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Research article

Quantification of the effect of agriculture on forest carbon stock: Case study of a Nigerian forest reserve

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Abstract: The competition for land between forest and agriculture has been a long-time issue. The tropical forest has been greatly reducing due to agricultural activities. There are few studies on the quantification of forest carbon stock loss caused by encroaching agricultural activities. Therefore, this study compared the biomass in the areas encroached by farming activities and forested areas; and also analyzed the forest cover change in Cross River South Forest Reserve, Nigeria. Data were obtained through forest inventory and satellite imageries. Eight sample plots of 0.25 ha were used (plots were laid in the forested and the encroached parts of the reserve). Established allometric equation was used to estimate the biomass. Satellite images from Landsat between 2002 and 2017 were used for the forest cover change. The results showed that there is a significant difference in the mean aboveground carbon density of the forested part (108.6571 tC ha^{-1}) and the encroached part (44.1567 tC ha^{-1}) of the reserve. The forest cover change of Forest Reserve showed that about 6,750 ha was deforested within the period with an annual rate of forest cover loss of 0.54%. It was concluded that the farming activities have negatively impacted the quantity of carbon stock of the forest reserve.

Keywords: Carbon stock - Forest cover change - Encroachment - Agriculture.

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INTRODUCTION

Forest and agriculture are two major land use types that compete with each other from time immemorial. The forest is usually seen as a reservoir of land to be pounced on when the lands used for the agricultural purpose are no longer fertile. In Africa, Nigeria was identified to have the greatest net loss of forest area between 2010 and 2015 which was estimated to be 410,000 ha yr^{-1} (Keenan *et al*. 2015). Deforestation and degradation of tropical forest account for 12±6 % of the total emission of CO_2 in 2008 (Van der Werf *et al*. 2009). Kumar *et al*. (2010) stated that agriculture is the proximate driver of about 80% of deforestation worldwide. According to Geist & Lambin (2002), commercial agriculture contributes about 35% of the deforestation in Africa while local and subsistence agriculture contribute between 27–40 % of the deforestation. The population growth which has also been on the increase at an exponential rate as a result, demand for food has also increased. Amongst the essential needs of man, food falls in the first category of these needs. Thus, the quest for satisfying this need makes people encroach the forest to cultivate their food crops. According to Minnen *et al.* (2008), there have been projections that most of the agricultural expansion will be in the tropics. The forest is also very vulnerable because of the low economic value placed on them particularly in the developing countries. Not until recently when programmes such as Clean Development Mechanism (CDM), Reducing Emissions from Deforestation and forest degradation (REDD+) were initiated to pay for the environmental service like carbon sequestration that the forest provides, that the forest began to increase in value. Programme like REDD+ is characterized with its financial incentive for conserving carbon in the forest (Ramananantoandro *et al.* 2015).

The importance of carbon sequestration by the forest cannot be underestimated amongst the services provided by the forest ecosystem (Thorsen *et al*. 2014). The ecological outcome of deforestation and forest degradation caused by agricultural activities include reduction in canopy cover, forest quality, structure, composition, productive capacity of the forest, loss of biodiversity and so on (Laestadius *et al*. 2011). The

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negative impact of deforestation and forest degradation on climate cannot be overemphasized as developing countries account for 5.8 Gigatonne CO_2 emissions per year through deforestation and forest degradation (UNFCCC 2007). The per hectare changes in carbon stocks due to land-use change account for half of the estimates of the global carbon flux (Houghton & Goodale 2004). Shifting cultivation involves clearing forest for cultivating agricultural crops for a period, abandoned and moving on to clear another area of the forest. This often causes degradation of land as the fallow period are shortened due to land scarcity. It has been identified as a carbon source in the tropics emitting about 0.22 Pg C yr^{-1} (Houghton & Goodale 2004).

