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CARBON SEQUESTRATION POTENTIAL OF KPASHIMI FOREST RESERVE, NIGER STATE, NIGERIA

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ABSTRACT

This study provides a preliminary assessment of the biophysical potential for carbon sequestration. Quantification of carbon stock and estimation of carbon sequestration potential was carried out in the Kpashimi Forest Reserve, Niger state, Nigeria. Carbon stock was measured in the six vegetation communities existing in the study area. Forty-eight randomly selected 20 x 20 metre quadrats were established wherein data was collected from the main forest carbon pools; including above ground tree, below ground root, undergrowth (shrub grasses), dead wood, litter and soil organic carbon. Biomass of the respective pools was quantified by destructive sampling and use of allometric equations. Thereafter, biomass values were converted to carbon stock equivalent. Four satellite imageries TM, SPOT, ETM+, and NIGERIASAT-1 of 1987, 1994, 2001 and 2007 respectively were used to estimate vegetation cover and carbon stock change over 20 years. The results showed that average carbon stock density (Mg C/ha) of the vegetation communities was in the decreasing order; Riparian forest (123.58 ± 9.1), Savanna woodland (97.71 ± 8.2), Degraded forest (62.92 ± 6.1), Scrubland (36.28 ± 4.1), Grassland (18.22 ± 5.1), and bare surface (9.31 ± 3.1). Deforestation and forest degradation between 1987 and 2007 have resulted in emission of 240.2 Mg (ton) C ha^{-1} at an annual rate of 12.01 Mg C ha^{-1}. This suggests that the study site has carbon sequestration potential of 240.2 Mg C ha^{-1} based on its capacity to increase carbon stock through restoration; back to speculated 1987 levels and even higher. Thus, the study recommends the need to analyse carbon offset project feasibility in the study area.

Keywords: Carbon stock, Sequestration, Forest reserve, Deforestation, Degradation, Climate change mitigation.

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Contribution/ Originality

This study contributes in the existing literature by providing a preliminary assessment of the biophysical potential for carbon sequestration. This study demonstrates that forestry based carbon offset projects have the potential to act as a climate change mitigation tool and a means of fostering sustainable forest preservation in the developing countries. This study is the first of its kind in the woodland savanna ecological zone of Niger state, Nigeria.

1. INTRODUCTION

In recent years, there is increasing concern over the effects of increasing carbon dioxide (CO_2) in the earth's atmosphere due to the burning of fossil fuels. Carbon sequestration by vegetation through photosynthesis is a major way to mitigate increase in atmospheric CO_2 concentration and climate change. As a result, quantification and monitoring of carbon stock has gained major attention in international climate change mitigation and adaptation negotiations (Houghton, 2005) (IPCC, 2006). This motivated the drive for robust, accurate and cost-effective methods for carbon stock estimation over large areas; particularly, with the launch of carbon crediting mechanisms in the developing countries such as UN-REDD. Moreover, the need for reporting carbon stock and fluxes for the Kyoto Protocol has increased the need for reliable estimation methods that are verifiable, spatially and temporally specific, and cover large areas at acceptable cost (IPCC, 2006). Due to the shortfall of the traditional ground based measurement which requires abundant manpower, resources, cost and time and inherently destructive, remote sensing techniques are required (Houghton *et al.*, 1995; Brown, 2002). The remotely sensed data, with its high correlations between spectral bands and vegetative parameters, make it most reliable primary source for large area biomass and carbon stock estimation; especially in areas of difficult access (Brown and Gaston, 1995; IPCC, 2007).

Previous research has traditionally focused on the role of ecosystems as carbon sinks, rather than as potential sources (Houghton *et al.*, 1995). Forest clearance results in emission of about 20% of total global emissions of carbon dioxide (CO_2) to the atmosphere (IPCC, 2007). Consequently, estimating forest carbon stock is of prime importance to assess the mitigation effects of forests on global warming and climate change (Brown and Gaston, 1995; Cao *et al.*, 2001). Furthermore, verification and accounting of carbon stock in forest ecosystems have been recognised as potential strategies to reduce and stabilize the atmospheric greenhouse gas concentrations (Brown, 1997; Houghton, 1997; Watson Robert *et al.*, 2000; IPCC, 2007).

