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ANALYSIS OF CARBON STOCK DENSITY IN PROTECTED AND NON- PROTECTED AREAS OF GUINEA SAVANNA IN NIGER STATE, NIGERIA

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ABSTRACT

Quantification of carbon stock has gained major attention in international climate change mitigation and adaptation negotiations. However, poor knowledge of the quantity of carbon stock in respective ecosystems is one major challenge in estimating carbon stock in developing countries. This study is aimed at estimating and comparing carbon stock density of protected (forest reserve) and non-protected (parkland) areas of guinea savanna in Niger state. The research methodology includes field survey inventory, biometric measurements and laboratory analysis. At each of the 45 sampling plot locations, Carbon stock was measured from six pools viz above ground tree, undergrowth, dead wood, litter, root and soil. within a quadrat sampling plot 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). Soil organic carbon concentration was estimated in the laboratory using Walkley-Black method. The findings of the study revealed that in terms of carbon stock in respective pools, in both protected and non-protected areas, soil pool was the highest, followed by tree and undergrowth; while litter, dead wood and root were the least in carbon stock. The average aggregate carbon stock density in the protected area is 118.2 Mg ha^{-1} which is greater than 69.3 Mg ha^{-1} recorded in the non-protected area. It was also observed 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 study concludes that if savannas were to be protected from fire, grazing and anthropogenic disturbances, most of them would accumulate substantial carbon and the sink would be larger; with a view to mitigating climate change effect.

Keywords: Carbon stock, climate change, density, guinea savanna, mitigation

INTRODUCTION

Carbon stock implies the quantity of carbon in a given pool or pools per unit area (Pearson, *et al.*, 2005). Quantification and monitoring of carbon stock has gained major attention in international climate change mitigation and adaptation negotiations because verification and accounting of carbon stock in forest ecosystems have been recognized as potential strategies to reduce and stabilize atmospheric greenhouse gas concentrations (United Nations Framework Convention on Climate Change-UNFCCC, 2010).

The international concern with carbon emissions and sequestration assessments require adequate coverage of locally quantified carbon stocks (Inter Governmental Panel on Climate Change- IPCC, 2006). However, several authors (Brown and Lugo, 1992; Chidumayo, 2002; Salis *et al.*, 2006; Williams *et al.*, 2008; Lewis *et al.*, 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 *et al.* (2009) noted that very few information on carbon stock are available for the tropical forests and the 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 savanna biome is characterized by co-dominance of trees and grasses, but ranges from grasslands where trees are virtually absent to more forest-like woodland ecosystems (Guinea Savanna) where trees are dominant (Pullan, 1974). A protected area is defined by International Union for Conservation of Nature - IUCN (2008) as a "clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values". The unprotected areas are parklands that are assumed to have similar environmental conditions but are rather not protected by status. Parklands are defined as landscapes in which mature trees occur scattered in cultivated or recently fallowed fields (Pullan, 1974).

Fire, logging, shifting cultivation and grazing in the savannas substantially reduce the stock of carbon. Conversely, protection from fire, deforestation and grazing causes these savannas to become closed canopy woodlands with accumulated high carbon stock.

The aim of the study is to quantify and compare carbon stock density of plant communities in the protected Kpashimi Forest Reserve and non-protected adjoining parkland area of guinea savanna in Niger state. Due to the shortfall of carbon stock research for ecological landscapes in Nigeria, it is logical that this gap in knowledge be bridged particularly for the savanna ecological areas characterized by heterogeneous plant communities.

CONCEPTUAL FRAMEWORK

The key ecosystem variable that determines carbon stock in a forest is the Net Primary Production -NPP (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 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 R_a (Malhi *et al.,* 2011). The classic model for the net primary production of ecosystem is given by equation 1

GPP (g C/m²/yr) = *NPP* (g C/m²/yr) + R_a(g C/m²/yr)………………(eq. 1)

Thus, the quantity of carbon stock can be estimated as equation 2

NPP (g C/m²/yr) = *GPP* (g C/m²/yr) - R_a(g C/m²/yr)………………(eq. 2)

MATERIALS AND METHODS

Study Site

The study area is located between latitude 8° 40′ to 8° 52′ North and 6° 39′ to 6° 49′ East covering approximately 213.101 kilometres square (Figure 1). It is characterized by alternating wet and dry season climate coded as 'Aw' by Koppen's classification. The mean annual rainfall is about 1,400 mm with mean annual temperature of about 28°C (Ojo, 1977). The geology of the study area is made up of cretaceous sedimentary rocks underlain by the Precambrian basement complex rocks (Forest Management Evaluation and Co-ordinating Unit -FORMECU, 1994). Phytogeographically, the study area lies within the southern Guinea savannah zone classified as woodland savannah vegetation with the understory dominated by annual grasses (Keay, 1953).