In Nigeria, there are few studies that provide information on the quantification of the loss of carbon stock of forest due to encroaching agricultural activities. However, this is important for proper forest management planning and policy-making particularly for programmes such as REDD+. Therefore, the objectives of the study were to compare the biomass in the areas encroached by farming activities and the forest areas of the forest reserve and also to analyze the forest cover change between the period of fifteen years (2002–2017).

METHODOLOGY

Study area

This study was carried out in Cross River South Forest Reserve, Cross River state, Nigeria. Cross River South Forest Reserve (CRS FR) was gazetted in 1956 (Fig. 1). The reserve lies in the rainforest region of the state. The forest is a rich rainforest but has been observed to be reducing in size from 52,630 ha in 1991 to 50,432 ha in 2001 (CRSFC 2001 cited by Oyebo *et al*. 2011). The climatic condition of Cross River state was described by Oates *et al*. (2007) to have an annual rainfall of 3,000 mm in the south and 2,500 mm in the north of the state. The central parts of the forest receive about 4,000 mm rainfall. Rainy season is between March and November with peaks in June/July and September. The average annual temperature is 27ºC and the mean monthly relative humidity ranges between 78% and 91% with an average of 85% (Oates *et al.* 2007).

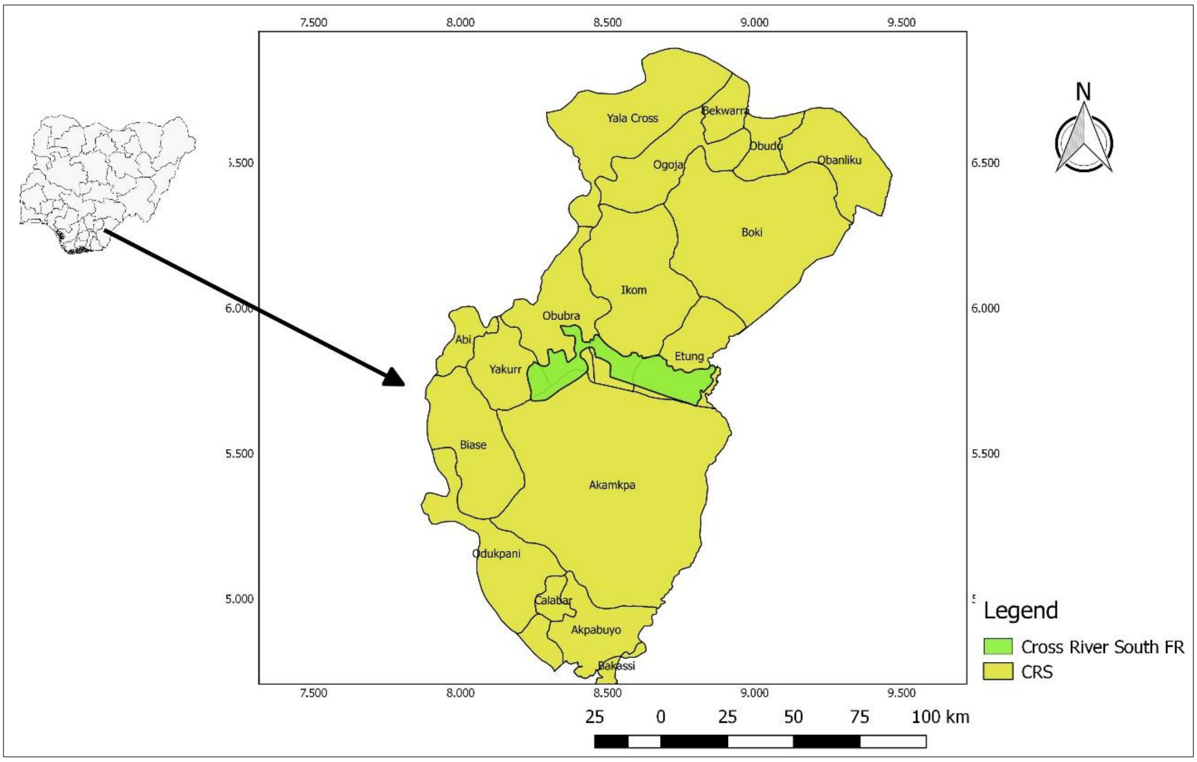

Figure 1. Map of Study Area.