Protected areas, which are designated with the primary aim of conserving biodiversity, generally constitute legal restrictions on land use change, and potentially play an important role in maintaining terrestrial carbon stocks (Clark *et al.*, 2008). It has been estimated that globally, ecosystems within protected areas store over 312 Gt carbon or 15% of the terrestrial carbon stock (Campbell *et al.*, 2008a). However, recent research indicates that whilst protected areas generally reduce deforestation relative to unprotected areas, they are not entirely free from land use change within them (Clark *et al.*, 2008). Therefore, it is pertinent to understand the extent and rate at which protected areas are affected by land use change, and the degree to which improving the effectiveness of existing protected areas could make an effective contribution to reducing emissions from deforestation and forest degradation.

Forestry based carbon offset projects have the potential to act as a climate change mitigation tool and a means of fostering sustainable forest preservation (Campbell *et al.*, 2008a; Jibrin *et al.*, 2013). While carbon sequestration has high potentials in areas with degraded savannahs, lack of localized field studies has limited the feasibility of initiating biotic carbon emissions offset projects in many of the Nigeria's threatened forests (Jibrin *et al.*, 2013). This study aims to assess carbon sequestration potential in the Kpashimi Forest Reserve. The objectives of the study includes to: (i) characterise vegetation cover changes associated with various plant communities in the forest reserve over 20 years period; (ii) quantify the carbon stock density of the forest reserve; (iii) estimate carbon stock changes in the forest reserve between 1987 and 2007; and (iv) determine the capacity for the forest reserve to sequester carbon.

(IPCC, 2003; IPCC, 2006). requires carbon stock changes to be estimated in an unbiased, transparent, and consistent manner, where uncertainties are determined and recorded over time. Nigeria became a signatory to the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, and ratified the Kyoto Protocol in 1994. Consequently, net carbon stocks in each forest type in Nigeria need to be assessed for reporting under Kyoto Protocol. Such an assessment is required by Nigeria under the UNFCCC and as a baseline for participation in the Clean Development Mechanism of the Kyoto Protocol.

The conceptual framework of the study is based on stock difference approach (IPCC, 2003). The stock difference approach implies that the total amount of carbon stored in a region is increased by increasing the area covered by a carbon dense cover type. The amount of carbon sequestered is estimated as the net change in carbon stocks over time (Iverson *et al.*, 1993). Thus, the amount of carbon sequestration is estimated as the net change in carbon stocks over time.

$$\Delta C = (C_{t2} - C_{t1}) / (t_2 - t_1)$$

Where:

ΔC = Annual carbon stock change in pool (tC/yr)

ΔC_{t1} = Carbon stock in pool at time t_1 (tC)

ΔC_{t2} = Carbon stock in pool at time t_2 (tC)

2. MATERIALS AND METHODS

2.1. Study Site

Kpashimi Forest Reserve 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). The study area lies within the tropical hinterland (tropical rainy climate with dry season) climatic belt of Nigeria; characterised by alternating wet and dry season 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). The topography is gently undulating, sloping generally towards different directions in different locations. Soils in the study area based on the CCTA (Commission de Cooperation Technique en Afrique) classification system belong to *ferruginous tropical soils*. In some depressional areas, and valley bottom positions *hydromorphic* soils are found; while those around the inselbergs and other residual hills, and at the bed of rivers, are *weakly developed* (Areola, 1978; Jaiyeoba and Essoka, 2006). The study area lies within the southern Guinea savannah zone classified as woodland savannah vegetation with the understory dominated by annual grasses (Keay, 1953; Jaiyeoba and Essoka, 2006).