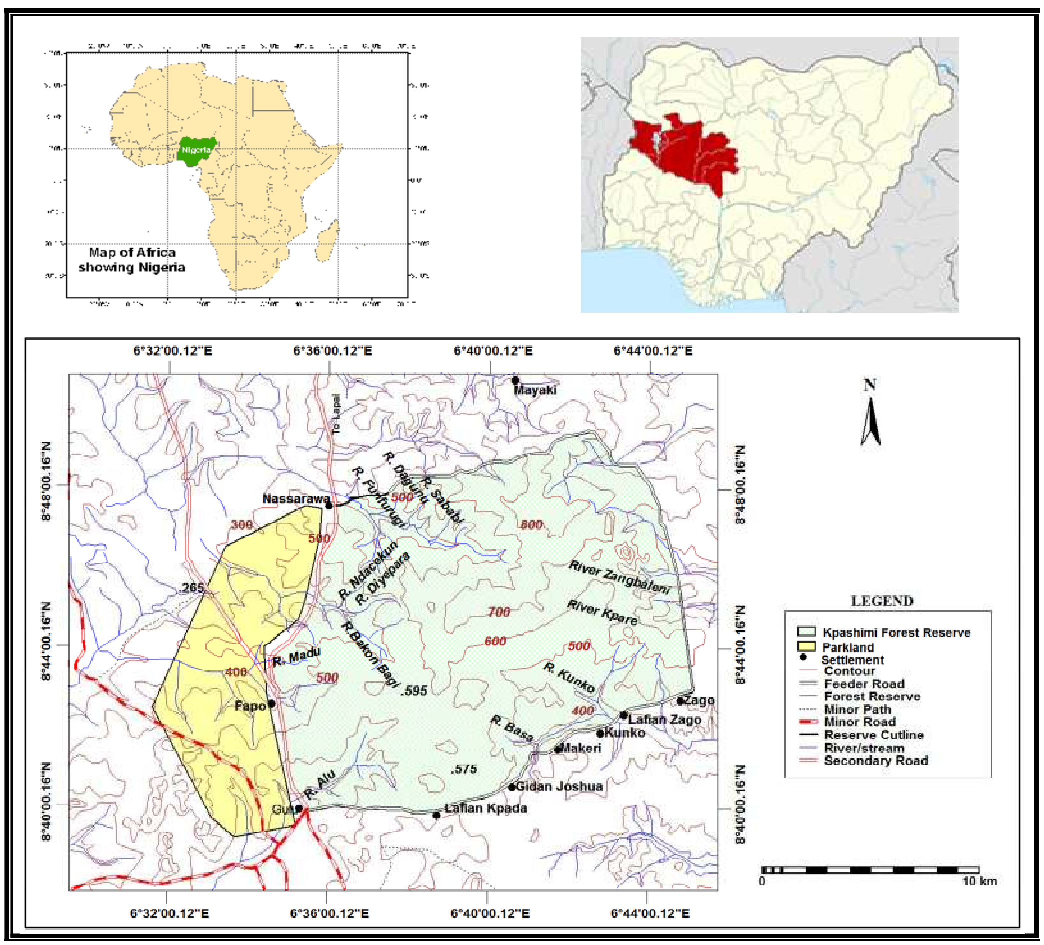

Figure 1: Geographical location of study area

MATERIALS AND METHODS

The research methodology featured field survey sampling, morphometric measurements and laboratory analysis. Reconnaissance survey was conducted at the preparatory stage and was followed by a pilot survey; for the determination of sampling frame. The detailed fieldwork for the project took place from September to October, 2015. A total of 45 sampling units (n) was determined for the study based on calculations using the formula. Figure 2 shows the sample plots layout covering the entire study area.

$$n = \frac{CV^2\, t^2}{E^2} \qquad \text{(Philip, 1994)}$$

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.