Data collection

The data were obtained through forest inventory and satellite imageries. Forest inventory was carried out to collect data for estimating the aboveground biomass and also remote sensing for analyzing the forest cover change of the forest reserve.

Forest cover change

i. *Satellite Imagery Analysis:* Satellite images between the period of 2002 and 2017 were acquired from Landsat 7 and 8 respectively from U.S. Geological Survey Global Visualization (www.glovis.usgs.gov). Imageries with spatial resolution of 30 m acquired were between December and February (Dry Season) to get cloud free images as possible. Table 1 shows the attributes of the imageries acquired.

Table 1. Attributes of Landsat Imageries.

Sensor	Path/Row	Date acquired	Band Composition
Landsat 7	188/056	01/08/2003	B1 - B5
Landsat 7	187/056	01/30/2002	B1 - B5
Landsat 8	188/056	01/06/2017	B2 - B6
Landsat 8	187/056	12/30/2016	B2 - B6

Landsat 7: Blue (1), Green (2), Red (3), NIR (4) and SWIR (5)
Landsat 8: Blue (2), Green (3), Red (4), NIR (5) and SWIR (6)

The analysis was done in QGIS (version 2.18.0) and R (R Core Team 2016). Training plots were defined to determine the forest cover change between 2002 and 2017. The classes were Forest (FF *i.e.* area which was forest in 2002 and also remained as forest in 2017), Deforestation (FN *i.e.* area which was forest in 2002 and became non-forest in 2017), Regeneration (NF *i.e.* area which was non-forest in 2002 and became forest in 2017), Non-Forest (*i.e.* area which was non-forest in 2002 and also remained as non-forest in 2017), Water (W) and Cloud (C). Random-Forest algorithm by Breiman (2001) was used to carry out a supervised classification for the Forest cover change based on the Landsat bands in R. Fifteen validation plots (pixel size of 30 m × 30 m) were randomly drawn for each of the classes and cross checked with the use of Google Earth.

ii. *Rate of Forest cover change analysis*: The rate of forest cover change was calculated using the formula of FAO (2015) below:

$$\text{Rate of forest cover change} = \left(\frac{A_2}{A_1}\right)^{1/(t2-t1)} - 1 \quad (1)$$

Where, A_1 = Area of the target forest cover at date 1, A_2 = Area of the target forest cover at date 2, t1 and t2 = date 1 and date 2.

In this study, A_1, A_2 and t2-t1 are as follows:

$$A_1 = 63347.76ha + 6750.72ha = 70098.48ha$$

$$A_2 = 63347.76ha + 1254.87ha = 64602.63ha$$

$$t_1 - t_2 = 15$$

Forest Inventory

Eight sample plots of 50 m × 50 m were laid in the forest reserve. Four plots in the encroached part of the forest with farming activities and four plots were laid in the forested part of the reserve. The inventory included the identification of tree species, measurement of diameter at breast height (DBH) and total height for trees with DBH ≥ 10cm in the plots.

The wood density of all the tree species were gotten from Global wood density database (Zanne *et al*. 2009) and African wood density database except the wood density of *Treculia obovoidea* N.E.Br. which was gotten from the study of Reyes *et al*. (1992) who found out the wood densities of Tropical African trees to have a mean of 0.5 g cm^{-3}. The Above ground biomass (AGB) was computed using the below allometric equation model (Chave *et al*. 2014).

$$\text{AGB} = 0.0559 \times (\rho DBH^2 H) \quad (2)$$

Where, ρ = Wood density, DBH= Diameter at Breast Height, H= Height

According to IPCC Guidelines for calculating national greenhouse gas inventories (Eggleston 2008), Aboveground Carbon Density (ACD) was computed using the formula mentioned below:

$$\text{ACD} = AGB\ x\ 0.47 \quad (3)$$

Data were analysed using frequencies, percentages, charts and t-test. T-test was to compare the aboveground carbon density in the encroached part and the forested part.