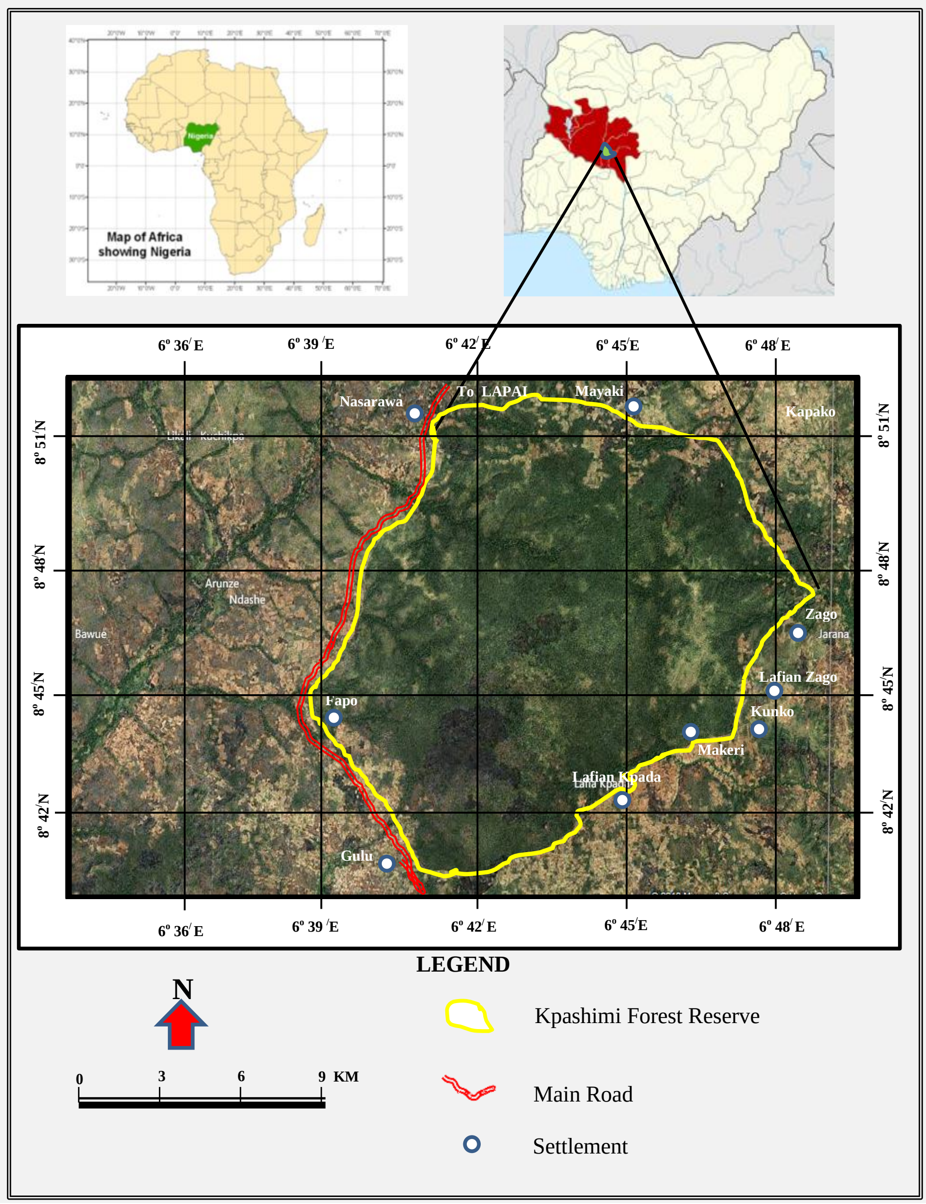

Figure 1. Map showing the location of study area

Source: Niger State Forest Management Unit.

2.2. Sampling Design

The sample size for the study was determined by the estimation of variation of tree stocking; as the variance of the dominant carbon pool captures most of the variance (Brown, 1997; MacDicken, 1997; IPCC, 2003) and Food and Agricultural Organization (2008). The field work was conducted towards the end of the rainy season; between 2nd September and 15th October, 2013. During the reconnaissance/pilot survey conducted prior to detailed field data collection, 15 randomly laid out samples plots (250 m^2) were distributed to cover all possible variation in the study area (IPCC, 2003). The mean and the standard deviation of the plot tree basal areas were calculated and the number of sampling units (n) was calculated using a standard formula (Philip, 1994):

$$n = \frac{CV^2 t^2}{E^2}$$

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 a desired precision at sampling error (E) of 10% at 95% confidence level was calculated to be 48 plots for the study area.

