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THE CARBON STOCKS OF TROPICAL FOREST RESERVES: AN ALLOMETRIC ANALYSIS OF OBA HILL PLANTATION, OSUN STATE, SOUTH-WEST NIGERIA

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Abstract

Forest ecosystems are significantly involved in the flow of carbon. Carbon is lost via deforestation and forest degradation, and can be sequestered at the same time by sustainable forest management. The study examined a Teak (Tectona grandis) plantation in Oba Hill Forest Reserve in Osun State Nigeria with focus on the land use pattern in the forest reserve and an estimation of the carbon content of the plantation. Using basic tools of GIS, statistically valid estimates of the percentage cover classes within the study area were created**.** The above-ground carbon content of the trees were estimated using Allometric equations having taken measurements of their diameter at breast height (DBH).The entire forest reserve covers a total of 52.9 km^2, of which 9.72 km^2still remained as natural forest, 33.8 km^2 was grassland-cultivated-deforested land and the planted forest (teak plantation) was about 9.4km^2. The plantation had an average tree density of 85 per hectare and total carbon content of 1,266.79tCO_2e at about 1.347tCO_2/ha. With a significant portion of the forest reserve already depleted and converted to cultivated land, there is a need to strengthen forest management and restore the capacity of the forest to maintain its primary role of bio-diversity conservation and climate change mitigation.

Keywords: Landuse, Carbon, Forestry, Teak

Introduction

Climate change as a concept has been promoted more rigorously in recent times in view of its implications on human existence and the need for strategies to either adapt to or mitigate it. It refers to a long term change in weather patterns of an area, and is mostly attributed to both human and natural factors. Ecosystems and climate are in a continuous loop of interactions yet feedbacks between the carbon cycle and climate has received most attention (Heimann & Reichstein, 2008).

Forest ecosystems are significantly involved in this flow of carbon, within which there is continuous exchange of carbon with the atmosphere due to both natural processes and human action. As such, the world's forests have absorbed as much as thirty percent of annual global anthropogenic carbon emissions – about the same amount as the oceans (Popoola, Aiyeloja, & Adedeji, 2012). With the current rate of degradation and the emerging threats of climate change, concerns abound as to the sufficiency of existing approaches to integrating environmental issues into economic policy development (**Schneider** and Smith, 2009; Carilla *et al.,* 2011; Adedayo *et al.,* 2013). Afforestation and reforestation activities are seen as potentially attractive mitigation strategies, as wood production and carbon sequestration and storage can be combined (Kaul *et. al.*, 2010). As much as forests act as carbon sinks, their rate of degradation makes it unrealistic to continue to rely on them to carry out this basic function.

Accurate estimation of aboveground biomass and carbon stock has gained importance in the context of the United Nations Framework Convention on Climate Change (UNFCCC), therefore in a bid to know the global status of forests and to understand the planetary carbon budget, it is imperative to generate accurate and reliable estimate of carbon stocks (Fagan and DeFries, 2009). Estimating carbon content involves assessing or calculating the carbon content of a particular carbon sink/reservoir. Estimation is carried out to know the carbon storage capacity of trees in and their contribution to climate change mitigation. The changes observed in carbon stock estimation will be of fundamental importance in accounting for carbon credits and cost-benefit ratio (Sedjo, 2001; Kohl *et al.*, 2009). Measurement of a tree biomass is done *in-situ* after calculation of the biomass of dried tree species; it involves both destructive and non-destructive methods (Pareta and Pareta, 2011).

Each ton of carbon sequestered is called carbon emission credit. Carbon credits have been suggested as a vehicle for improving the efficiency of carbon-mitigating activities. Paradigm activities have been undertaken whereby carbon credits can be obtained for protecting an existing forest in jeopardy, establishing a new forest, or undertaking procedures that reduce carbon emissions associated with timber harvests (Downie, 2007). Carbon credit entails putting carbon storage in the form of a commodity so that there can be a uniform unit of that commodity to sell. Selling carbon credits can create partnerships between forest land owners and industry, while slowing down the accumulation of carbon in the atmosphere. Carbon sequestration credits are sold to industry to offset for carbon emissions (TFF, 2007). Offsetting carbon credit is being considered for protecting forests that otherwise would be destroyed, creating new forests and reducing carbon emissions from some current practices.