RESULTS AND DISCUSSION

Quantification of the Carbon Stock

The stand density of the plots in the forested part of the reserve ranged between 168 and 312 trees ha^{-1} compared to the plots in the agriculture encroached part of the reserve which ranged between 60 and 148 trees ha^{-1} (Table 2). Two plots of the forested part fell within the range of 245 and 467 trees ha^{-1} recommended for the stand densities of tropical forests (Campbell *et al.* 1992).

Table 2. Basal area (m^2 ha^{-1}) and Stand densities (N ha^{-1}) per hectare of the forest and the farm.

Plot No.	Basal area (m^2 ha^{-1})	Stand densities (N ha^{-1})	State
1	23.197	312	Forest
2	15.941	252	Forest
3	14.215	168	Forest
4	17.362	212	Forest
1	3.760	136	Farm
2	8.971	60	Farm
3	8.705	144	Farm
4	10.966	148	Farm

The diameter distribution of the encroached part (Farm) of the FR (Fig. 2) shows that 65% of the trees are in the diameter class of 10–20 cm. The reason majority of trees of this class are left is because the tree crowns are not so big to cast shade on the crops the farmers have planted. In the forested part (Fig. 3), less than 50% of the trees are in the diameter class of 10–20 cm and 40.4% fell in 20–40 cm diameter class. The prominent inverse J-shape of the diameter distribution curve of the forested part of the FR is an exact representative how a natural forest should be. However, both the forest part and the encroached part of the FR have high regeneration potential. According to the study of Baishya *et al.* (2009), the FR has potential for high carbon sequestration because of the presence of large number of trees in the small DBH classes.