2.3. Vegetation Cover Classification and Change Detection

The study made use of four satellite imageries TM, SPOT, ETM+, and NIGERIASAT-1 of 1987, 1994, 2001 and 2007 respectively. Using Erdas Imagine version 9.2, the images were rectified, and transformed. Geocoding was performed using second-degree polynomial function by rotation, scale, skew and offset adjustment. Thus the images were georeferenced using the UTM map projection (Zone 32 N) World Geodetic System, 1984 datum (WGS 84) coordinates system. Image enhancement was done by selection and stacking of band 4, 3, and 2 for TM, and ETM+ and bands 3, 2, and 1 for SPOT XS and NIGERIASAT-1. This aided in eliminating redundant information due to inter band correlation (Lillesand *et al.*, 2006) and better described the vegetation biophysical characteristics derived from Visible, Near Infrared, and Mid Infrared portions of the Electro Magnetic Spectrum. Thereafter, the respective images were imported into ArcGIS 9.2 software; and classified using Maximum Likelihood Classification algorithm by the extraction of Normalised Difference Vegetation Index (NDVI) based on supervised classification (see figure 2). In the Arc GIS environment, the vegetation cover classes (savanna woodland, riparian forest, degraded forest, grassland scrubland and bare surface) were identified. Eight pixels were randomly selected from each of the vegetation classes on the imagery; and their coordinates recorded. Post classification change detection was then carried out based on the four imageries pixels per area coverage.

