribution of species and tree sizes in a forest area. Vegetation structure includes forest measurement variables like girth, height, diameter, crown cover, basal area, (Husch *et al*., 1982). Composition is the assemblage of plant species that characterize the vegetation (Martin, 1996). It is from

the knowledge of clear understanding of stand structure, species composition and its difference within and between stand that we can explain observable spatial variation in carbon stock density. It is established as a principle in biogeography (Principle of environmental gradient) that plant communities vary from place to place in their structure and composition. It is also established that biomass density vis a vis carbon stock density is a function of plant community structure and composition. Consequently, biomass/carbon stock density tends to vary from place to place and from species to species. It is therefore imperative that the peculiar plant community structure and composition of the study area be characterised so that we can see how variation in structure and composition is reflected in variation in biomass cum carbon stock density.

2.1.3 The Principles of Ecological Amplitude and Environmental Heterogeneity

The Principle of Ecological Amplitude states that a tree species "may grow and reproduce over a certain range of habitats, referred to as it ecological amplitude" (Fritts, 1976). Ecological Amplitude is the degree of adaptation of a living organism to changes in its environment. A species trait, ecological amplitude is expressed quantitatively as the range of environmental changes within which a given species is able to carry on its normal vital activities. Ecological amplitude can be examined as either the reaction of a species to individual environmental factors or to an aggregate of factors.

The genetic characteristics of a plant species allows it to be adapted to a specific range of environmental conditions, which is called its ecological amplitude (Daubenmire, 1968, 1972). Ecological amplitude can be related to a variety of site factors such as elevation, aspect, geology, and soil type. Together these factors create the underlying foundation, or a geomorphic template, upon which the biological landscape is constructed. Ecological amplitude dictates whether a plant can tolerate the

environmental conditions of a particular site. But action of the environment on an individual plant or the overall community is neither uniform nor consistent because unusual events are quite normal.

The environmental heterogeneity hypothesis (MacArthur and MacArthur, 1961; MacArthur and Wilson, 1967; Ricklefs, 1977) states that species richness increases with the number of ecological niches; that is, species coexistence is facilitated in more heterogeneous environment because different taxa can capitalize on different environmental conditions. While environmental heterogeneity has been defined in many different ways (Kolasa and Rollo, 1991), three major components can be distinguished: the variability of environment or range of environmental conditions, habitat spatial configuration, and variation over time. The hypothesis has been tested using many taxonomic groups across different spatial grains (average distance among observations) and extents (size of the whole study area) ranging from meters to thousands of kilometers. An extensive meta-analysis by Field *et al.* (2009) found that environmental heterogeneity was the primary factor driving species richness for 63 of the 273 cases (23%) assessing the relative importance of environmental heterogeneity versus other environmental factors. Environmental heterogeneity, however, had a stronger effect on species richness in studies conducted at small grain sizes (39% of the cases), suggesting that the relationship is contingent on the spatial scale.

The diversity of ecologically similar organisms that live together has for long been a central issue in community ecology. The best adapted species should long ago have replaced all the others, unless the process of replacement through competition is continually obstructed or interrupted. In a heterogeneous environment where patches offer different conditions for growth, or have been disturbed at different times in the

past, competitive exclusion is likely to be very slow, and might never reach completion (Palmer, 1994). More heterogeneous environments would then be expected to support a greater number of species (Williams, 1964).

The effect of heterogeneity on species diversity is such that clearly, the occurrence of a particular species at a site depends on the presence of suitable habitat, as well as the ability of species to reach the site. Once established, the persistence of a species at a site depends on local system dynamics, i.e. the outcome of species interactions and changes in the environment over time. Therefore, local biodiversity should be influenced both by the number of types of habitat that are present and by the rates of ecological processes such as immigration, competitive exclusion, and emigration or death. It has been shown that the rates of such processes are affected by spatial configuration of the environment. For example competitive exclusion can be delayed indefinitely in spatially structured environments (Tilman, 1994; Tilman and Kareiva, 1997; Amarasekare, 2003).

Spatial environmental heterogeneity is thought to promote species diversity through three major mechanisms: First, an increase in environmental gradients and in the amount of habitat types, resources and structural complexity should increase the available niche space and thus allow more species to coexist (Tews *et al*., 2004). Second, environmentally heterogeneous areas are more likely to provide shelter and refuges from adverse environmental conditions and periods of climate change, which in turn should promote species persistence (Kallimanis *et al.*, 2010; Fjelds *et al*., 2012). Third, the probability of speciation events resulting from isolation or adaptation to diverse environmental conditions should increase with higher spatial environmental heterogeneity (Antonelli and Sanmart, 2011). In essence, environmental heterogeneity is regarded as one of the most important factors governing species richness gradients.

An increase in available niche space, provision of refuges and opportunities for isolation and divergent adaptation are thought to enhance species coexistence, persistence and diversification.

2.1.4 The Forest Carbon pools

A carbon pool is defined as a reservoir which has the capacity to accumulate or release carbon (FAO, 2004). The biomass (phytomass and necromass) of forests provide estimates of carbon pools in forest vegetation (Brown, 1997). The six main carbon pools in forest ecosystems are aboveground trees, aboveground non-tree (undergrowth shrubs, grasses and herbs), forest floor (or litter), dead wood, belowground roots, and soil organic matter (IPCC, 2003; and FAO, 2008; Pearson *et al.*, 2005, 2007). Figure 2.3 illustrates the carbon pools in forest ecosystems. The classification of carbon pools is not strict and it is not the number of categories that is important but their completeness; pools must not be double-counted and significant pools should not be excluded (Brown, 1997; IPCC, 2006). With harvested wood products (HWPs) increasingly recognised as an additional and potentially substantial carbon pool which exists outside of traditional forest boundaries (Lui and Han, 2009), many carbon pool classifications are being adapted to also include HWPs. The scope of this study is however, confined to carbon stock density within the forest reserve and adjoining parkland and therefore excludes the HWPs.

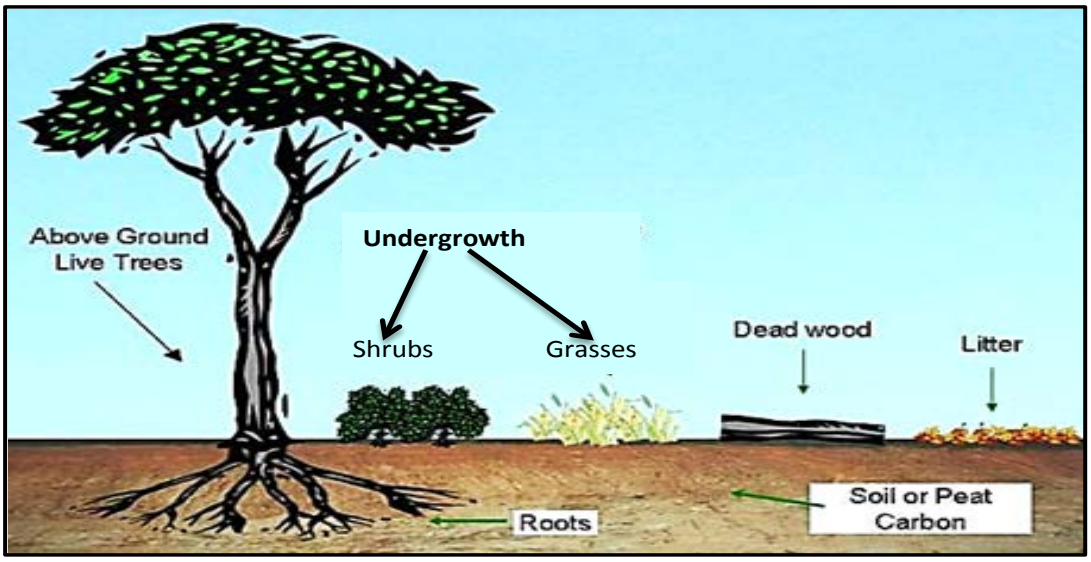


Figure 2.3: Forest Carbon Pools
Source: Adapted and modified from Goslee and Petrova (2012).

The IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC, 2003) defines five carbon pools, in three groups (as illustrated in Figure 2.4) for measuring and monitoring purposes. These include:

Group 1: Living biomass (Phytomass). This group includes above-ground tree and non-tree biomass and belowground biomass, or roots.

Group 2: Dead organic matter (Necromass). This group includes dead wood and litter.

Group 3: Soil organic carbon. This group includes soil carbon.

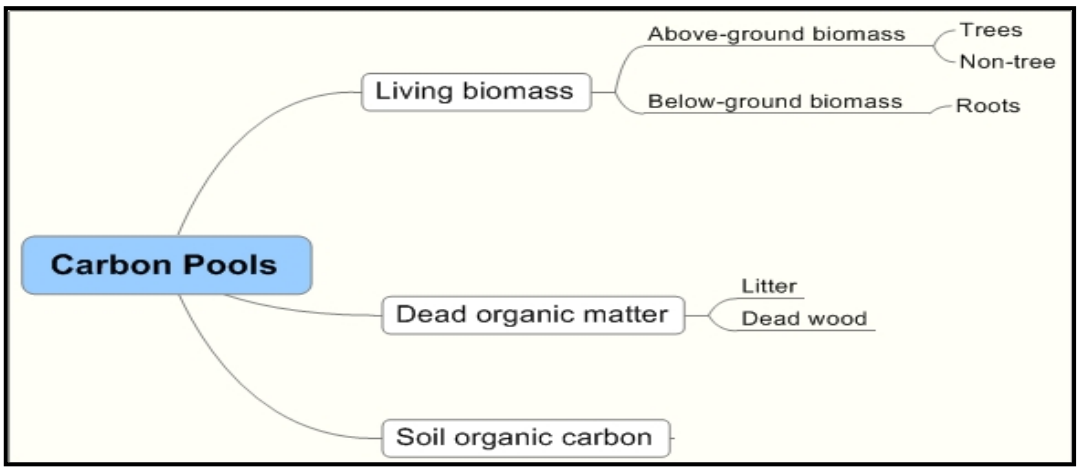


Figure 2.4: Grouping of the Carbon Pools
Source: Adapted from IPCC GPG (2003)

The carbon dioxide fixed by plants during photosynthesis is transferred across the different carbon pools. The above-ground biomass of a tree constitutes the major portion of the carbon pool. It is the most important and visible carbon pool of the terrestrial forest ecosystem (Ravindranath and Ostwald, 2008). Any changes in land use system; like forest degradation and deforestation, has a direct impact on this component of the carbon pool. The root biomass constitutes all the live roots and plays important role in the carbon cycle by transferring and storing carbon in the soil (IPCC, 2006). The dead mass of litter and woody debris are not a major carbon pool as they contribute merely a small fraction to the carbon stocks of forests (Ravindranath and Ostwald, 2008). Soil organic matter is also a chief contributor to the carbon stocks of forests (Lal, 2005; Kumar, Pandey and Pandey, 2006), next only to the above-ground biomass (Ravindranath and Ostwald, 2008). Soils are a major source of carbon emissions following deforestation (Page *et al.*, 2002).

The generalized flowchart of terrestrial carbon cycle (Figure 2.5) shows all five pools and associated fluxes including inputs to and outputs from the system, as well as all possible transfers between the pools. The carbon cycle includes changes in carbon stocks due to both continuous processes (*i.e.* growth and decay) and discrete events (*i.e.* disturbances such as harvest, fire, insect outbreaks, land-use change and other events). Continuous processes can affect carbon stocks in all areas in each year, while discrete events cause emissions and redistribute ecosystem carbon in specific areas (*i.e.* where the disturbance occurs) in the year of the event.

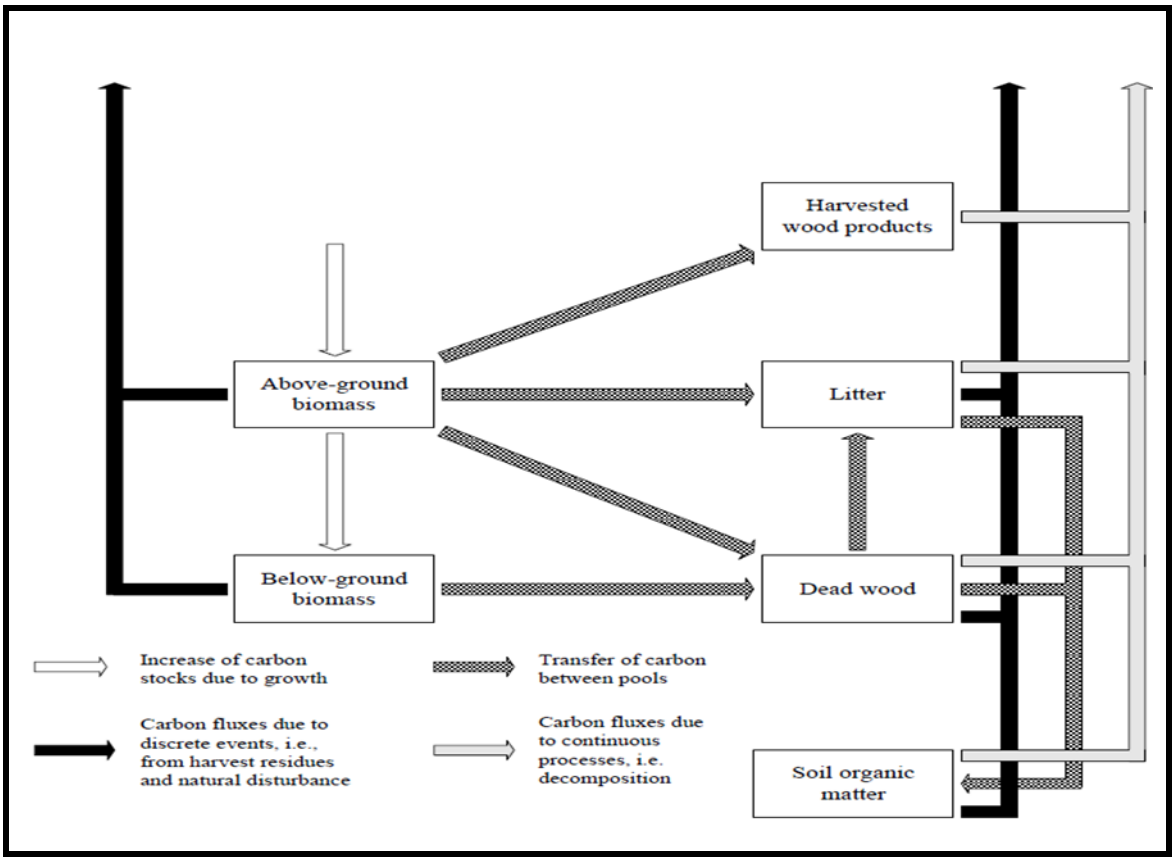


Figure 2.5: Generalized Carbon Pools and Flows of Terrestrial ecosystems.
Source: Adapted from IPCC (2006)

2.1.5 Forest Carbon Cycle and Climate change

Forests are important carbon pools which continuously exchange CO_2 with the atmosphere, due to both natural processes and human action (IPCC, 2003). Three major components (or sets of processes) together constitute cycling of carbon in forest trees.

1. *Carbon uptake and assimilation***,** including immediate respiratory losses which detract from previously 'fixed' carbon in photosynthetic plant cells;
2. *Carbon transport, allocation and partitioning* of carbon for storage, structural and metabolic use in above-ground and below-ground parts of the tree; and
3. *Return of forest carbon to the atmosphere* via oxidative pathways, notably via the food chain, biological decay and combustion of forest biomass and forest products.

Understanding forests' role in greenhouse effect requires a better understanding of carbon cycle at forest level (see Figure 2.6). Organic matter contains carbon susceptible to be oxidized and returned to the atmosphere in the form of CO_2. (Houghton *et al.*, 2001). The oxidation of carbon found in organic matter and the subsequent emissions of CO_2 result from the processes of respiration of living biomass, decomposition of organic matter and combustion. Increasing CO_2 concentrations in the atmosphere will reduce radiative cooling of the earth, resulting in positive radiative forcing (i.e. global warming) Forest vegetation and soil may act as significant sinks or sources of atmospheric CO_2, depending on land use, forest management and environmental conditions. Thus, the relationship between carbon cycle and climate change is for two main reasons. Firstly, biomass in an ecosystem determines the carbon amount that will be emitted to the atmosphere in form of carbon dioxide, carbon monoxide or methane in the case of disturbance. Secondly, it is used for removal of carbon that is already available in the atmosphere.

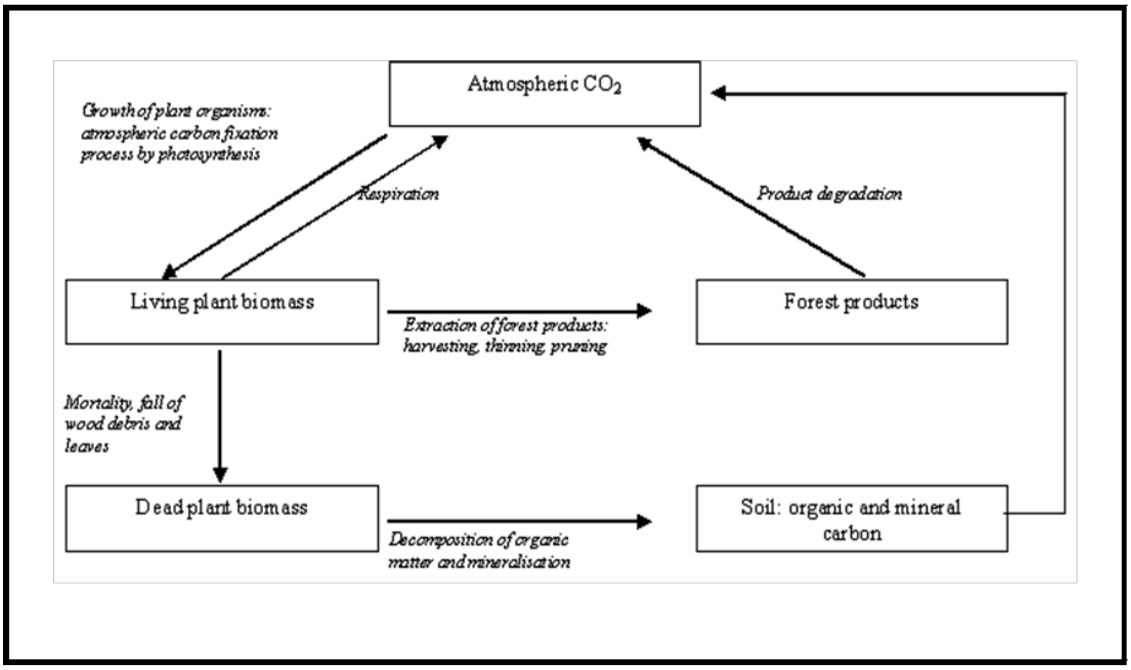


Figure 2.6: The carbon cycle in the forest
Source: Mégevand (1998)

The process of photosynthesis explains why forests function as CO_2 sinks, removing CO_2 from the atmosphere. Atmospheric CO_2 is fixed in the plant's chlorophyll parts and carbon is integrated to complex organic molecules which are then used by the whole plant (Houghton and Hackler, 2001). The role of forests in climate change is thus three-fold:

- they are carbon pools
- they become sources of CO_2 when they burn, or, in general, when they are disturbed by natural or human action
- they are CO_2 sinks when they grow biomass or extend their area.

Based on IPCC (2001) analysis, the earth's biosphere constitutes a carbon sink that absorbs approximately 2.3 Gt C annually. This represents nearly 30 percent of all fossil fuel emissions (totalling from 6.3 to 6.5 Gt C yr^{-1}) and is comparable to the CO_2 emissions resulting from deforestation, 1.6 to 2 Gt C yr^{-1}. The carbon cycle (photosynthesis, plant respiration and the degradation of organic matter) in a given forest is influenced by climatic conditions and atmospheric concentrations of CO_2. The distinction between natural and human factors influencing plant growth is thus sometimes very difficult to make.

2.1.6 Role of forests as carbon sinks

Under Kyoto Protocol, forests are considered important for their unique role as carbon sinks because they are capable of capturing and storing carbon dioxide from the atmosphere (FAO, 2005b). According to FAO (2005a), each time there is a forest growth of 2 cubic meters of wood; roughly 1 ton of carbon of the air is captured. Forests act as carbon sink by increasing above ground biomass through increased forest cover and by increased level of soil organic carbon content (Banskota *et al*., 2007). Biomass is

defined as “mass of all organic matter per unit area at particular time (reported in g/m^2 or kg/ha)” (FAO, 2008). Forest biomass represents the largest terrestrial carbon sink and accounts for approximately 90% of all living terrestrial biomass (Dixon *et al*., 1994; Tan *et al*., 2007). The amount of carbon sequestered or emitted by a forest can be estimated from the biomass accumulation since approximately half of forest dry biomass weight constitutes carbon (MacDicken, 1997; Cairns *et al*., 2003; FAO, 2005a; Banskota *et al*., 2007; FAO, 2008). Forest biomass can be measured both in terms of fresh weight or dry weight.

2.2 Review of Literature

2.2.1 Overview of Global Biomass/Carbon stock estimates

Estimates of biomass density for many of the world's forests have been made. For example, under the International Biological Program (IBP) biomass density estimates were made for many intensive study sites covering most of the major forest regions of the world (Reichle, 1981). A detailed summary of biomass density studies in tropical forests, from lowland to montane and from wet to very dry zones, was made by Brown and Lugo (1982). A later study by Olson *et al*. (1983) produced a global map of the biomass density of all ecosystem types, including disturbed and undisturbed forests, at a 0.50 x 0.50 grid-scale of resolution. Such ecological studies are generally designed to characterize local forest structure and the study sites are usually not truly randomly located nor represent the population of interest (Brown and Lugo, 1992). These types of studies are suitable for studying local forests but not for making inferences about larger populations (Brown *et al*., 1989). At the global level, 19 percent of the carbon in the earth's biosphere is stored in plants, and 81 percent in the soil. In all forests, tropical, temperate and boreal together, approximately 31 percent of the carbon is stored in the

biomass and 69 percent in the soil. In tropical forests, approximately 50 percent of the carbon is stored in the biomass and 50 percent in the soil (IPCC, 2000).

According to FPAN (2010), a review of literature on global spatial carbon stock revealed that Permanently moist or humid evergreen forest generally stores more carbon (200-300 t C per ha) than dry or seasonally dry forests (150-250 t C per ha). Savannah biome hold much lower quantities of carbon per hectare (60-70 t C per ha), but are significant due to their large extent. However, nearly all estimates of carbon stock from tropical forests are based on a handful of biome-average datasets, where a single representative value of forest carbon per unit area is applied to broad forest categories or biomes (Houghton *et al.,* 2001; De Fries *et al.,* 2002; Achard *et al.,* 2004; Ramankutty *et al.,* 2007). Grace *et al*. (2006) reviewed carbon fluxes in tropical savannas. They found that carbon sequestration rates in these ecosystems may average 0.14 tonnes carbon per hectare or 0.39 tonnes carbon per hectare per year. They concluded that if savannas were to be protected from fire and grazing, most of them would accumulate substantial carbon and the sink would be larger.

Early global estimates of the C pools in forests used the average biomass density (half of which is carbon) derived from direct field measurements of biomass (Whittaker and Likens, 1975; Ajtay *et al.*, 1979). The biomass carbon map for the world's vegetation - updated version of Olson *et al*. (1983), which is commonly used in global carbon models, is also based on such direct measurement studies. These global estimates have been further used to calculate or assess global carbon budgets (White *et al*., 2000; IPCC, 2001; Saugier *et al*., 2001). However, as a non-random sampling approach, the direct measurement of biomass on a local level does not accurately represent the average biomass within a region or country because it is often biased towards plots with large

diameter trees, resulting in an overestimation of biomass (Brown *et al*., 1989; Botkin and Simpson, 1990; Dixon *et al.*, 1994; Schroeder *et al*., 1997; Fang *et al.*, 1998; Jenkins *et al*., 2001; Kauppi, 2003). Other approaches have used well-designed and statistically sound regional or national forest inventories available for many countries as a key data source to calculate forest biomass and account for the carbon budgets at regional scales (Brown *et al*., 1989; Kauppi *et al*., 1992; Liski *et al.*, 2003; Kauppi, 2003; Smith *et al*., 2003, 2004; Fang *et al*., 2001, 2005).

Partly as a result of concerns over climate change and the role of the carbon cycle in Africa, considerable emphasis has been placed recently on biomass and carbon surveys. There has been a number of important large-scale surveys, such as project CarboAfrica (Merbold *et al.*, 2009), examining net productivity and emissions from forest degradation and the resulting C-balance. Mitchard *et al.* (2009) used radar backscatter to predict above-ground biomass and found a consistent pattern at several African sites. He further presented a summary of current data and underlines the importance of savannas in view of their extent, fire regimes and strong inter-annual Net Ecosystem Productivity (NEP) variability, as well as their high degree of unpredictability in the overall C-budget. The estimation of carbon stocks at a landscape scale in Australia using airborne synthetic aperture radar (SAR) was outlined by Collins *et al*. (2009) and from hyperspectral and multispectral imagery by Guerschman *et al.* (2009). Published allometric data for the principal trees (*Eucalyptus miniata* and *E. tetrodontata*) were used to convert basal area measurements to estimates of above-ground biomass, which were then combined with below-ground biomass data to assess carbon stocks.

It is noteworthy that the earliest compilations of biome averages were made decades ago and have been subsequently updated and modified by the research community (Olson *et*

al., 1983; Brown and Lugo, 1992). This continuous updating of biome averages makes it difficult to identify original data sources and other key information. Many contemporary estimates of forest carbon stocks are based on multiple versions or iterations of analyses. Often, 'best guesses' are employed as multiple biome averages are combined or modified (Watson *et al.*, 2000; Houghton *et al.*, 2001; IPCC, 2006).

Analysis of forest inventory data archived by the FAO and others have also been used to develop biome averages. Forest inventory data can provide high quality information for a particular region, but existing inventories were generally not collected using sampling schemes appropriate for biome scale. While highly accurate for specific locations, these data were collected to describe only very local conditions and cover a tiny portion of total forest area (Brown, 1997). Consequently, these compilations could be highly biased (depending on where the individual point measurements are made), and provide only rough approximations of forest carbon stocks over larger spatial scales.

Country-level estimates of forest carbon stocks reported in the FAO Forest Resources Assessments are also based on forest inventory data, but these estimates are highly suspect because of inadequate sampling for the national scale and inconsistent methods (Brown, 1997; FAO, 2005a). Moreover, data on belowground biomass for trees are generally much less available than those for aboveground biomass. This lack of belowground data has been a barrier to accurate accounting for and monitoring changes in carbon stocks in forests (Miyakuni *et al*., 2005). In the FAO (2005a) report, national forest carbon estimates based on inventory data remain very questionable, with more than half of tropical countries relying on 'best guesses' rather than actual measurements.

Furthermore the biomass stock of tropical forests and its distribution remain poorly resolved at the regional scale (Fearnside, 1996; Houghton *et al*., 2001; Houghton,

2005b). Consensus is also yet to be reached on how much carbon is being emitted by changes in tropical land use (Malhi and Grace, 2000; Malhi *et al*., 2002; Fearnside and Laurance, 2003; Achard *et al*., 2004; De Fries *et al*., 2007; Ramankutty *et al*., 2007; Van der Werf *et al*., 2009). There is thus an urgent need for calibrating and improving methods for determining tropical forest biomass and its spatial distribution (Goetz *et al*., 2009). There is thus a clear need for country- and region-specific studies to address the validity and reliability of carbon stock data. Ideally, such studies would utilise good ecological plot data such as obtainable in this current study in Kpashimi Forest reserve and adjoining parkland in Niger state, Nigeria.

Attempts to estimate biomass and carbon density of tropical forests have been made by the scientific community for use in models that assess the contribution of tropical deforestation and biomass burning to the increase in atmospheric carbon dioxide and other trace gases (Brown *et al*., 1989; Houghton, 2005; Hall *et al*., 2006). Brown and Lugo (1982, 1984) have made two estimates of the total biomass (above and below ground) of tropical forests from two distinctly different data bases. For the first estimate in 1982, they synthesised data from literature on total biomass of tropical forest vegetation estimated by direct measurements on experimental plots (either by destructive harvest techniques or by applying regression equations derived from destructively harvested trees). They obtained a weighted average total above ground biomass (TAGB) for closed forests of 282 Mg/ha (a range of 144-513 Mg/ha) and for open forests of 55 Mg/ha (a range of 28-82 Mg/ha).

In the second analysis, Brown and Lugo (1984) used data reported by country for all major forest types as given by Food and Agriculture Organization of the United Nations (1981). They converted commercial wood volumes to TAGB to commercial biomass)

and obtained a weighted average TAGB of 150 Mg/ha for undisturbed tropical closed forests and 50 Mg/ha for open forests. The two methods thus gave markedly different biomass estimates for closed forests but similar estimates for the open forests. As most land use changes are occurring in closed tropical forests, where biomass varies the most, it is necessary to obtain more accurate and precise biomass estimates for these forests in order to improve understanding of the role of tropical forests in the global carbon cycle. Improving the estimates of tropical forests biomass requires a broader data base than that provided by ecological studies that measure biomass directly. The few studies that measured biomass directly cover a small area of tropical forests (combined area of all studies <30 ha), and are generally biased towards larger biomass plots (Brown and Lugo, 1984).

2.2.2 Carbon stock densities of biomes

Ecosystems can be grouped into biomes, which reflect natural geographic differences in soils and climate, and consequently different vegetation types (Woodward *et al*., 2004). These biomes differ greatly in their capacity to assimilate and store carbon. The aggregate biome carbon storage is a function of density and areal extent. While the absolute size of terrestrial carbon pools is valuable for global policy making, at the project level, ecosystem and landscape-level carbon densities and sequestration rates are most relevant.

***Tropical forests*:** The mean carbon density of tropical forests has been estimated at between 170– 250 Mg ha^{-1} in biomass (Malhi *et al*., 2006; Chave *et al*., 2008; Lewis *et al*., 2009) and 90–200 Mg ha^{-1} in soil (Amundson, 2001), for a combined density of 260–450 Mg ha^{-1}. Particular forest types have been estimated to have much higher

densities; for example, Australian temperate moist *Eucalyptus regnans* forest has been estimated to have a total carbon density of 1867 Mg ha^{-1} (Keith *et al.*, 2009).

Temperate grasslands: Temperate grasslands are distributed globally and have been nearly wholly converted (Trumper *et al*., 2009). Temperate grasslands are characterized by high degrees of grazing. The literature review by Epple (2012) reported biomass carbon stocks between approximately 7–21 Mg ha^{-1} in both above- and below ground pools. Soil carbon estimates reported are 191 Mg ha^{-1} for temperate grassland soils down to three meters (Jobbágy and Jackson, 2000) and Epple (2012) reports values of 236 Mg ha^{-1} for the top 1 m of soil. Finally, Amundson (2001) reported average values of 133 Mg ha^{-1} for cool temperate steppe and 76 Mg ha^{-1} for temperate thorn steppe. Trumper *et al*. (2009) reported average biomass values of 7 Mg ha^{-1} and soil carbon values of 133 Mg ha^{-1}.

Tundra ecosystems: Tundra ecosystems have low above-ground biomass but a higher degree of below-ground biomass (De Deyn *et al.*, 2008). Because of low temperatures that lead to slow decomposition rates and cryogenic mixing of soils, tundra ecosystems store vast quantities of carbon in sediments. Epple (2012) cites carbon storage densities between 128–440 Mg ha^{-1} down to 1 m. However, tundra soils can be hundreds of meters deep.

Tropical grasslands and savannahs: Tropical grasslands and savannahs are broad ecosystem types comprising a continuum from treeless grasslands to open forest. The savanna biome is characterized by co-dominance of trees and grasses, but ranges from grasslands where trees are virtually absent to more forest-like ecosystems where trees are dominant (De Deyn *et al*., 2008). Fire is an important characteristic of savannah biomes. Tropical grasslands and savannahs are primarily located in Africa, South

America and Australia (Grace *et al.*, 2006). Total carbon stocks of global tropical grasslands based on the UNEP-WCMC top-down analysis have been estimated at 285 Gt C, with an average carbon density of 137 Mg ha^{-1} (Trumper *et al*., 2009; Epple, 2012). Grace *et al*. (2006) provided literature review based estimates of 9.4 Mg ha^{-1} for above-ground biomass carbon, 19 Mg ha^{-1} for below-ground biomass carbon, and 174 Mg ha^{-1} for soil organic carbon.

Generally, above-ground biomass is a function of tree density in the ecosystem. A recent study of African savannahs reported total soil organic carbon stock of approximately 110 Mg ha^{-1}, although it reported very high spatial heterogeneity and little correlation between soil carbon stocks and vegetation. When soil carbon stocks are considered, these ecosystems can have total carbon densities that approach those of forests.

Ciais *et al.* (2011) and Epple (2012) reported strong knowledge gaps with respect to tropical savannahs and grassland ecosystems. They also reported that these ecosystems are not well incorporated into terrestrial ecosystem models, which makes their role in global carbon cycle difficult to assess. As an example, they cite the fact that most models of fire activity for grasslands are parameterized by data derived from temperate grasslands.

Savannah ecosystems are highly threatened with habitat conversion, which has been estimated at around 1 per cent per year and may have constituted a large proportion of converted ecosystems (Grace *et al*., 2006). Land-use change to croplands or intensive grazing can release large quantities of carbon from biomass and soils but the long-term effect critically depends on soil type and subsequent management practices (Grace *et al.*, 2006). In fact, because of high rates of loss and degradation, emission from

savannah ecosystems may approach emissions from tropical deforestation (Grace *et al.*, 2006).