Teak (*Tectona grandis Linn* F.) is an agro-forestry tree species, grown in plantation condition as an exotic species in most tropical African countries and managed for its production purposes (Ball *et. al.* 1999; Luukkanen and Appiah, 2013). Its growth survives naturally over a wide range of climatic condition, from very dry to very moist but grows well under warm and humid condition, and thrive best on well-drained alluvial soil (Kaosa-ard, 1998; Fernandez-Moya *et. al.,* 2014). Its growth (and quality) however, depends largely on some factors which include the seed quality and type, soil properties, environmental variables and management techniques (Rance*et. al.,* 2013). It is rated as a high priority species in many countries, providing both social and economic benefits, and is extensively used by many industries (especially carpentry and wood processing industries) for diverse purpose, ranging from poles to plywood (Kaosa-ard, 1998).

The dominating advantages of teak species as identified by Luukkanen and Appiah (2013) are its fast growth, tolerance to a wide range of soils and rainfall, durability, resistance to serious pest problems, fire resistance (development of thick bark), easy cultivation and domestication with superior wood and woodworking quality, amongst others. The study was therefore aimed at assessing the current land use pattern in the forest reserve and providing estimates of the above-ground carbon content of the teak plantation within it.

The Study Area

The Oba Hill Forest Reserve is situated in Osun State which is an inland state in Southwestern Nigeria, bounded by Kwara State, Ekiti State, Ondo State, Ogun State and Oyo State. It extends approximately within the coordinates $7^0 30'$and $7^0 76'$N to $4^0 30'$ and $4^0 56'$E, and has a total land area of about 9,251 km^2 (Fig 1). The state lies within the transition zone of the tropical equatorial climate of southern Nigeria. The total amount of annual rainfall is about 1200 mm and an annual mean temperature of about 21°C. The annual temperature range is about 3°C. Like other areas in southern Nigeria, the rainy seasonal regime follows the Inter-Tropical Discontinuity (ITD). The northeast trade wind brings harmattan weather during the dry season (November to March). The higher altitude of the region moderates the climate of the region to the extent that the state enjoys a relatively cooler climate than the lower surrounding regions throughout the year.

The soils in the state belong to the highly ferruginous tropical red soils associated with basement complex rocks. As a result of the dense humid forest cover in the area, the soils are generally deep and of two types, namely deep clayey soils formed on low smooth hill crest and upper slopes; and the more sandy hill wash soils on the lower slopes. The well drained clay soils of the hill crest and slopes are very important because they provide the best soils for cocoa and coffee cultivation in the state. The lighter loams are more suitable for cultivating the local food crops, such as yam, cassava and maize.

The state is covered by secondary forest and in the northern part, the derived savannah mosaic predominates. Originally, virtually all parts of the state had natural lowland tropical rainforest vegetation; but this has given way to secondary forest re-growths. Among the reasons for these are