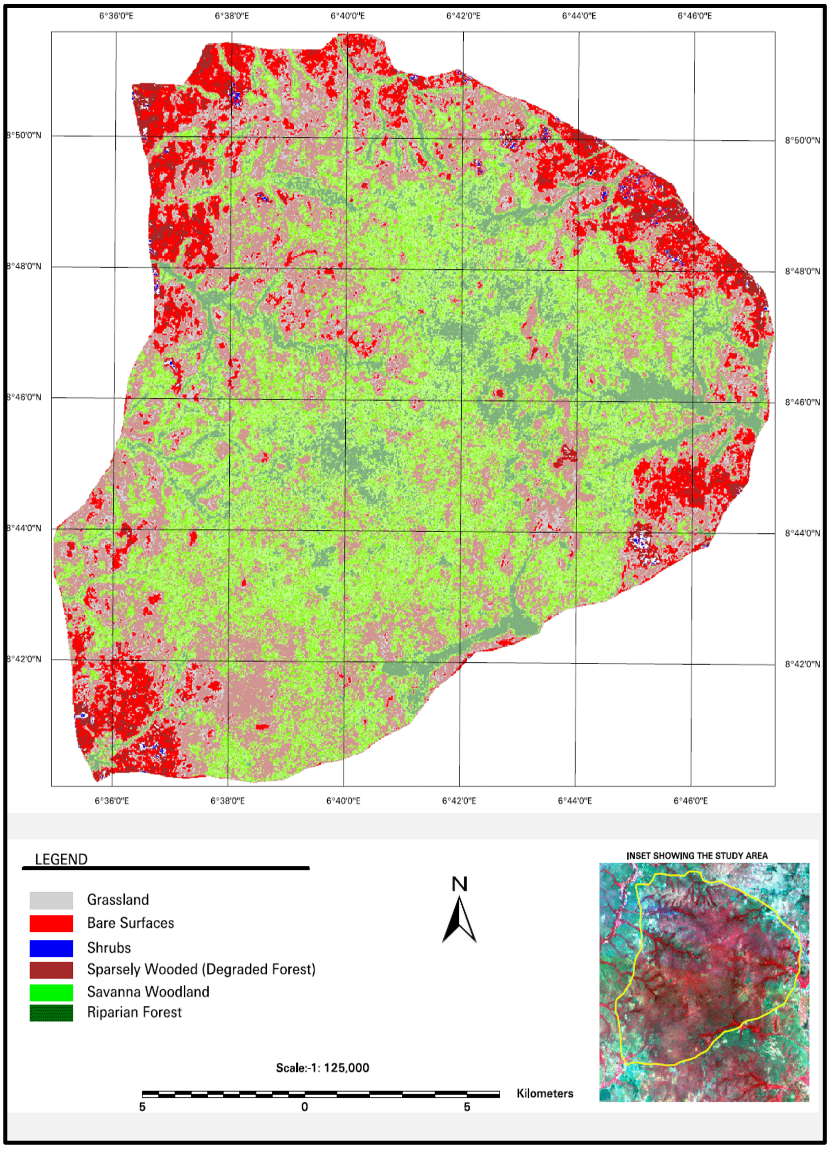

Figure-2. Classified Vegetation Cover Map, Kpashimi Forest Reserve, 2007

2.4. Field Data Collection

Carbon density was estimated based on data taken in forty-eight 20 x 20 metre sample plots from six carbon pools: live tree aboveground biomass, tree belowground biomass, coarse deadwood (≥10 cm diameter), litter, herbaceous vegetation, and soil (Brown, 1997; MacDicken, 1997).

Aboveground biomass of the individual trees was estimated from stem diameter at breast height, of 1.3 m by employing published generic allometric equation for dry topics by Brown *et al.* (1989).

$$AGB = \exp \{-1.996 + 2.32 * \mathrm{Ln}(D)$$

Where:

Ln means "natural log of (…)"

AGB = above-ground biomass in kg

DBH = diameter at breast height (1.3 m)

Belowground biomass was calculated as a proportion of aboveground biomass using an allometric equation derived for tropical trees by Cairns *et al.* (1997).

$$RBD(t/ha) = \exp\{-1.0587 + 0.8836 \text{ x } \ln (AGB\ t/ha)\}$$

Where:

RBD = Root biomass density in tons/hectare (t/ha)

AGB = above-ground biomass density in tons per hectare (t/ha)

Dead wood biomass was estimated using the line-intersect method (IPCC, 2003), following the procedures of Harmon and Sexton (1996). The volume per hectare was estimated for each density class as follov

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

Where: $d1, d2, \ldots, dn$ = Diameters of intersecting pieces of dead wood (cm);

L = Length of the line; meters

Finally, the biomass of dead wood was calculated by the formula:

$$AGB_{WD}=\rho V*_{WD}$$

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)

Clip plots were used to measure understory vegetation and litter biomass (MacDicken, 1997). For the analysis of moisture content, all sub samples (undergrowth, dead wood and litter) collected from the field were transported to the laboratory, and each sample was oven dried at 85 °C constant-temperature. After drying, conversion ratios between the oven-dry and fresh weights were calculated using the formula below:

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

where,

DW_W : whole dry weight

DW_S : dry weight of sample

FW_W : whole fresh weight

FW_S : fresh weight of sample

Soils were sampled in the same subplots as herbaceous vegetation and litter. After the vegetation and litter was removed, soil samples were subsequently collected from the depth of 0 to 15 cm and 16 to 30 cm within the quadrats, air dried and sieved through 2.0 mm mesh. Soil organic C was analysed in the laboratory by Walkley and Black (1934) method. The bulk density was determined from undisturbed oven-dried core samples at 105°C. Soil C per hectare was calculated from the organic C content and the bulk density using equation:

$$SOC = [SOC] \times BD \times Depth \times 10$$

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)

Average carbon density estimates for the sampled vegetation communities were calculated by aggregating contributions from all measured carbon pools. It was assumed that 50% of vegetative biomass was carbon and carbon stock is converted to *Mg* CO_2 equivalent by multiplying by 3.67 (the value of 3.67 reflects the ratio of molecular weights between carbon [12] and carbon dioxide [44]) (MacDicken, 1997; IPCC, 2003).