Deserts and dry shrublands: Deserts and dry shrublands cover a large surface area. Trumper *et al*. (2009) provided a global mean carbon density of desert and dry shrubland ecosystems of approximately 64 Mg ha^{-1} (Epple, 2012). Biomass carbon stocks in deserts and shrubs are relatively low. Epple (2012) reported values from literature of between 0.09 Mg ha^{-1} – 3.3 Mg ha^{-1}. Because aridity reduces the rate of microbial decomposition and soil respiration, soil carbon stocks in desert and dry shrublands can be relatively lower. Epple (2012) reports values in the literature between 14 Mg ha^{-1} – 270 Mg ha^{-1}, with lower stocks in tropical deserts and higher stocks in temperature and boreal deserts and shrublands. Vegetation distribution can have significant effect on the carbon storage in soils (White II *et al*., 2009). While some recent studies have reported localized high measurements of carbon sequestration in desert ecosystems, a recent study indicates that there is still a significant knowledge gap as to the carbon balance of deserts ecosystems (Schlesinger *et al*., 2009).

Agricultural soils: Agricultural soils contain less soil carbon than natural ecosystems, and this loss of soil carbon from soils constitutes a major historical emission of carbon of around 42–78 Gt C or approximately 20 to 80 Mg ha^{-1} (Lal, 2004). However, because of their relatively impoverished condition, there is significant mitigation potential in agricultural soils especially when intergrated with agroforestry practices; which would enhance carbon sequestration through increased deadwood and litter falls on agricultural soils (Lal, 2004a).

2.2.3 Carbon stock estimate in Nigeria

Very few studies have been carried out to quantify carbon stock in Nigerian forests. Where available, such studies are rather of coarse scale. For instance, Federal Government of Nigeria – FGN (2003), revealed that total carbon stored in the forest formation in Nigeria is estimated to be 2.84 GtC. Of this figure, the moist deciduous forest contributed most. Estimated carbon stock over the studied forest formation as at year 1990 were: Tropical rain forest (236.224 MtC- Million tons of Carbon), Moist deciduous (2269.99 MtC), Dry deciduous (184.91 MtC), Very dry (100.63 MtC), and Hill and Montane (44.96 MtC). In terms of carbon stock per hectare, tropical rainforest has the highest value of 197.35 Mg C ha^{-1}, while dry deciduous forest has the least of 125.32 Mg C ha^{-1}. Ravilious *et al.* (2010) combined estimates of above - and below-ground biomass and soil organic carbon to 1 metre depth. According to this analysis, a total of 7.5 Gt of carbon is stored in the biomass and soils of Nigeria's terrestrial ecosystems. The largest areas of high carbon density were found in the southern parts of the country, mostly along the Niger Delta and in the rainforest regions. The highest carbon density class, which holds 20% of the country's carbon, covers 7% of the country's land area. These analyses of carbon stock in Nigeria do not provide the precise quantity of carbon stock in specific plant communities in Nigeria. It becomes imperative therefore to quantify biomass/carbon stock in specific plant communities; which will go a long way in providing a more accurate data on carbon stock in specific plant communities.

2.2.4 Techniques of monitoring Biomass/Carbon in Forests

According to FAO (2009), there are four main methods of monitoring biomass and combinations thereof:

a) In situ destructive direct biomass measurement;

b) In situ non-destructive biomass estimations (using equations or conversion factors);

c) Inference from remote sensing (experimental stage);

d) Models developed from allometric equations.

Conventional methods of measuring biomass values in the field are so far the most accurate and reliable method; although they are often time consuming, labour demanding and cannot cover spatial distribution of biomass in larger areas (de Gier, 2003; Houghton, 2005a; Lu, 2006). Biomass can be estimated in a destructive and non-destructive means in the field based surveys. The destructive method is to fell down specific number of sample trees, which are weighed to make a biomass equation which is not considered as a practical solution (Brown, 1997). In non-destructive methods, regression equations are developed (Foody *et al*., 2003) based on data from felled trees using measurable dimension; such as diameter (Brown, 1997). Biomass and trunk diameter are highly correlated and therefore regression models can be used that convert trunk diameter data to biomass data.

Allometric models are developed and applied to forest inventory data to assess biomass and carbon stocks of forests. The models are developed by establishing a relationship between the various physical parameters of trees such as diameter at breast height, height of tree trunk, total height of the tree, crown diameter, tree species, etc (Brown, 1997). Equations developed for single species and for mixture of species give estimate of biomass for specific sites and for large-scale global and regional comparisons (Brown, 2002). The allometric equations that relate biomass of several tree components to diameter at breast height (DBH) are most often used to calculate biomass values. Other variables such as height can also be used in the regression equations. However, it

is not always necessarily that input of these variables will contribute to improvement of the equation based on DBH (Wang, 2006). According to Brown (2002), DBH alone explains more than 95% of the variation in aboveground tropical forest carbon stocks, even in highly diverse regions. Hence, the most simple and commonly used technique for deriving forest above ground biomass is through the use of DBH -based allometric equations. This explains why this study used DBH as single predictor variable of biomass stock.

With the advancement of earth observing satellites, biomass can be estimated from field based observation with the combination of remote sensing tools as well as statistical instruments to further understand the correlations associated with ground data and remotely sensed data. In order to obtain carbon value from the biomass calculated, it is assumed that 50 percent of it is carbon and hence biomass value is multiplied by 0.5 to obtain the corresponding carbon value (Malhi and Grace, 2000; Garzula and Saket, 2003). This conversion factor is used for all species of trees as it is assumed that carbon concentration of biomass varies only slightly between different tree types (Garzula and Saket, 2003). However, IPCC (2006) default carbon fraction of 0.47 was adopted in this study.

Forest biomass is the organic matter resulting from primary production through photosynthesis minus consumption through respiration and harvest (Malhi, 2011). Assessment of biomass provides information on the structure and functional attributes of a forest and is used to estimate the quantity of timber, fuel and fodder components (Brown, 1997). With approximately 50% of dry forest biomass comprised of carbon (Westlake, 1966), biomass assessments also illustrate the amount of carbon that may be lost or sequestered under different forest management regimes (Houghton and Hackler,

2001; Malhi *et al.*, 2011). Carbon is lost to the atmosphere as CO_2. To convert carbon in biomass to CO_2, the tonnes of carbon are multiplied by the ratio of the molecular weight of carbon dioxide to the atomic weight of carbon (44/12) (Pearson *et al.*, 2005, 2007). Estimating the biomass density of forest components is therefore, the first step in forest carbon accounting.

A carbon source is a carbon pool from which more carbon flows out than flows in (IPCC, 2006). Forests can often represent a net source (rather than sink) of carbon due to the processes of decay, combustion and respiration. A carbon sink is a carbon pool from which more carbon flows in than out; forests can act as sink through the process of tree growth and resultant biological carbon sequestration (Brown, 2002). Forests can switch between being a source and a sink of carbon over time, with the stock of the forest referring to the absolute quantity of carbon held within a forest component at a specified time. Stock accounting sums carbon pools at a single point in time. Decisions on which carbon pools should be included are largely dependent on the availability of existing data, costs of measurement and the level of conservativeness required (MacDicken, 1997). Trees often represent the greatest fraction of total biomass of a forested area, with other carbon pools only a fraction of the total tree biomass. The understory is estimated to be equivalent to 3% of above-ground tree biomass, dead wood 5-40%, and fine litter only 5% of that in the above-ground tree biomass. Below ground biomass is more variable, ranging between 4 - 230%, and can be more than two times greater than that in the above-ground tree biomass (Brown, 1997). Above ground biomass in trees also responds more rapidly and significantly as a result of land-use change than other carbon pools. As a consequence, majority of carbon accounting efforts are focussed on tree AGB, for which there is a considerable forest science

research base (Brown and Lugo, 1984, 1992; Brown *et al*., 1995; Fearnside, 1996; Brown, 2002).

2.2.5 Estimation of carbon stock in specific forest carbon pools

Above ground Phytomass: Total standing aboveground biomass of woody vegetation is often one of the largest carbon pools. This pool comprises of all woody stems, branches and leaves of living trees, creepers, climbers, epiphytes and herbaceous undergrowth (Kurniatun *et al*., 2001). The Tree Biomass carbon pool consists of all living parts of a tree above the soil, inclusive of stems, stumps, branches, bark, seeds and foliage. The most comprehensive method to establish the biomass of this carbon pool is direct sampling, whereby vegetation is harvested, dried to a constant mass and the dry-to-wet biomass ratio established. Direct sampling of trees however, is both expensive and somewhat counter-productive in the context of promoting carbon sequestration. Two further approaches for estimating biomass density of tree biomass exist and are more commonly applied. The first directly estimates biomass density through biomass regression equations. The second converts wood volume estimates to biomass density using biomass expansion factors (Brown, 1997).

Where stand tables (the tally of all trees in a particular diameter class) are available, the biomass per average tree of each diameter class of the stand table can be estimated through biomass regression equations, also called allometric equations. Alternatively, the results of direct sampling of tree diameter in the area of interest can be used in these regression equations. The total biomass of forest stand is then derived from the average tree biomass multiplied by number of trees in the class, summed across all classes. In both tropical and temperate forests, such diameter measurements explain more than 95% of the variation in tree biomass (Brown, 2002).

Undergrowth (understory vegetation) biomass: The undergrowth biomass includes all live understory vegetation including shrubs and grasses (IPCC, 2006). With the tree component of a forest the major fraction of biomass, and so carbon, the understorey is often omitted from accounting (Brown, 2002). This omission results in a conservative carbon stock estimate but is justified only in areas where trees are present in high density. Neglecting the shrub layer in open woodlands, savannah or in young successional forest may significantly underestimate carbon density (Brown, 2002).

Similarly, the carbon budgets of trees and forest soil have been modelled extensively, but understory vegetation is not usually included in these analyses (Liski *et al*., 2002, Nabuurs *et al*., 2003). In comparison to other components of forest ecosystems, the biomass of understorey vegetation is considered to be small and is sometimes dismissed as negligible (Ståhl *et al*., 2004). However, the biomass of understorey vegetation may be substantial in the savanna areas characterized by continuous layer of shrubs and grasses.The most comprehensive method to establish the biomass of this carbon pool is destructive sampling, whereby vegetation is harvested, dried to a constant mass and the dry-to-wet biomass ratio established (Brown, 1997, 2002).

Root Biomass: The Root Biomass carbon pool consists of the biomass contained within live roots. Although less data exists, regression equations from root biomass data have been formulated which predict root biomass based on above-ground biomass carbon (Brown, 2002; Cairns *et al*., 1997). Cairns *et al*. (1997) reviewed 160 studies covering tropical, temperate and boreal forests and found a mean root-to-shoot (RS) ratio of 0.26, ranging between 0.18 and 0.30. Although roots are believed to depend on climate and soil characteristics (Brown and Lugo, 1982), Cairns *et al*. (1997) found that RS ratios were constant between latitude (tropical, temperate and boreal), soil texture (fine,

medium and coarse), and tree-type (angiosperm and gymnosperm). The application of default RS ratios represents a trade-off between costs of time, resources and accuracy. Root biomass can also be assessed locally by taking soil cores from which roots are extracted; the oven dry weight of these roots can be related to the cross-sectional area of the sample, and so to the root biomass on a per area basis (MacDicken, 1997).

Deadwood: The Deadwood carbon pool includes all non-living woody biomass and includes standing and fallen trees, roots and stumps with diameter over 10cm. Often ignored, or assumed in equilibrium, this carbon pool can contain 10-20% of that in the tree pool in mature forest (Delaney *et al*., 1998). However, in immature forests and plantations both standing and fallen dead wood are likely to be insignificant in the first 30-60 years of establishment. The primary method for assessing carbon stock in Dead wood pool is to sample and assess the wet-to-dry weight ratio, with large pieces of Dead wood measured volumetrically as cylinders and converted to biomass on the basis of wood density, and standing trees measured as live trees but adjusted for losses in branches (less 20%) and leaves (less 2-3%) (MacDicken, 1997). Methods to establish the ratio of living to dead biomass are under investigation, but data is limited on the decline of wood density as a result of decay (Brown, 2002).

Litter: The litter carbon pool includes all non-living biomass with a size greater than the limit for soil organic matter (SOM), commonly 2mm, and smaller than that of deadwood, 10cm diameter. This pool comprises biomass in various states of decomposition prior to complete fragmentation and decomposition where it is transformed to SOM. Local estimation of litter pool again relies on the establishment of wet-to-dry mass ratio. Where this is not possible default values are available by forest type and climate regime from IPCC ranging from 2.1 tonnes of carbon per hectare in

tropical forests to 39 tonnes of carbon per hectare in moist boreal broadleaf forest (IPCC, 2006).

Soil Organic Carbon: Soil organic Carbon includes Organic carbon in mineral and organic soils (including peat) to a specified depth (Lal and Bruce, 1999). Inorganic forms of carbon are also found in soil: however, forest management has greater impact on organic carbon and so inorganic carbon impact is largely unaccounted. Soil organic Carbon is influenced through land use and management activities that affect the litter input; for example how much harvested biomass is left as residue, and Soil organic Carbon output rates, for example tillage intensity affecting microbial survival. In Soil organic Carbon accounting, factors affecting the estimates include the depth to which carbon is accounted, commonly 30cm (IPCC, 2006), and the time lag until the equilibrium stock is reached after a land use change, commonly 20 years.

2.2.6 Summary of Literature Review

Climate change during the last decades has increased the need of information on the amount of forest biomass and carbon stocks because estimating forest carbon stock is of paramount importance to assess mitigation effects of forests on global warming and climate change. Accurate measurement of forest carbon is difficult to obtain without the precise measurements of biomass. Many studies focused specifically on tropical forest within Latin America with wide ranging results in carbon storage and distribution estimates. Other studies have focused upon tropical Asia. Relatively few carbon stock estimates have been carried out in Africa, but there are a large number of datasets available, providing carbon estimates for a variety of ecosystems, regions, and carbon pools. However, majority of studies focused mainly on above ground biomass and soil carbon, while carbon storage in other carbon pools is less well known. The dearth of

data on quantitative biomass/carbon stock measurements coupled with the uncertainties associated with extrapolated biome average values in tropical savannas resulted in significant gap in the carbon budget of the study area; yet there is no reliable data for local estimates.

From the foregoing review of literature, reliable data on biomass/carbon estimation of plant communities remains a key challenge in tropical savannas. As more forests come under threat from deforestation and degradation, additional information on carbon stocks and pools in tropical forests and savannas worldwide is required to understand controls on carbon stocks and cycling. Forests are the largest carbon pool on earth; acting as a major source and sinks of carbon. Thus, it has the potential to form a significant component in the mitigation of global warming and adaptation to climate change. Estimation of forest carbon stocks will enable us to ascertain the amount of carbon loss during deforestation or the amount of carbon that a forest can store when such forests are regenerated. Therefore, the importance of this study cannot be overemphasised.

CHAPTER THREE

ENVIRONMENT OF STUDY AREA

3.1 Location

The study area is comprised of Kpashimi Forest Reserve and adjoining Parkland area; located between Latitude 8° 39′ to 8° 50′ North and Longitude 6° 34′ to 6° 46′ East (see Figure 3.1).

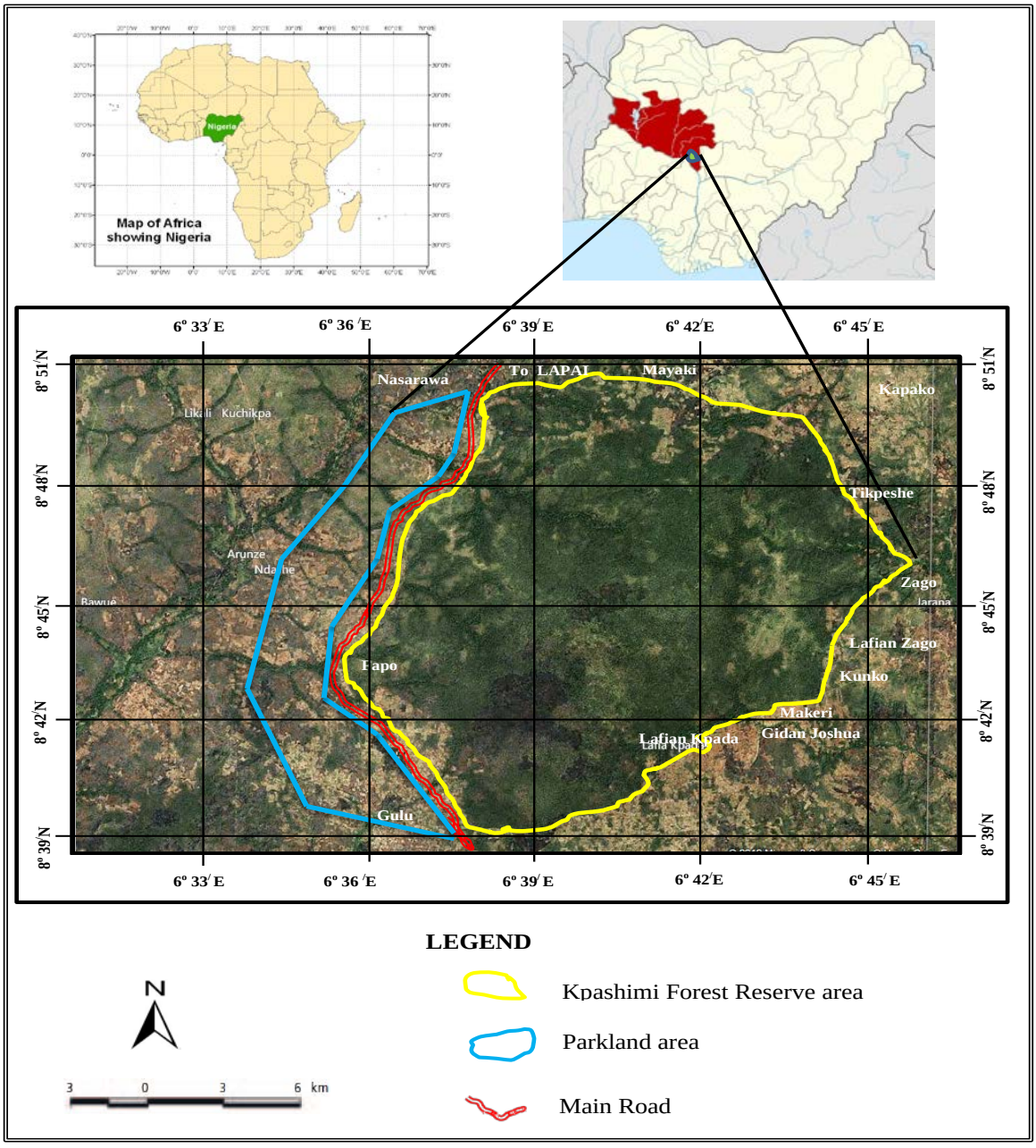


Figure 3.1: Location of Kpashimi Forest Reserve and Parkland area
Source: Niger State Geographic Information System Unit, Minna.

The study site lies 90 kilometres south of Minna, the capital of Niger State. It lies in the Southern Guinea savannah ecological zone. The forest reserve covers approximately 213.101 square kilometres while the delineated parkland situated adjacent to the forest reserve is some 58.361 square kilometres. The two areas are only separated by a trunk 'A' road; as shown on Figure 3.1.

The Kpashimi Forest Reserve was legally constituted through the Northern Nigerian Regional Public Notice Section N.R.L.N.20 of 1961 by the then Lapai Native Authority. The aim was to achieve the long-term conservation of nature with associated ecosystem services and cultural values (KFRMP, 1999). The Reserve is one of the few protected areas in the vast savannah woodland ecological zone of Nigeria and provides a suitable site for determining benchmark carbon stock in the area. The adjoining Parkland area is characterised by mature trees scattered in cultivated or recently fallowed fields. The Parkland is assumed to experience similar environmental conditions as the forest reserve but is obviously subjected to more human interference and hence more degraded.

3.2 Settlement and Population

The settlement pattern is either nucleated. Ethnic composition of the area includes Nupes, Dibo, Kakanda, Basange, Kami, Gupa, and Gana-gana ethnic groups. All the neighbouring communities to the forest reserve are linked by road (see Figure 3.2). Three of the villages including Nassarawa, Fapo and Gulu are linked by tarred motor road from Lapai to Gulu, while the remaining villages including Mayaki, Kpashimi, Zago, Kunko, and Lafian Kpada are linked by feeder road from Duna through Kpako, Gurudi and Tikpeshe to Gulu. Only four of the villages have primary Schools while three have Primary Health Centres. The Gulu community is largest in the area. It has in

addition, a Girls' Secondary School, Police Station, an Area Court, pipe borne water, electricity and a modern market. Most basic amenities are lacking in the remaining villages. The communities rely mainly on local resources and small scale farming for their livelihoods. Thus the study area is surrounded by predominantly rural communities (KFRMP, 1999). The study area is sparsely populated; with a population of 110,127 (National Populatio Commission NPC, 2006).

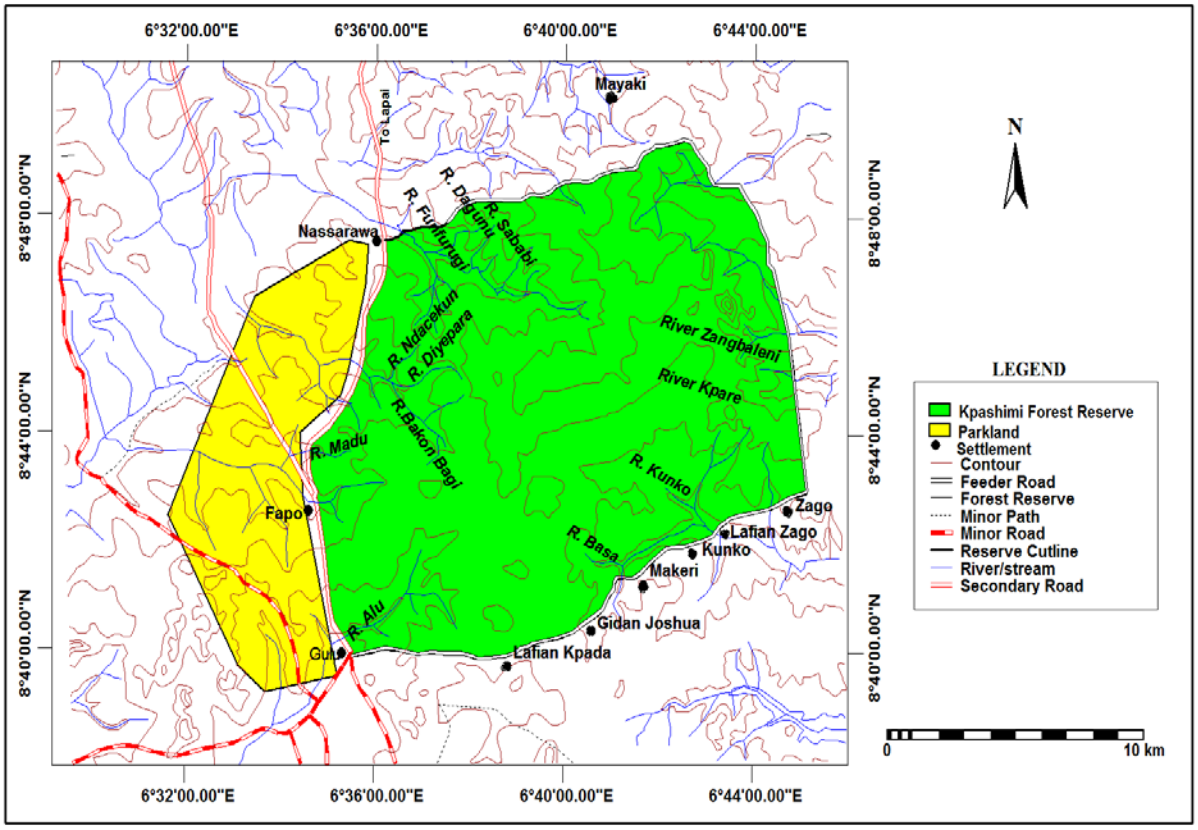


Figure 3.2: Location of settlements, rivers and roads in the study area
Source: Adapted and modified from Nigeria 1:100,000 GULU SHEET 206 Federal Surveys, Nigeria, 1967 (1000/62/12 -67)

3.3 Climate

The study area has a sub-humid tropical continental climate characterised by alternating wet and dry season; coded as 'Aw' by Koppen's classification. The mean annual rainfall is about 1,400 mm while mean annual temperature is about 28^{o}C (Ojo, 1977).

The data available for description of the climate parameters are those of the closest meteorological station at Minna.

***Rainfall*:** The mean annual rainfall for the study area is about 1,400 mm. The rainy season lasts for about 6 months (April-October) while the average number of rainy days is about 140 days (Ojo, 1977). The onset of wet season is usually in April/May, attains its single maximum peak in August and terminates in the month of October. The general atmospheric circulation of air masses is responsible for the alternation between wet and dry season in the study area. The principal air masses affecting the weather of the study area are the Tropical maritime (Mt) and the Tropical Continental (Ct) air masses. The Mt moving in south-west direction across the Atlantic ocean is moisture laden and brings rain to the area, while the Ct which is dry air flowing North- east across the Sahara desert effect dry season. Thus, occurrence of wet and dry season are in response to the annual North-South oscillation of the Inter Tropical Discontinuity; (ITD) which is the boundary between Mt and Ct. Wet season sets in when ITD lies north of the study area while Mt prevails (April-October), and dry season occurs when ITD lies south of the study area while Ct prevails over November- March (Udo, 1970; Ojo, 1977).

Rainfall intensity ranges from 60mm/hour to 90mm/hour. Squall line weather conditions are also common resulting in the incidence of dense, dark cumulonimbus clouds with thunder and lightning followed by strong winds and rainfall of very high intensity (Iloeje, 1982; Ojo, 1977). Such rainfall may last for up to half an hour, and is then followed by drizzle of several hours duration. This weather is then replaced by a few days of bright clear skies (State Environmental Action Plan -SEAP, 1999). The mean monthly rainfall and the trend is illustrated in Figures 3.3 and 3.4

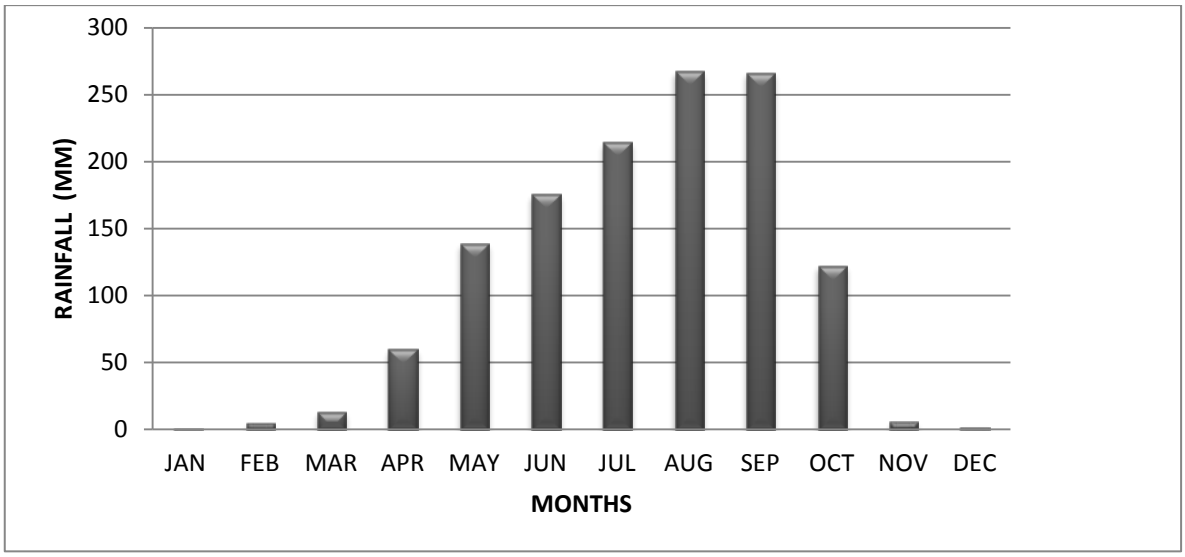


Figure 3.3: Mean monthly rainfall pattern in Minna (1916-2015)
Source: MAMS (Minna Airport Meteorological Station), Minna.

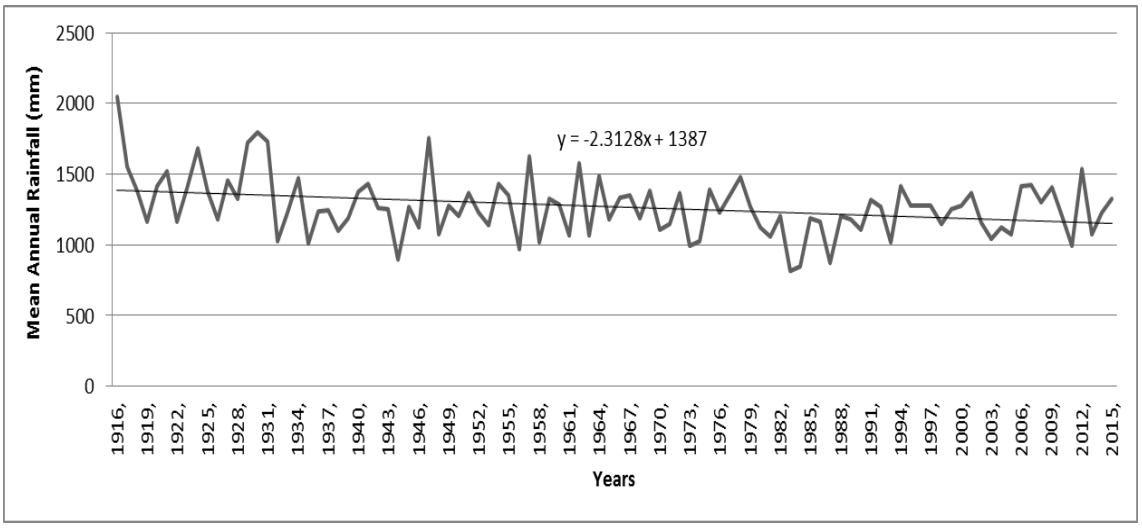


Figure 3.4: Yearly Rainfall trend over Minna (1916 – 2015)
Source: NIMET- MAMS (Minna Airport Meteorological Station), Minna.

***Temperature*:** Mean annual temperature of about 28^{o}C with annual range of about 3^{o}C is experienced in the study area. During the rainy season, temperature drops considerably especially between July and August, due to dense cloud cover. However, dry season is characterised by high diurnal ranges of about 11^{o}C especially between December and January (Idisi, 1997). Figures 3.5 and 3.6 show the mean monthly temperature, and annual trend respectively.

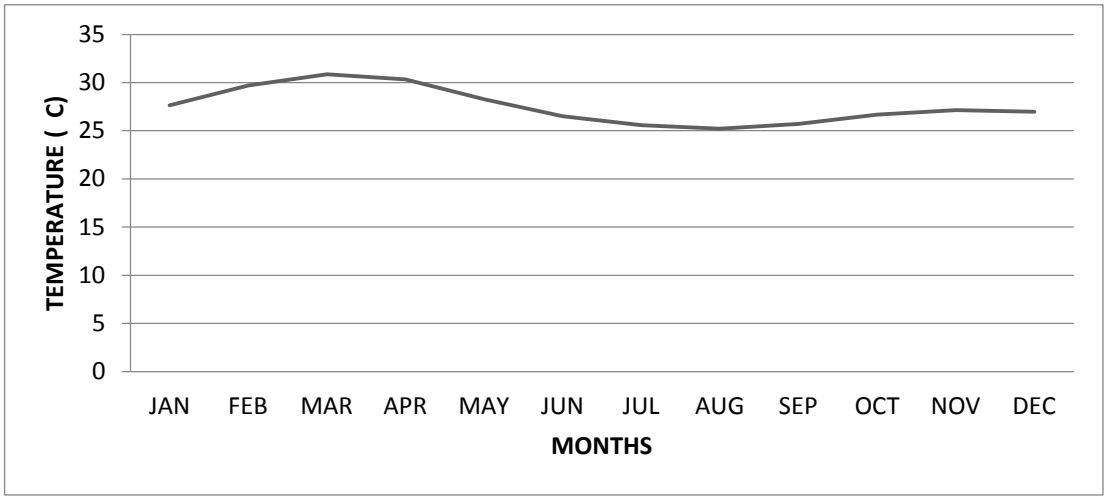


Figure 3.5 :Mean monthly temperature in Minna (1951-2015)
Source: MAMS (Minna Airport Meteorological Station), Minna.

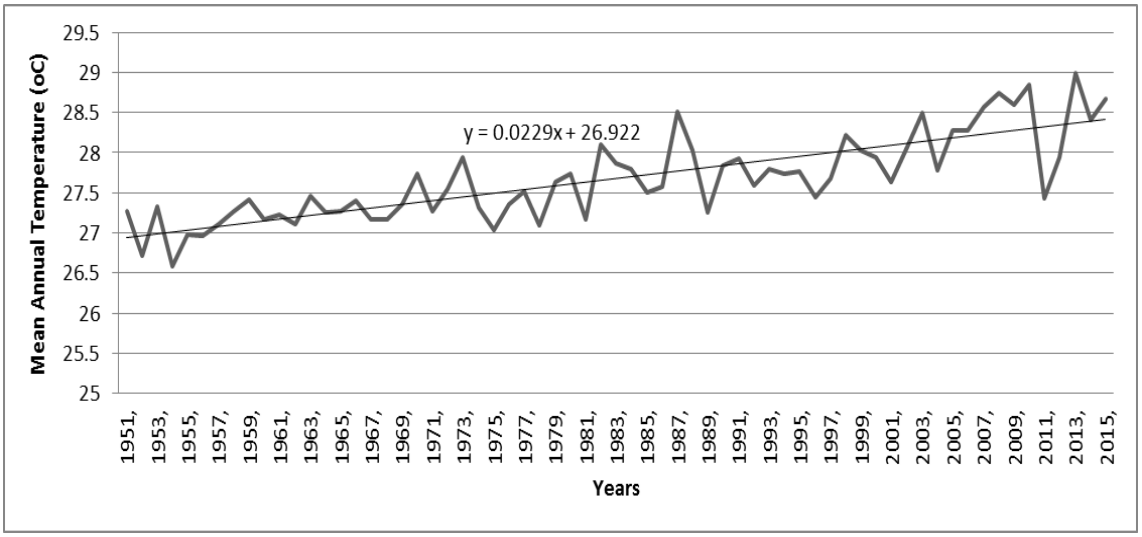


Figure 3.6:Yearly Temperature trend in Minna (1951-2015)
Source: NIMET- MAMS (Minna Airport Meteorological Station), Minna.