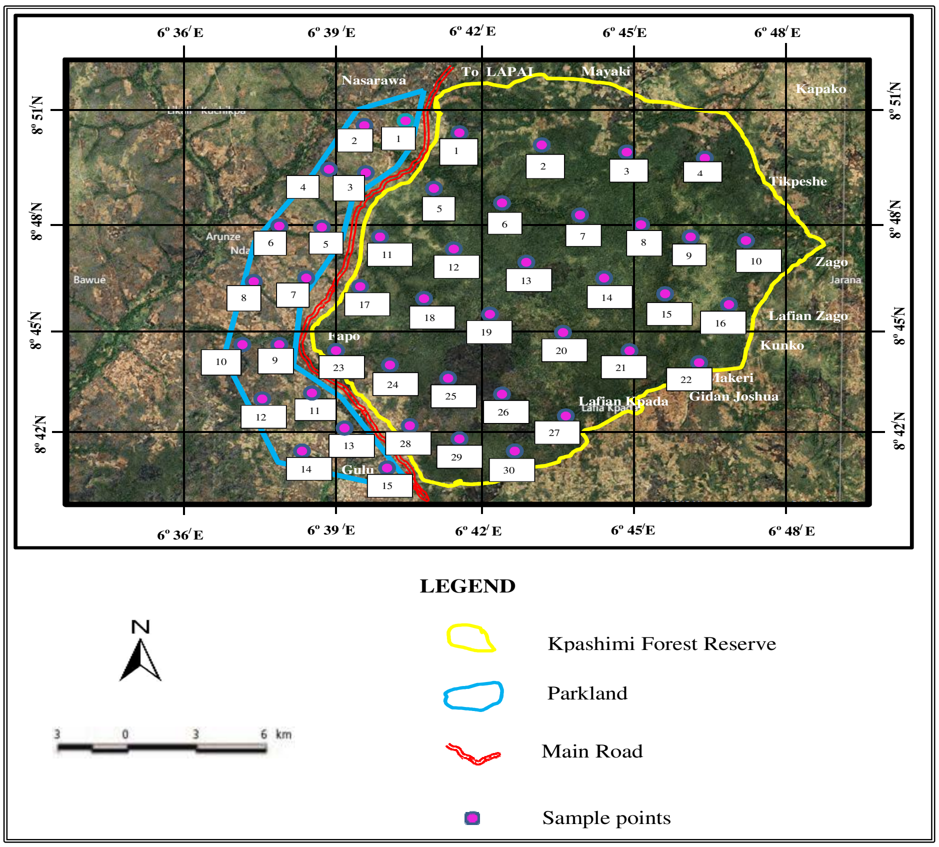

Figure 2: Location of Sample plot over the study area

At each of the 45 sampling plot locations, Carbon stock was measured from six pools namely above ground tree, undergrowth, dead wood, litter, root and soil. within a quadrat sampling plot 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). Soil organic carbon concentration was estimated in the laboratory using Walkley-Black method. Measurement of carbon in the respective pools was carried out based on the techniques presented in table 1.

TABLE 1: Carbon Pool measurement techniques

S. No	Pool	Method	Source
1.	Above ground tree	Phytomass sampling / allometry model	Walker *et al* (2012)
2.	Below ground tree Root	Allometry model	Pearson *et al* (2005)
3.	Undergrowth	Clip plot method	MacDicken, (1997)
4.	Dead wood	Line transect method	Walker *et al* (2012)
5.	Litter	Clip plot method	Pearson *et al* (2005)
6.	Soil	Soil core / Laboratory analysis	MacDicken (1997)

All laboratory analysis were carried out at the Soil Science Laboratory, School of Agriculture and Agricultural Technology, Federal University of Technology, Minna, Niger State. Both descriptive and inferential statistics were used for data analysis. The descriptive statistics used to summarize the data include average mean, standard deviation, standard error, percentage, minimum and maximum values. The student's *t* –test was used to test for differences in carbon stock at 0.001 significant level.

RESULTS AND DISCUSSION

The carbon stock density in the respective pools is presented in Table 2. It 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 2: 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	Forest Reserve	30	93.99	139.98	118.19	9.40
Stock (Mg ha^{-1})	Parkland	15	56.51	79.81	69.33	5.92

Source: Fieldwork, 2015

Comparatively, 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.