3. RESULTS AND DISCUSSION

3.1. Vegetation Cover Changes

Table 1 indicates that in 1987, Savanna woodland constitutes 34% of the vegetation cover but eventually decreased to 18% in 2007. On the other hand, Degraded forest increased from 21.8% in 1987 to 32.4% in 2007. It is also evident that while the area coverage of Bare surface, Degraded forest and Scrubland are on the increase, that of the Savanna woodland and Riparian Forest were on the decline. Exceptionally, Grassland coverage experienced an increase between 1987 and 2001 but eventually declined between 2001 and 2007. It is also observable that in the last seven years of the study period (between 2001 and 2007), Riparian forest and Savanna woodland coverage increased marginally; implying that the rate of forest degradation slowed between 2001 and 2007. The observed changes could be attributed to human and climatic factors. For instance, Jibrin (2009) observed anthropogenic interference in the study area and also observed declining trend in the amount of rainfall received in the area. A sharp fall in rainfall was recorded between 1988 and 1996 this might have resulted in the shrinking of Savanna woodland and corresponding expansion of Grassland and Scrubland vegetation communities.

Table-1. Area Coverage of The Vegetation Communities Over The Examined Period

VEGETATION COMMUNITIES	**1987**		**1994**		**2001**		**2007**	
	Area(ha)	**%**	**Area(ha)**	**%**	**Area(ha)**	**%**	**Area(ha)**	**%**
Bare surface	2311.78	*10*	2441.36	*10.6*	2888.8	*12.5*	3237.84	*14*
Grassland	2247.18	*9.7*	3787.73	*16.4*	4753.58	*20.6*	2623.48	*11.3*
Scrubland	2467.03	*10.7*	2115.23	*9.1*	2075.35	*9*	2971.76	*12.8*
Degraded Forest	5032.32	*21.8*	6007.11	*26*	7356.85	*31.8*	7480.38	*32.4*
Savanna Woodland	7930.3	*34.3*	6266.58	*27.1*	3845.02	*16.6*	4148.28	*18*
Riparian Forest	3132.44	*13.5*	2503.04	*10.8*	2201.45	*9.5*	2659.31	*11.5*
TOTAL	23121.05	*100*	23121.05	*100*	23121.05	*100*	23121.05	*100*

As illustrated in figure 3, it is obvious that while Degraded forest, Bare surface and Scrubland increased between 1987 and 2001, Savanna woodland and Riparian forest experienced decrease in area coverage. Savanna woodland recorded the highest change by 47.7%, followed by Riparian forest 15.1%. Consequently, deforestation and forest degradation in the study area could have resulted in much carbon emission over the period under study.

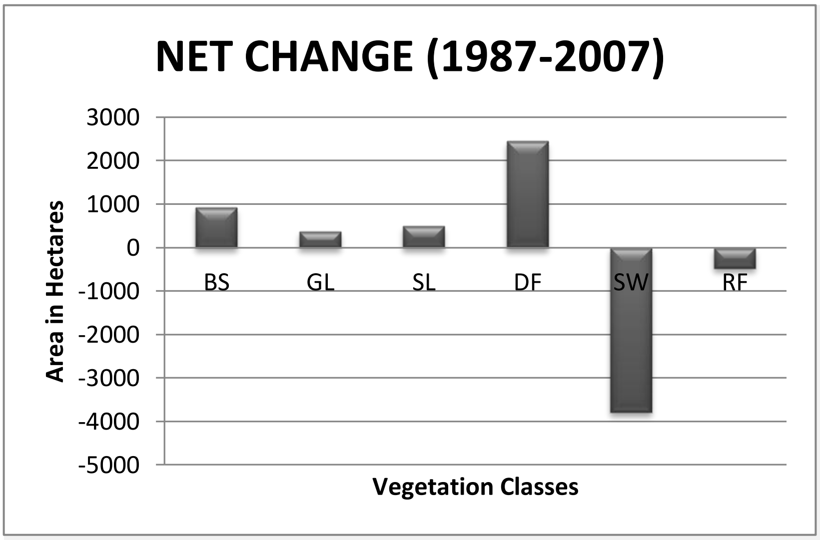

Figure -3. Net Change between 1987 and 2007

3.2. Carbon Stock in Pools

Analysis of Carbon stock in the respective pools shows that the soil carbon pool dominates with highest stock values across the vegetation communities; while the least stock values were recorded for the litter pool. Average carbon stock density of the vegetation communities was in the decreasing order; (see Table 2) Riparian forest (123.58 ± 9.1), Savanna woodland (97.71 ± 8.2), Degraded forest (62.92 ± 6.1), Scrubland (36.28 ± 4.1), Grassland (18.22 ± 5.1), and bare surface (9.31 ± 3.1).