***Humidity*:** Relative humidity within the study area varies both temporally and seasonally. On the average, due to combined effect of prevailing wind and solar radiation, relative humidity could be as low as 20% at the peak of dry season - January to April- in the afternoon and as high as 60% in the wet season -June to October- (Iloeje, 1982; Ojo, 1977).

The quantity of carbon stock is greatly influenced by a number of environmental factors such as climate and soil as well as anthropogenic disturbance (IPCC, 2003). Climatic factors are primary factors that regulate biomass in an area. Soil moisture (that originates from precipitation) and soil temperature affect plant productivity and microbial activity as well as their decomposition rates (Houghton *et al*., 2001). An increase in soil moisture increases detritivore abundance and activity. This may lead to higher rates of litter decomposition and incorporation of litter into the soil and therefore increasing SOC concentration and reduced bulk density (Lal, 2004a). As long as soils are well drained and there is no lack of oxygen, high temperatures and high soil moisture increase decomposition rates (Allen *et al*., 2010; Sombroek *et al*., 1993). Furthermore, variations in temperature across savannas create significant difference in water use efficiency, strongly influencing the biomass production, the length of growing season and SOC concentrations. The amount and kind of biomass that is produced depends on the length of growing season and has significant impact on the SOC concentration in soils (Lal, 2004b). In general carbon stock stocks globally increase with precipitation and decrease with temperature (Hiederer, 2009).

3.4 Geology

The sedimentary rocks otherwise referred to as Nupe sandstone underlies as much as 85% of the study area. The rocks consists mainly of coarse grits, conglomerates, fine grained sandstone, silt stones and local shales, overlain by a cap of iron stones (Udo, 1970; SEAP, 1999). The sandstone overlies directly the basement complex rocks. The basement complex rocks are represented by series of older meta sediments, migmatite, and gneisses of Cambrian age. These rocks have been variedly metamorphosed (FORMECU, 1994; SEAP, 1999).

3.5 Relief, Geomorphology and Drainage

Topography of the study area is characterised by undulating plains (see Figure 3.7). Generally, the altitude of the reserve is about 450 meters above sea level (FORMECU, 1994). The area is dotted by flat topped hills such as messas, bute and inselbergs; that rise up to 100 meters above surrounding plains. Some areas are characterised by alluvial flood plains of widely spaced streams and rivers on the Nupe sandstone landscapes.

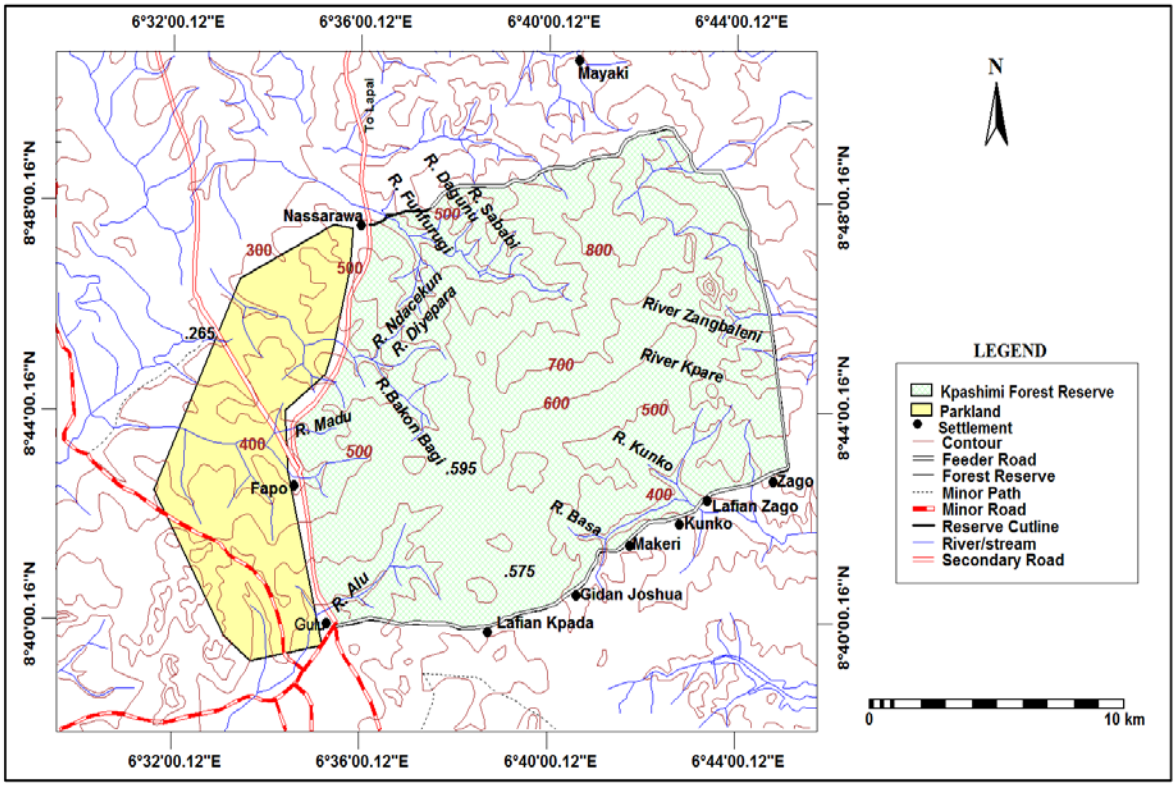


Figure 3.7: Relief and Drainage system Kpashimi forest reserve.
Source: Adapted and modified from Nigeria 1:100,000 GULU SHEET 206 Federal Surveys, Nigeria, 1967 (1000/62/12 -67)

As shown in Figure 3.7, the entire study area is drained by a number of streams including Alu, Madu, Ndacekun, Diye-para and Bokungi in the west; Funfurugi, Sababi, and Dagunu in the north; Kpare and Zangbelemi in the east that drain into River Gurara. Kunko and Basa streams are in the southern part of the reserve and drains in to River Niger. The forest reserve forms part of the watershed of Rivers Gurara and Niger. In general, the drainage pattern is dendritic flowing southward by direction.

3.6 Soils

Soils in the study area represent an interface between intensive chemical weathering of rocks and an active surface and subsurface denudation system (Areola, 1978; Jaiyeoba and Essoka, 2006). Due to the geology and geomorphology of the study area; being predominantly underlained by basement complex rocks dominated by granites, gneisses, migmatites, quartzites and schist, a wide variety of soils are developed (Bennett *et al*., 1979). The upland soils under the basement complex formation around Minna are generally deep, weakly to moderately structured sand to sandy clay with gravelly and concretionary layers in the upper or beneath the surface layers (Ojanuga, 2006). Alhassan *et al*. (2012) observed quartz to be the prominent mineral constituents of the soils around Minna. They also noticed high kaolinite clay content which was observed to be responsible for relatively low plasticity of the soils. Other workers identified some soils around Minna to have clay content in their B-horizons 1.2 times more than the overlying layer which indicated that they have well developed argillic horizons in their profiles (Adeboye *et al*., 2009). The argillic horizon, according to Soil Survey Staff (2010) is a subsurface diagnostic horizon with a significantly higher percentage of phyllosilicate clay than the overlying soil material. Most soils in the area are formed over deeply weathered basement complex rocks or those developed on the sedimentary Nupe sandstone. These based on the CCTA (Commission de Cooperation Technique en Afrique) classification system belong to *ferruginous tropical soils.*

The *Ferrugenous Tropical soils on Basement Complex Rocks* are classified as Alfisols (United States Department of Agriculture-USDA, 1975) or Luvisols (FAO/UNESCO, 1988). They have well-developed A, B and C horizons. Some also have an E horizon, and a textural B horizon which shows weakly- developed prismatic structure. There is frequently a marked separation of free iron oxides, which may either be leached out of

the profile, or precipitated within the profile in the form of spots or concretions. Apart from soils derived from schist, there is a general tendency for the soils to be coarse sand dominated and often gritty. The texture of B horizon usually falls in the order of sandy clay loams, but soils with less than 20% clay are not uncommon. Soils on schist parent rocks are markedly fine sand dominated, and in the B horizon readily gives rise to the formation of sandy clays, clay loams and even clays. The reserve of weatherable minerals is often appreciable. The clay is usually kaolinite but often contain small amount of 2:1 lattice clay. The CEC of soil is low (20-40 me/100g clay) and base saturation of the B horizon generally exceed 40%. Profiles are seldom thicker than 250cm. Colour fall in the 10YR and 7.5YR Munsell Colour range; exceptionally in the 5YR range. Most have faint to prominent reddish mottles. The topsoil develops a weak crumb structure and lower horizons, aweak or moderate subangular blocky. The top soil are generally well drained over most of the year and are moderately acid. The soil organic carbon is highly variable but generally low. (SEAP, 1999; Jaiyeoba and Essoka, 2006).

The *Ferrugenous tropical soils on Nupe Sandstones* can be divided in to two groups including fine sand dominated and coarse sand dominated soils. These have been defined by Valette (1973) as having more than 25% fine sand or coarse sand respectively. The sandstone plains are made up of very deep soils with a textural B horizon at variable depths. Based on Munsell Soil Colour Charts (Munsell Colour Company, 2009), the soils of the upper and middle slopes are (2.5YR to 10YR Munsell Colour); practically always unmottled and devoid of included materials like ion concretions and quartz gravel. These soils are liable to strong leaching processes and were classified as ferrasols. Towards the lower topography positions, there is a tendency for the soils to become paler in colour, 5-10YR Munsell Colour or even 2.5Y, mottled

and somewhat concretionary (State Environmental Action Plan -SEAP, 1999; Jaiyeoba and Essoka, 2006).

The *hydromorphic Soils* are soils of the valley bottom and flood plains. They vary texturally depending on the nature of alluvial deposits. Surface horizons are dark grey and faintly mottled, becoming well mottled lower down the profile where the colour is dark grey brown to grey brown. Structure range between well developed sub angular blocky to prismatic in the surface but usually massive at lower horizon. The soils have poor to very poor drainage, but well developed where the stream has incised into the valley. The soil reaction range from slightly acidic to neutral 6-7 pH. Organic carbon is moderate to high in the surface layer. Total nitrogen and phosphorus are low and exchangeable bases vary; depending on the parent material (SEAP, 1999; Jaiyeoba and Essoka, 2006).

The *Weakly developed soils* are Entisols and Cambisols (FAO/UNESCO, 1988) with a low level of profile development, which is reflected in the very weak differentiation of genetic horizons. They are of two major categories including lithosols and newly deposited soils. *Lithosols* are weakly developed soils which show low level of profile development reflected by weak differentiation of genetic horizons. They contain coarse elements with shallow soils overlying impenetrable ionpan on top of ferrugenised sadstone rocks. They contain ferruginised fragments of rocks overlying weathered rocks. Structures are often moderate sub angular blocky throughout. Texture range from sandy loam in the top layer to sandy clay loam in the lower layer. They are moderately acidic, generally low in organic carbon and Cation Exchange Capacity. *Depositional soils* include juvenile soils with A and C horizons developed at from recently deposited materials, most especially from riverine alluvium. The absence of well-developed

horizons is mainly due to brevity of the profile forming period. (SEAP, 1999; Jaiyeoba and Essoka, 2006).

Understanding the carbon stock of plant communities requires knowledge of environmental factors affecting their formation. This is particularly important in the study area where diversity of soils, hydrology and anthropogenic disturbances would motivate comparison among sites. Moreover it will enable us to examine factors responsible for the magnitude and distribution of carbon stocks in the study area. Similarly, soil physical and chemical properties like texture, pH, soil moisture and mineralogy influence the soil organic carbon content (Lal, 2001; Lal, 2004a, 2004b, 2004c).

3.7 Vegetation

The study area lie within the southern Guinea savanna zone (Keay, 1953; Areola, 1978). If left undisturbed, the trees may form fairly close canopies and grass/shrub undergrowth that does not impede the observer from seeing through is formed. Although located in the relatively low population density area of Nigeria, most of the natural vegetation cover has suffered profound anthropogenic modification. The vegetation communities are largely an expression of climatic and edaphic factors which have been modified by man's activities (Jaiyeoba and Essoka, 2006). Where settlements are widely spaced or absent, the vegetation consists of remnants of climax vegetation that have survived anthropogenic modification. In the immediate surroundings of settlements are savanna parkland which consists of trees of economic values that are scattered throughout cultivated fields and short-term fallows. They are covered with mostly annual grass such as *Rhynchelytrum repens, Panicum kerstingii, Setaria Africa-fusca, Aristida sp.* And *Hackelochloa granularia.* The trees consist of indigenous

species being remnant of once dense tree savanna woodland and trees deliberately planted by man. Prominent among such trees are *Ceiba pentandra, Tamarindus indica, Adansonia digitata* and *Mangifera indica*. Others are *Vitex doniana, Vitaleria paradoxa, Borassus aethiopum, Afzelia Africana, Acacia albida, Khaya senegalenesis, Parkia bigloboza, Daniellia oliveri, Ficus sycomorus, Pterocarpus erinaceus*.

A little further out from settlement areas, the vegetation consists typically of shrubby coppice and sucker regeneration from stumps and root stocks that have not yet been eliminated by cultivation (Shrub savanna). *Pennisetum polystachyon* and *P. pedicellatum* grasses are common in the early stages of newly fallowed land, but typically perennial *Andropogoneae* soon follows these. Afforested vegetation communities are rear but nevertheless abound, especially within built- up areas. They often serve as avenue and compound planting on watershed sites, and combine both indigenous and exotic species, such as *Daniellia oliver, Khaya senegalensis, Mangifera indica, Dalbergia sissoo,* and *Gmelina arborea.*

The forest reserve vegetation consists largely of indigenous species and some few exotic species deliberately planted by reforestation. The Kpashimi forest reserve exhibits high tree density and species diversity per unit area due to its protection status. The most common species in the reserve include: *Vitalleria paradoxa, Irvingia gabonensis, Parkia biglobosa, Anogeissus leiocarpus, Pterocarpus erinaceous, Detarium microcarpum, Prosopis Africana, Danellia oliveri, Afzelia Africana, Khaya senegalensis, Burkea Africana, Combretum molle, Terminalia avicennoides, Adansonia digitata, Tamarindus indica, Isoberlina doka, Acacia albida, Vitex doniana, Mangifera indica, Lophira ,lanceolata, Terminalia glaucescens, Ceiba pentandra, Elaeis guineensis, Anona senegalensis, Acacia tortilis, Hyphaenia thebeica, Azadirachta*

indica, Acacia raddiana, Acacia niotica, Borassus eathiopium, Bombax costatum, Acacia Senegal, Ximenia Americana, Balanites aegyptiaca, Anacardium occidentale, Afromosia laxiflora, Psidium guajavca, Gmalina arborea, Cola gigantean, Ficus polita, Nauclea latifolia, Antiaris Africana, Parinary polyandra and *Tectona grandis*.

The carbon stock in forest ecosystems depend on forest type, forest density and productive capacity of the site and thus varies even within a specific forest ecosystem (Malhi *et al*., 1999). The stock may increase due to growth of young trees, as well as regeneration of new ones leading to increase in the density of forest stands (Malhi and Grace, 2000). Alternately, it may decrease due to forest fires, disease, wind storms, drought, failure in protection/illegal logging or advance of the agricultural frontier into the site, etc. Predicting forest carbon stocks thus requires an understanding of factors that control the potential biomass at a site (Malhi *et al.*, 2002). An understanding of the structure and composition of woodland community species distribution and quantitative properties of their diversity is important in this study because they constitute variables that determine carbon stock in a forest.

3.8 Landuse

Generally, land use practices of the study area include forestry, farming, grazing, quarrying, hunting and gathering. These activities form important part of the economy of the study area.

***Forestry*:** As a legally constituted protected area, Kpashimi forest reserve is managed by the state government for sustainable provision of forest products and services, biodiversity conservation and watershed protection. The Forest Reserve corresponds to category VI of the International Union for Conservation of Nature (IUCN) protected

area management classification (IUCN, 1994, 2008). That is, protected area managed mainly for the sustainable use of natural ecosystem.

***Farming*:** The major occupation of inhabitants is farming. Farmlands are located around or close to the settlements. Encroachment of farmlands into the buffer zone of the protected area is common and characterised by shrubs merging into woodland savanna. Rainfed crops are mostly Sorghum, Millet, Maize, grown on ridges and yam, and cassava grown on mounds. The traditional farming system involves shifting cultivation/bush fallowing; usually small scale in nature and depends largely on household labour and use of simple farm implements. Trees are planted around the houses for shade and for fruits, nuts. Edible leaves and medicinal products. Some of these trees include neam (*Azadirachta indica*), oranges, tangerine and lime (*Citrus spp*.), oilpalm (*Elaeis guineensis*), mango (*Mangifera indica*), pawpaw (*Carica papaya*), guava (*Psidium guajavca*) and calabash tree (*Persea Americana*). In addition, Small vegetable gardens are found close to the house. Species grown include water leaf (*Talinun spp*.), bitter leaf (*Veronica amygdalina*), and fluted pumpkin (*Telfairia occidentails*). Wide variety of vegetables are frequently grown during the dry season in areas where there are perennial streams or other sources of water supply, like old mine quarry pond. These sites often become waterlogged or flooded during the rainy season but good use is made of available moisture during the dry season. These vegetables include spinach (*Amaranthus caudatus)*, lettuce, okra (*Hibiscus esculentus*), cucumber (*Cucumis sativas*), garden egg (*Solanum melongena*), tomato (Lycopersicon esculentum), onions (*Albium cepa*) and water melon (*Citrullus vulgaris*).

***Grazing*:** Domesticated livestock that graze freely around settlements include sheep, goat, chicken and ducks. However, of significant importance is the grazing by Fulani

cattle that have made the forest reserve a regular route as they migrate seasonally in search of green pastures.

***Quarrying and Cottage Industry*:** Quarrying activities carried out in the study area include quarrying of sand, gravels, and shaft sands deposited on river beds; as well as quarrying of stone or lateritic soil from lateritic outcrops or hills found in the area. The major forestry related cottage industries in this area are Shea butter processing condiment (Dawa-Dawa) processing and wood carvings in Gulu.

***Hunting and Gathering*:** Hunting is a tradition and a source of livelihood to some villagers. Men usually go hunting for wild animals and stay several days in the bush. Some hunters may encroach into the forest reserve in search of wild animals popularly called 'bush meat'. Gathering involves collecting of wild plants and animal products such as fruits, nuts, roots and tubers, tree barks, honey, herbal leaves, fodder, tree branches and grass for thatching roof, and other non-timber forest products. These serve as food, raw material, or for medicinal purposes. Most of these products are collected for domestic consumption while a few are for commercial purposes and traditional artisan craft making.

Land-use changes and land cover strongly influence carbon stock and distribution within ecosystems (Hairiah *et al.*, 2001; Houghton and Hackler, 2006). Changes in land use from natural forest to other land-uses has been more rapid in the past few decades than at any time in developing countries (Houghton and Hackler, 2006). The differences in carbon storage among plant communities reflect variation in a number of factors, including tree community composition, disturbance history, and successional stage, climate, and soil fertility (Brown and Lugo, 1990). Moreover, biomass of the woody material, and the magnitude of carbon stock, depends on how the land cover is managed

(Moreira, 2000). As more forests come under threat from deforestation and degradation, additional information on carbon stocks and pools in ecosystems is required to understand controls on carbon stocks and cycling.

3.9 Land Degradation

Land degradation is a common environmental problem observable in Kpashimi forest reserve and most especially its surroundings. The phenomenom is closely linked to population distribution pattern, relief features, nature of soils, land use and climatic factors (State Environmental Action Plan -SEAP, 1999). Land degradation in the study area is manifested in loss of vegetation due to deforestation and forest degradation; occurrence of gully, sheet and rill erosion, flooding, soil compaction, deteriorating soil organic matter and fertility; and desertification. Where one or more of these occur, it usually has devastating effects on the communities (SEAP, 1999). Unplanned utilization of renewable and non-renewable resources by rapidly growing population creates situations of environmental degradation; with dire consequences on the living organisms; man inclusive. Exploitation of land beyond certain limit could be responsible for most land degradation in the study area (SEAP, 1999). The most common land degradation in the study area includes soil and vegetation degradation.

Soil degradation is manifested by decline in soil qualities commonly caused through improper use by humans. This includes physical, chemical and/or biological deterioration. Examples are loss of organic matter, decline in soil fertility, decline in structural conditions, erosion, adverse changes in salinity, acidity or alkalinity and then effects of toxic chemicals, pollutants or excessive flooding.

Vegetation degradation is observable by reduction in biomass, decrease in species diversity, or decline in quality in terms of nutritional value for livestock and wildlife.

These pressures may be reflected by the Land cover/land use change caused by fires (past or on-going), deforestation, and denudation through overgrazing. The environmental degradation due to loss of biodiversity is related to agricultural activities. However, further direct causes of degradation in the study area are fire and overgrazing. In general, the present savanna vegetation is closely bound to the annual fires caused by man.

The implications of physical and cultural characteristics of the study area reviewed in the foregoing paragraphs (in this chapter) is that, several environmental variables would be responsible for the magnitude and distribution patterns of phytomass density over the study area. Theoretically, there is some relationship between vegetation types and climate conditions. However, climatic conditions alone do not explain the distribution of biomass everywhere. Soil, geomorphology, radiation and hydrological features, as well as management and land-use change, determine forest structure, species composition, and biomass/carbon stock; while anthropogenic factors such as human disturbance, management practices and land use history affect forest carbon stock density. Forests disturbed by humans are not only variable due to natural causes but also due to a variety of human activities that can reduce or enhance carbon stocks. The effect of human-caused variation depends on the intensity of activities and the duration. Thus variation brought about by human activities generally increases the variation in forest carbon stocks. Disturbances, especially fires and grazing, are important factors shaping the ecosystem structure and composition, creating plant communities of lower biomass density at some places; hence, lower carbon stock. Therefore, to measure forest carbon stocks, the prevailing environmental conditions in the study area need to be considered.

CHAPTER FOUR

MATERIALS AND METHODS

This chapter describes methodological approach to the research. It begins with a description of types and sources of data; followed by research design and description of field techniques employed for data collection. Finally, it considered the statistical techniques employed in data analysis. The study employed biometric forest inventory techniques which drew heavily on the standard techniques for field measurements of vegetation and soil. The Forest inventory involved measuring and assessing forest variables to provide information about the quantity and quality of the plant community parameters. The principles of forest inventory based on standard operating procedures on sampling determination, sample plot layout, morphometric measurement techniques and data analysis were employed accordingly.

4.1 Research Design and Methodology

The research field work was carried out in three main phases:

Phase I- Reconnaissance survey and desktop review.

Phase II- Pilot survey.

Phase III- Detailed Field work for biometric data collection.

4.2 Types and Sources of Data

This study utilised both the primary and secondary data to achieve stated research objectives. The types of data acquired are summarised in Table 4.1, while the integrated approach methodology employed in this study is summarised in Fig. 4.1.

Table 4.1: Types and sources of data acquired for the study

S/N	DATA REQUIRED	SOURCES OF DATA
1	**Structure and Composition of Plant communities** i. Tree height (metre) ii. Tree Diameter at Breast Height –DBH (cm) iii. Tree basal area (m^2 ha^{-1}) iv. Tree Crown cover (%) v. Shrub cover (%) vi. Grass cover (%) vii. Tree density/ha viii. Tree species richness (Margalef) ix. Tree species Diversity -The Shannon index (H′) x. Tree species dominance	Field survey, inventory and Morphometric measurements
2	**Biomass / Carbon stock in pools** i. Above ground tree biomass (kg) ii. Undergrowth biomass (kg / m^2) iii. Necromass (kg / m^2) iv. Belowground tree biomass (kg) v. Soil bulk density (Mg /m^3) vi. Soil organic carbon (Mg C/ ha^{-1}) vii. Biomass (Mg C/ ha^{-1}) viii. Carbon Stock Density (Mg C/ ha^{-1})	Field survey, sampling and Laboratory analysis.
3	i. Environmental Baseline conditions of Study area.	Desktop review of literature from Library, Internet, ministries and establishments.

Source: Author's Fieldwork 2013

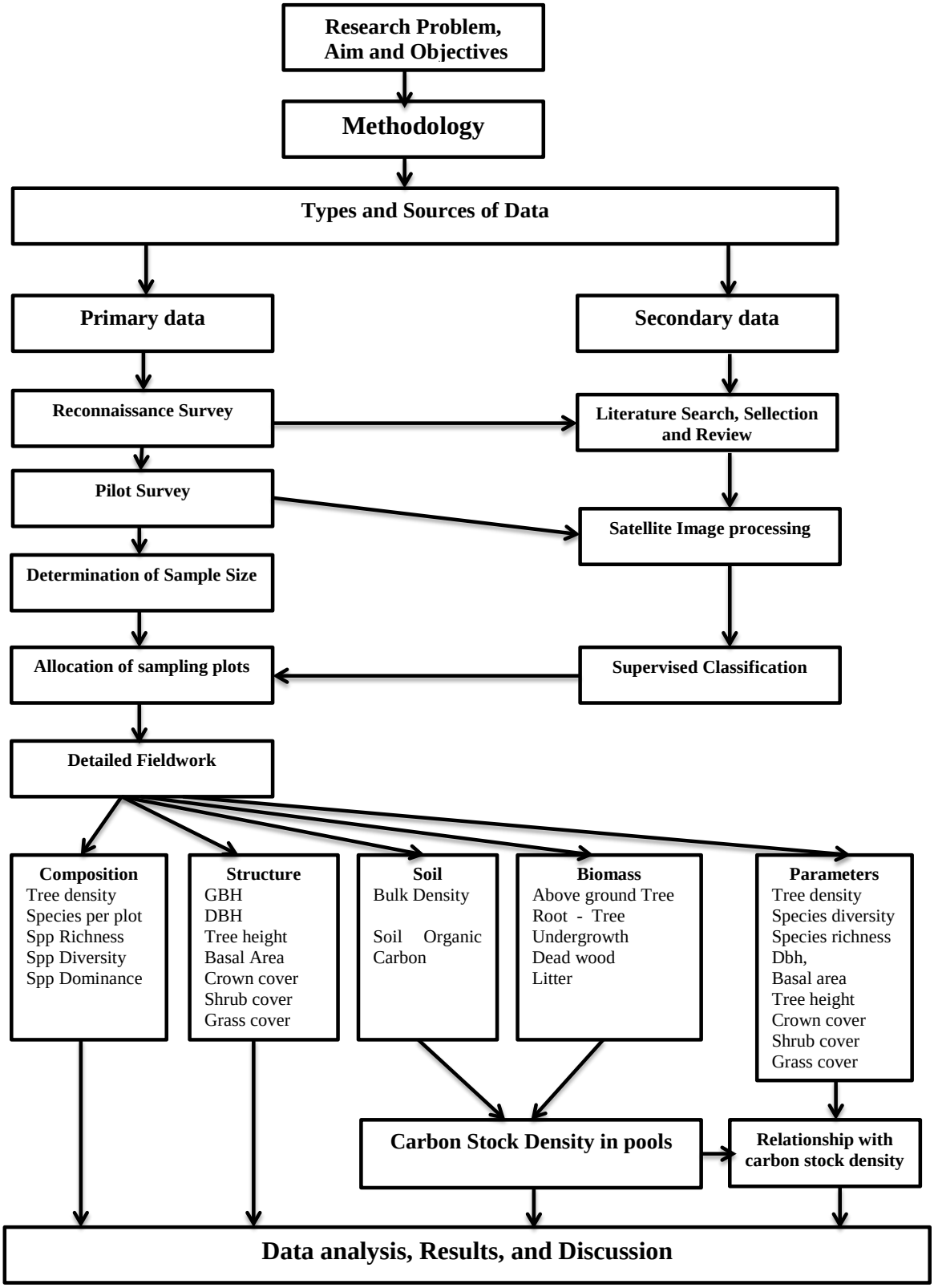


Figure 4.1: Flow chart of methodology adopted for the study
Source: Author's Fieldwork 2013

4.2.1 Reconnaissance Survey

Reconnaissance survey for the study was undertaken between 3rd and 4th of October, 2011. The objectives of the survey were to:

i. gain a general environment overview of the study area,
ii. acquire relevant data on the environment of the study area such as land use types, plant species distribution, plant life forms and growth conditions,
iii. consult and seek cooperation of Ministry of Environment and Forest Resources in the research endeavour,
iv. liaise with and solicit the cooperation of community leaders and local population in the research endeavour.

The outcome of the reconnaissance survey included a better familiarization with the study area; pledge of support by the Niger state Forest Management Unit under the Ministry of Environment and Forest Resources, Minna, Niger State; acquisition of relevant environmental baseline data (maps, official publications and the forest reserve management plan) of the study area; sensitization of local communities on the objectives of the study; selection and determination of a parkland area located adjacent to the forest reserve as study sites. The spatial boundaries of the study area was also clearly defined to facilitate accurate measurement, accounting, and verification as suggested by MacDicken (1997) and Brown (2002). Area tracking by Global Positioning System (GPS) was carried out to delineate the parkland study area as shown in Plate I.



Plate I: Tracking study area boundary using GPS

4.2.2 Major vegetation communities used for sampling frame

Based on observations made on the structure of vegetation communities in the study area; during reconnaissance survey, the following plant communities were identified and used for deciding a sampling scheme that would represents inherent variability of plant communities in the study sites; in order to provide the basis for spatial variability analysis of carbon stock in the study area. The brief and simple description of plant communities given below is based on observation during the reconnaissance survey and literature review; before the actual field data collection.

i. *Savanna Woodland*: These are deciduous and semi deciduous woodland. The plant community consists of climax vegetation that have undergone little anthropogenic modification. The savanna woodland occur either as continous or discrete entity throughout the reserve (see Plate II a).

ii. *Riparian Forest*: On narrow strips bordering streams and rivers, occurs the gallery forest or riparian forests. Many of this forest have been spared due to difficulty of access and periodic flooding regimes (see Plate II b).

iii. *Tree savanna*: These are degraded forest areas that are sparsely wooded and covered by scattered trees, separated by other undergrowth ground cover

vegetation. The vegetation community has emerged as a result of anthropogenic interference, evidenced by fallen tree stumps and branches and young regenerating trees (see Plate II c).

iv. *Scrubland*: This consists typically of shrubby coppice and sucker regeneration from stumps and rootstocks vegetation community that have not yet been eliminated by cultivation (see Plate II d).

v. *Grassland*: These are dominated by grassy and herbaceous vegetation where livestock grazing or fuel wood cutting have eliminated tree stands and bottomland sites; such as floodplains, basal slopes and river banks (see Plate II e).



Plate II: Forest Reserve vegetation communities used for sampling frame

The parkland study site was also categorised into three as follows:

i. *Traditional Agroforestry land* are farmland where planted trees are integrated with annual or perennial crops. Most common trees involved include Cashew, Guava and Mango trees (see Plate III a).

ii. *Old fallow land* are areas that have been under fallow for more than ten years (> 10 years) based on information provided by communities (see Plate IIIb).

iii. *Recent fallow land* are areas that have been under fallow for less than ten years (≤ 10 years) based on information provided by communities (see Plate III c).



(a) Agroforestry (b) Old fallow land (c) Recent fallow

Plate III: Parkland vegetation communities used for sampling frame

4.2.3 Pilot Field Survey

Having established the categories of vegetation communities to be sampled, a pilot field survey was conducted between 25th and 27th of September, 2012. The objectives of the pilot survey were to undertake feasibility study for data collection methodology; take preliminary inventory of tree species composition of the study area and to collect data for the determination of sample size for the study.

The outcome of the pilot survey was that firstly, the feasibility study for the data collection methodology made it possible for adequate planning for detailed field work. Secondly, data was collected for determining sample size. In line with measurement

protocol outlined in Verplanke and Zahabu (2009), the size of the sample (number of sample plots needed for any given forest) is assumed to depend on the variability of the forest structure - the more variable, the more plots needed in order to get an accurate estimate of overall biomass. Also recommended is the use of 15 sample plots randomly distributed over each study site. The default plot dimension of 250 m^2 is also recommended to be used for pilot surveys; as it is suitable for moderately dense vegetation cover.

Based on the measurement protocol briefly outlined above, fifteen sample plots were randomly laid out in each of the two sites (forest reserve and parkland); in order to cover the natural variability within the study area (IPCC, 2003). Within each plot, all live trees having a diameter at breast height (DBH) ≥5cm in each plots was measured using a DBH tape. The basal area of trees was subsequently determined. The indigenous tree species were identified by use of identification guide mannual of the *Trees of Nigeria* (Keay, 1989) and by assistance of a botanist and para-taxonomist in the Forest Management Unit of the Ministry of Environment and Forest Resources, Minna. The taxonomy used for naming species follows that of the African Plants Database (version 3.4.0). Voucher specimens were subsequently identified by the botanist who is versed with flora of the area. Unidentified trees species were recorded as Sp 1...Sp 2 likewise and named 'others'. A checklist of tree species was then prepared to facilitate identification and enumeration of tree species in the final comprehensive field work. A total of 58 species were identified during the pilot field survey and their list is summarised in Appendix XVIII. The tree species list was prepared by compiling a list of all tree species encountered in all the measured plots. This was then followed by their appropriate botanical names. The two columns of names were then sorted alphabetically by botanical names, and assigned species identification codes. This was used for

convenient species identification in the detailed field work data collection and computation process. All measurements taken were recorded on data sheet –Appendix VIII.

Using the data from 15 plots, the mean and standard deviation of plot basal area were determined. Subsequently, the number of sampling units (*n*) required was calculated as presented in section 4.2.4.2.

4.2.4 Detailed Field Survey

The detailed fieldwork for the project took place from September to October, 2013. The techniques of field measurement adopted for this study draws heavily on standard techniques for forest carbon inventory and mensuration prescribed in MacDicken (1997); IPCC (2003); Pearson *et al*. (2005, 2007); IPCC, (2006); Hairiah *et al*. (2010); FAO (1995, 2012); and Walker *et al*., (2012). The inventory was carried out towards the end of the rainy season in the study area; when species could be easily identified.