Data analysis of the mean carbon stock in the respective pools shows that the amount of carbon stock in respective pools in decreasing order of quantity within the forest reserve are soil > tree > undergrowth > litter > dead wood > root. Comparatively, the decreasing order of quantity in the parkland are soil > undergrowth > tree > litter > root > dead wood >. It can be observed that 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. The percentage distribution of the mean carbon stock in the respective pools is illustrated in figure 3.

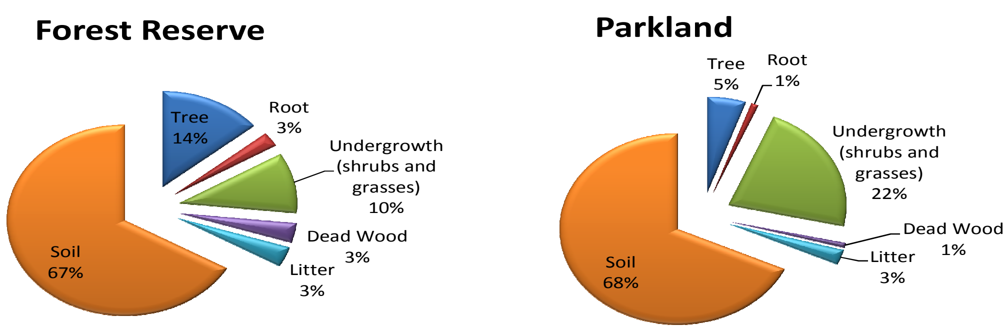

Figure 3: Distribution of the mean carbon stock in the respective pools
Source: Fieldwork, 2015

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. 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 is significant difference in carbon stock density between the forest reserve and parkland study sites where t (43) = 18.34, p < 0.001). The higher organic carbon content of the forest reserve reflects a high organic matter turn over and fewer disturbances through tillage and harvesting operations. 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).

Findings presented on carbon stock density (in pools and site) shows 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 (1992), 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.

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*., 2008; 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 sites tend to 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, 1995; 1998; Lal, 2002; Anikwe *et al*., 2003), the higher organic carbon content of the forest reserve reflects a high organic matter turn over due to conservation and fewer disturbances through tillage and harvesting operations (Jaiyeoba, 1995). It is noteworthy that bush burning, logging, harvesting of Non Timber Forest Products, shifting cultivation and grazing in the savannas substantially reduce carbon stock (Jibrin, 2013; Jibrin, 2017), and determine the species composition to a large extent (Jibrin and Jaiyeoba, 2013). However, where there is effective protection from fire, deforestation and grazing these areas could become savanna woodland forests having high biomass density; with substantial carbon stock (Grace *et al* 2006; Jibrin *et al.,* 2014). The carbon stock in forest ecosystems thus 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). On the other hand, 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 (Jibrin, 2016). In view of the foregoing analysis, the carbon stock density would vary between protected areas and non-protected areas in any ecological landscape. The degree of such variation will only be determined by whether there is significant differences or not; as shown in this study.

CONCLUSION AND RECOMMENDATION

In conclusion, this study reveals that there is statistically significant difference in the spatial distribution of carbon stock over the study area; particularly between the protected and non-protected areas. Considering the degradation status of the vegetation in the non-protected areas, apparently, there is tremendous capacity for the study area to store carbon and act as carbon sink if properly managed by protection. This study thus provides more accurate and reliable estimate of carbon stock in the study area; which eliminates the problem of uncertainties associated with biome average estimates. It also provides a benchmark against which future estimates of carbon stock can be compared, and sets a baseline for calculating changes in carbon stocks over time. This study suggests that forestry based carbon offset projects can be effective in mitigating global carbon emissions from deforestation and forest degradation in the study area. In view of the observed potentials of carbon sequestration capacity in the study area, this study recommends the need for defining a concrete community based sustainable forest management such as carbon offset trading by local communities 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).

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Authors' Contribution

The entire research work was planned and executed by Jibrin, A., under the supervision of Prof. Jaiyeoba, I.A. and Prof. Oladipo, E.O; who both contributed immensely in the design of methodology and provided inputs in the analysis of data. ,

Conflict of Interest

There is no conflict of interest among the authors.

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