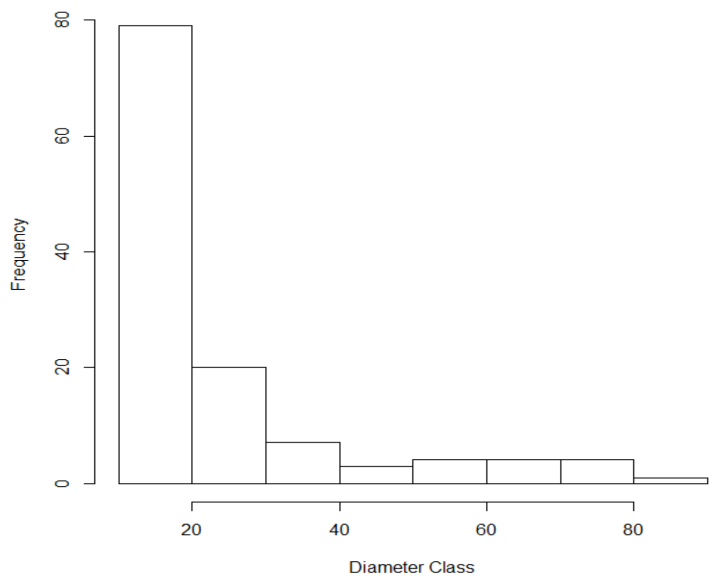

Figure 2. Diameter distribution of the Encroached part of the FR

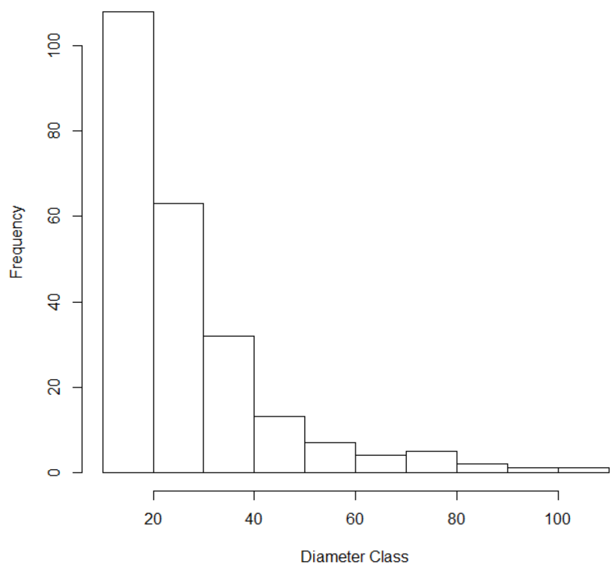

Figure 3. Diameter distribution of the forested part of the FR

The Aboveground Carbon Density (ACD) of the forest and farm depicts that the minimum and maximum ACD estimated in the forest and farm plots are (80.01 and 138.20 tC ha^{-1}) and (8.802 and 58.930 tC ha^{-1}), respectively (Fig. 4). The mean values of the forested part (forest) and the encroached part (farm) of the forest were 108.6571 and 44.1567 tC ha^{-1}, respectively. Comparing their mean values using t-test, it showed that there is a significant difference in the ACD with a p-value of 0.0126. Comparing the carbon in the forested part and the farm of the reserve, the difference between the mean value of the carbon stock is large (64.5 tC ha^{-1}). Although the ACD of the forested area is still quite lower than the aboveground carbon density for a West African tropical forest which is about 143.35 tC ha^{-1} (Lewis *et al.* 2013). Baishya *et al.* (2009) reported the aboveground carbon density of India's natural forest to be about 153 tC ha^{-1}. This indicates a very great impact encroachment of farming activities have on the carbon stock of the forest thus contributing to the atmospheric CO_2 causing climate change.

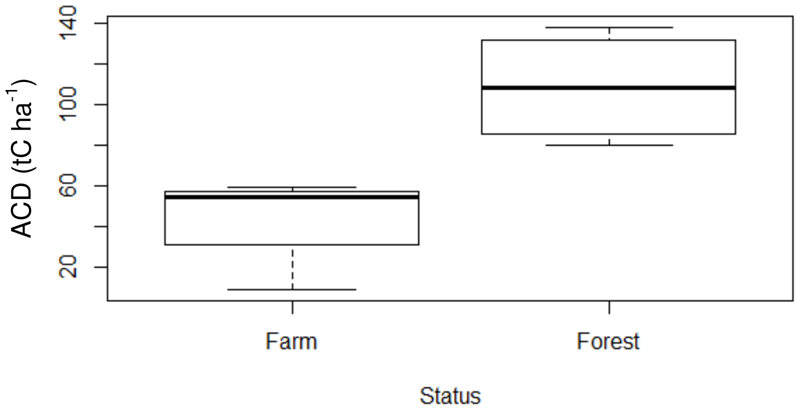

Figure 4. A boxplot of the Aboveground Carbon Density of the Forested and Encroached part of the Reserve

Although the farmers do not establish a monoculture field of arable crops, they leave some trees on the farm. This is not because of their love or the knowledge of the importance of the trees but rather their inability to cut some of these trees (cost and energy). Most of these farmers set the trees on fire to kill the trees before they start cultivation on land (Fig. 5). This is similar to the findings of Olarewaju *et al.* (2017), who reported that forests are being degraded by communities to support their livelihood. Jose & Bardhan (2012) reported the total estimated aboveground biomass carbon in agroforest plot was 20.8 tC ha^{-1}. This is quite lower compared to the mean value of carbon (44.1567 tC ha^{-1}) of the farm plots of this study, but the latter will result into release of more CO_2 into the atmosphere as the encroachers will still get rid of the trees by burning them. It is obvious that the difference in the basal area and ACD between the forested part and the farm is due to the farming activities which has encroached the forest reserve.