4.2.4.1 *Size of Sample Plots*

The size of sampling plot was determined based on the area per tree principle suggested by MacDicken (1997) and presented in Table 4.2. The rule of thumb is that plot size should accommodate at least 7 large trees. Based on this, a plot dimension of 500 m^2 quadrats with 22.4 meter length and breadth dimensions was used for this study; as this surface is suitable and widely used for savannah vegetation plant communities (MacDicken,1997). For undergrowth (shrubs and grasses) and litter, four $1m^2$ subplots placed randomly within the main plot were used; as recommended by IPCC (2003). Four fixed size square frames encompassing $1m^2$ were placed on the ground for clipping the undergrowth and litter contained therein. For soils, one sample was taken from each of the $1m^2$ subplot quadrants at two depths (0-15cm and 15-30cm), with the aid of soil

core sampler of 188.5 cm^3 volume (2 cm radius x 15 cm length cylinder). Within each of the four $1m^2$ quadrats, sample was first taken for shrubs and grasses, then for litter and lastly for soil (Pearson *et al.*, 2005).

Table 4.2: Plot radii for carbon inventory plots

Plot size (m^2)	**Plot radius (m)**	**Area per tree (m^2 $tree^{-1}$)**	**Nature of vegetation**
100	5.64	0 - 15	Very dense vegetation with large number of small diameter stems, uniform distribution of larger stem
250	8.92	15 - 40	Moderately dense woody vegetation
500	12.62	40 - 70	Moderately sparse woody vegetation
666.7	14.56	70 - 100	Sparse woody vegetation
1,000	17.84	> 100	Very sparse woody vegetation

Source: MacDicken (1997)

4.2.4.2 *Determination of Sample size*

Philip (1994) method for the calculation of sample size was employed in this study. This method requires that sample size for the study is determined by estimation of variation of tree stocking (which is the dominant above ground carbon pool); based on the assumption that the variance of the dominant carbon pool captures most of the variance in total above ground carbon stock. Furthermore, the level of precision required for a carbon inventory need to be decided. Accurate estimates of carbon stocks can be achieved at a reasonable cost to within 10 per cent of the true value of the mean at 95 per cent confidence level. This method was adopted because it is widely used in

carbon stock inventories and recommended by Brown (2002) and IPCC (2003). Consequently, based on the preliminary inventory data collected; during pilot survey, the mean and standard deviation of plot tree basal areas was calculated, precision sampling error (E) of 10% at 95% confidence level and the number of sampling units (n) was determined using the formula (equation 4.1).

$$n = \frac{CV^2\, t^2}{E^2}$$ (Philip, 1994)…….(4.1)

Where:

CV = is the coefficient of variation of tree basal area at breast height
t = is the t value for the 95% confidence interval.
E = is the allowable sample error of estimation.

The number of sampling units (n) required to attain precision sampling error (E) of 10% at 95% confidence level was calculated to be 30 plots for the Kpashimi Forest Reserve study site and 15 plots for the parkland study site. (see Table 4.3).

Table 4.3: Determination of required sample size for the study

Study Site	**Area (Hectares)**	**$\bar{x}$**	**SD**	**CV**	**Value of Students *t* at P = 10%**	**Error of Estimation (E)**	**Sampling Units required (Plots)**
Forest Reserve	21,293.79	5.62	1.75	0.31	1.75	0.10	29.43 (30)
Parkland	5,831.63	4.96	1.13	0.22	1.75	0.10	14.82 (15)
Total sampling plots required for the entire study							**45**

Note: $\bar{x}$- Mean, SD- Standard Deviation, CV- Coefficient of Variation

4.2.4.3 *Location of sample plots*

Having established the sample size, it became necessary to determine current area coverage of respective plant communities so as to facilitate the proportional distribution

of sample plots over the study area. Consequently, an analysis of satellite imagery of the study area was carried out mainly to extract relative proportional area coverage of plant communities.

4.2.4.4 *Analysis of satellite imagery data*

This section was required to identify the current area coverage of respective plant communities; which will now provide the basis for proportional allocation of sampling plots across the study area.

Nigeriasat-1 imagery (32 meter resolution of 10/9/2009) was acquired from the National Space Research and Development Agency (NASRDA), Nigeria. With the aid of ERDAS Imagine (version 9.3) software, the imagery was geometrically corrected, enhanced, georeferenced and classified into five plant communities based on the major plant communities in Kpashimi forest Reserve. The maximum likelihood (ML) algorithm was employed for pixel-based classification of Nigeriasat-1 bands 3, 2 and 1. The classification involved extraction of NDVI (Normalized Difference Vegetation Index) by supervised classification based on Maximum Likelihood Classifier (MLC) algorithm (Ahmad, 1986; Bulten and Clevers, 1993). The Maximum Likelihood Classifier assumes that a pixel has certain probability of belonging to a particular class. These probabilities are equal for all classes and the input data in each band follows the Gaussian (normal) distribution function (Lillesand *et al.*, 2004). The resulting land cover map of forest reserve is presented as Figure 4.2. Due to the resolution level of the imagery, classification of parkland categories could not be achieved; because the categories were not discernible (not distinctly distinguished). The entire parkland area looked rather homogenous and similar to the grassland category of the forest reserve. Consequently, the classification was restricted to the forest reserve plant communities.

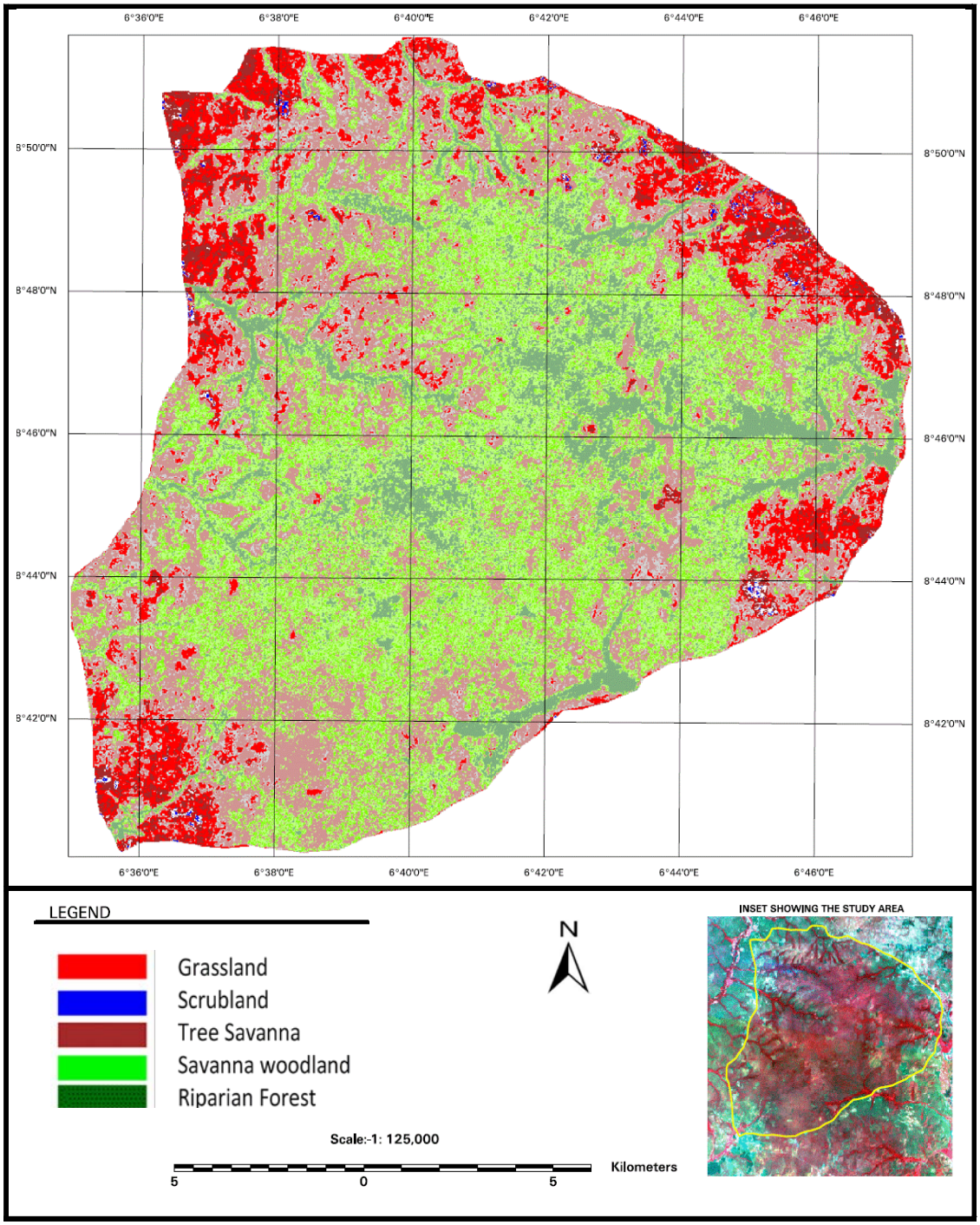


Figure 4.2: Classified Nigeria Sat 1 Image of the Study Area

Location of sample plots over the study area done on the basis of a sampling scheme that represents inherent variability of plant communities in the study area. Based on the remotely sensed imagery classification, quantitative data on the area coverage of respective plant communities was generated as presented in Table 4.5. The percentage

area occupied by the plant communities in decreasing order was savanna woodland (41%); tree savannah (25%); grassland (15.9%); Riparian forest (9.6%) and scrubland (8.2%).

On the basis of proportional area coverage, sample points were allocated to respective plant communities proportionately (see Table 4.4) by using the general formula:

$$n_h = (N_h/N)n$$

Where n_h is the number of plots in each strata,
N is total area of forest reserve,
N_h is specific plant community area in hectares
n is the sample size for the entire study area.

Table 4.4: Proportional sample allocation over plant communities in the forest reserve.

Plant community	**Area (ha)**	**Proportion (%)**	**Sample points**
Savanna woodland	8730.5	41.0	12
Riparian Forest	2044.2	9.6	3
Tree Savanna	5387.3	25.3	7
Scrubland	1746.1	8.2	3
Grassland	3385.7	15.9	5
TOTAL	21293.8	100	30

Source: Author's Fieldwork 2013

Since it was not possible (from satellite imagery) to classify plant communities in the parkland study site because differences could not be discerned (the entire area shows the same land cover), specific area coverage of the respective plant community categories could not be ascertained. Consequently, equal number of sample points was allocated. Thus, old fallow land (> 10 years), recent fallow land (≤ 10 years), and traditional agroforestry land, were allocated five sample points each; totalling 15 sample points calculated for the parkland study site.

Table 4.5: Distribution of sample plots and their coordinates

Site	Plant Communities	Sample Plots	Coordinates of Sample Plots	
Forest Reserve	Savanna woodland	1	8º 48′ 36″ N	6º 36′ 58″ E
		2	8º 47′ 54″ N	6º 41′ 20″ E
		3	8º 43′ 14″ N	6º 35′ 25″ E
		4	8º 47′ 33″ N	6º 43′ 24″ E
		5	8º 47′ 01″ N	6º 37′ 29″ E
		6	8º 44′ 32″ N	6º 36′ 12″ E
		7	8º 45′ 17″ N	6º 42′ 10″ E
		8	8º 44′ 00″ N	6º 37′ 42″ E
		9	8º 44′ 34″ N	6º 38′ 05″ E
		10	8º 42′ 24″ N	6º 38′ 57″ E
		11	8º 43′ 12″ N	6º 39′ 28″ E
		12	8º 40′ 55″ N	6º 37′ 20″ E
	Riparian Forest	1	8º 46′ 37″ N	6º 38′ 33″ E
		2	8º 40′ 24″ N	6º 38′ 38″ E
		3	8º 46′ 10″ N	6º 39′ 49″ E
	Tree Savanna	4	8º 42′ 31″ N	6º 42′ 09″ E
		5	8º 41′ 36″ N	6º 35′ 49″ E
		6	8º 44′ 25″ N	6º 39′ 55″ E
		7	8º 42′ 36″ N	6º 43′ 30″ E
		8	8º 48′ 15″ N	6º 39′ 26″ E
		9	8º 42′ 07″ N	6º 40′ 10″ E
		10	8º 42′ 46″ N	6º 36′ 54″ E
	Scrubland	1	8º 45′ 38″ N	6º 41′ 11″ E
		2	8º 44′ 44″ N	6º 44′ 03″ E
		3	8º 41′ 44″ N	6º 41′ 22″ E
	Grassland	1	8º 44′ 53″ N	6º 36′ 39″ E
		2	8º 43′ 39″ N	6º 44′ 05″ E
		3	8º 42′ 37″ N	6º 40′ 59″ E
		4	8º 43′ 31″ N	6º 42′ 35″ E
		5	8º 43′ 40″ N	6º 41′ 19″ E
Parkland	Agroforestry	1	8º 46′ 44″ N	6º 34′ 39″ E
		2	8º 42′ 21″ N	6º 33′ 37″ E
		3	8º 48′ 38″ N	6º 36′ 19″ E
		4	8º 48′ 52″ N	6º 35′ 25″ E
		5	8º 41′ 24″ N	6º 34′ 10″ E
	Old fallow land	1	8º 47′ 30″ N	6º 36′ 29″ E
		2	8º 47′ 53″ N	6º 35′ 26″ E
		3	8º 46′ 27″ N	6º 36′ 01″ E
		4	8º 40′ 23″ N	6º 40′ 10″ E
		5	8º 41′ 59″ N	6º 34′ 52″ E
	Recent fallow land	1	8º 43′ 31″ N	6º 34′ 47″ E
		2	8º 43′ 15″ N	6º 33′ 23″ E
		3	8º 45′ 29″ N	6º 35′ 24″ E
		4	8º 41′ 25″ N	6º 35′ 10″ E
		5	8º 44′ 58″ N	6º 34′ 15″ E

Source: Author's Fieldwork 2013

Allocation of sample points over the forest reserve site was done with the aid of the classified Nigeriasat-1 image of 2009; using Arc GIS 9.2. On display, the plant community classes were identified by pixels. Sample points were determined by randomly selecting pixels according to proportional sample points for each plant community; and their coordinates recorded. Plot allocation over the parkland study site was done in the field; by identifying plant community categories and selecting sites randomly. Each selected plot was geographically referenced (Plot locations were recorded at the plot centre) using a Geographic Positioning System (Garmin GPSmap 76). The coordinates of allocated sample points are presented in Table 4.5.

4.2.4.5 *Laying of Sampling Plot*

In order to navigate to predetermined latitude and longitude of each plot, the plots' coordinates (see Appendix I) were loaded into the GPS; using DNR Garmin software. Thereafter, sample plots were navigated to in the field with the aid of a GPS receiver as shown in Plate IV. The actual field work started by laying down sample plots on the ground with the aid of GPS compass and tape measure (see Plate V).



Plate IV: Locating a sampling plot with the aid of a GPS receiver



Plate V: Laying out a 500m^2 Plot

4.2.4.6 *Equipment and Instruments*

The following equipment / instruments (illustrated in Plates V and VI) were used for the field data collection.

i. Handheld GPS receiver (Garmin GPSMAP 76CSx)
ii. Prismatic Compass
iii. Ranging poles
iv. Measuring tapes (50m)
v. clinometers
vi. diameter tape and 1.3 m pole for measuring dbh
vii. Digital and Hanging spring balance scales (250g, 5kg, 10kg, 50kg, 200kg)
viii. pruning saw, shears and cutlass.
ix. Base map
x. 1m x 1m and quadrat sampling frames
xi. Soil core / sampling probes
xii. Coloured rope and pegs



Plate VI: Instruments used for measurements equipments



Plate VII: Inventory crew with

4.2.4.7 *Measurement of plant community characteristics*

Tree height: Clinometers were used to determine the angle of elevation, while the distance from foot of the tree to the observer was recorded. The height of the observer at eye level was noted. The height of the tree was calculated by using the formula: equation 4.2 (Gareth, 1991). Measurements taken were recorded on data sheet – Appendix IX.

$$X = Y * tan Å + Z \text{.....(4.2)}$$

Where: X= tree height, y = distance from the tree to the observer, Å= angle of elevation z = height of the observer at eye level

Tree Diameter at Breast Height: Tree DBH was determined by converting measured girth at breast height (GBH) (see Plate VIII) to DBH using the formula: equation 4.3, by Hairiah *et al.*, (2010). All measurements taken were recorded on data sheet –Appendix IX.

$$DBH = \frac{GBH}{\pi} \text{.....(4.3)}$$



Plate VIII: Measuring Girth at Breast Height

Basal Area: This is the cross sectional area of the tree trunk at 1.3 meters above the ground. The basal area was obtained by the formula: equation 4.4.

$$G = \pi * \frac{Di^2}{4} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.4)$$

Where: G is basal area, π= 3.14, Di is the diameter of tree at 1.3m above the ground level

Crown cover, Shrub cover, Grass cover: Estimation of canopy cover of a tree or group of trees in each quadrat was by line transect method. Trees whose projected canopy intersect the transect line were recorded. The total length of the projected canopy was then divided by the total length of the tape to give an estimate of crown cover in percentage (see equation 4.5). Same procedure applies to Shrub cover and Grass cover. (Eyre *et al*., 2006). All measurements taken were recorded on data sheet –Appendix XIV.

$$\text{Crown cover} = \frac{\text{Total estimated crown cover}}{\text{Total length of transect}}\ x\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.5)$$

Tree Species Density : Data collection consisted in recording and identifying all woody tree species. The tree density of the stands (*N*), that is, the average number of trees per plot expressed in trees/ha using equation 4.6 (Eyre *et al*., 2006).

$$N = \frac{n}{s} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.6)$$

Where: n is the overall number of trees in the plot, and s is the area of plot (s = 0.05ha).

Tree Species Richness: Species richness or variety index (d) was determined by the formula (Margalef, 1958). To compare diversity within each plot precisely, Margalef's index was calculated by the equation 4.7.

$$d = \frac{S}{\sqrt{N}} \qquad \text{.....4.7}$$

Where, *S* = number of species, *N* = number of individuals of all species.

Tree Species Diversity: Species diversity of each plot was determined using Shannon Weiner index (Shannon and Weiner, 1963). The Shannon index (H′) is a measure of biodiversity calculated from the relative abundance of species in a community. The Shannon index was used to measure diversity and is calculated by multiplying a species proportional abundance by the natural log of that number (see equation 4.8). This index is widely employed to measure biological diversity (Magurran, 2004). The Shannon index was determined for all tree species in each plot.

$$H' = -\sum_{i=1}^{s} p_i \ln p_i, \qquad \text{.....4.8}$$

Where: *pi= ni /N*; *ni is* the number of individual trees present for species *i*, *N* is the total number of individuals, and *S* is the total number of species.

Tree species dominance: Tree species dominance was determined based on the plant Species Importance Value (S.I.V.) developed by Cottam and Curtis (1956). According to this index, tree species in a given ecosystem can be classified in terms of their importance in that ecosystem. The plant Species Importance Value (S.I.V.) is defined as the sum of its relative density, relative dominance, and relative frequency according to the formular:

SIV = relative density + relative dominance + relative frequency

Where:

$$\text{Relative density} = \frac{Number\ of\ individuals\ of\ a\ species}{Total\ number\ of\ individuals}\ x\ 100$$

$$\text{Relative dominance} = \frac{Total\ basal\ area\ of\ a\ species}{Total\ basal\ area\ of\ all\ species} \quad x\ 100$$

$$\text{Relative frequency} = \frac{Frequency\ of\ a\ species}{Sum\ frequency\ of\ all\ species} \quad x\ 100$$

Where:

Density is the number of individuals (n/N).
Dominance is the basal area (m^2/ha).
Frequency is the number of plots in which a species is represented.

In general, the relative density, relative dominance, and relative frequency, vary in the range 0 – 100%, so the Species Importance Value (SIV) index range from 0 (absence of dominance) to 300 (mono dominance). The values of S.I.V. allow identifying the leading dominant entities, i.e. those species and families having the highest ecological value. Reitsma (1988) considered those having S.I.V. > 10 as ecological dominant species. Relative Density, dominance, frequency, and species importance values were computed to characterize the species composition. Based on the assessment of phytosociological characteristics (density, frequency, basal area dominance and S.I.V.).

4.3 Sampling of Tree Biomass (Phytomass)

Direct measurement of plant biomass requires harvesting, cutting and sorting, drying and weighing (Brown and Lugo, 1982, 1984; Brown, *et al.*, 1989; Brown, 1997). Sampling of aboveground tree phytomass was carried out as follows.

4.3.1 Selection of Tree Species and DBH range for phytomass sampling

Tree species were selected based on their DBH and species importance or dominance in the plant community (MacDicken, 1997; Pearson *et al* 2005, 2007). The species importance or dominance was calculated for all tree species, and then, five most dominant tree species with S.I.V. 15 and above in the study area were selected for biomass sampling based on Species Importance Value of Cottam and Curtis (1956); determined for the study site (see Table 4.6).

Table 4.6 Selected species with the highest Species importance value index (S.I.V.).

S. NO.	SPECIES NAME	RELATIVE DENSITY	RELATIVE DOMINANCE	RELATIVE FREQUENCY	S.I.V.
1	*Vitellaria paradoxa*	13.82	13.08	5.84	32.73
2	*Irvingia gabonensis*	9.20	15.94	3.24	28.38
3	*Parkia biglobosa*	8.04	9.84	5.32	23.20
4	*Anogeissus leiocarpus*	7.65	9.32	4.67	21.64
5	*Pterocarpus erinaceous*	7.43	4.02	4.28	15.73

For the determination of DBH range of the species, DBH data from field measurements was used. Frequency table was prepared using 10cm class intervals. The tree with a DBH close to the mean DBH value for each class was then determined. Table 4.7 indicates the mean DBH of trees across the classes for all five selected species that were harvested for sampling biomass.

Table 4.7: DBH Class Groups of Tree Biomass Sample

CLASS INTERVALS	FREQUENCY (N)	PERCENT	GIRTH (CM)	MEAN DBH (CM)
1-10.4	211	11.6	22.6	7.2
10.5-20.4	490	27.0	52.8	16.8
20.5-30.4	544	30.0	78.2	24.9
30.5-40.4	461	25.4	110.5	35.2
40.5-50.4	101	5.6	136.0	43.3
50.5-60.4	9	.5	175.2	55.8
Total	1816	100.0		

4.3.2 Procedures of Tree Biomass sampling

In line with standard practice e.g. Brown (1997); Pearson *et al*. (2005); Hairiah *et al*. (2010) and Walker *et al*. (2012), a total of 30 sample trees was required for biomass sampling. The 30 sample trees were distributed equally between six DBH classes (six sample trees per Species). Once a desired species with specified mean diameter was identified from the data collected in the field, the plot was visited for harvesting. Before felling, species name of trees were identified and the diameter at breast height (DBH) and height were measured. Trees were felled at ground level (at 0.3 m) with machete or chainsaw according to tree size and split into fractions. The branches, and leaves were separated from the trunk and the above ground portion of each sample tree was divided into three components (stem, branch, and leaf) (see Plates IXa,b,c). Stems and branches were trimmed and cross cut into manageable billets ranging from 1 to 2.5 m in length (Plate X a). Thereafter, fresh weight of each component was measured immediately, with the aid of hanging spring balance scale; using a bipod (anchor rope to tree) system for obtaining fresh weights of tree components (Plate X b).



Plate IX: (a) Felling (b) cutting and (c) sorting of trees component parts



Plate X: (a) Trimming into billets and (b) Spring balance bipod system for weighing.

Leaves were collected into separate bundles where the green weight of each was weighed. Small subsamples from each bundle were collected, labelled and measured for green weight analysis in the laboratory. Subsample of stem, branch, and leaf, approximately 200 g each were extracted as discs or aliquots, labelled, (see Plate XI a, b) for determination of their oven dry biomass in laboratory. This was later used to calculate total dry weight of each component.

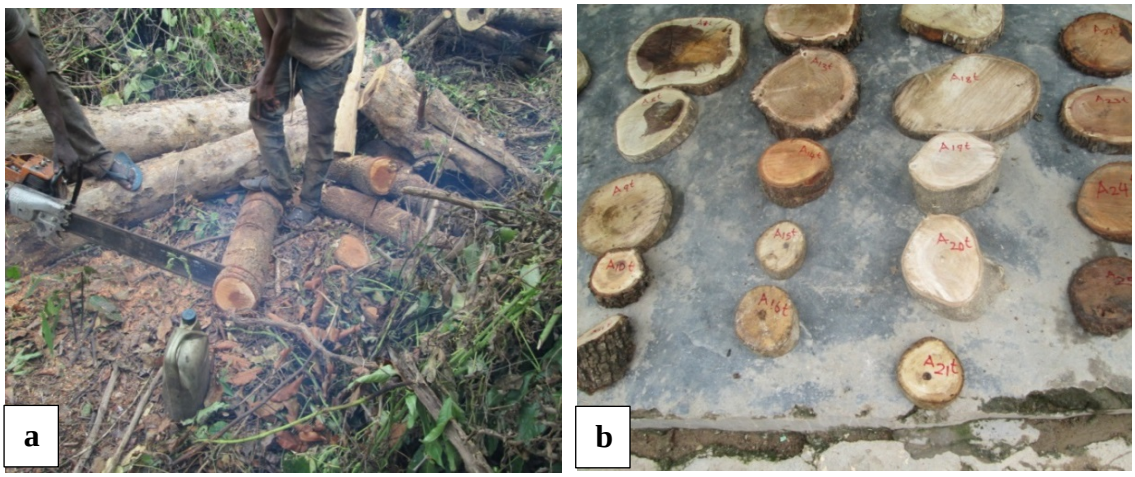


Plate XI: (a) Extraction of aliquots and (b) Labelling of the disc aliquots.

4.3.3 Laboratory analysis of phytomass samples

The collected samples were analysed for biomass in the laboratory. Samples included discs from trunks, and branches and samples from leaves (see Plate XII a, b.). The volume of the discs was determined by the water-displacement method (Brown, 1997). Following the volume measurement, the discs were oven dried to constant weight at 70^{O} C for 48- 96 hours. All measurements taken were recorded on data sheet –Appendix XVI. Total dry weight (TDW) of each organ of sample tree was calculated from its total fresh weight (TFW), the fresh weight of its organ sample (SFW) and its dry weight of sample (SDW) based on the eqution 4.9.

$$TDW = \frac{SDW}{SFW} x\, TFW \quad \text{.....(4.9)}$$

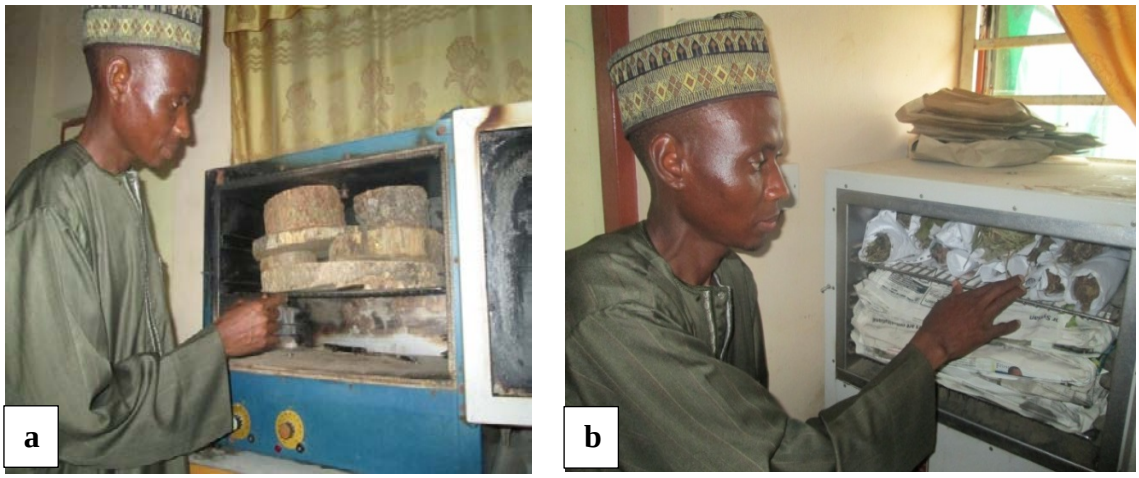


Plate XII: (a) Oven drying of dead wood and aliquots and (b) Oven drying of leaves, undergrowth and litter.

4.4 Assessment of Carbon Stock

Carbon stock form part and parcel of the biomass (phytomass and necromass) which makes it imperative that technically, biomass is first quantified and carbon stock is subsequently derived by simple conversion of biomass stock into carbon fraction. Carbon inventory data was collected from six major carbon pools including: Above

ground trees, Undergrowth, Dead wood, Litter, Live tree roots and soil organic matter. Definition of these carbon components and pools are presented in Table 4.8. Both biomass and carbon stock data were collected from the same sample points, using the same samples from the six respective pools.

Table 4.8: Carbon components and Pools measured

Forest Carbon Components	**Forest Carbon Pools**	**Definition**
Above Ground Biomass	Above Ground Tree **(T)**	Live trees above ground including stem, branches and leaves.
	Undergrowth **(U)**	Live understory vegetation including Shrubs and Grasses.
	Dead wood **(D)**	All fallen, standing dead trees, and coarse woody debris ≥10 cm in diameter on the forest floor.
	Litter **(L)**	All dead leaves, reproductive parts, and woody debris <10 cm in diameter on the forest floor.
Below Ground Biomass	Tree Roots **(R)**	All living biomass of live roots > 2mm.
	Soil Organic Matter **(S)**	Includes organic carbon in mineral soils to 30 cm depth.

Source: Modified from IPCC (2006)

All of these pools were accounted for, to generate a realistic assessment of current carbon stocks and carbon sequestration potential (IPCC, 2003). Therefore, the total carbon stock of the study area was determined by the formula:

Total Carbon (in tons) =T_{ree} (tc) + $U_{ndergrowth}$ (tc) + $D_{ead\ wood}$ (tc) + L_{itter}(tc) + R_{oot}(tc) + S_{oil} (tc)

The overall steps and methods for carrying out carbon stock data collection is illustrate on a flow chart as Figure 4.3 .Except for soil, which can be measured directly in units of carbon, biomass always is oven dried and generally is converted to units of carbon by multiplying biomass by 0.47 (IPCC, 2006; Brown, 1997).

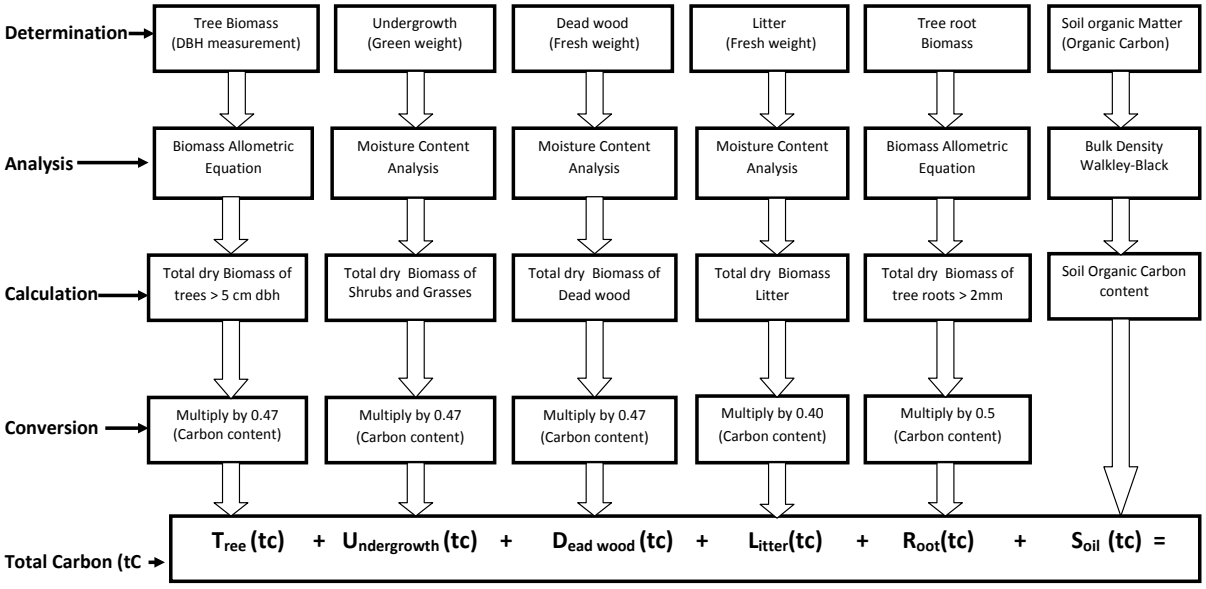


Figure 4.3: Flowchart of procedures for measuring major carbon pools.
Source: Modified from McDicken, (1997)

4.4.1 Above Ground Tree Phytomass

Aboveground biomass of each tree (dry weight, kg) was estimated using allometric equation with the field measured DBH. The application of appropriate allometric equation for biomass estimation is of crucial importance for reducing errors (Chave *et al*., 2005). However, species and site specific allometric equations were not available for the study area. The general allometric equation (see equation 4.10) developed by Brown *et al.* (1989) was used.

$$Y = \exp\{-1.996 + 2.32 \times \text{Ln}(\text{DBH})\} \quad \ldots\ldots(4.10)$$

Where exp {…}means "raised to the power of {…}"
Ln = "natural log of (…)"
Y = above-ground biomass in kg
DBH = diameter at breast height (1.3 m)

The allometric equation developed by Brown *et al.* (1989) was chosen because it was developed for dry tropical trees (dry transition to moist with annual rainfall > 900 mm) which is applicable to the study area. The above ground tree biomass was then

converted to carbon stock using the conversion co-efficient of 0.47 as recommended by IPCC (2006). All measurements taken were recorded on data sheet –Appendix IX.