Table-2. Mean carbon stock in Pools across vegetation communities (Mg C ha^{-1})

Carbon pools	Savanna Woodland		Riparian Forest		Degraded Forest		Scrubland		Grassland		Bare Surface	
Tree	19.83	± 6.5	25.08	± 8.5	12.77	± 6.5	7.36	± 4.5	3.70	± 2.3	1.89	± 0.8.5
Root	8.01	± 2.6	10.13	± 3.6	5.16	± 1.6	2.97	± 0.6	1.49	± 0.5	0.76	± 0.6
Under Growth	2.62	± 1.6	3.31	± 1.9	1.69	± 0.8	0.97	± 0.8	0.49	± 0.8	0.25	± 0.1
Dead Wood	3.27	± 1.0	4.14	± 1.5	2.11	± 0.9	1.21	± 0.7	0.61	± 0.4	0.31	± 0.2
Litter	2.55	± 0.7	3.23	± 2.7	1.64	± 0.7	0.95	± 0.5	0.48	± 0.9	0.24	± 0.1
Soil	61.43	± 6.1	77.70	± 8.1	39.56	± 7.1	22.81	± 3.7	11.45	± 3.1	5.85	± 2.1
Total	97.71	± 8.2	123.58	± 9.1	62.92	± 6.1	36.28	± 4.1	18.22	± 5.1	9.31	± 3.1

Note: ± is the Standard Error of the Mean

3.3. Changes in Carbon Stock Density and Sequestration Potential

Extrapolation of the mean carbon density in the year 2007 yielded an approximate total carbon storage of 1390.4 Mg (ton) C ha^{-1}; which is comparatively lower than the baseline of 1630.6 Mg C ha^{-1} in 1987 (see table 3). This suggests incidence of carbon loss due principally to emission from deforestation and forest degradation. A total loss of 240.2 Mg C ha^{-1} was incurred at an annual rate of 12.01 Mg C ha^{-1}.

Table-3. Change in carbon stock Mg C ha^{-1} (t C ha^{-1})

Vegetation Communities	Mean Carbon Stock (Mg ha^{-1})	Area (Hectare)		Carbon Stock		
		1987	**2007**	**1987**	**2007**	**Change**
Savanna Woodland	97.71	7930.3	4148.28	774.9	405.3	-369.5
Riparian Forest	123.58	3132.44	2659.31	387.1	328.6	-58.5
Degraded Forest	62.92	5032.32	7480.38	316.6	470.7	+154.0
Scrubland	36.28	2467.03	2971.76	89.5	107.8	+18.3
Grassland	18.22	2247.18	2623.48	40.9	47.8	+6.9
Bare Surface	9.31	2311.78	3237.84	21.5	30.1	+8.6
Total				1630.6	1390.4	-240.2

As presented in table 3, vegetation cover changes between 1987 and 2007 resulted in loss of 240.2 Mg C ha^{-1} in the forest reserve; which is equivalent to emission of 881.5 Mg of CO$_2$ per hectare at an annual rate of 12.01 Mg C ha^{-1} or 44 Mg of CO$_2$ per hectare. Based on the theory of "the stock-difference approach," in which the total amount of carbon stored in a region is increased by increasing the area covered by a carbon dense cover type, the regeneration of proportionate hectares of forest reserve would result in sequestration of same 240.2 Mg C ha^{-1}; which indicates the carbon sequestration capacity of the reserve at 12.01 Mg C ha^{-1} per anum.