Figure 5. Woman burning a tree on the cultivated land inside the forest reserve.

Forest cover change of the Forest Reserve

The validation matrix (Table 3) was used to calculate the accuracy of the classification. The values of the specific index (figure of merit) calculated for each of the classes were: deforestation (0.61), forest (0.75), regeneration (0.87), non-forest (0.75), water (0.87) and cloud (0.67).

Cohen Kappa's statistics function was used to determine the accuracy of the classification (Kappa's value is either less than or equal to 1, where 1 corresponds to a perfect classification). The corrected accuracy (Cohen's Kappa) of 0.83 was obtained for the forest cover change to cross check if a good classification was done in this study. Overall, the corrected accuracy shows a good classification.

Table 3. Confusion matrix for validated points.

	C	FF	FN	NF	NN	W	Actual
C	10	0	0	0	0	0	10
FF	0	15	2	1	0	2	20
FN	3	0	11	0	0	0	14
NF	0	0	0	13	0	0	13
NN	2	0	2	1	15	0	20
W	0	0	0	0	0	13	13
Predicted	15	15	15	15	15	15	90

Note: C, Cloud; FF, Forest; FN, Deforestation; NF, Regeneration; NN, Non-Forest; W, Water.

The result shows that the Forest cover change between 2002 and 2017 indicates that a lot of deforestation took place in CRS FR during the fifteen-year period (Fig. 6). About 8% of the total area of CRS FR was deforested during the period (Table 3). Observation on field confirms this as there were a lot of farming activities taking place within the forest reserve. The imagery analysis showed that there were areas in the forest reserve that were not forested in 2002 but in 2017 it was obvious there was natural regeneration of about 1.6%. The areas that were forested in 2002 and still remains as forest in 2017 occupies about 78.7% of the entire area of the forest reserve area. The forest cover change of CRS FR showed that an area of about 6,750 ha was deforested between 2002 and 2017, though there was natural regeneration of about 1,250 ha (Table 4).