4.4.2 Undergrowth Phytomass

Undergrowth was estimated using moisture analysis sampling technique (IPCC, 2003). This technique uses 4 small square frames each encompassing an area of 1 m^2, (Plate XIII a) to collect all material inside the frame, including herbaceous plants, grasses, and shrub. The material inside the frame was cut/clipped to ground level, pooled by plot to give a composite sample, and weighed (Plate XIII b). Well-mixed subsample was collected weighed and oven-dried to determine dry-to-wet mass ratios. These ratios were used to convert the entire sample to oven-dry mass. All measurements taken were recorded on data sheet–Appendix X.



Plate XIII: (a) Determination of 1m^2 quadrat and (b)fresh weight of undergrowth.

4.4.3 Dead wood Necromass

Measurement of dead wood necromass was carried out within the 500 m^2 plot by employing the line-intersect method (IPCC, 2003). A transect line of 22.4 meter length was laid running north-south of the plot, the diameters of all pieces of wood > 10cm that intersect the line were measured (see Plate XIV a, b), and the dead woods were

organised into three density classes: rotten (fully decomposed), intermediate (partially decomposed), and sound (see Plate XV a, b).



Plate XIV: (a) Measurement of rotten dead wood and (b) intermediate sound dead wood

All measurements taken were recorded on data sheet –Appendix XI. The volume per hectare was estimated for each density class based on the equation 4.11 (Brown, 1974; IPCC, 2003).

$$Volume\ (m^3 / ha) = \pi^2 * \left(\frac{d_1^2 + d_2^2 + \ldots d_n^2}{8 * L} \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots 4.11$$

Where: *d1*, *d2*, ..., *dn* = Diameters of intersecting pieces of dead wood (cm);
L = Length of the line; meters



Plate XV: Samples of dead wood collected for oven drying shown in decomposition classes

Samples were collected (see Plate XV) and oven dried at 85 ^{o}C for 48 hours, to a constant weight for density (dry weight per green volume) determination in each of the density classes. Density was calculated based on the equation 4.12.

$$WD = \frac{SDWc}{SV} \qquad \text{…….……....4.12}$$

Where: *WD* is wood density in g/cm^3;

SDWc is dry weight of sample aliquot

SV is volume of sample.

The volume was determined by equation 4.13.

$$Volume = \pi * \left(\frac{Diameter_1 + Diameter_2}{2} \Big/ 2 \right)^2 * \left(\frac{Width_1 + Width_2}{2} \right) \qquad \text{……...4.13}$$

That is, volume = π x (average diameter/2)^2 x average width of sample

Finally, the biomass of woody debris (Dead wood) is calculated by the formula (see equation 4.14).

$$AGB_{WD} = \rho V *_{WD} \text{……..(4.14)}$$

Where:

AGB_{WD}: aboveground biomass of woody debris (Mg/ha)

ρ : wood density of downed woody debris (g/cm3)

V_{WD} : volume of woody debris per unit area (m^3/ha)

4.4.4 Litter Necromass

Litter Biomass was measured with the aid of four 1m^2 quadrat frames. All litter within the frames was collected and weighed (Plate XVIa, b). A well-mixed subsample (80 to 100g) was then collected and placed in a marked bag. The subsample is used to determine oven-dry-to-wet mass ratios to convert the total wet mass to oven-dry mass. All measurements taken were recorded on data sheet –Appendix XII.



Plate XVI: (a) Collection from quadrat and (b) Taking fresh weight of litter

Oven drying of samples: All samples taken were labelled in the field with individual identification codes as contained on data sheet –Appendix XVII. To analyse moisture content, all subsamples of shrub, grasses, dead wood and litter collected from the field were transported to the laboratory, and each sample was oven dried at 85 °C constant-temperature. Oven-drying takes 2 days for leaves and for wood biomass under 10 cm in diameter, while 4 days for wood biomass over 10 cm in diameter. After drying, conversion ratios between the oven-dry and fresh weights were calculated using the formula (equation 4.15).

$$\boldsymbol{DW_W = \frac{DW_S}{FW_S} \times FW_W} \quad \text{.....(4.15)}$$

where,

DW_W : whole dry weight
DW_S : dry weight of sample
FW_W : whole fresh weight
FW_S : fresh weight of sample

All measurements taken were recorded on data sheet –Appendix XV.

4.4.5 Tree Root Phytomass

Measures of above-ground biomass have been found to be the best predictor for root biomass in past studies (Cairns *et al.*, 1997; Kurz and Apps, 1999). Belowground tree biomass was calculated for each tree by using a regression model (equation 4.16) relating aboveground biomass density (AGB) to root biomass density (RBD) derived for tropical trees (Cairns *et al*., 1997):

RBD (t/ha) = exp{-1.0587 + 0.8836 x Ln (AGB t/ha)}……..(4.16)

Where:

RBD = Root biomass density in tons/hectare (t/ha)
AGB = above-ground biomass density in tons per hectare (t/ha)
exp {…}means "raised to the power of {…}"
Ln means "natural log of (…)"

All measurements taken were recorded on data sheet –Appendix IX.

***Conversion of Biomass to Carbon*:** All biomass data obtained in the field measurements were converted to carbon stock by multiplying the weight of oven-dry matter by the carbon fraction. The formula used for the conversion of biomass to carbon stock is presented as equation 4.17.

$$CSi = TDWi * CFi \quad \text{……..(4.17)}$$

Where: *CSi* is carbon stock of component *i* in kg; *TDWi* is total oven dry weight of component *i* in kg; and *CFi* is carbon content in biomass of component *i* in percent

The IPCC, (2006) recommended carbon fraction of 0.47 was applied in converting oven dried biomass to carbon stock while litter pool was converted by 0.4 carbon fraction.

4.4.6 Soil Organic Carbon

To obtain organic carbon stocks in the mineral soil or organic soil, three types of variables were measured: soil depth, soil bulk density (calculated from the oven-dry weight of soil from a known volume of sampled material), and concentrations of

organic carbon (Nelson and Sommers, 1982; Robertson *et al*., 1999; Lal *et al.*, 1998, 2001).

Soil Organic Carbon: For the determination of soil organic carbon, sample was taken from each of the four $1m^2$ subplot quadrants placed randomly within the main plot (500 m^2). That is, soil was sampled in the same subplots as herbaceous vegetation and litter; after the vegetation and litter was removed. Soil core (188.5 cm^3 volume) was used to take samples from each of the four $1m^2$ subplot quadrants at two depths (0-15cm and 15-30cm) – see Plate XVII. Composite samples were formed by mixing well four samples taken from different points. The four samples were put together to form composite sample for the respective layers (0-15cm and 15-30cm) in two separate buckets (first bucket for 0-15cm depth and the second bucket for 15-30cm depth), sieved through a 2 mm mesh and mixed well. Then small sample from each bucket was taken in plastic bag, labelled and taken away for laboratory analysis.

Soil carbon content and bulk density were analysed at the Soil Science Laboratory, School of Agriculture and Agricultural Technology, Federal University of Technology, Minna. Per cent organic carbon concentration was estimated in the laboratory using Walkley- Black method. The procedure followed in the Walkley and Black (1934), method as outlined in (Okalebo *et al*., 2002) was used.



Plate XVII: Collection soil sample for organic carbon analysis

***Principle*:** Organic carbon was determined by the sulphuric acid and aqueous potassium dichromate ($K_2Cr_2O_7$) mixture. After complete oxidation from the heat of solution and external heating (Nelson and Sommers, 1982), the unused or residual $K_2Cr_2O_7$ (in oxidation) is titrated against ferrous ammonium sulphate. The used $K_2Cr_2O_7$, the difference between added and residual $K_2Cr_2O_7$, gives a measure of organic C content of soil. The chemical reaction in the method is;

$$\mathbf{2Cr_2O_7^{2-} + 3C + 16\ H^+ \rightarrow 4Cr^{3+}\ 3CO_2 + 8\ H_2O}$$

The carbon content of the soil is obtained by: %

Organic carbon (%) = (T x 0.3 x 0.2) / sample weight (g)

Soil Bulk Density: For the sampling of soil for the determination of the bulk density, within each plot a spot was randomly selected and soil samples taken. Two separate coring rings of volume 98.2 cm^3 (2.5 cm radius x 5 cm length cylinder) were used to collect samples in two depths (0 -15 cm and 16 – 30 cm) see Plate XVIII. The sampling had to be done very carefully to ensure that the soil was not disturbed. It was carried out by driving the coring ring vertically into the soil using a rubber mallet and a block of wood. The coring ring containing the soil was then cautiously dug out of the soil to

prevent any loss of soil from the ring. Excess soil on the outside of the coring ring was scraped off with a knife and thereafter, the core rings were covered with two plastic cover.



Plate XVIII: Collection of soil sample for bulk density

The core samples were kept in laboratory oven to dry at a temperature of 105^{o}c for about 72 hours. To estimate the actual dry soil weight, average weight for the core sampler ring was pre-defined and subtracted from the overall weight of the sample while it was in the ring. Sensitive balance (0.001 precesion) was used to weigh the samples. Bulk density was then calculated using equation 4.18.

$$\rho_b = \frac{ODW}{CV - (RF / PD)} \qquad \text{.....4.18}$$

Where

ρb = Bulk density of the < 2mm fraction, (g/cm^3)

ODW = Oven-dry mass of fine fraction (<2 mm) in g

CV = Core volume (cm^3)

RF = Mass of coarse fragments (> 2 mm) in g

PD = Density of coarse (quartz) fragments (g/cm^3). This often is given as 2.65 g/cm^3

The soil organic carbon pool (SOC) in each layer was estimated using equation 4.19.

$$SOC = [SOC] \times BD \times Depth \times 10 \quad \text{(4.19)}$$

Where:

SOC : soil organic carbon (Mg/ha)

[SOC]: the concentration of soil organic carbon in a given soil mass (g C/kg soil sample)

BD : bulk density, the soil mass per sample volume (Mg/m^3)

Depth : the depth of the soil sample (m)

All measurements taken were recorded on data sheets –Appendix XIII, while the summary of data on parameters of soil carbon stock is given in Appendix VI.

Data at the plot level were extrapolated to the area of a full hectare to produce carbon stock estimates per hectare. All measurements were converted to Mega gram per hectare. This standardisation is required so that results can be easily interpreted and also compared to other studies (Pearson, *et al*., 2005, 2007). The formula for converting from a per plot estimate of Carbon stock (in metric tons) to per hectare estimate (in metric tons per hectare) was calculated using equation 4.20.

$$Ct/h = (Ah / Ap) * Ctp \quad \text{(4.20)}$$

Where:

Ct/h : the estimate of carbon stock in metric tons per hectare.

Ah : the area of one hectare in square meters = ($10{,}000 m^2$).

Ap : the area of the plot, frame or soil core (m^2).

Ctp : the plot level estimate of carbon stocks in metric tons.

4.5 Methods of Data Analysis

Statistical analyses of data in this study were performed using IBM SPSS software - Version 19 (SPSS Inc., USA) and Microsoft Excel 2010 (Microsoft Corporation, USA). The descriptive statistics used to summarize the data include average mean, standard deviation, standard error, minimum and maximum values and coefficient of variation.

The differences in carbon stock densities among plant communities across study area were tested by use of analysis of variance (ANOVA). The student's *t* –test was used to test for differences in carbon stock and vegetation parameters between pairs of vegetation communities and specifically between the forest reserve and parkland. Stepwise multiple regression analysis was used in identifying the relative importance of independent variables (tree density, tree species diversity, tree species richness, DBH, basal area, height, crown cover, shrub cover, and grass cover) in predicting dependent variable (biomass/carbon stock) in the study area. Statistical tests were performed at 0.05, 0.01, and 0.001 significant levels.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Floristic Composition and Structure of Plant Communities

5.1.1 Composition of Woody Species over the study area

A total of 2,161 individual woody stands representing 58 species, 49 genera and 18 families were identified and enumerated in all plant communities found in the study area. Table 5.1 shows that the dominant tree species in the study area in the decreasing order are *Vitalleria paradoxa,* (13.8%) *Irvingia gabonensis* (9.2%), *Parkia biglobosa* (8.0%), *Anogeissus leiocarpus* (7.7%), *Pterocarpus erinaceous* (7.4%), *Detarium microcarpum* (5.7%), *Prosopis africana* (5.7%), *Danellia oliveri* (4.2%), and *Afzelia Africana* (3.5%); which together account for about 65.2 % of species dominance in the study area.

Furthermore, the most dominant families are *Fabaceae, Malvaceae, Moraceae,* and *Combrataceae*. The observed dominance of specific species and species families over the study area can be attributed to the effect of species ecological amplitude (environmental tolerance) whereby plant communities are basically a consequence of rigorous habitat selection that denies opportunity to all but a relatively few of the great variety of species (Daubenmire, 1968, 1972; Tivy, 1971; Fritts, 1976). Thus, plant species tend to be grouped in different combinations forming more or less definite communities. Each community is characterized by certain species which are inconspicuous or unrepresented in other communities.

Table 5.1: Floristic Composition of Woody Species over the Study Area

S/N	Tree Species	Genus	Family	Local Name	Total	%
1	*Acacia albida*	*Acacia*	*Fabaceae*	Gawo	21	1
2	*Acacia nilotica*	*Acacia*	*Fabaceae*	Bagaruwa	11	0.5
3	*Acacia raddiana*	*Acacia*	*Fabaceae*	Namji Bagruwa	12	0.6
4	*Acacia senegal*	*Acacia*	*Fabaceae*	Dakwara	4	0.2
5	*Acacia tortilis*	*Acacia*	*Fabaceae*	Bagaruwa ja	15	0.7
6	*Adansonia digitata*	*Adansonia*	*Malvaceae*	Kuka	23	1
7	*Afromosia laxiflora*	*Afromosia*	*Fabaceae*	Baajinii	10	0.4
8	*Afzelia africana*	*Afzelia*	*Fabaceae*	Apa	76	3.5
9	*Albizia zysia*	*Albizia*	*Fabaceae*	Fasa dagaa	1	0.1
10	*Anacardium occidentale*	*Anacardium*	*Anarcardiaceae*	Kashu	1	0.1
11	*Anogeissus leiocarpus*	*Anogeissus*	*Combretaceae*	Marke	17	0.8
12	*Annona senegalensis*	*Annona*	*Annonaceae*	Gubduu	165	7.7
13	*Antiaris africana*	*Antiaris*	*Moraceae*	Farin Loko	5	0.2
14	*Azadirachta indica*	*Azadirachta*	*Maliaceae*	Dogon Yaro	7	0.3
15	*Balanites aegyptiaca*	*Balanites*	*Zygophyllaceae*	Aduwa	10	0.4
16	*Bombax costatum*	*Bombax*	*Malvaceae*	Gujiiyaa	10	0.4
17	*Borassus eathiopium*	*Borassus*	*Malvaceae*	Guntsuu	13	0.6
18	*Burkea africana*	*Burkea*	*Fabaceae*	Icen kurdii	48	2.2
19	*Carica papaya*	*Carica*	*Malvaceae*	Gwanda	2	0.1
20	*Ceiba pentandra*	*Ceiba*	*Malvaceae*	Gaude	20	0.9
21	*Citrus sinensis*	*Citrus*	*Pieridae*	Lemu mai zaki	1	0.1
22	*Cocos nucifera*	*Cocos*	*Malvaceae*	Ikunu-Kpauta	1	0.1
23	*Cola gigantea*	*Cola*	*Malvaceae*	Labuje	7	0.3
24	*Cola nitida*	*Cola*	*Malvaceae*	Ajauruu	1	0.1
25	*Combretum molle*	*Combretum*	*Fabaceae*	Wuyan damoo	48	2.2
26	*Danellia oliveri*	*Danellia*	*Caesalpiniaceae*	Yaka	92	4.2
27	*Detarium microcarpum*	*Detarium*	*Caesalpiniaceae*	Taura	123	5.7
28	*Diosyros mespiliformis*	*Diospyros*	*Fabaceae*	Kanya	1	0.1
29	*Elaeis guineensis*	*Elaeis*	*Fabaceae*	Kwaakwa	18	0.8
30	*Ficus capensis*	*Ficus*	*Moraceae*	Baure	1	0.1
31	*Ficus polita*	*Ficus*	*Moraceae*	Durumi	2	0.1
32	*Ficus sycomorus*	*Ficus*	*Moraceae*	Dushe	1	0.1
33	*Gardenia terifolia*	*Gardenia*	*Moraceae*	Katanbiri	4	0.2
34	*Gmalina arborea*	*Gmelina*	*Lamiaceae*	Malaina	4	0.2
35	*Hyphaenia thebeica*	*Hyphaenia*	*Moraceae*	Goriba	13	0.6
36	*Irvingia gabonensis*	*Irvingia*	*Irvingiacea*	Hakokari	199	9.2
37	*Isoberlina doka*	*Isoberlina*	*Moraceae*	Kwambala	30	1.4
38	*Khaya senegalensis*	*Khaya*	*Meliaceae*	Madaci	74	3.4
39	*Lophira lanceolata*	*Lophira*	*Ochinaceae*	Namijin kadany	20	0.9

40	*Mangifera indica*	*Mangifera*	*Anacardiaceae*	Mangoro	13	0.6
41	*Nauclea latifolia*	*Nauclea*	*Fabaceae*	Igiyaa	5	0.2
42	*Parinary polyandra*	*Parinary*	*Fabaceae*	Gwanjaa kusa	4	0.2
43	*Parkia biglobosa*	*Parkia*	*Mimosaceae*	Dorawa	174	8
44	*Prosopis africana*	*Prosopsis*	*Fabaceae*	Kirya	124	5.7
45	*Prosopis julifera*	*Prosopsis*	*Fabaceae*	Akiye	1	0.1
46	*Psidium guajavca*	*Psidium*	*Guajavceae*	Gwaiba	13	0.6
47	*Pterocarpus erinaceous*	*Pterocarpus*	*Fabaceae*	Madobiya	161	7.4
48	*Sterculia tragacantha*	*Sterculia*	*Fabaceae*	Kusuru	5	0.2
49	*Strychnos innocua*	*Strychnos*	*Fabaceae*	Namijin kookiya	4	0.2
50	*Tamarindus indica*	*Tamarindus*	*Fabaceae*	Tsamiya	20	0.9
51	*Tectona grandis*	*Tectona*	*Verbenaceae*	Teak	4	0.2
52	*Terminalia avicennoides*	*Terminalia*	*Combretaceae*	Idi	33	1.5
53	*Terminalia glaucescens*	*Terminalia*	*Combretaceae*	Baushe	20	0.9
54	*Uapaka togoensis*	*Uapaka*	*Fabaceae*	Ka fafago	1	0.1
55	*Vitellaria paradoxa*	*Vitellaria*	*Sapotaceae*	Kadanya	299	13.8
56	*Vitex doniana*	*Vitex*	*Lamiaceae*	Dinya	20	0.9
57	*Ximenia americana*	*Ximenia*	*Olacaceae*	Tsada	10	0.4
58	*Ziziphus americana*	*Ziziphus*	*Rhamnaceae*	Kurna	1	0.1
59	Others (Unidentified)				142	6.6
					2161	100

Source: Author's Fieldwork 2013

5.1.2 Species Importance Value

Table 5.2 shows the woody species relative density (RD), relative dominance (RDo) and relative frequency (RF) were computed to determine the woody species importance value (SIV) over the entire study area.

Table 5.2: Species Importance Value Index over the study area

S. NO.	WOODY SPECIES	Total No.	RD	RDo	RF	SIV
1	*Vitalleria paradoxa*	299	13.82	13.08	5.84	32.73
2	*Irvingia gabonensis*	199	9.20	15.94	3.24	28.38
3	*Parkia biglobosa*	174	8.04	9.84	5.32	23.20
4	*Anogeissus leiocarpus*	165	7.65	9.32	4.67	21.64
5	*Pterocarpus erinaceous*	161	7.43	4.02	4.28	15.73
6	*Detarium microcarpum*	123	5.67	4.41	3.76	13.85
7	*Prosopis africana*	124	5.73	4.46	3.50	13.69
8	*Danellia oliveri*	92	4.24	3.90	3.76	11.91
9	*Afzelia africana*	76	3.52	3.90	3.37	10.80

10	*Khaya senegalensis*	74	3.41	3.68	2.33	9.43
11	*Burkea africana*	48	2.20	2.00	2.33	6.53
12	*Combretum molle*	48	2.20	2.11	1.95	6.26
13	*Terminalia avicennoides*	33	1.54	1.39	2.33	5.27
14	*Adansonia digitata*	23	1.05	1.04	3.11	5.20
15	*Tamarindus indica*	20	0.94	0.91	3.11	4.96
16	*Isoberlina doka*	30	1.38	1.15	1.82	4.35
17	*Acacia albida*	21	0.99	0.79	2.46	4.25
18	*Vitex doniana*	20	0.94	1.09	1.95	3.98
19	*Mangifera indica*	13	0.61	0.45	2.72	3.78
20	*Lophira lanceolata*	20	0.94	0.77	1.82	3.52
21	*Terminalia glaucescens*	20	0.94	0.72	1.69	3.34
22	*Ceiba pentandra*	20	0.94	1.03	1.30	3.26
23	*Elaeis guineensis*	18	0.83	0.71	1.69	3.22
24	*Annona senegalensis*	17	0.77	0.54	1.56	2.87
25	*Acacia tortilis*	15	0.72	0.97	1.17	2.86
26	*Hyphaenia thebeica*	13	0.61	0.50	1.69	2.79
27	*Azadirachta indica*	7	0.33	0.39	1.95	2.66
28	*Acacia raddiana*	12	0.55	0.42	1.69	2.66
29	*Acacia nilotica*	11	0.50	0.50	1.30	2.29
30	*Borassus eathiopium*	13	0.61	0.32	1.30	2.22
31	*Bombax costatum*	10	0.44	0.38	1.30	2.12
32	*Acacia senegal*	4	0.17	0.14	1.43	1.73
33	*Ximenia Americana*	10	0.44	0.35	0.91	1.70
34	*Balanites aegyptiaca*	10	0.44	0.44	0.78	1.65
35	*Anacardium occidentale*	1	0.06	0.02	1.56	1.63
36	*Afromosia laxiflora*	10	0.44	0.25	0.91	1.60
37	*Psidium guajavca*	13	0.61	0.30	0.65	1.55
38	*Gmalina arborea*	4	0.17	0.06	1.04	1.26
39	*Cola gigantea*	7	0.33	0.26	0.65	1.24
40	*Ficus polita*	2	0.11	0.06	1.04	1.20
41	*Nauclea latifolia*	5	0.22	0.32	0.52	1.06
42	*Antiaris africana*	5	0.22	0.18	0.52	0.92
43	*Parinary polyandra*	4	0.17	0.16	0.52	0.84
44	*Tectona grandis*	4	0.17	0.20	0.39	0.75
45	*Ficus sycomorus*	1	0.06	0.04	0.65	0.75
46	*Strychnos innocua*	4	0.17	0.19	0.39	0.74
47	*Citrus sinensis*	1	0.06	0.02	0.65	0.72
48	*Carica papaya*	2	0.11	0.07	0.52	0.70
49	*Sterculia tragacantha*	5	0.22	0.08	0.39	0.69
50	*Ficus capensis*	1	0.06	0.00	0.52	0.58
51	*Gardenia terifolia*	4	0.17	0.07	0.26	0.50
52	*Cocos nucifera*	1	0.06	0.09	0.13	0.28
53	*Cola nitida*	1	0.06	0.05	0.13	0.24
54	*Prosopis julifera*	1	0.06	0.05	0.13	0.23
55	*Diosyros mespiliformis*	1	0.06	0.04	0.13	0.22
56	*Uapaka togoensis*	1	0.06	0.03	0.13	0.21
57	*Ziziphus americana*	1	0.06	0.02	0.13	0.21
58	*Albizia zysia*	1	0.06	0.02	0.13	0.20
59	Others	142	6.55	5.76	4.54	16.85
	Total	**2161**	**100.00**	**100.00**	**100.00**	**300.00**

Source: Author's Fieldwork 2013

Reitsma (1988) considered those species having S.I.V. > 10 as ecological dominant species. Based on the Species Importance Value index analysis presented in Table 5.2, the ecologically dominant tree species in the study area in decreasing order are *Vitellaria paradoxa,*(32.73) *Irvingia gabonensis,* (28.38) *Parkia biglobosa,* (23.20) *Anogeissus leiocarpus,* (21.64) and *Pterocarpus erinaceous* (15.73). Others include *Detarium microcarpum* (13.85) *Prosopis Africana* (13.69) *Danellia oliveri* (11.91) *Afzelia Africana* (10.80). This confirms findings by Keay (1989) that, Southern Guinea savannah in Niger state is the major *Vitellaria paradoxa* zones in Nigeria. Similarly, Odebiyi *et al*. (2004) reported high population of *vitellaria paradoxa and parkia biglobosa* over moist and dry Guinea savanna in Nigeria; with *Vitellaria paradoxa* being more dominant. In contrast, Mama and Adeniyi (2005), found the dominant tree species in the savanna were *Anogeissus leiocarpus, Burkea Africana, Vitellaria paradoxa, Burkea Africana and Pterocarpus erinaceus.* Boffa (1999) and Hall *et al*. (1996) also reported *Vitellaria paradoxa* as the most dominant in savanna where it is associated with other species such as *Parkia biglobosa, Acacia senegalis and Terminalia avicenniodes.* The foregoing analysis reveals that the study area is characterized by typical Guinea savanna tree species. Moreover, plant species tend to be grouped in different combinations forming more or less definite communities due to the effect of ecological amplitude or environmental tolerance (Daubenmire, 1968; Fritts, 1976). The implication of most dominant tree species in the study site is that they contribute most of the above ground carbon stock.

5.1.3 Structure of woody species over the study area

Woody species consists of trees and saplings. In line with Walker *et al*. (2012) classification, trees are defined as stems with DBH of > 6 cm and a height of ≥1.3 m; while saplings were considered as woody stems < 6 cm DBH and a height of >1.3 m.

The data analysis on the four basic structural properties (tree height, DBH, basal area and biomass) of woody species in the study area; across the vegetation communities is presented in Figure 5.1. The distribution of structural classes indicate that the height class distribution of trees produced a reverse "J" shaped curve (Figure 5.1a) with shorter trees (0.5 - 20 meter) dominating. Similarly, the diameter class distribution of woody species in the study area produced a reverse "J" shaped curve (Figure 5.1b) whereby trees with lower DBH (0.5cm-12cm) dominates. The observed significant proportion of low woody species height and DBH shows that the area is dominated by regenerating saplings with woody stems having less than 6 cm DBH and less than 1.3 m height.

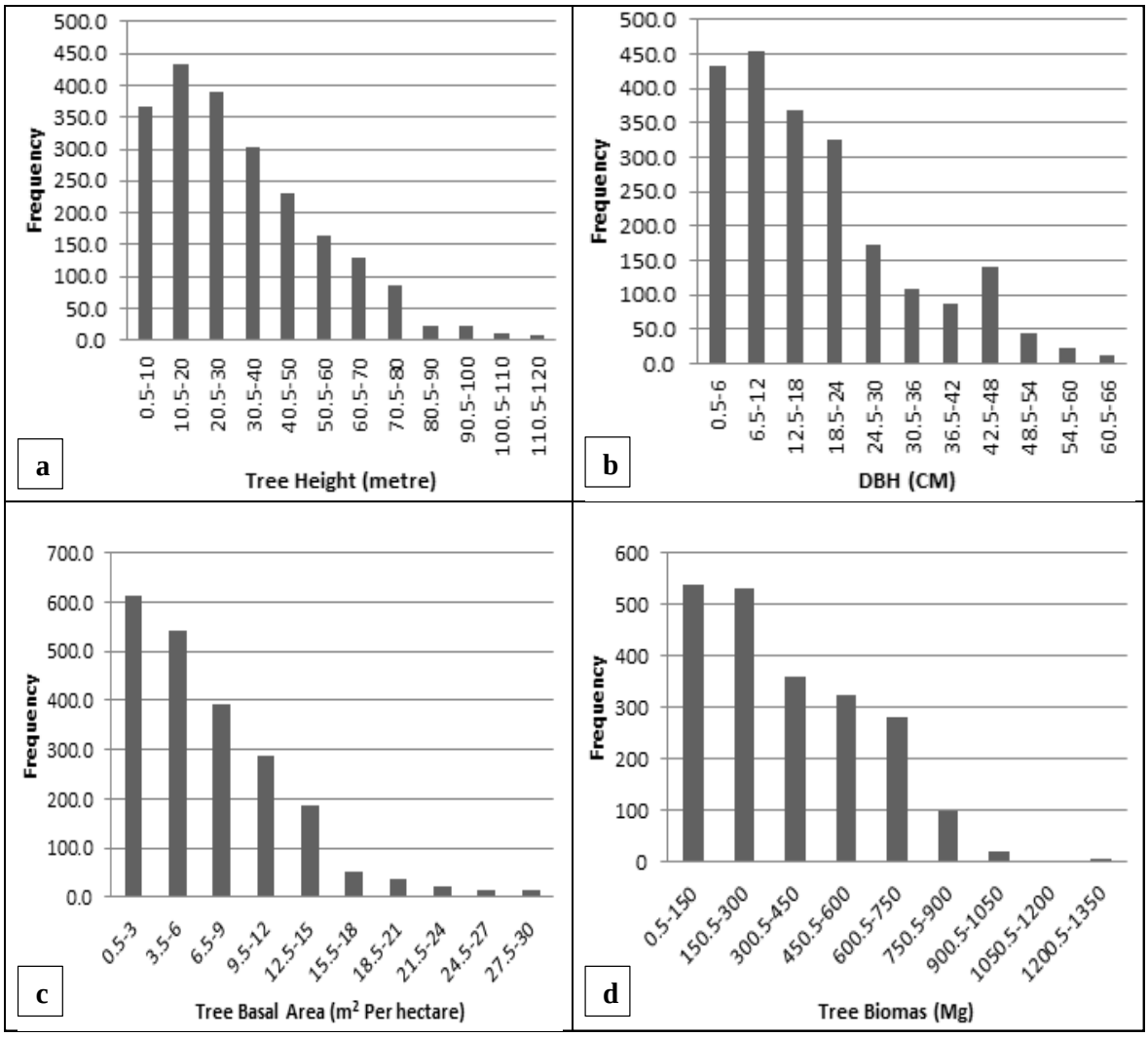


Figure 5.1: Distribution of woody species structural classes

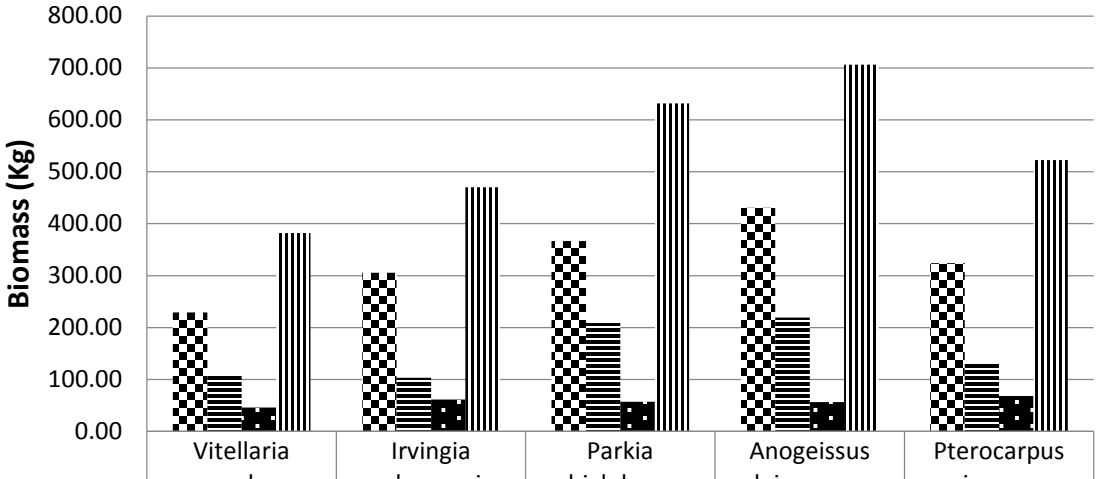
The class distribution of tree basal area and tree biomass indicates a reverse "J" shaped curves (Figures 5.1c and 5.1d); which shows that trees with lower basal area (0.5 – 6m^2 /ha) and trees with lower phytomass (0.5-150 Mg) are most dominant. The reverse J-shaped pattern of woody species structural class distribution for tree height, DBH, basal area, and biomass implies that more trees are in the juvenile classes with active regeneration status sequel to anthropogenic disturbance by deforestation and degradation. The relatively lower structural attributes in the study area is an indicator of woodland deforestation, degradation, fragmentation and local species extinction; a result of unsustainable harvesting for firewood, charcoal production, grazing and shifting cultivation that is commonly practiced in the study area.

More trees in the juvenile class imply active regeneration of woody species in the study area; which is a good sign of sustainability of the plant communities. Other studies have reported similar size class distributions (Kalaba *et al*., 2012, Chidumayo, 1997, Shirima *et al*., 2011). However, inverse J-distribution assumes equal mortality rates among size classes which Isango (2007) regarded as biologically unrealistic. That notwithstanding, the regenerating status of the woody species indicate high potentials for carbon sequestration if adequate management will be sustained by conserving the woody species.

5.1.4 Biomass of the most dominant tree species

At species level, plants vary in their biomass and carbon content and the relative contribution of these species can be assessed by determining the species that contribute most to the aggregate carbon stock in the study site. The relative contribution of plant species was assessed by determining the Species Importance Value (SIV); as described in section 5.1.1. Based on the criteria of tree species with S.I.V. ≥15, phytomass of five

most dominant species were measured by harvesting, cutting, sorting, oven-drying, and weighing and the data is presented in Appendix V. The phytomass of five most dominant tree species in decreasing order are *Anogeissus leiocarpus,* (705.82 kg) *Parkia biglobosa*, (631.47 kg) *Pterocarpus erinaceous*, (522.23 kg) *Irvingia gabonensis* (469.72 kg) and *Vitellaria paradoxa* (381.80 kg) (see Figure 5.2). The result shows that tree species have different phytomass weight and would store different amount of carbon. It is noteworthy that *Anogeissus leiocarpus* which is the 4th on the list of Species Importance Value, weighed highest, while *Vitellaria paradoxa* in the 1st position of Species importance value, weighed least among the five most dominant species in the study area. This study thus indicates that though there are five most important tree species in the study area, their contribution to total above ground carbon stock varies. The finding in this study implies that *Anogeissus leiocarpus* is the species with highest potential to store carbon in the study area.