A comparative analysis of the carbon sequestration capacity rate of the Kpashimi Forest Reserve which indicates 12.01 Mg C ha^{-1} (12.01 t C ha^{-1}) year $^{-1}$ shows it is higher than 6.4 t ha^{-1} year $^{-1}$ and 8.1t C ha^{-1} year $^{-1}$ found in Open shrub savannah of Lamto, Cote d'Ivoire and Dense shrub savanna of Lamto, Cote d'Ivoire respectively (Mordelet and Menaut, 1995); 7.6 t C ha^{-1} year $^{-1}$ in the Woodlands of Orinoco Lanos, Venezuela (San Jose and Montes, 2001); 6.2 t C ha^{-1} year $^{-1}$ Grass savannah of Nairobi National Park, Kenya, (Long *et al.*, 1989). However it is close to carbon sequestration rate of 12.2 t C ha^{-1} year $^{-1}$ recorded in the Savanna woodland of Sambalpur, India; but lower than 22.8 t C ha^{-1} year $^{-1}$ found in Savanna woodland of Varanasi, lowland, India; and 18 t C ha^{-1} year $^{-1}$ in the Savanna woodland of Varanasi, upland, India (Singh *et al.*, 1985). World over, carbon sequestration capacity shows considerable variation depending upon the type of savanna system, although most of the higher values are from India, at sites where the savanna is largely a degraded form of sub-humid rain forest (Singh *et al.*, 1985).

Finding from this study is in line with Grace *et al.* (2006) that found carbon sequestration rate (net ecosystem productivity) in tropical savanna ecosystems which ranges from 1 to 12 t C ha^{-1} year $^{-1}$. Furthermore they revealed that, the lower values are found in the arid and semi-arid savannas occurring in extensive regions of Africa, Australia and South America; while the global average of the cases reviewed was 7.2 t C ha^{-1} year $^{-1}$.

In addition, findings from this study also confirm previous research (Clark *et al.*, 2008; Campbell *et al.*, 2008a; Campbell *et al.*, 2008b) which indicate that whilst protected areas generally reduce deforestation relative to unprotected areas, they do not entirely eliminate carbon stock change within them. Thus, conservation effectiveness in the study area needs to be strengthened.

Above all, this study illustrates that forestry based carbon offset projects can be effective in mitigating global carbon emissions from deforestation and forest degradation. However, since every individual project is implemented on a local scale, local factors would inevitably determine its success or failure (Brown, 1997; Houghton, 1997; Watson Robert *et al.*, 2000). For instance, Jibrin *et al.* (2013) posited that sustainable carbon offset projects depends not only the biophysical potential of an area to sequester more carbon, but also on the project's ability to account for the needs of the area's inhabitants and other stakeholders.

4. SUMMARY, CONCLUSION AND RECOMMENDATIONS

Analysis of vegetation cover dynamics revealed that Degraded forest, Bare surface and Scrubland expanded between 1987 and 2007 while Savanna woodland and Riparian forest experienced reduction by 47.7%, and 15.1% respectively. Analysis of Carbon stock in the respective plant communities indicates riparian has the highest carbon stock density (Mg C ha^{-1}) while carbon stock in pools shows that the soil carbon pool dominates with highest stock values across the vegetation communities. Vegetation cover changes between 1987 and 2007 resulted in decrease of 240.2 Mg C ha^{-1} in the forest reserve; which is equivalent to emission of 881.5 Mg of CO_2 per hectare at an annual rate of 44 Mg CO_2 per hectare. The implication of the findings in this study is that there are potentials for further carbon sequestration in the Kpashimi forest reserve as a "carbon sink" area.

This study recommends the need to analyse carbon offset project feasibility in the study area and to make it enough flexible to adapt to the regional, national and local constraints. There is a need to increase the sample size of destructively sampled trees to cover more species. Moreover, there is a need for temporal periodic studies to understand carbon stock dynamics in the study area. These require further detailed assessment to evaluate carbon stock dynamics on the woodland. Consequently, predicting forest carbon stocks requires an understanding of the factors that control the potential biomass at a site and the expected rate of carbon accumulation on sites recovering from disturbance. Further research is also required to demonstrate the feasibility of large area measurement schemes because there are technical challenges of measuring changes in above and belowground carbon stocks over large areas in savannas; with the required accuracy. Due to the limitations associated with optical imageries in biomass assessment (as employed in this study), rader imageries are rather recommended for further studies.

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