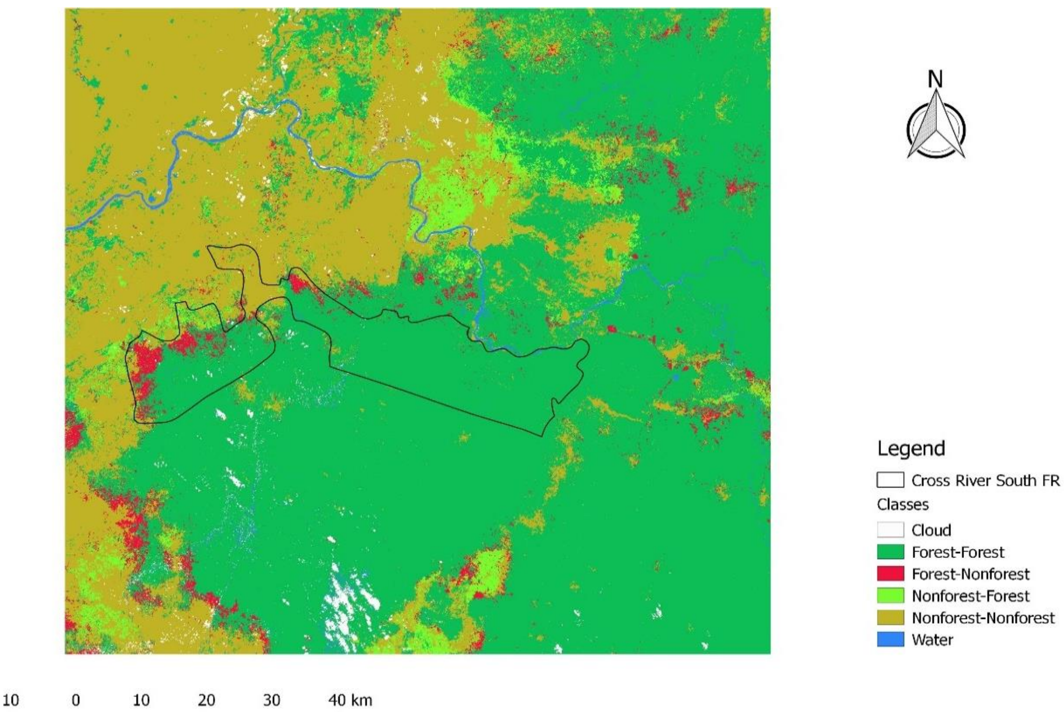

Figure 6. Forest Cover Change Map of Cross River South Forest Reserve between 2002 and 2017.

The annual rate of forest cover loss was 0.54%. This shows that in the nearest future, there would be further encroachment of farming activities in the forested area of the reserve if it is business-as-usual. Using this rate of forest cover loss to forecast, the implication is that in another 20 years' time the forest cover would decrease by 6977.08 ha or more. The rate of forest cover loss observed in this study is similar to that of India's forest cover loss which ranged between 0.2 and 0.65 (Reddy *et al*. 2017). The result is also similar to the global Gross Forest Cover Loss estimated to be 0.6% per year (Hansen *et al.* 2010). FAO (2015) reported that the global annual rate of forest cover loss to be 0.08%; this was attributed to the forest loss in the Tropics while there was forest expansion in the Temperate and Boreal regions (Sloan & Sayer 2015).

Table 4. Forest cover change of the forest reserve between 2002 and 2017.

FR	Total area (ha)	Forest (ha)	Deforested area (ha)	Regeneration (ha)
CRS	80534.07	63347.76	6750.72	1254.87

Although an indefinite moratorium on timber extraction was declared in Cross River state in 2008 (Ministry of Environment 2014), it has not been able to curtail deforestation as more of the forest are being converted for agricultural purpose in this FR. This agrees with the findings of Brandt & Agrawal (2015), who found out that some forest policies aided deforestation in the Congo basin. The findings of Suleiman *et al*. (2017) showed that the major factors causing forest cover change in Falgore game reserve, Nigeria are the increase of fuelwood harvest, overgrazing and expansion of crop cultivation. However, Ochege & Okpala-Okaka (2017) generalized that forest cover loss is as a result of human disturbance. The findings of Orimoogunje *et al*. (2009) in the study on land use changes and forest reserve management of Oluwa forest reserve Nigeria, showed that a large portion of the forest reserve is being depleted as a result of agriculture. In Southeast Asia, crop production has also been a major cause of deforestation for the past three decades (Imai *et al*. 2018). The study of Hor *et al*. (2014) in Ratanakiri Province Cambodia identified the expansion of agriculture especially swidden practice as a significant factor contributing to the decrease of forest area.

During this study, interviews were conducted to get information from the local people. The people, however, said they go mainly into the forest reserve for their farming activities because of the fertility of the forest soil. They also confirmed that the encroachment of the reserve was aggravated as a result of the early starters who did not face any penalty for their actions (moving into the forest to farm). However, population growth and poverty is another factor that also enhanced the farmers encroaching the reserve. The issue of population growth resulting to deforestation is consistent with previous studies (Imai *et al.* 2018).

CONCLUSION

Quantitative analysis of the ACD of the encroached part and the forested part of the FR showed that there is a significant difference. It can be concluded that farming activities in FR have a negative impact on the carbon stock of the forest. Also, there is a loss in the forest cover of the FR within the period of fifteen years. The continuous forest cover loss will result to release of more greenhouse gases. This means the forest will be a carbon source instead of a sink. The FR should not the neglected but should be well managed for its rich carbon stock potential as the regeneration potential in both the encroached part and the forested part is high. Thus, it is important that the state forestry department should plan for the restoration and management of this forest reserve.

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