	Vitellaria paradoxa	Irvingia gabonensis	Parkia biglobosa	Anogeissus leiocarpus	Pterocarpus erinaceous
Trunk	229.08	305.32	366.23	430.55	323.78
Branches	106.92	103.33	208.38	218.80	130.58
Leaves	45.80	61.08	56.85	56.45	67.92
Total	381.80	469.72	631.47	705.82	522.23

Figure 5.2: Comparison of biomass of the five most dominant tree species

5.1.5 Characteristics of Plant communities

The data obtained per plot on plant community characteristics is given in appendices II, III, and IV. The characterization of plant communities in the study area was based on their structural properties and composition. The plant communities inventoried include Savanna Woodland (SW), Riparian Forest (RF), Tree Savanna (TS), Scrubland (SL), Grassland (GL), Agroforestry (AGF), Old Fallow Land (OFL), and Recent Fallow land (RFL). The parameters measured include Tree Density (TD), Species Richness (SR), Shannon Wiener Diversity Index (SWD), Species per Plot (SP), Tree Crown Cover (TCC), Shrub Cover (SC), Grass Cover (GC), Tree Height (TH), Diameter at Breast Height (DBH), Basal Area (BA) and Biomass. Table 5.3 presents the summary of parameters measured.

Tree Density and Species richness

With reference to Table 5.3, mean values of tree density per hectare and Species richness was higher in Savanna Woodland and Riparian Forest. Scrubland and Tree Savanna recorded intermediate value, while Grassland, Agroforestry, Old fallow land and Recent Fallow land recorded lower values; reflecting the intensity of degradation in the respective communities as tree density and species richness decreased with land use intensity particularly in the parkland site plant communities affected by agroforestry and farming activities.

Table 5.3: Summary statistics of characteristics of Plant community

PLANT COMMUNITIES	MEASURED PARAMETERS										
	TD (ha)	**SR** (Mglf)	**SWD** (H′)	**SP** (500 m^2)	**TCC** (%)	**SC** (%)	**GC** (%)	**TH** (metre)	**DBH** (cm)	**BA** (m^2 ha^{-1})	**BIOMASS** (mg)
SW											
$\bar{X}$	935.00	2.69	2.67	20.67	55.33	18.50	22.83	17.10	25.62	6.03	29.57
SD	147.49	0.29	0.13	2.23	8.03	7.08	9.09	0.66	2.90	1.16	5.77
CV%	11.05	10.79	4.81	10.79	14.51	38.26	39.83	3.84	11.31	19.28	19
RF											
$\bar{X}$	846.67	2.77	2.78	21.33	49.00	23.67	26.33	16.69	24.89	5.64	23.91
SD	152.75	0.15	0.06	1.15	4.36	8.33	5.69	1.43	2.91	0.93	6.69
CV%	13.32	5.41	2.13	5.41	8.90	35.18	21.59	8.54	11.70	16.44	27
TS											
$\bar{X}$	874.29	2.45	2.57	18.86	46.14	24.43	26.29	16.56	24.15	5.60	23.57
SD	237.97	0.41	0.23	3.13	11.47	12.47	10.26	0.96	3.28	1.53	4.45
CV%	20.26	16.61	8.94	16.61	24.85	51.07	39.03	5.81	13.57	27.26	19
SL											
$\bar{X}$	780.00	2.47	2.59	19.00	26.33	49.67	29.00	16.36	24.12	5.36	20.57
SD	163.71	0.26	0.01	2.00	7.02	5.03	6.24	1.53	3.42	1.19	2.10
CV%	15.16	10.53	0.53	10.53	15.16	25.59	21.53	9.34	14.18	22.20	10
GL											
$\bar{X}$	580.00	2.42	2.59	18.60	16.80	20.00	46.40	15.88	22.22	4.63	18.32
SD	270.92	0.28	0.11	2.19	11.65	10.07	12.01	1.48	2.88	1.14	8.21
CV%	25.09	11.78	4.23	11.78	24.89	50.37	45.50	9.35	12.97	24.66	45
AGF											
$\bar{X}$	360.00	1.61	2.30	12.40	14.00	17.80	18.60	12.06	19.18	3.63	9.70
SD	94.87	0.30	0.17	2.30	1.00	4.09	10.21	1.64	2.82	1.04	3.03
CV%	20.62	18.57	7.24	18.57	7.14	8.55	14.89	13.58	14.70	28.64	31
OFL											
$\bar{X}$	276.00	2.35	2.44	13.40	18.00	36.20	37.00	12.97	21.26	4.10	10.70
SD	133.72	0.17	0.15	1.34	1.58	8.29	2.35	0.78	4.18	1.43	2.14
CV%	28.09	12.90	6.93	12.90	11.29	17.94	3.35	5.99	19.64	34.75	20
RFL											
$\bar{X}$	244.00	1.36	2.36	12.60	13.40	50.20	52.40	11.90	18.12	2.99	8.18
SD	157.10	0.22	0.22	2.88	1.14	5.81	8.02	1.23	2.62	0.76	2.92
CV%	35.38	9.16	9.16	22.86	7.92	11.56	11.08	10.36	14.48	25.61	35.7
ANOVA (F-ratio)	**26.81**	**17.69**	**9.02**	**17.69**	**32.66**	**15.88**	**36.71**	**22.22**	**4.63**	**5.05**	**16.31**
Level of Sig.	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Source: Author's Fieldwork 2013

Abbreviations:

TD= Tree Density
SR= Species Richness
SWD= Shannon Wiener Diversity
SP= Species per Plot
TCC= Tree Crown Cover
SC= Shrub Cover
GC= Grass Cover
TH=Tree Height
DBH= Diameter at Breast Height
BA= Basal Area
SW= Savanna Woodland
RF= Riparian Forest
TS= Tree Savanna
SL= Scrubland
GL= Grassland
AGF= Agroforestry
OFL= Old Fallow Land
RFL= Recent Fallow land
Mglf= Margalef Index
ANOVA= Analysis of Variance

The mean tree stand density (stem per hectare) of 244-935 stems/ha observed in the study area was lower than that of Miombo woodlands in Tanzania, which varied between 700–1038 stems/ha (Isango, 2004; Backeus *et al*., 2006). The oserved difference could be attributed to higher rainfall amount (650 to 1,500 mm) in the miombo woodlands located in the southern Africa, differences in plant species physiognomic characteristics, and intensity of anthropogenic disturbance. The increase of species richness is accompanied by an increase in aboveground biomass (Hector *et al*., 1999; Tilman *et al*., 2001; Flombaum *et al*., 2008) which in turn according to Rasse *et al*. (2005), is likely to result in higher litter and belowground biomass input, which are major parameters for carbon storage.

Shannon Weiner Diversity

Table 5.3 indicates that higher mean values of Shannon Weiner Diversity and Species Per Plot recorded in Riparian forest and Savanna woodland can be attributed to less anthropogenic interference and heterogeneity of the environment (MacArthur and MacArthur, 1961; MacArthur and Wilson, 1967; Ricklefs, 1977). In contrast, Scrubland Grassland, Tree Savanna, Agroforestry, Old fallow land and Recent Fallow land were characterized by lower mean values which could be attributed to high incidence of deforestation and forest degradation in the plant communities (Jibrin, 2009, Jibrin and Jaiyeoba, 2013, Jibrin, 2014). The Shannon Weiner's diversity index of 2.3–2.8 recorded in the study area can be compared to 1–2.85 recorded in the Miombo woodland; having lower range limit (Tuite, 1992; Isango, 2004; Malimbwi *et al*., 1998). The Shannon-Wienner index values obtained in this study range between 2.30 and 2.78; and is within the range for tropical savannah and woodlands (Savadogo, 2007). Shannon index values greater than 2 are indicative of medium to high diversity

(Barbour *et al*., 1999). The values thus show that the study area could be characterized by medium biodiversity.

Tree crown cover and Tree Height

The mean values of Tree crown cover and Tree Height as presented in Table 5.3, were highest in Savanna woodland, followed by Riparian forest and Tree Savanna, whereas lower mean values were observed for Scrubland, Grassland, Tree Savanna, Agroforestry, Old fallow land and Recent Fallow land. Generally, tree crown cover in the study area (13- 55 %) were lower than 20–75% obtainable in Tanzania Miombo woodland (Boaler, 1966). Similarly, the highest mean tree height in the study area (17.1 metre) were lower compared to that of the Miombo woodland (15–30 meter). The observed differences in the mean tree crown cover and tree height over the study area can be attributed to physiognomic characteristics of the trees found in each plant community (Jibrin, 2013a). Moreover, protection status and inaccessibility of some areas (especially the Savanna Woodland and Riparian forest) has spared some tree species that grow taller and keep wide crown cover.

Percentage Shrub Cover and Grass Cover

Considering Shrub Cover and Grass Cover over the study area, higher mean values were found in Recent Fallow land, followed by scrubland and Grassland. Old fallow land and Tree Savanna recorded moderate values; while lower values were observed for Riparian forest, Tree Savanna, Savanna woodland and Agroforestry (see Table 5.3). The observed higher values of shrub cover and grass cover in the Recent Fallow land, scrubland and Grassland were attributed to degradation status and ecological amplitude of plant species in the plant communities (Daubenmire, 1968; Fritts, 1976). Frequent fire also encourages the growth of grass and herbs and retard the growth of woody

plants. On the other hand lower mean values of Shrub Cover and Grass Cover over the other plant communities reflect the predominance of tree species and or due to elimination by man's interference; particularly in Agroforestry areas.

Diameter at Breast Height and Basal Area

Considering Table 5.3, Diameter at Breast Height and Basal Area measured over the various plant communities indicate higher values for Savanna Woodland, Riparian Forest and Tree Savanna. Lower mean values were recorded for Scrubland, Grassland, Agroforestry, Old fallow land and Recent Fallow land. The highest mean tree diameter at breast height (DBH) recorded in the study area (25.62 cm) was lower than records from Miombo woodland Tanzania (65 cm) (Malimbwi and Temu 1984, Isango, 2004). Likewise, highest mean basal area in the study area 6.03 m^2 ha^{-1} was lower than (16.7 m^2 ha^{-1}) of other studies in Tanzania (Boaler and Sciwale, 1966, Backeus *et al.*, 2006). The observed higher values of DBH and Basal area in the Savanna Woodland, Riparian Forest and Tree Savanna reflects structure of tree species that characterize the plant communities. The observed lower values in the other communities could be due to elimination of bigger trees by logging, deforestation or bush burning.

Biomass (Phytomass)

The mean phytomass stock in the various plant communities as presented in Table 5.3 was in decreasing order SW > RF >TS >SL > GL > OFL > AGF > RFL; reflecting the phytomass gradient due to degree of degradation. Generally, the Savanna woodland, Riparian forest, and tree savanna with comparatively higher mean values of Tree Density, Species richness, Shannon Weiner Diversity, Species per plot, Tree Crown cover, Tree Height, Diameter at Breast Height, and Basal Area exhibits higher biomass and carbon storage by growth and decomposition. In contrast, Scrubland, Grassland,

Agroforestry, Old fallow land and Recent Fallow land characterized by lower mean values of Tree Density, Species richness, Shannon Weiner Diversity, Species per plot, Tree Crown cover, Tree Height, Diameter at Breast Height, and Basal Area, exhibited lower phytomass accumulation and release due to lower biomass carbon stock and degradation; but show higher potentials of biomass fixing by photosynthesis. Also, most of the plant communities with higher mean values exhibit lower coefficient of variation and vice versa. In contrast, Scrubland, Grassland, Agroforestry, Old fallow land and Recent Fallow land were characterized by higher mean values of Shrub cover and Grass cover which had lower phytomass accumulation. Consequently, the spatial distribution of carbon stock among the plant communities over the study area would be influenced by their inherent structural properties, composition and degradation status. Generally, the analysis of variance (ANOVA) indicates significant differences on all parameters measured across the respective plant communities. This suggests that there are significant differences in the characteristics of plant communities and consequently, would influence spatial distribution of carbon stock in the study area.

Table 5.4 presents results of *t*-test performed to identify variables which differ most between pair of plant communities. The variables of Tree Density, Species Richness, Shannon Wiener Diversity, Species per Plot, Tree Crown Cover, Shrub Cover, Grass Cover, Tree Height, Diameter at Breast Height, and Basal Area, indicated significant differences between the pairs involving one of plant community in the forest reserve site (SW, RF, TS, SL, and GL) and one other community from parkland site (AGF, OFL, and RFL). The observed statistically significant differences between a number of these pairs suggests a high contrast between the plant structure and composition of the forest reserve and that of the parkland area. It also suggests close similarity of measured

variables within study sites rather than between study sites; reflecting a sharp contrast in the degree of degradation in the respective sites.

Table 5.4: Results of student's *t*-test on parameters between pairs of plant communities

PAIR OF PLANT COMMUNITIES	MEASURED PARAMETERS										
	TD (ha)	**SR** (Mglf)	**SWD** (H')	**SP** (500 m^2)	**TCC** (%)	**SC** (%)	**GC** (%)	**TH** (metre)	**DBH** (cm)	**BA** (m^2 ha^{-1})	**BMS** (mg)
SW/RF	1.97	-0.49	-1.53	-0.49	1.29	-1.10	-0.63	0.77	0.39	0.53	1.482 *
SW/TS	1.83	1.47	1.11	1.47	2.06	-1.33	-0.76	1.45	1.02	0.70	2.361 *
SW/SL	2.63 *	1.18	0.97	1.18	1.77	-0.27	-1.10	1.35	0.78	0.89	2.597 **
SW/GL	2.54 *	1.75	1.20	1.75	1.76	-0.35	-0.67	2.41 *	2.21 *	2.28 *	3.246 ***
SW/AGF	12.13 ***	6.91 ***	4.94 ***	6.91 ***	11.27 ***	-8.58 ***	-9.14 ***	9.32 ***	4.20 ***	3.99 ***	7.201 ***
SW/OFL	11.21 ***	9.50 ***	7.32 ***	9.50 ***	11.22 ***	-7.01 ***	-11.24 ***	11.23 ***	2.49 ***	2.93 **	7.001 *
SW/RFL	11.15 ***	6.26 ***	3.70 ***	6.26 ***	11.15 ***	-8.81 ***	-10.56 ***	11.50 ***	4.98 ***	5.34 ***	7.777 ***
RF/TS	-0.18	1.29	1.50	1.29	0.41	-0.10	0.01	0.17	0.33	0.05	0.094
RF/SL	0.52	1.75	5.48 **	1.75	0.56	0.71	-0.55	0.28	0.30	0.32	2.825 **
RF/GL	0.38	1.96	2.83 *	1.96	0.31	0.53	-0.01	0.76	1.26	1.30	2.988 **
RF/AGF	8.01 ***	6.13 ***	4.75 ***	6.13 ***	18.11 ***	-5.65 ***	-6.46 ***	4.04 **	2.74 *	2.75 *	4.238 **
RF/OFL	6.54 ***	11.67 ***	6.96 ***	11.67 ***	16.94 ***	-3.72 **	-15.73 ***	4.90 ***	1.31 0.24	1.65 0.15	4.264 ***
RF/RFL	6.18 ***	4.89 ***	3.25 *	4.89 ***	17.66 ***	-5.38 ***	-8.61 ***	5.04 ***	3.40 **	4.43 ***	4.741 ***
TS/SL	0.62	-0.07	-0.12	-0.07	-0.03	0.62	-0.42	0.26	0.02	0.24	1.092 *
TS/GL	0.64	0.16	-0.10	0.16	-0.10	0.65	-0.02	0.97	1.06	1.20	1.439 *
TS/AGF	6.29 ***	3.90 ***	2.28 ***	3.90 ***	6.16 ***	-3.99 ***	-7.06 ***	6.02 ***	2.74 *	2.48 *	6.009 *
TS/OFL	5.88 ***	5.62 ***	3.65 ***	5.62 ***	6.14 ***	-3.38 **	-9.24 ***	6.88 ***	1.35	1.72	5.940 *
TS/RFL	5.96 ***	3.52 **	1.65	3.52 **	6.08 ***	-4.26 ***	-8.35 ***	7.38 ***	3.40 **	3.49 **	6.724 ***
SL/GL	0.00	0.26	0.08	0.26	-0.06	-0.05	0.34	0.44	0.85	0.87	0.451
SL/AGF	6.95 ***	4.10 **	2.95 *	4.10 **	10.70 ***	-8.71 ***	-5.97 ***	3.67 **	2.23	2.17	5.396 **
SL/OFL	5.73 ***	7.40 ***	5.05 ***	7.40 ***	10.40 ***	-4.93 ***	-13.75 ***	4.27 **	0.99 0.36	1.28 0.25	6.354 ***
SL/RFL	5.47 ***	3.34 *	1.82	3.34 *	10.51 ***	-7.52 ***	-7.95 ***	4.56 ***	2.82 *	3.51 **	6.339 **
GL/AGF	4.83 ***	4.36 ***	3.23 **	4.36 ***	6.27 ***	-5.72 ***	-5.98 ***	3.86 ***	1.68	1.44	2.203 *
GL/OFL	4.47 ***	7.14 ***	5.37 ***	7.14 ***	6.24 ***	-4.49 ***	-7.97 ***	3.88 ***	0.42	0.64	2.009 *
GL/RFL	4.54 ***	3.71 **	2.11	3.71 **	6.19 ***	-5.81 ***	-7.12 ***	4.61 ***	2.35 *	2.67 *	2.602 *
AGF/OFL	-0.22	1.68	1.55	1.68	0.00	0.39	-0.30	-1.12	-0.92	-0.60	-0.602
AGF/RFL	0.19	-0.12	-0.48	-0.12	-0.59	-0.76	-0.65	0.18	0.62	1.12	1.806 *
OFL/RFL	0.35	-1.55	-1.82	-1.55	-0.46	-0.88	-0.64	1.64	1.42	1.54	1.554 *

Level of significance: *=0.05, **=0.01, ***0.001 Source: Author's Fieldwork 2013

Abbreviations:

TD= Tree Density	SC= Shrub Cover	SW= Savanna Woodland	AGF= Agroforestry
SR= Species Richness	GC= Grass Cover	RF= Riparian Forest	OFL= Old Fallow Land
SWD= Shannon Wiener Diversity	TH=Tree Height	TS= Tree Savanna	RFL= Recent Fallow land
SP= Species per Plot	DBH= Diameter at Breast Height	SL= Scrubland	Mglf= Margalef Index
TCC= Tree Crown Cover	BA= Basal Area	GL= Grassland	BMS= Biomass

With respect to biomass (phytomass) parameter, significant difference was observed between all pairs of plant communities except between riparian forest and tree savanna, Scrubland and Grassland; which were attributed to close similarity of the environmental parameter of the two communities. Virtually, most pairs of plant communities showed significant differences in their biomass. By implication, there was considerable variability in biomass over the study area.

5.2 Carbon Stock Density

5.2.1 Carbon stock density of vegetation communities

The data collected on carbon stock per plot in the forest carbon pools is given in Appendix VII. The summary of carbon stock in the various plant communities is presented in Table 5.5. The mean carbon stocks of plant communities in decreasing order are Savanna woodland (127.30 Mg ha^{-1}), Riparian Forest (116.31 Mg ha^{-1}), Tree Savanna (114.44 Mg ha^{-1}), Scrubland (111.47 Mg ha^{-1}), Grassland (106.72 Mg ha^{-1}), Agroforestry (78.53 Mg ha^{-1}), Old Fallow Land (72.50 Mg ha^{-1}), and Recent Fallow land (66.31 Mg ha^{-1}). Under similar environmental conditions different plant species have different structures and mortality rates. Variation in the structure and composition of plant communities and quantitative properties of their diversity constitute variables that determine variation in carbon stock over a landscape (Struhsaker, 1997; Babaasa *et al*., 2004).

Table 5.5: Carbon stock density of vegetation communities (Mg ha^{-1})

Plant Communities	N	Minimum	Maximum	Mean	Std. Dev.	CV %	ANOVA
Savanna woodland	12	117.53	139.98	127.30	6.37	5.01	
Riparian Forest	3	116.07	116.48	116.31	0.22	0.19	
Tree Savanna	7	112.21	115.32	114.44	1.03	0.90	
Scrubland	3	111.08	112.11	111.47	0.56	0.50	
Grassland	5	93.99	110.99	106.72	7.20	6.75	
Agroforestry	5	75.43	82.38	78.53	2.85	3.63	
Old fallow land	5	71.33	73.73	72.50	1.14	1.58	
Recent fallow land	5	60.28	70.44	66.31	4.00	6.03	
Total	**45**	**60.28**	**139.98**	**102.94**	**23.34**	**22.67**	***F* = 160.69, P <0.01**

Source: Author's Fieldwork, 2013

To ascertain the degree of variation in carbon stock, the analysis of variance (ANOVA) was applied and indicates significant differences in carbon stock across the respective plant communities; where $F(7,37) = 160.69$, $P<0.01$ reflect heterogeneous nature of plant communities in the study area. The observed differences in carbon stock of various plant communities therefore could be attributed to the number of trees, tree species richness and diversity, variability in tree height, DBH, basal area, and biomass of trees.

Table 5.6 presents results of *t*-test performed to identify variation in carbon stock between pair of plant communities which reveal that virtually all pairs of plant communities showed significant differences in their carbon stock; except between Scrubland and Grassland, were attributed to close similarity in biomass density and physiognomic characteristics. By implication, the *t*-test result supports results of analysis of variance in that most pairs of plant communities show statistically significant values. The observed statistically significant differences between a number

of these pairs suggest considerable variability in carbon stock over the study area as a result of high contrast between the plant communities inherent characteristics.

Table 5.6: Result of Student's t-test Analysis of carbon stock between pairs of plant communities

PAIR OF PLANT COMMUNITIES	CARBON STOCK (Mg / ha^{-1})
Savanna Woodland / Riparian Forest	2.90 **
Savanna Woodland / Tree Savanna	5.24 ***
Savanna Woodland / Scrubland	4.18 ***
Savanna Woodland / Grassland	5.86 ***
Savanna Woodland / Agroforestry	16.21 ***
Savanna Woodland / Old Fallow Land	18.76 ***
Savanna Woodland / Recent Fallow Land	19.64 ***
Riparian Forest / Tree Savanna	3.02 *
Riparian Forest / Scrubland	14.05 ***
Riparian Forest / Grassland	2.23 *
Riparian Forest / Agroforestry	22.19 ***
Riparian Forest / Old Fallow Land	63.62 ***
Riparian Forest / Recent Fallow Land	20.97 ***
Tree Savanna / Scrubland	4.61 ***
Tree Savanna / Grassland	2.85 *
Tree Savanna / Agroforestry	31.10 ***
Tree Savanna / Old Fallow Land	66.51 ***
Tree Savanna / Recent Fallow Land	31.01 ***
Scrubland / Grassland	1.10
Scrubland / Agroforestry	19.19 ***
Scrubland / Old Fallow Land	53.99 ***
Scrubland / Recent Fallow Land	18.86 ***
Grassland / Agroforestry	8.13 ***
Grassland / Old Fallow Land	10.49 ***
Grassland / Recent Fallow Land	10.97 ***
Agroforestry / Old Fallow Land	4.39 ***
Agroforestry / Recent Fallow Land	5.57 ***
Old Fallow Land / Recent Fallow Land	3.33 **

Note: Level of significance: *=0.05, **=0.01, ***0.001 Source: Author's Fieldwork, 2013

For comparative purposes, mean carbon stock density for the entire study area has been estimated with a range of 60 – 140 Mg ha^{-1} (see Table 5.5). The mean carbon stock density of the study area (103 Mg ha^{-1}) was lower than the biome average estimate 137 Mg ha^{-1} for Tropical savannahs by Trumper *et al.* (2009) and Epple (2012). Similarly, mean carbon stock density of the study area was lower than 150-250 Mg ha^{-1} estimated for dry or seasonally dry forests; but higher than 60-70 Mg ha^{-1} estimated for savannah biome by FPAN (2010). In Nigeria's first National Communication under the UNFCCC (FGN, 2003), average carbon stock density value for dry deciduous forest of Nigeria (the study area inclusive) indicates 125.32 Mg ha^{-1}, which is higher than the mean value obtained in this study. This comparative analysis revealed that carbon stock density values often quoted for the study area, are at variance with the local realities. Hence, the significance of this study can be seen in the acquisition of a refined estimate of carbon stock density value for the study area; which is more accurate and more reliable than biome average estimates.

5.2.2 Carbon stock in pools over the study area

Carbon stock density was measured from six carbon pools: aboveground tree, undergrowth (shrubs and grasses) coarse deadwood (≥10 cm diameter), litter, belowground tree root, and soil. Plot carbon density was found for each carbon pool and sum of the pools stock yielded total carbon density for the plot expressed in Mg ha^{-1}. Table 5.7 presents the descriptive statistics on the current carbon stock stored in the respective pools. Table 5.7 shows that within the forest reserve, carbon stock in the above ground tree pool range from 7.3 to 26.8 Mg ha^{-1} while the parkland stored less (between 2.0 to 6.1Mg ha^{-1}). Carbon stock in the tree pool is also more variable in the forest reserve than in the parkland as indicated by values of standard deviation. The undergrowth pool carbon stock in the forest reserve varied from 6.8 to 19.9 Mg ha^{-1},

whereas in the parkland variability was lower with carbon stock ranging from 11.6 to 21.1 Mg ha^{-1}. This indicates that the parkland has more carbon stock in the undergrowth pool than the forest reserve.

Table 5.7: Summary of carbon stock density in pools (Mg ha^{-1})

POOL	SITE	N	Minimum	Maximum	Mean	Standard Deviation
Tree	Forest Reserve	30	7.27	26.78	16.55	4.64
	Parkland	15	2.01	6.13	3.68	1.37
Undergrowth	Forest Reserve	30	6.80	19.90	12.09	3.19
	Parkland	15	11.60	21.10	15.43	2.76
Dead Wood	Forest Reserve	30	1.81	6.71	3.92	1.45
	Parkland	15	0.00	1.66	0.56	0.54
Litter	Forest Reserve	30	1.90	6.20	4.02	1.07
	Parkland	15	1.20	2.60	1.76	0.46
Root	Forest Reserve	30	1.32	4.47	2.86	0.76
	Parkland	15	0.38	1.06	0.67	0.23
Soil	Forest Reserve	30	64.20	91.60	78.76	6.87
	Parkland	15	35.30	53.90	47.22	4.86
Aggregate Carbon Stock (Mg ha^{-1})	Forest Reserve	30	93.99	139.98	118.19	9.40
	Parkland	15	56.51	79.81	69.33	5.92

Source: Author's Fieldwork 2013

Within the forest reserve carbon stock in the dead wood, litter and root pools range from 1.8-6.7 Mg ha^{-1} , 1.9-6.2 Mg ha^{-1} , 1.3-4.5 Mg ha^{-1} respectively; while in the parkland, carbon stock in the same pools (dead wood, litter and root) range from 0-1.7 Mg ha^{-1} , 1.2-2.6 Mg ha^{-1} , 0.4-1.1 Mg ha^{-1} respectively. This shows that carbon stock in dead wood, litter and root pools were greater and more variable in the forest reserve than in the parkland based on the standard deviation values. Soil carbon pool contains between 64.2 to 91.6 Mg ha^{-1} of carbon stock in the forest reserve; whereas the parkland contains about 35.3 to 53.9 Mg ha^{-1}. Therefore, carbon stock in the soil pool within the forest reserve almost doubles that contained in the parkland soil pool. Variability was also

higher in the forest reserve soil carbon stock than in the parkland as indicated by the standard deviation values. Over all, it can be observed that the average aggregate carbon stock density in the forest reserve is 118.2 Mg ha^{-1} which is greater than 69.3 Mg ha^{-1} recorded in the parkland.

Analysis of percentage distribution of mean carbon stock in the respective pools (see Figure 5.3) in decreasing order of quantity within the forest reserve are soil 78.76 Mg ha^{-1} (67%), tree, 16.55 Mg ha^{1} (14%) undergrowth 12.09 Mg ha^{-1} (10%), litter 4.02 Mg ha^{-1} (3%), dead wood 3.92 Mg ha^{-1} (3%) and root 2.86 Mg ha^{-1} (3%). Comparatively, the decreasing order of quantity in parkland are soil 47.22 Mg ha^{-1} (68%), undergrowth 15.43 Mg ha^{-1} (22%), tree 3.68 Mg ha^{-1} (5%), litter 1.76 Mg ha^{-1} (3%), root 0.67 Mg ha^{-1} (1%) and dead wood 0.56 Mg ha^{-1} (1%). In both study sites (Forest reserve and parkland), soil carbon stock was the highest in magnitude, while dead wood and root were the least in carbon stock.

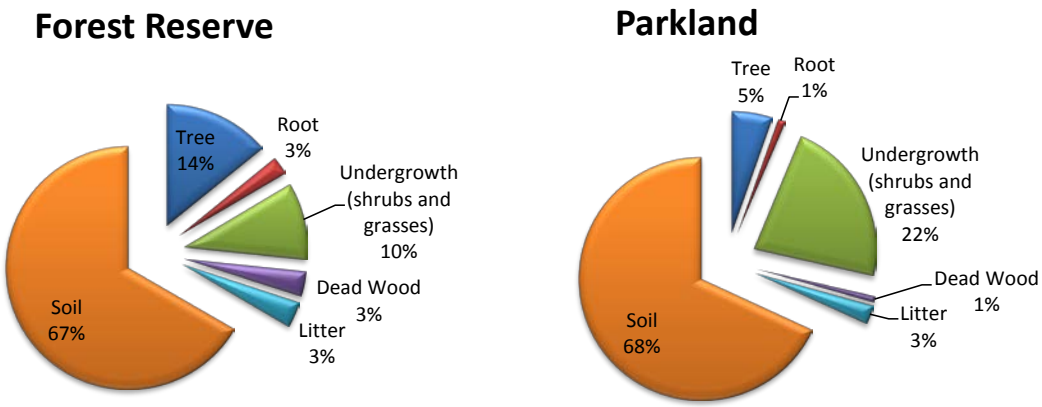


Figure 5.3: Percentage distribution of the mean carbon stock in the respective pools

When the analysis of differences in carbon stock density between the forest reserve and the parkland was carried out, the student *t*–test revealed that there was significant difference in carbon stock density between the forest reserve and parkland study sites, where t (43) = 18.34, $p < 0.001$). This reflects a high contrast between the plant

structure and composition of the forest reserve and that of the parkland area. It also reflects the protected and non-protected status of the two adjacent sites Forest reserve and parkland). By implication, biomass of woody material, and therefore the magnitude of carbon store, depends on how they are managed (Moreira, 2000). Deforesttion and forest degradation, fire and grazing substantially reduce the store of carbon, and determine species composition to a large extent (Grace *et al.*, 2006). This emphasizes that protection from deforesttion and forest degradation, fire and grazing, causes savanna woodlands to accumulate biomass with a very high carbon stock.

With regards to research null hypothesis I, ANOVA result indicates significant differences in carbon stock across the respective plant communities; where $F(7,37) = 160.69$, $P<0.01$. Similarly, the student *t*–test revealed that there exist significant difference in carbon stock density between the forest reserve and parkland study sites where $t\ (43) = 18.34$, $p < 0.001$). Consequently, the null hypothesis is rejected. This reflects a high contrast between carbon stock density of the forest reserve and that of the parkland area.

Findings presented on carbon stock density (in pools and site) demonstrate that, differences in carbon storage between study sites reflect variation in a number of factors; including plant community structure, composition, diversity, disturbance history, and successional stage. This is in conformity with previous studies such as Brown and Lugo (1982, 1984), Malhi *et al*. (2002), Chave *et al.* (2003), Houghton (2005a), Grace *et al.* (2006), Williams *et al*. (2008), FPAN (2010). The observed differences in carbon stock between the forest reserve and parkland can be explained by the contrasting peculiar physiognomic and composition attributes of the two study sites; as inventoried and characterised in this study. Therefore, this study reaffirms that spatial

variation of factors that control the potential biomass at a site are responsible for spatial variation in carbon stock density.

5.2.3 Exploration of Carbon stock Predictors

The interactions of various factors results in significant biomass/carbon stock variations at local landscape and global scale (Houghton, 2005a; Malhi *et al*., 2011). In order to identify the best set of predictors among potential biomass predictor variables in the study site- tree density (x_1), tree species diversity (x_2), tree species richness (x_3), DBH (x_4), basal area (x_5), height (x_6), crown cover (x_7),shrub cover (x_8), and grass cover (x_9) were used in a stepwise multiple regression analysis to predict carbon stock (y). The result yielded these possible combinations in the stepwise regression analysis:

a. Predictors: $\beta_0 + \beta_1$Grass Cover

b. Predictors: $\beta_0 + \beta_1$Grass Cover + β_2Tree Height

c. Predictors: $\beta_0 + \beta_1$Grass Cover + β_2Tree Height + β_3Basal Area

d. Predictors: $\beta_0 +$ β_1Grass Cover + β_2Tree Height +β_3Basal Area + β_4 Tree Density

e. Predictors: $\beta_0 +$ β_1Tree Height + β_2Basal Area +β_3Tree Density

f. Predictors: $\beta_0 +$ β_1Tree Height + β_2Basal Area + β_3Tree Density + β_4DBH

g. Predictors: $\beta_0 + \beta_1$Basal Area + β_2Tree Density + β_3DBH

The stepwise variable selection was reached in seven steps with two variables removed (tree diversity and crown cover). At each step, unique combinations of variables were constituted. The final step (No. 7) model contained three of the nine predictors as indicated in Table 5.8.

Table 5.8: Results of multiple regressions with stepwise variable selection

Step no.	Regression equation	R^2	SEE
1	$CS = \beta_0 + \beta_1 GC$	0.84	10.93
2	$CS = \beta_0 + \beta_1 GC + \beta_2 TH$	0.89	9.34
3	$CS = \beta_0 + \beta_1 GC + \beta_2 TH + \beta_3 BA$	0.90	8.82
4	$CS = \beta_0 + \beta_1 GC + \beta_2 TH + \beta_3 BA + \beta_4 TD$	0.92	8.03
5	$CS = \beta_0 + \beta_1 TH + \beta_2 BA + \beta_3 TD$	0.92	7.94
6	$CS = \beta_0 + \beta_1 TH + \beta_2 BArea + \beta_3 TD + \beta_4 DBH$	0.93	7.55
7	$CS = \beta_0 + \beta_1 BA + \beta_2 TD + \beta_3 DBH$	0.93	7.51

Note: CS = Carbon Stock; GC = Grass Cover; TH = Tree Height; BA = Basal Area; TD = Tree Density; DBH = Diameter at Breast Height; SEE = Standard Error of the Estimate.
Source: Author's Fieldwork 2013

The coefficients of determination (R^2) ranged from 0.84 to 0.93 which indicates that over 84% of variability in carbon stock of the study site can be explained by these variable combinations. The standard error of the estimates (SEE) for the respective models is shown in Table 5.8. All the R^2 values were considerably high and increased with further steps while standard error of the estimates decreases marginally with further steps. In the final model, with maximum R^2 value and lowest SEE, the result output of step number seven is presented in Table 5.9.

Table 5.9: Stepwise regression final results

Model	*b*	SE-*b*	Beta	Pearson *r*	*t* - Test	*F*-test
(Constant)	45.793	9.849			4.650	
Basal Area	-0.912	0.197	-0.307	-0.852	-4.624	
Tree Density	0.037	0.004	0.556	0.907	8.561	
DBH	1.622	0.349	0.236	0.684	4.642	173.9

Note : The Dependent variable was Carbon Stock, $R^2 = 0.927$, Adjusted $R^2 = 0.922$.

The final model was statistically significant, $F(3,41) = 173.9$, $P < 0.05$, and accounted for approximately 93% of the variance in carbon stock ($R^2 = 0.927$, Adjusted R^2=

0.922). Carbon stock was primarily predicted by levels of DBH, tree density, and basal area. The raw and standardized regression coefficients of the predictors together with their correlations with carbon stock, are shown in Table 5.9. The results suggest that tree density, DBH and basal area were very strong indicators of carbon stock. Based on *t*- test values, the coefficients and fit statistics from fitting the biomass prediction model indicate that *p*-values for the intercept and slope are significantly different from 0 ($p < 0.001$).

Various authors reported that increasing the number of predictors; particularly incorporating the crown diameter and tree height improves precision of the models. Chave *et al*. (2005) reported that for tropical forests, the most important predictors of tree biomass were, in decreasing order of importance, trunk diameter at 1.3 m (DBH), wood specific gravity, total height and forest type. The most commonly used independent variable from a variety of vegetation types is stem diameter (DBH) or stem circumference (Dayton, 1978; Hofstad, 2005; Dias *et al*., 2006 and Salis *et al*., 2006). Inclusion of tree height sometimes improves the relationship (Chidumayo, 1988; Brown *et al*., 1989), although not always (Brown *et al*., 1989). It is also a covariate with stem diameter. Crown diameter, area or volume have also been used as the predictor variable by some authors (Kelly and Walker, 1977 and Deshmukh, 1992; Jibrin, 2013b), but generally yield weaker regression relationships than stem circumference (Jibrin and Abdulkadir, 2015), and become very variable in dense vegetation where crown size is constrained (Tietema, 1993; Powell, 2008). Combinations of diameters, height and crown dimensions may provide the best predictive capacity, but are rarely worth the extra time and effort required to measure all three (Hofstad, 2005). Findings from this study reveal that the three most important set of predictors of biomass/carbon stock in the study area, were tree density, DBH and basal area.

With regards to research null hypothesis II, the stepwise multiple regression analysis revealed that the final model was statistically significant, $F(3,41) = 173.9$, $P < 0.05$, and accounted for approximately 93% of the variance in carbon stock ($R^2 = 0.927$, Adjusted $R^2 = 0.922$). Consequently, the null hypothesis is rejected.

5.3 Discussion

Savanna are variously described throughout their distributional range, but much still remains to be understood in terms of local variation in community composition, diversity, and spatial structure of these forests (Menaut, 1983). Findings from this study revealed that all measured parameters of plant community structure and composition vary considerably within and among the different plant communities; which reflects the heterogeneity of plant community characteristics across the study area (Menaut *et al.*, 1995; Jibrin and Jaiyeoba, 2013). An intrinsic feature of savanna plant communities is that they do not only differ in tree density, but also in species composition (Menaut, 1983; Adejuwon and Adesina, 1992). Differences in physiological and ecological factors between savanna and forests are expected to determine the distribution of these species (Menaut, and César 1982; Longman and Jenik, 1992). Riparian forest is often found on sites with greater water and nutrient availability, and savannas exist on dryer sites, where nutrient availability is lower (Menaut, Gignoux, Prado and Clobert, 1990; Furley, 1992). Furthermore, in savannas, trees have to compete with the herbaceous layer for these scarce resources, which can severely impacts growth (Riginos, 2009; Scholes and Archer, 1997; Van der Waal *et al*., 2009). Last, disturbances such as herbivory and fires are frequent in savannas (Menault, Lepage, and Abbadie 1995; Van Langevelde *et al*., 2003). The implication of combined effect of these factors is that the spatial variation in carbon stock density in the study area would be influenced by variation in the plant community characteristics.

The influence of plant community composition on carbon stock as found in this study, reflects the importance of functional traits of dominant plant species (Bunker *et al*., 2005). Increasing plant species diversity has been proposed as contributing to greater ecosystem carbon sequestration (Fornara and Tilman, 2008; Saha *et al.*, 2009). The relatively low woody species diversity and richness in the parkland plant communities may be an indicator of woodland degradation, fragmentation and biodiversity loss, resulting from unsustainable harvesting for fuel wood, grazing, seasonal fires and shifting cultivation (Vermeulen, 1996; Malimbwi *et al*., 2005; Banda *et al*., 2006). On the other hand, relatively high species richness of the forest reserve could be attributed to protection status of the reserve (Jibrin *et al*., 2013b) and also due to habitat heterogeneity, which increase tree diversity of woodlands and savannas in Africa (Menaut *et al.*, 1995). In addition, the differences in species composition among different plant communities is often explained as due to micro-site factors (Vermeulen, 1996; Malimbwi *et al*., 2005; Banda *et al*., 2006). Frost (1996) pointed out that tree growth in savannah ecosystems is generally determined by edaphic factors, principally nutrient and moisture availability, landscape position, effects of fire, and anthropogenic disturbances.

The human impacts and activities observed in the parkland were wood cutting and dead wood collecting, illegal bush fires, foot paths, mushroom and fruit gathering. The human activities noted in the study area constitute forms of pressure on plant resources (Jibrin *et al*., 2013b). Although human use inevitably alters the appearance and size class profile of savannas, there are contrasting studies on human impacts on woody plant species richness. Several studies indicate no decrease in species richness (Vermeulen, 1996; Malimbwi *et al*., 2005; Banda *et al*., 2006), whilst others (Giliba *et al.*, 2011; Mwase *et al*., 2007) show a significant decrease. However, there is need for a

thorough assessment of these impacts on species richness and diversity within the reserve. In general, the more the number of trees per plot, the higher the carbon stock measured. This suggests that tree number per hactare can be expressed by density which contributes significantly to total carbon stock contents. Such findings are not surprising since aboveground carbon stocks varied widely, depending on the extent of the tree cover and associated characteristics as reported by Grace (2004). The differences in tree carbon between plant communities may also results from sizes and age of tree species constituted in these communities. Normally, forest types with larger trees accumulate more biomass, hence higher carbon stock contents.

According to Tivy (1971), the structure and composition of plant communities vary in relation to variations in the complex environmental factors that occur from place to place through time. Though not without some peculiarities, the plant communities in the study area possess attributes nearly similar to other related plant communities in the other geographical locations. This conforms to the principle of ecological amplitudes (Daubenmire, 1968; Fritts, 1976) that stresses that plant communities vary from place to place but whenever areas of equivalent environmental conditions are encountered, essentially the same plant assemblage reappears.

Comparative analysis of carbon stock density revealed that the mean carbon stock density obtained for the study area in this study was 103 Mg ha^{-1} with a rage of 60 – 140 Mg ha^{-1} while the forest reserve study site has mean carbon stock density of 118.2 Mg ha^{-1} (range 94-140 Mg ha^{-1}) which is comparatively lower than closed-canopy evergreen forests in Africa, with an average estimate of 200 Mg ha^{-1} ; ranging 174-244 Mg ha^{-1} (Lewis *et al.,* 2009); and a range of 150-250 Mg ha^{-1} reported by FPAN (2010) for seasonally dry forests. Also, Munishi and Shear (2004) reported over 300 Mg ha^{-1}

carbon stock in Tazanian Eastern Arc afromontane forests. The mean carbon stock density of the study area is also lower than the biome average estimate 137 Mg ha-1 for Tropical savannahs by Trumper et al. (2009) and Epple (2012).

According to Grace *et al.* (2006) the amount of carbon stored above ground in savannas depends on how much tree cover there is, and can range from less than 2 Mg ha^{-1} for tropical grasslands to over 30 Mg ha^{-1} for woodland savannas. Results from this study weighted mean above ground tree carbon stock of 16.55 Mg ha^{-1} was less than Frost's (1996) average of 26 Mg ha^{-1} for dry Miombo woodlands in Zimbabwe and Zambia; but almost of same range compared with results from Shirima (2011) 23.3 Mg ha^{-1}, and Zahabu (2008) 22.5 Mg ha^{-1} for woodlands of Tanzania. However, it was higher than Menaut and Cesar (1979), for woodland of Lamto, Cote d'Ivoire, Chamshama, Mugasha and Zahabu (2004) and Munishi *et al*. (2010), reported 20.4 Mg ha^{-1}, 19.04 Mg ha^{-1} and 19.12 Mg ha^{-1}, respectively, for woodlands of Tanzania while Ribeiro *et al.* (2008), found 19.5 Mg ha^{-1} for Mozambique woodlands.

Analysis of results in this study also revealed that soil carbon stock dominated the total; contributing 78.75 Mg ha^{-1} (63%) in the forest reserve and 47.22 Mg ha^{-1} (65.2%) in the parkland. This was in line with Grace *et al*. (2006) findings that in savanna woodlands, soil carbon stocks typically exceed woody carbon stocks. Furthermore, the ratio between soil carbon and total carbon stocks in the study area was similar to 60% reported in Walker and Desanker (2004) for Malawian Miombo woodlands. However, the mean soil carbon stock of the forest reserve was far lower than 174 Mg ha^{-1} reported by Grace *et al*. (2006) for the savannah woodlands.

Disparity was also observed in the soil organic carbon stock between the forest reserve and the parkland. It was also observed that higher soil organic carbon (range 64.2-91.6

Mg ha^{-1}) was found in forest reserve, whereas lower stock (range 35.3-53.9 Mg ha^{-1}) was observed in parkland. Previous studies by Jaiyeoba (1995), Lal (2002b) and Anikwe *et al*. (2003) showed that tillage adversely affects carbon storage in the soil. Soil carbon is also generally reduced after clearance for agriculture (Jaiyeoba, 1988, 1995; Walker and Desanker 2004 Jibrin *et al*., 2014). For instance, Williams *et al.*, (2008) reported that soil organic carbon stocks in the top 0.3 m on abandoned land had a narrower range (21–74 Mg ha^{-1}) than stocks in woodland soils (18–140 Mg ha^{-1}). Also, Walker and Desanker (2004) reported that upon conversion to agricultural land, Miombo woodland loses around 47 percent of its soil carbon. It is therefore not surprising that parkland site recorded lower soil carbon stock.

Land use dynamics affects carbon stock contents in most ecosystems. For example, woodlands store large amount of carbon stock, but once converted to agricultural land, the amount tend to decrease. Conversion of forest into cropland has also been reported to be associated with devastating loss in carbon (Majule and Shishira, 2008). Major reasons for that loss have been pointed out to be due to human disturbances such as fire, tillage practice which increase the rate of soil organic matter decomposition and the actual process of clearing the vegetation.The conversion to an agricultural land use invariably results in the depletion of Soil Organic Carbon (SOC) stock by 20–50% (Schlesinger, 1985, 1997). The depletion of SOC stock is attributed to numerous factors including: decrease in the amount of biomass (above- and belowground) returned to the soil, change in soil moisture and temperature regimes which accentuate the rate of decomposition of organic matter, high decomposability of crop residues due to differences in C:N ratio and lignin content (Post and Mann, 1990; Lal, 2005; Jibrin, Jaiyeoba and Abdulkadir, 2015), tillage-induced perturbations, decrease in soil aggregation and reduction in physical protection of the soil organic matter, and increase

in soil erosion (Davidson and Ackerman, 1993; Lal, 2005). Thus, agricultural soils and especially eroded agricultural soils usually contain lower SOC stock than their potential capacity.

In a nutshell, the structure and composition of savannas are strongly determined by their woody component; particularly by large trees, which play a key role in ecosystem function (Belsky *et al*., 1989; Dean, Milton and Jeltsch, 1999; Treydte *et al*., 2008) primarily in nutrient cycling that accounts for a great deal of the carbon pool (Hairiah *et al*., 2001). This component is in turn constrained by a combination of climate, disturbances e.g. drought, fire, and herbivory and human activities (Archibald *et al*., 2005; Desanker *et al*., 1997; Ribeiro *et al*., 2008a; Sankaran *et al*., 2005). There is increasing concern that loss of mature trees in landscapes subjected to deforestation and degradation, as well as intense fires may result in the transformation of woodlands into scrublands, grasslands or parklands (Ribeiro *et al*., 2008b; Ribeiro *et al*., 2008a; Bond, Midgley and Woodward, 2003; Druce, Pretorius and Slotow, 2008; Owen-Smith *et al*., 2006) with the associated loss of biodiversity and biomass and thus a decrease in carbon stocks. Consequently, parkland study site have reduced carbon contents due to reduced tree cover and increased mineralization as a result of surface disturbance. Since abundance of herbs and shrubs undergrowth favour higher organic carbon stock (Jaiyeoba, 1988, 1995; Lal, 2002a; Anikwe *et al*., 2003), the higher organic carbon content of the forest reserve reflects a high organic matter turn over and fewer disturbances through tillage and harvesting operations.

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATION

6.1 Summary

This study examined the biomass and carbon stock density of Kpashimi Forest Reserve and adjoining parkland area in Niger State, Nigeria. In the recent past decades, research activities on forest biomass and carbon stocks have intensified due to the significant roles played by vegetation cover in the global carbon cycle and global atmospheric change. Climate change during the last decades has increased the need of information on the amount of forest biomass and carbon stocks for climate policy formulation. Estimation of Carbon stock density is a basic step in carbon accounting and consideration of land use options to promote carbon sequestration. Benchmark sites are vital as they allow determination of deviations under different land uses. This is particularly important in savanna ecological area of Nigeria in which variation in a number of factors, including plant community physiognomic attributes, species composition and diversity, successional stage, soil properties, hydrology and disturbances are likely to return highly variable carbon stock density.

The study employed biometric forest inventory techniques which drew heavily on the standard techniques for field measurements of vegetation and soil. The methodology is based on principles of forest mensuration; following standard operating procedures on sampling determination, sample plot layout, morphometric measurement techniques and data analysis as prescribed by the FAO and IPCC.

Reconnaissance survey was conducted in October, 2011 while pilot survey took place in September, 2012. Detailed fieldwork for the project took place from September to October, 2013. The inventory was carried out towards the end of rainy season in the

study area; when species could be identified easily. The plant communities inventoried include Savanna Woodland (SW), Riparian Forest (RF), Tree Savanna (TS), Scrubland (SL), Grassland (GL), Agroforestry (AGF), Old Fallow Land (OFL), and Recent Fallow land (RFL). The plant community parameters measured include Tree Density (TD), Species Richness (SR), Shannon Wiener Diversity (SWD), Species per Plot (SP), Tree Crown Cover (TCC), Shrub Cover (SC), Grass Cover (GC), Tree Height (TH), Diameter at Breast Height (DBH), Basal Area (BA) and Biomass.

Measurement of plant community parameters was carried out in 45 quadrat sampling plots of 500 m^2. Four fixed size square frames encompassing $1m^2$ were placed on the ground for clipping undergrowth (shrubs and grasses) and litter contained therein. For the determination of soil organic carbon, one sample was taken from each of the $1m^2$ subplot quadrats at two depths (0-15cm and 15-30cm), with the aid of soil core sampler of 188.5 cm^3 volume (2 cm radius x 15 cm length cylinder). The four samples collected per plot were mixed by depth category to produce two composite samples. For the determination of bulk density, two separate coring rings of volume 98.2 cm^3 (2.5 cm radius x 5 cm length cylinder) were used to collect undisturbed soil samples at two depths (0 -15 cm and 16 – 30 cm). Within each of the four $1m^2$ quadrats, sample was first taken for shrubs and grasses, then for litter and lastly for soil.

Carbon stock data was collected from six major carbon pools viz above ground trees, Undergrowth, Dead wood, Litter, Live tree roots and Soil. Measurement of carbon pools was achieved by their respective techniques such as: Above ground tree pool by biomass sampling/allometry equation; Below ground tree pool by allometry model; Undergrowth pool by clip plot method; Dead wood pool by line transect method; Litter pool by clip plot method; and Soil pool by soil core sampling/laboratory analysis

method. Samples collected were weighed at sampling points with the aid of weighing scales. Thereafter, subsamples of wood aliquots, shrub, grasses, dead wood, litter collected from the field and transported to the laboratory for moisture content analysis at constant-temperature. Soil samples for organic carbon and bulk density was also subjected to laboratory analysis. The summation of carbon stock in the respective pools give the total carbon stock per sample plot. Data at the plot level were extrapolated to the area of a full hectare to produce carbon stock estimates per hectare. All measurements were converted to Mega gram per hectare.

Descriptive statistics used to summarize the data include average mean, standard deviation, standard error, percentage, minimum and maximum values and coefficient of variation. The variation in carbon stock densities among plant communities across study area were tested by use of analysis of variance (ANOVA). The student's *t* –test was used to test for differences in carbon stock and vegetation parameters between pairs of vegetation communities and specifically between the forest reserve and parkland. Stepwise multiple regression analysis was used in identifying key predictors of carbon stock in the study area. Statistical tests were performed at 0.05, 0.01, and 0.001 significant levels.

The results obtained on characteristics of plant communities revealed that the ecologically dominant tree species (based on specie importance value S.I.V.) in the study area in descending order were *Vitalleria paradoxa, Irvingia gabonensis, Parkia biglobosa*, *Anogeissus leiocarpus*, *Pterocarpus erinaceous*, *Detarium microcarpum, Prosopis africana*, *Danellia oliveri*, and *Afzelia Africana*; which together account for about 65.2 % of total species dominance. Moreover, the most dominant families were *Fabaceae, Malvaceae, Moraceae,* and *Combrataceae*. The study showed that species

composition followed the trend in the eco-region with dominance of typical Guinea savanna tree species.

The distribution of structural attributes of tree species height, DBH, basal area, and biomass produced a reverse "J" shaped curves; whereby trees with lower height, DBH, basal area and biomass dominate. It thus shows that the area is dominated by regenerating saplings and seedlings with considerably high potential for carbon sequestration. The phytomass of five most dominant tree species in decreasing order are *Anogeissus leiocarpus,* (705.82 kg) *Parkia biglobosa,* (631.47 kg) *Pterocarpus erinaceous,* (522.23 kg) *Irvingia gabonensis* (469.72 kg) and *Vitellaria paradoxa* (381.80 kg). The implication of the most dominant tree species in the study site is that they contribute most to the above ground biomas/carbon stock.

The mean tree stand density (stem per hectare) of 244-935 stems/ha observed in the study area seem to be lower than that of Miombo woodlands in Tanzania which varied between 700–1038 stems/ha. The Shannon-Wienner index values obtained in this study lie between 2.30 and 2.78; which corresponds with the range for tropical savannah and woodlands. Generally, tree crown cover in the study area (13- 55 %) was lower than 20–75% obtainable in Tanzania Miombo woodland. Similarly, the highest mean tree height in the study area (17.1 metre) was lower compared to that of the Miombo woodland with the range of 15–30 meter. The observed higher values of shrub cover and grass cover in the Recent Fallow land, scrubland and Grassland was attributed to degradation status and ecological amplitude of plant species in the plant communities. The highest mean tree diameter at breast height (DBH) recorded (25.62cm) was lower than records from Miombo woodland Tanzania (65cm). Likewise, the highest mean

basal area in the study area 6.03 m^2ha^{-1} which is lower than (16.7 m^2ha^{-1}) of other studies in Tanzania.

The mean phytomass stock in the various plant communities was in decreasing order SW > RF >TS >SL > GL > OFL > AGF > RFL; reflecting the phytomass gradient. Generally, the Savanna woodland, Riparian forest, and tree savanna with comparatively higher mean values of Tree Density, Species richness, Shannon Weiner Diversity, Species per plot, Tree Crown cover, Tree Height, Diameter at Breast Height, and Basal Area exhibits higher biomass carbon storage by growth and decomposition. In contrast, Scrubland, Grassland, Agroforestry, Old fallow land and Recent Fallow land characterized by lower mean values of Tree Density, Species richness, Shannon Weiner Diversity, Species per plot, Tree Crown cover, Tree Height, Diameter at Breast Height, and Basal Area, exhibits lower phytomass accumulation and release; due to lower carbon storage and degradation status.

Generally, analysis of variance (ANOVA) indicated significant difference on all parameters measured across the respective plant communities. This reflects the heterogeneity of plant community characteristics across the study area. It is generally established that habitat heterogeneity (patchiness) increases tree diversity in dry forests, woodlands and savanna. Generally, there are significant differences in the characteristics of plant communities and consequently, this would influence the spatial distribution of carbon stock in the study area.

The mean carbon stocks of plant communities in decreasing order were Savanna woodland (127.30 Mg ha^{-1}), Riparian Forest (116.31 Mg ha^{-1}), Tree Savanna (114.44 Mg ha^{-1}), Scrubland (111.47 Mg ha^{-1}), Grassland (106.72 Mg ha^{-1}), Agroforestry (78.53 Mg ha^{-1}), Old Fallow Land (72.50 Mg ha^{-1}), and Recent Fallow land (66.31 Mg ha^{-1}).

To ascertain the degree of variation in carbon stock, analysis of variance (ANOVA) was applied and findings indicate significant differences in carbon stock across the respective plant communities; where $F(7,37) = 160.69$, $P<0.01$ which reflect heterogeneous nature of plant communities in the study area. Similarly, results of *t*-test performed to identify variation in carbon stock between pair of plant communities revealed that virtually, all pairs of plant communities showed significant differences in their carbon stock except between Scrubland and Grassland; which can be attributed to close similarity in biomass density and physiognomic characteristics. This suggests that there is considerable variability in carbon stock over the study area as a result of high contrast between the plant communities' inherent characteristics.

Comparative analysis of mean carbon stock in the respective pools show carbon stock in decreasing order of quantity within the forest reserve as soil 78.76 Mg ha^{-1} (67%), tree 16.55 Mg ha^{1} (14%) undergrowth 12.09 Mg ha^{-1} (10%), litter 4.02 Mg ha^{-1} (3%), dead wood 3.92 Mg ha^{-1} (3%) and root 2.86 Mg ha^{-1} (3%). Comparatively, the decreasing order of quantity in the parkland are soil 47.22 Mg ha^{-1} (68%), undergrowth 15.43 Mg ha^{-1} (22%), tree 3.68 Mg ha^{-1} (5%), litter 1.76 Mg ha^{-1} (3%), root 0.67 Mg ha^{-1} (1%) and dead wood 0.56 Mg ha^{-1} (1%). Therefore, in both study sites (Forest reserve and parkland), soil carbon stock was the highest in magnitude, while dead wood and root were the least in carbon stock.

Over all, average aggregate carbon stock density in the forest reserve was 118.2 Mg ha^{-1} which is greater than 69.3 Mg ha^{-1} recorded in the parkland. When the analysis of differences in carbon stock density between the forest reserve and the parkland was carried out, the student *t*–test revealed that there was significant difference in carbon stock density between the forest reserve and parkland study sites where $t(43) = 18.34$, *p*

< 0.001). This reflects a high contrast between plant structure and composition of the forest reserve and that of the parkland area. The higher organic carbon content of the forest reserve reflects a high organic matter turn over and fewer disturbances through tillage and harvesting operations. The mean carbon stock density obtained for the study area was 103 Mg ha^{-1} with a range of 60 – 140 Mg ha^{-1} which was comparatively lower than closed-canopy evergreen forests in Africa, with an average estimate of 200 Mg ha^{-1}; ranging 174-244 Mg ha^{-1}; and a range of 150-250 Mg ha^{-1} for seasonally dry forests. The mean carbon stock density of the study area was also lower than the biome average estimate 137 Mg ha^{-1} for Tropical savannahs.

The potential biomass predictor variables in the study site viz tree density (x_1), tree species diversity (x_2), tree species richness (x_3), DBH (x_4), basal area (x_5), height (x_6), crown cover (x_7), shrub cover (x_8), and grass cover (x_9) were subjected to stepwise multiple regression analysis to predict carbon stock. The stepwise variable selection was reached in seven steps with two variables removed (tree diversity and crown cover). The prediction models contained five of the nine variables. Findings from this study reveal that the three most important set of predictors of biomass/carbon stock in the study area, were tree density, DBH and basal area.

6.2 Conclusion

This study provides a scientific contribution for accurate estimations of biomass and carbon stock in Guinea savanna ecological area of Niger state, Nigeria. These estimates are useful benchmark against which future estimates can be compared, and sets a baseline for calculating changes in carbon stocks over time. A successful assessment and monitoring of carbon stock in savanna plant communities will largely depend on the

establishment of baseline inventory data on species composition, diversity and distribution of plant communities in the study area.

The description of species composition, structure and diversity of different plant communities confirms the principle of habitat heterogeneity (patchiness) which increases tree diversity in dry forests, woodlands and savannah. The ecologically dominant tree species (based on specie importance value S.I.V.) in the study area in descending order were *Vitalleria paradoxa, Irvingia gabonensis, Parkia biglobosa, Anogeissus leiocarpus*, *Pterocarpus erinaceous*, *Detarium microcarpum*, *Prosopis africana*, *Danellia oliveri*, and *Afzelia Africana*; which together account for about 65.2 % of total species dominance. The dominance of specific species also confirms the principle of ecological amplitude. The results were in sequence with previous studies which together show consistent ecological patterns. Species composition and structure followed trend in the eco-region with dominance of typical Guinea savanna tree species.

Structural attributes of tree species height, DBH, basal area, and biomass produced a reverse "J" shaped curves; whereby trees with lower height, DBH, basal area and biomass dominate. It thus shows that the area is dominated by regenerating saplings and seedlings. This implies considerably high carbon sequestration potential in the study area. Tree species that contribute most to the above ground biomass stock in the study area were *Anogeissus leiocarpus*, (705.82 kg) *Parkia biglobosa*, (631.47 kg) *Pterocarpus erinaceous,* (522.23 kg) *Irvingia gabonensis* (469.72 kg) and *Vitellaria paradoxa* (381.80 kg). Finding in this study implies that *Anogeissus leiocarpus* is the tree species with highest potential to store carbon in the study area.

Mean carbon stock density of plant communities in decreasing order were Savanna woodland (127.30 Mg ha^{-1}), Riparian Forest (116.31 Mg ha^{-1}), Tree Savanna (114.44

Mg ha^{-1}), Scrubland (111.47 Mg ha^{-1}), Grassland (106.72 Mg ha^{-1}), Agroforestry (78.53 Mg ha^{-1}), Old Fallow Land (72.50 Mg ha^{-1}), and Recent Fallow land (66.31 Mg ha^{-1}). Differences in carbon storage among plant communities in the Kpashimi forest reserve and adjoining parkland area reflect variation in a number of factors, including tree community physiognomic characteristics, composition, disturbance history, successional stage, and soil properties.

Mean carbon stock in the respective pools showed that soil carbon pool was the highest in magnitude, followed by tree and undergrowth; while litter, dead wood and root were lower in carbon stock.

The average aggregate carbon stock density in Kpashimi forest reserve was 118.2 Mg ha^{-1} which is greater than 69.3 Mg ha^{-1} recorded in the parkland. Mean carbon stock density obtained for the entire study area was 103 Mg ha^{-1} with a range of 60 – 140 Mg ha^{-1}. Although Carbon stock density in the study area was relatively low compared to similar eco-regions in the tropics, the characteristics of plant communities in the study area present good potential for carbon sequestration especially in soils and woody biomass. Apparently, there was tremendous capacity for the study area to store carbon and act as carbon sink if properly managed.

This study also revealed that carbon stock was primarily predicted by levels of DBH, tree density, and basal area. This work adds to the scanty but growing number of studies which demonstrate good relationships between plant community characteristics and total carbon stock, from which reliable allometric models can be developed for a more accurate measurement of carbon stock in the study area.

6.3 Recommendations

i. This study recommends the preservation of tree species such as *Anogeissus leiocarpus, Parkia biglobosa, Pterocarpus erinaceous, Irvingia gabonensis and Vitellaria paradoxa* for carbon offset purposes; because they are indeginous, ecologically important and show high carbon sequestration potential by virtue of their biomass stocks.

ii. The carbon stock predictor models derived here provide an ideal opportunity for further work on the verification of woody biomass/carbon stock calculations, thus leading to more meaningful estimations.

iii. This study recommends strenghthening of and enforcement of forestry laws to ensure sustainability of this ecosystem. This will go along way in the realization of full carbon sequestration potential of the study area.

iv. Forest management activities and practices in the study area should focus on fire management and human land-use practices such as restriction on logging, bush burning, and adequate supply of kerosene, electricity and gas as alternative household cooking fuels. This would enhance carbon sink and reduce carbon emmission of the plant communities in the study area.

v. Niger state Government in collaboration with the Federal Ministry of Environment should initiate a carbon offset trading project in the study area; which will provide window of opportunities for accessing carbon credits through the Clean Development Mechanism (CDM) tool of the Kyoto Protocol under the United Nations Framework Convention on Climate Change (UNFCCC).

vi. Further research to demonstrate the feasibility of large area measurement schemes in the study area would be required. In addition, there is the need for temporal periodic studies to understand carbon stuck dynamics in the study area.

This will contribute towards a clear understanding of the existing carbon dynamics in the area.

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APPENDICES

APPENDIX I

COORDINATES OF SAMPLING POINTS

FOREST RESERVE			
S / No.	**PLOT SITE No.**	**LATITUDE**	**LONGITUDE**
1	1 FR	8º 48′ 36″ N	6º 36′ 58″ E
2	2 FR	8º 48′ 15″ N	6º 39′ 26″ E
3	3 FR	8º 47′ 54″ N	6º 41′ 20″ E
4	4 FR	8º 47′ 33″ N	6º 43′ 24″ E
5	5 FR	8º 47′ 01″ N	6º 37′ 29″ E
6	6 FR	8º 46′ 37″ N	6º 38′ 33″ E
7	7 FR	8º 46′ 10″ N	6º 39′ 49″ E
8	8 FR	8º 45′ 38″ N	6º 41′ 11″ E
9	9 FR	8º 45′ 17″ N	6º 42′ 10″ E
10	10 FR	8º 44′ 44″ N	6º 44′ 03″ E
11	11 FR	8º 44′ 53″ N	6º 36′ 39″ E
12	12 FR	8º 44′ 34″ N	6º 38′ 05″ E
13	13 FR	8º 44′ 25″ N	6º 39′ 55″ E
14	14 FR	8º 43′ 40″ N	6º 41′ 19″ E
15	15 FR	8º 43′ 31″ N	6º 42′ 35″ E
16	16 FR	8º 43′ 39″ N	6º 44′ 05″ E
17	17 FR	8º 44′ 32″ N	6º 36′ 12″ E
18	18 FR	8º 44′ 00″ N	6º 37′ 42″ E
19	19 FR	8º 43′ 12″ N	6º 39′ 28″ E
20	20 FR	8º 42′ 37″ N	6º 40′ 59″ E
21	21 FR	8º 42′ 31″ N	6º 42′ 09″ E
22	22 FR	8º 42′ 36″ N	6º 43′ 30″ E
23	23 FR	8º 43′ 14″ N	6º 35′ 25″ E
24	24 FR	8º 42′ 46″ N	6º 36′ 54″ E
25	25 FR	8º 42′ 24″ N	6º 38′ 57″ E
26	26 FR	8º 42′ 07″ N	6º 40′ 10″ E
27	27 FR	8º 41′ 44″ N	6º 41′ 22″ E
28	28 FR	8º 41′ 36″ N	6º 35′ 49″ E
29	29 FR	8º 40′ 55″ N	6º 37′ 20″ E
30	30 FR	8º 40′ 24″ N	6º 38′ 38″ E
PARKLAND SAMPLE POINTS COORDINATES			
31	1 PL	8º 48′ 38″ N	6º 36′ 19″ E
32	2 PL	8º 48′ 52″ N	6º 35′ 25″ E
33	3 PL	8º 47′ 30″ N	6º 36′ 29″ E
34	4 PL	8º 47′ 53″ N	6º 35′ 26″ E
35	5 PL	8º 46′ 27″ N	6º 36′ 01″ E
36	6 PL	8º 46′ 44″ N	6º 34′ 39″ E
37	7 PL	8º 45′ 29″ N	6º 35′ 24″ E
38	8 PL	8º 44′ 58″ N	6º 34′ 15″ E
39	9 PL	8º 43′ 31″ N	6º 34′ 47″ E
40	10 PL	8º 43′ 15″ N	6º 33′ 23″ E
41	11 PL	8º 41′ 59″ N	6º 34′ 52″ E
42	12 PL	8º 42′ 21″ N	6º 33′ 37″ E
43	13 PL	8º 41′ 25″ N	6º 35′ 10″ E
44	14 PL	8º 41′ 24″ N	6º 34′ 10″ E
45	15 PL	8º 40′ 23″ N	6º 40′ 10″ E

APPENDIX II

Summary of Plant Structural Characteristics in Forest Reserve and Parkland

FOREST RESERVE				
Plot No.	**Girth At Breast Height (cm)**	**Tree Basal Area (m^2 ha^{-1})**	**Diameter At Breast Height (cm)**	**Tree Height (metre)**
1	93.7 ± 3.9	7.8 ± 0.5	29.8 ± 1.2	17.4 ± 0.8
2	99.1 ± 6.1	9.0 ± 0.9	31.5 ± 1.9	18.6 ± 1.1
3	96.5 ± 4.0	8.2 ± 0.6	30.7 ± 1.3	18.0 ± 0.8
4	91.1 ± 4.1	7.3 ± 0.5	29.0 ± 1.3	16.9 ± 0.7
5	85.0 ± 3.5	6.5 ± 0.4	27.1 ± 1.1	17.4 ± 0.7
6	86.7 ± 3.6	6.7 ± 0.5	27.6 ± 1.2	17.9 ± 0.7
7	79.2 ± 3.5	5.5 ± 0.4	25.2 ± 1.1	17.0 ± 0.6
8	86.6 ± 4.2	6.6 ± 0.6	27.6 ± 1.3	18.0 ± 0.8
9	75.3 ± 3.3	5.2 ± 0.4	24.0 ± 1.1	17.2 ± 0.7
10	75.6 ± 4.1	5.2 ± 0.5	24.1 ± 1.3	16.0 ± 0.7
11	74.9 ± 3.9	5.0 ± 0.5	23.8 ± 1.3	15.8 ± 0.7
12	79.2 ± 3.4	5.6 ± 0.4	25.2 ± 1.1	16.8 ± 0.6
13	73.0 ± 3.4	5.0 ± 0.4	23.3 ± 1.1	16.5 ± 0.7
14	60.9 ± 4.3	3.6 ± 0.5	19.4 ± 1.4	15.2 ± 0.9
15	70.7 ± 3.3	4.6 ± 0.4	22.5 ± 1.0	16.1 ± 0.6
16	81.6 ± 4.6	6.3 ± 0.7	26.0 ± 1.5	18.2 ± 0.8
17	69.7 ± 4.5	4.8 ± 0.5	22.2 ± 1.4	16.4 ± 0.8
18	79.3 ± 3.7	5.7 ± 0.5	25.2 ± 1.2	18.3 ± 0.6
19	74.3 ± 3.7	5.2 ± 0.5	23.7 ± 1.2	17.3 ± 0.6
20	60.7 ± 4.3	3.6 ± 0.5	19.3 ± 1.4	14.2 ± 0.7
21	73.9 ± 4.9	5.2 ± 0.6	23.5 ± 1.5	16.4 ± 0.7
22	71.4 ± 4.2	4.9 ± 0.5	22.7 ± 1.4	15.9 ± 0.6
23	75.1 ± 4.4	5.5 ± 0.6	23.9 ± 1.4	16.5 ± 0.7
24	71.0 ± 4.4	5.1 ± 0.6	22.6 ± 1.4	16.4 ± 0.7
25	76.8 ± 4.9	5.8 ± 0.7	24.5 ± 1.6	17.0 ± 0.8
26	70.7 ± 4.1	4.8 ± 0.5	22.5 ± 1.3	15.8 ± 0.7
27	65.1 ± 4.2	4.2 ± 0.5	20.7 ± 1.3	15.0 ± 0.6
28	71.9 ± 5.1	5.2 ± 0.7	22.9 ± 1.6	16.3 ± 0.8
29	69.4 ± 3.9	4.8 ± 0.5	22.1 ± 1.2	15.9 ± 0.7
30	68.5 ± 4.8	4.8 ± 0.7	21.8 ± 1.5	15.1 ± 0.7
PARKLAND				
31	73.1 ± 7.3	5.2 ± 0.9	23.3 ± 2.3	13.7 ± 0.9
32	64.8 ± 6.3	4.0 ± 0.8	20.6 ± 2.0	13.3 ± 0.6
33	77.7 ± 6.0	5.3 ± 0.7	24.8 ± 1.9	13.9 ± 1.0
34	52.9 ± 4.4	2.6 ± 0.5	16.8 ± 1.4	13.0 ± 0.5
35	61.9 ± 3.6	3.4 ± 0.4	19.7 ± 1.1	13.4 ± 0.6
36	51.4 ± 6.1	2.7 ± 0.6	16.4 ± 1.9	12.5 ± 0.9
37	54.8 ± 5.1	2.8 ± 0.6	17.5 ± 1.6	13.1 ± 0.7
38	43.8 ± 3.4	1.8 ± 0.3	14.0 ± 1.1	10.1 ± 0.5
39	64.7 ± 4.6	3.8 ± 0.5	20.6 ± 1.5	12.5 ± 0.7
40	62.6 ± 6.1	3.5 ± 0.6	19.9 ± 1.9	11.2 ± 0.6
41	83.3 ± 5.4	5.9 ± 0.7	26.5 ± 1.7	12.9 ± 0.7
42	58.4 ± 5.3	3.4 ± 0.5	18.6 ± 1.7	10.9 ± 0.8
43	58.5 ± 4.8	3.0 ± 0.5	18.6 ± 1.5	12.6 ± 0.8
44	53.4 ± 6.5	2.8 ± 0.6	17.0 ± 2.1	9.9 ± 0.9
45	58.0 ± 5.9	3.3 ± 0.6	18.5 ± 1.9	11.8 ± 0.9

Note: ± indicates Standard Error Of The Mean (SEM)

APPENDIX III

Summary of Crown cover, Shrub Cover, and Grass Cover in the Forest Reserve and Parkland

FOREST RESERVE			
PLOT NO.	**TREE CROWN COVER (%)**	**SHRUB COVER (%)**	**GRASS COVER (%)**
1	47	27	31
2	35	47	31
3	55	24	21
4	43	26	33
5	63	12	11
6	52	21	20
7	51	17	31
8	39	25	34
9	65	10	8
10	47	19	31
11	45	22	25
12	61	21	18
13	69	12	11
14	38	21	40
15	62	6	10
16	55	17	21
17	49	23	27
18	57	13	21
19	63	7	15
20	34	34	36
21	39	28	32
22	38	22	36
23	48	13	21
24	45	9	12
25	48	26	31
26	51	28	31
27	53	15	22
28	46	25	31
29	65	20	37
30	44	33	28
PARKLAND			
31	13	44	61
32	15	52	72
33	15	49	68
34	16	46	73
35	14	45	68
36	13	51	85
37	14	53	72
38	14	43	66
39	13	54	65
40	15	45	74
41	12	57	69
42	14	43	61
43	16	56	85
44	15	49	64
45	13	34	72

APPENDIX IV

Summary of Plant community Composition and Diversity in the Forest Reserve and Parkland

FOREST RESERVE					
PLOT NO.	**NO. OF TREE /PLOT**	**TREE DENSITY / Ha**	**NO. OF SPP /PLOT**	**SPECIES RICHNESS (Margalef)**	**SHANNON DIVERSITY INDEX (H′)**
1	64	1280	23	2.99	2.914
2	43	860	15	1.95	2.241
3	64	1280	17	2.21	2.520
4	56	1120	19	2.47	2.691
5	74	1480	20	2.60	2.562
6	64	1280	20	2.60	2.720
7	49	980	22	2.86	2.795
8	47	940	19	2.47	2.601
9	76	1520	24	3.12	2.756
10	52	1040	17	2.21	2.598
11	43	860	16	2.08	2.483
12	69	1380	21	2.73	2.616
13	76	1520	20	2.60	2.647
14	44	880	18	2.34	2.619
15	74	1480	22	2.86	2.750
16	62	1240	19	2.47	2.490
17	55	1100	22	2.86	2.736
18	67	1340	21	2.73	2.752
19	73	1460	21	2.73	2.621
20	47	940	18	2.34	2.589
21	47	940	18	2.34	2.589
22	56	1120	19	2.47	2.644
23	68	1360	20	2.60	2.668
24	69	1380	25	3.25	2.912
25	59	1180	17	2.21	2.424
26	65	1300	17	2.21	2.308
27	63	1260	21	2.73	2.576
28	55	1100	18	2.34	2.682
29	76	1520	23	2.99	2.724
30	59	1180	22	2.86	2.837
PARKLAND					
31	24	480	12	1.56	2.206
32	23	460	14	1.82	2.487
33	19	380	9	1.17	2.105
34	26	520	12	1.56	2.332
35	34	680	11	1.43	2.155
36	21	420	9	1.17	2.083
37	22	440	12	1.56	2.287
38	31	620	16	2.08	2.589
39	29	580	15	1.95	2.546
40	13	260	9	1.17	2.058
41	17	340	9	1.17	1.925
42	30	600	15	1.95	2.439
43	16	320	11	1.43	2.307
44	17	340	12	1.56	2.278
45	23	460	11	1.43	2.201

APPENDIX V

Summary of data on sampled phytomass of tree components

S./NO	SPECIES NAME	TRUNK (Kg)	BRANCHES (Kg)	LEAVES (Kg)	TOTAL BIOMASS (Kg)
1	*Vitellaria paradoxa*	34.7	16.2	6.9	57.8
2	*Vitellaria paradoxa*	92.4	43.1	18.5	154
3	*Vitellaria paradoxa*	161.7	75.5	32.3	269.5
4	*Vitellaria paradoxa*	231	107.8	46.2	385
5	*Vitellaria paradoxa*	369.6	172.5	73.9	616
6	*Vitellaria paradoxa*	485.1	226.4	97	808.5
7	*Irvingia gabonensis*	43.3	14.7	8.7	66.6
8	*Irvingia gabonensis*	129.8	43.9	26	199.7
9	*Irvingia gabonensis*	216.4	73.2	43.3	332.9
10	*Irvingia gabonensis*	317.3	107.4	63.5	488.2
11	*Irvingia gabonensis*	476	161.1	95.2	732.3
12	*Irvingia gabonensis*	649.1	219.7	129.8	998.6
13	*Parkia biglobosa*	52.7	30	8.2	90.9
14	*Parkia biglobosa*	158.2	90	24.6	272.8
15	*Parkia biglobosa*	281.3	160.1	43.7	485
16	*Parkia biglobosa*	404.3	230	62.7	697.1
17	*Parkia biglobosa*	509.8	290.1	79.1	879
18	*Parkia biglobosa*	791.1	450.1	122.8	1364
19	*Anogeissus leiocarpus*	62	31.5	8.1	101.6
20	*Anogeissus leiocarpus*	186	94.5	24.4	304.9
21	*Anogeissus leiocarpus*	310	157.5	40.7	508.2
22	*Anogeissus leiocarpus*	454.7	231.1	59.6	745.4
23	*Anogeissus leiocarpus*	682	346.6	89.4	1118
24	*Anogeissus leiocarpus*	888.6	451.6	116.5	1456.8
25	*Pterocarpus erinaceous*	47	19	9.9	75.8
26	*Pterocarpus erinaceous*	141	56.9	29.6	227.4
27	*Pterocarpus erinaceous*	235	94.8	49.3	379.1
28	*Pterocarpus erinaceous*	344.7	139	72.3	555.9
29	*Pterocarpus erinaceous*	517	208.5	108.4	833.9
30	*Pterocarpus erinaceous*	658	265.3	138	1061.3

APPENDIX VI
Summary of Data on Parameters of Soil Carbon Stock in the Forest Reserve and Parkland

FOREST RESERVE							
PLOT NO.	1-15 CM DEPTH			16-30 CM DEPTH			**TOTAL SOIL (Mg ha^{-1})**
	Db (g/cm3)	**ORG. C (%)**	**SOIL CARBON (Mg ha^{-1})**	**Db (g/cm3)**	**ORG. C (%)**	**SOIL CARBON (Mg ha^{-1})**	
1	1.20	3.13	56.34	1.25	1.88	35.25	91.59
2	1.29	2.47	47.79	1.36	1.05	21.42	69.21
3	1.21	3.18	57.72	1.26	1.56	29.48	87.2
4	1.20	3.09	55.62	1.29	1.75	33.86	89.48
5	1.28	2.8	53.76	1.32	1.51	29.90	83.66
6	1.21	2.75	49.91	1.23	1.15	21.22	71.13
7	1.29	2.71	52.44	1.32	1.42	28.12	80.55
8	1.23	2.51	46.31	1.28	1.35	25.92	72.23
9	1.24	2.95	54.87	1.31	1.71	33.6	88.47
10	1.20	2.15	38.70	1.22	1.85	33.86	72.56
11	1.18	2.75	48.68	1.26	1.47	27.78	76.46
12	1.11	3.37	56.11	1.15	1.13	19.49	75.6
13	1.28	2.71	52.03	1.34	1.39	27.94	79.97
14	1.20	2.42	43.56	1.26	1.09	20.60	64.16
15	1.29	2.21	42.76	1.33	1.44	28.73	71.49
16	1.25	2.35	44.06	1.30	1.15	22.43	66.49
17	1.20	2.68	48.24	1.22	1.97	36.05	84.29
18	1.18	2.80	49.56	1.23	1.59	29.34	78.90
19	1.25	2.68	50.25	1.32	1.56	30.89	81.14
20	1.19	2.27	40.52	1.25	1.97	36.94	77.46
21	1.29	2.15	41.60	1.38	1.77	36.64	78.24
22	1.25	2.59	48.56	1.37	1.35	27.74	76.31
23	1.24	2.95	54.87	1.29	1.68	32.51	87.38
24	1.13	2.80	47.46	1.21	1.48	26.86	74.32
25	1.20	2.95	53.10	1.27	1.75	33.34	86.44
26	1.26	2.80	52.92	1.32	1.56	30.89	83.81
27	1.18	2.80	49.56	1.26	1.51	28.54	78.10
28	1.11	3.13	52.11	1.14	1.42	24.28	76.40
29	1.14	2.83	48.39	1.21	1.75	31.76	80.16
30	1.22	2.18	39.89	1.37	1.92	39.46	79.35
PARKLAND							
31	1.37	1.81	37.20	1.42	0.63	13.42	50.61
32	1.39	1.51	31.48	1.45	0.80	17.40	48.88
33	1.33	1.34	26.73	1.39	1.01	21.06	47.79
34	1.36	1.63	33.25	1.42	0.52	11.08	44.33
35	1.38	1.06	21.94	1.47	0.94	20.73	42.67
36	1.38	1.89	39.12	1.45	0.68	14.79	53.91
37	1.45	1.10	23.93	1.49	0.81	18.10	42.03
38	1.33	1.01	20.15	1.38	0.73	15.11	35.26
39	1.39	1.22	25.44	1.46	0.96	21.02	46.46
40	1.42	1.90	40.47	1.50	0.51	11.48	51.95
41	1.52	1.63	37.16	1.61	0.52	12.56	49.72
42	1.56	1.15	26.91	1.65	0.93	23.02	49.93
43	1.38	1.06	21.94	1.51	1.00	22.65	44.59
44	1.52	1.42	32.38	1.65	0.82	20.30	52.67
45	1.37	1.31	26.92	1.43	0.96	20.59	47.51

APPENDIX VII

Mean carbon stock in the respective forest carbon pools

FOREST RESERVE							
PLOT NO.	**TREE (Mg ha^{-1})**	**ROOT (Mg ha^{-1})**	**UNDER GROWTH (Mg ha^{-1})**	**DEAD WOOD (Mg ha^{-1})**	**LITTER (Mg ha^{-1})**	**SOILCARBON (Mg ha^{-1})**	**TOTAL CARBON (Mg ha^{-1})**
1	25.11	4.22	11.2	3.67	4.2	91.6	139.98
2	20.34	3.32	12	4.78	5	69.2	114.65
3	26.78	4.47	9.4	5.08	5.5	87.2	138.44
4	20.53	3.48	9.3	1.81	3.8	89.5	128.40
5	23.63	4.06	8.1	2.7	5.1	83.7	127.25
6	21.04	3.60	8.8	5.71	6.2	71.1	116.48
7	12.74	2.25	12.1	2.42	6	80.6	116.07
8	15.31	2.63	12.1	4.74	5.1	72.2	112.11
9	18.84	3.32	7.3	2.45	4.5	88.5	124.87
10	13.09	2.30	12.2	6.08	5	72.6	111.22
11	10.15	1.80	15.5	3.28	3.8	76.5	110.99
12	18.81	3.28	15.3	6.6	4.4	75.6	123.99
13	18.02	3.17	7.6	2.92	3.2	80.0	114.88
14	7.27	1.32	14.8	2.34	4.1	64.2	93.99
15	16.16	2.87	12.8	1.91	2.8	71.5	108.03
16	19.70	3.33	13.8	3.26	3.8	66.5	110.38
17	12.62	2.21	19.9	3.8	4.1	84.3	126.92
18	18.64	3.23	13.9	6.71	3.3	78.9	124.68
19	18.36	3.20	11.2	3.25	5.4	81.1	122.55
20	7.80	1.41	17.6	4.03	1.9	77.5	110.20
21	11.90	2.07	17	3.01	3.1	78.2	115.32
22	13.06	2.29	15.8	3.25	4	76.3	114.70
23	18.68	3.19	11.4	5.42	3.4	87.4	129.47
24	17.21	2.95	9.5	4.83	3.4	74.3	112.21
25	17.06	2.90	12.6	2.36	2.2	86.4	123.56
26	15.18	2.65	6.8	2.61	3.3	83.8	114.34
27	12.73	2.25	10.4	3.01	4.6	78.1	111.08
28	14.32	2.44	12.5	5.82	3.5	76.4	114.97
29	17.52	3.05	9.9	3.91	3	80.2	117.53
30	14.03	2.41	11.8	5.8	3	79.4	116.39
PARKLAND							
31	6.13	1.06	14.7	0.58	1.5	50.6	74.59
32	4.38	0.78	17.4	0.83	1.5	48.9	73.77
33	4.82	0.85	15.9	0	1.6	47.8	70.96
34	2.96	0.56	19.1	1.07	2.1	44.3	70.12
35	5.13	0.96	16.2	0	2.4	42.7	67.36
36	2.54	0.47	21.1	0.49	1.3	53.9	79.81
37	2.77	0.52	15.2	0.91	1.6	42.0	63.02
38	2.29	0.46	15.9	0	2.6	35.3	56.51
39	5.04	0.92	12	0	1.8	46.5	66.23
40	2.01	0.38	11.6	0.32	1.2	51.9	67.45
41	4.81	0.84	12	0	1.4	49.7	68.77
42	4.62	0.85	18.4	0.31	2.5	49.9	76.61
43	2.08	0.40	13	1.66	1.3	44.6	63.03
44	2.13	0.40	15.2	1.25	1.6	52.7	73.25
45	3.46	0.63	13.8	0.995	2	47.5	68.40

APPENDIX VIII

DATA SHEET FOR PILOT SURVEY

Site number :…….

Name of Village : …….

Land Use Type : …….

Location (GPS) : Latitude……Longitude……

Sample Plot size : …….

Sample taken by : ……..

Date : …….

S/No.	SPECIES	GIRTH	DBH*	COMMENT**
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				

Note: * All trees within the plot with DBH ≥ 5 cm should be measured

**Key words describing the forest and terrain within and around the plot: Examples: Dense, open, scattered trees,
poorly stocked, plantation, multi-storey, newly thinned, heavily lopped, etc.

Unidentified trees species should be recorded as Sp 1...Sp 2 likewise and distinguishable characteristics are noted as comments

APPENDIX IX

DATA SHEET - TREE AND ROOTS

Site number :…….
Name of Village : …….
Land Use Type : …….
Location (GPS) : Latitude…….Longitude……..
Sample area : …….
Sample taken by : ……..
Date : …….

S. / No.	Spp. code	Height (m)	Girth (cm)	DBH (cm)	Biomass (kg / tree)	Root Biomass (kg)
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
29						
30						
				TOTAL BIOMASS		

Comments……
……
……
……..

Note : dbh = Girth / π, cm where π =3.14

Root Biomass (Tropical) = exp (-1.0587 + 0.8836 x ln ABD)
Where: ABD = *aboveground biomass density (t/ha)*

DATA SHEET - TREE AND ROOTS (Cont'd)

S. / No.	Spp. code	Height (m)	Girth (cm)	BH (cm)	Biomass (kg / tree)	Root Biomass (kg)
31						
32						
33						
34						
35						
36						
37						
38						
39						
40						
41						
42						
43						
44						
45						
46						
47						
48						
49						
50						
51						
52						
53						
54						
55						
56						
57						
58						
59						
60						
61						
62						
63						
64						
65						
66						
67						
68						
69						
70						
71						
72						
73						
74						
75						
76						
77						
	TOTAL BIOMASS					

APPENDIX X

DATA SHEET - UNDERGROWTH

Site number :…….

Name of Village : …….

Land Use Type : …….

Location (GPS) : Latitude……Longitude……

Sample Plot size : …….

Sample taken by : ……..

Date : …….

S. / No.	Sample -Fresh Weight (kg)	Subsample – Fresh weight (kg)	Subsample Dry weight (kg)	Total Dry Weight Kg / m^2
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
			TOTAL	

Comments……
……
……
…….

Note : Total dry weight (kg / m^2) = $\frac{\text{Total fresh weight (kg) x Subsample dry weight(g)}}{\text{Subsample fresh weight (g) x Sample area } (m^2)}$

APPENDIX XI

DATA SHEET – DEAD WOOD

Site number :…….

Name of Village : …….

Land Use Type : …….

Location (GPS) : Latitude……Longitude……

Length of Transect : ……..

Sample Plot size : …….

Sample taken by : ……..

Date : …….

S. / No.	Length (cm)	Diameter (cm)	Height (m)	Class of decomposition	Wood density (g cm^3)	Dry weight of necromass (kg)
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
					TOTAL	

Comments……
……
……
……

Note: Class of decomposition: 1 = Sound, 2 = Partial, 3 = Rotten

APPENDIX XII

DATA SHEET – LITTER

Site number :…….

Name of Village : …….

Land Use Type : …….

Location (GPS) : Latitude……Longitude……

Sample Plot size : …….

Sample taken by : ……..

Date : …….

S. / No.	Sample -Fresh Weight (kg)	Subsample – Fresh weight (kg)	Subsample Dry weight (kg)	Total Dry Weight Kg / m^2
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
			TOTAL	

Comments……
……
……
……
…….

Note : Total dry weight (kg / m^2) = $\frac{\text{Total fresh weight (kg) x Subsample dry weight(g)}}{\text{Subsample fresh weight (g) x Sample area } (m^2)}$

APPENDIX XIII

DATA SHEET – SOIL

Site number :…….

Name of Village : …….

Land Use Type : …….

Location (GPS) : Latitude……Longitude……

Sample taken by : ……..

Date : …….

S. / No.	Soil depth (cm)	Soil Bulk density (gcm^3)	Soil Organic carbon (%)	Carbon (kg/m^2)
1	0 - 15 cm			
2	15 - 30 cm			
3				
4				
5				
6				
7				
TOTAL				

Comments……
……
……
…….

Note:

***C (t/ha)* = [(*soil bulk density, (g/cm*^{3}**) × *soil depth* (*cm*) × % *C*)] ×100**

APPENDIX XIV

DATA SHEET – TREE CROWN, SHRUB AND GRASS COVER

Site number :…….

Name of Village : …….

Land Use Type : …….

Location (GPS) : Latitude……Longitude……

Length of Transect : ……..

Sample Plot size : …….

Sample taken by : ……..

Date : …….

Segments	Crown cover lenght (meter)	Shrub cover lenght (meter)	Grass cover length (meter)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
TOTAL			
Percentage Cover			

Comments……
……
……
……
…….

Note : Percentage cover = $\frac{\text{Total estimated length of cover (m)}}{\text{Total length of transect (m)}}$ x 100

APPENDIX XV

DATA SHEET – LABORATORY ANALYSIS OF SUBSAMPLES

PLOT NO……. ……...
DATE……
LABORATORY……
…..

(A) Tree Biomass Samples

Spp. Code	Sample I.D.	Trunk / Disc			Branches / Disc			Leaves		
		Volume	Disc Vol	Dry mass	FW_W	FW_S	DW_W	FW_W	FW_S	D

(B) Undergrowth Biomass Samples

Sample I.D.	FW_W	FW_S	DW_S	DW_W

(C) Litter Necromass

Sample I.D.	FW_W	FW_S	DW_S	DW_W

(D) Dead wood Necromass

Sample I.D.	Average Diameter (cm)	Disc Thickness (cm)	Dry Weight (g)

(E) Soil Bulk Density

Sample I.D.	Depth (cm)	Volume (cm^3)	D_b <2mm (g/cr

(F) Soil Organic Carbon

Sample I.D.	Depth (cm)	Volume (cm^3)	Carbon Content (%)

Name, Signature and Date……

APPENDIX XVI

DATA SHEET - LABORATORY ANALYSIS OF SAMPLED TREE PHYTOMASS

Plot Number……

Tree Species……

Tree Diameter at Breast Height (cm)……..

Tree Height (meter)……

(A) Estimation of Tree Trunk Mass

Lower Radius (r1)	**Upper Radius (r2)**	**Length (m)**	**Volume(cm^3)**	**Density (g/cm^3)**	**Mass**

Volume = (π **r1**^{2} + π **r2**^{2})/2 x **L**

Where **r1** = radius at one end of the trunk, **r2** = radius at the other end of the trunk and **L** = length of the trunk

Mass = Volume x Density

(B) Analysis of Dry Mass Fraction

Component	**FW_W** (Kg)	**FW_S** (Kg)	**DW_S** (Kg)	**DW_W** (Kg)	**Remark**
Trunk					
Branches					
Leaves					
Total Biomass (Kg)					

$$DW_W = \frac{DW_S}{FW_S} \times FW_W$$

Where,

DWW: whole dry weight

DWS: dry weight of sample

FWW: whole fresh weight

FWS: fresh weight of sample

APPENDIX XVII

SAMPLE LABELLING CODES

TREE	UNDERGROWTH	LITTER	DEAD WOOD	SOIL BULK DENSITY	SOIL ORG. CARBON
A1 T,B,L)	B1	C1	D1 (a, b, c)	E1 (a, b)	F1(a, b)
A2(T,B,L)	B2	C2	D2 (a, b, c)	E2 (a, b)	F2(a, b)
A3(T,B,L)	B3	C3	D3 (a, b, c)	E3 (a, b)	F3(a, b)
A4(T,B,L)	B4	C4	D4 (a, b, c)	E4 (a, b)	F4(a, b)
A5(T,B,L)	B5	C5	D5 (a, b, c)	E5 (a, b)	F5(a, b)
A6(T,B,L)	B6	C6	D6 (a, b, c)	E6 (a, b)	F6(a, b)
A7(T,B,L)	B7	C7	D7 (a, b, c)	E7 (a, b)	F7(a, b)
A8(T,B,L)	B8	C8	D8 (a, b, c)	E8 (a, b)	F8(a, b)
A9(T,B,L)	B9	C9	D9 (a, b, c)	E9 (a, b)	F9(a, b)
A10(T,B,L)	B10	C10	D10 (a, b, c)	E10 (a, b)	F10(a, b)
A11(T,B,L)	B11	C11	D11 (a, b, c)	E11 (a, b)	F11(a, b)
A12(T,B,L)	B12	C12	D12 (a, b, c)	E12 (a, b)	F12(a, b)
A13(T,B,L)	B13	C13	D13 (a, b, c)	E13 (a, b)	F13(a, b)
A14(T,B,L)	B14	C14	D14 (a, b, c)	E14 (a, b)	F14(a, b)
A15(T,B,L)	B15	C15	D15 (a, b, c)	E15 (a, b)	F15(a, b)
A16(T,B,L)	B16	C16	D16 (a, b, c)	E16 (a, b)	F16(a, b)
A17(T,B,L)	B17	C17	D17 (a, b, c)	E17 (a, b)	F17(a, b)
A18(T,B,L)	B18	C18	D18 (a, b, c)	E18 (a, b)	F18(a, b)
A19(T,B,L)	B19	C19	D19 (a, b, c)	E19 (a, b)	F19(a, b)
A20(T,B,L)	B20	C20	D20 (a, b, c)	E20 (a, b)	F20(a, b)
A21(T,B,L)	B21	C21	D21 (a, b, c)	E21 (a, b)	F21(a, b)
A22(T,B,L)	B22	C22	D22 (a, b, c)	E22 (a, b)	F22(a, b)
A23(T,B,L)	B23	C23	D23 (a, b, c)	E23 (a, b)	F23(a, b)
A24(T,B,L)	B24	C24	D24 (a, b, c)	E24 (a, b)	F24(a, b)
A25(T,B,L)	B25	C25	D25 (a, b, c)	E25 (a, b)	F25(a, b)
A26(T,B,L)	B26	C26	D26 (a, b, c)	E26 (a, b)	F26(a, b)
A27(T,B,L)	B27	C27	D27 (a, b, c)	E27 (a, b)	F27(a, b)
A28(T,B,L)	B28	C28	D28 (a, b, c)	E28 (a, b)	F28(a, b)
A29(T,B,L)	B29	C29	D29 (a, b, c)	E29 (a, b)	F29(a, b)
A30(T,B,L)	B30	C30	D30 (a, b, c)	E30 (a, b)	F30(a, b)
A31(T,B,L)	B31	C31	D31 (a, b, c)	E31 (a, b)	F31(a, b)
A32(T,B,L)	B32	C32	D32 (a, b, c)	E32 (a, b)	F32(a, b)
A33(T,B,L)	B33	C33	D33 (a, b, c)	E33 (a, b)	F33(a, b)
A34(T,B,L)	B34	C34	D34 (a, b, c)	E34 (a, b)	F34(a, b)
A35(T,B,L)	B35	C35	D35 (a, b, c)	E35 (a, b)	F35(a, b)
A36(T,B,L)	B36	C36	D36 (a, b, c)	E36 (a, b)	F36(a, b)
A37(T,B,L)	B37	C37	D37 (a, b, c)	E37 (a, b)	F37(a, b)
A38(T,B,L)	B38	C38	D38 (a, b, c)	E38 (a, b)	F38(a, b)
A39(T,B,L)	B39	C39	D39 (a, b, c)	E39 (a, b)	F39(a, b)
A40(T,B,L)	B40	C40	D40 (a, b, c)	E40 (a, b)	F40(a, b)
A41(T,B,L)	B41	C41	D41 (a, b, c)	E41 (a, b)	F41(a, b)
A42(T,B,L)	B42	C42	D42 (a, b, c)	E42 (a, b)	F42(a, b)
A43(T,B,L)	B43	C43	D43 (a, b, c)	E43 (a, b)	F43(a, b)
A44(T,B,L)	B44	C44	D44 (a, b, c)	E44 (a, b)	F44(a, b)
A45(T,B,L)	B45	C45	D45 (a, b, c)	E45 (a, b)	F45(a, b)

APPENDIX XVIII

LIST OF TREE SPECIES

SPECIES CODE	TREE SPECIES SCIENTIFIC NAMES	FAMILY
01	*Acacia albida*	*Fabaceae*
02	*Acacia niotica*	*Fabaceae*
03	*Acacia raddiana*	*Fabaceae*
04	*Acacia senegal*	*Fabaceae*
05	*Acacia tortilis*	*Fabaceae*
06	*Adansonia digitata*	*Malvaceae*
07	*Afromosia laxiflora*	*Fabaceae*
08	*Afzelia africana*	*Fabaceae*
09	*Albizia zysia*	*Fabaceae*
10	*Anacardium occidentale*	*Anarcardiaceae*
11	*Anogeissus leiocarpus*	*Combretaceae*
12	*Anona senegalensis*	*Annonaceae*
13	*Antiaris africana*	*Moraceae*
14	*Azadirachta indica*	*Maliaceae*
15	*Balanites aegyptiaca*	*Zygophyllaceae*
16	*Bombax costatum*	*Malvaceae*
17	*Borassus eathiopium*	*Malvaceae*
18	*Burkea africana*	*Fabaceae*
19	*Carica papaya*	*Malvaceae*
20	*Ceiba pentandra*	*Malvaceae*
21	*Citrus sinensis*	*Pieridae*
22	*Cocos nucifera*	*Malvaceae*
23	*Cola gigantea*	*Malvaceae*
24	*Cola nitida*	*Malvaceae*
25	*Combretum molle*	*Fabaceae*
26	*Danellia oliveri*	*Caesalpiniaceae*
27	*Detarium microcarpum*	*Caesalpiniaceae*
28	*Diosyros mespiliformis*	*Fabaceae*
29	*Elaeis guineensis*	*Fabaceae*

30	*Ficus capensis*	*Moraceae*
31	*Ficus polita*	*Moraceae*
32	*Ficus sycomorus*	*Moraceae*
33	*Gardenia terifolia*	*Moraceae*
34	*Gmalina arborea*	*Lamiaceae*
35	*Hyphaenia thebeica*	*Moraceae*
36	*Irvingia gabonensis*	*Irvingiacea*
37	*Isoberlina doka*	*Moraceae*
38	*Khaya senegalensis*	*Meliaceae*
39	*Lophira lanceolata*	*Ochinaceae*
40	*Mangifera indica*	*Anacardiaceae*
41	*Nauclea latifolia*	*Fabaceae*
42	*Parinary polyandra*	*Fabaceae*
43	*Parkia biglobosa*	*Mimosaceae*
44	*Prosopis africana*	*Fabaceae*
45	*Prosopis julifera*	*Fabaceae*
46	*Psidium guajavca*	*Guajavceae*
47	*Pterocarpus erinaceous*	*Fabaceae*
48	*Sterculia tragacantha*	*Fabaceae*
49	*Strychnos innocua*	*Fabaceae*
50	*Tamarindus indica*	*Fabaceae*
51	*Tectona grandis*	*Verbenaceae*
52	*Terminalia avicennoides*	*Combretaceae*
53	*Terminalia glaucescens*	*Combretaceae*
54	*Uapaka togoensis*	*Fabaceae*
55	*Vitellaria paradoxa*	*Sapotaceae*
56	*Vitex doniana*	*Lamiaceae*
57	*Ximenia americana*	*Olacaceae*
58	*Ziziphus americana*	*Rhamnaceae*
59	Others (Unidentified)	