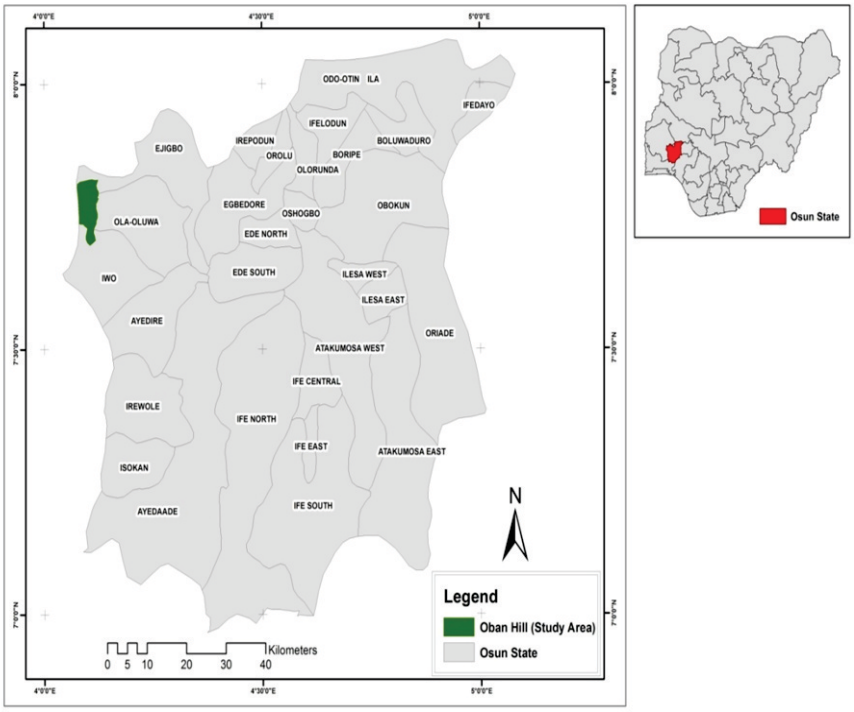

Fig.1: The Study Area

fuelwood production, road construction, clay and sand quarrying and traditional farming practices. Human interference, by way of cocoa plantation, has also replaced the forest. Hence, the natural tree species has given way to oil palm, gmelina and dense thickets. Mature forests still exist in the Owu forest reserve at the southern part of the State. Part of this high forest has recently been cleared to make way for forest plantations of *Tectona grandis* and *Gmelina arborea.*

The Oba Hill Forest Reserve is a reserve that spreads across three local government areas namely: Iwo, Ola-Oluwa and Ejigbo. It covers about 52km^2 of hilly terrain with deep gorges and lies between latitude 7^0 39′N and longitude 4^0 9′E. It is a mixture of rainforest and derived savannah vegetation. The forest reserve is among the protected areas where wildlife resources are geared towards optimum utilization and effective conservation of its resources. It is blessed with varieties of tourist attractions, the development of which is of great diverse in natural and cultural values, and had promoted the ecological tourism potential of Iwo land (Wahab *et. al.,*2014).

Material and Methods

GPS readings were taken at vital points around the plantation. These were then processed with the Landsat 8 image (191/55) and Google image acquired, coupled with the digitized topographical map of the area. Data processing and analysis were carried out using the ESRI ArcGIS 9.3 software suite. The acquired topographical map and Google image of the study area were overlain on the Osun State administrative map in order to delineate the boundary of Oba Hill Forest Reserve that falls within Osun Administrative Area; manual digitizing and NDVI were used to create statistically valid estimates of the percentage cover classes within the study area**.**

Based on different growth level/size of trees across the plantation and the 6ft uniform planting space, the area was divided into four irregular quadrats. Each quadrat was sub-divided into cells measuring 30m by 30m, 20% of which was sampled, and within each quadrat, 10% of the tree population was sampled (Table 1).

The diameter at breast height (DBH) of the trees was measured at a distance of 1.3m from the ground. The measurements collected were imputed into the conversion factor using the Allometric Equation 1 (after Olayode, Bada and Popoola*,* 2015) to estimate for the biomass of the tree and further converted to carbon content using Equation 2 (after Borah, Nath & Das*,* 2013).

Table 1: The Tree Sampling Procedures

Quadrat	Size (km^2)	Size (ha)	Total Number of Cells	Number of Sampled Cells	Total Number of Tree Population	Sampled Tree Population per Cell	Total Sampled Tree Population
Q1	2.9	290	97	19	24,832	26	494
Q2	1.8	180	60	12	15,360	26	312
Q3	1.9	190	63	13	16,128	26	338
Q4	2.8	280	93	19	23,808	26	494

Source: Field Surveys and Calculation

lnB = 2.56 + 0.04DBH..................*(1)*

Where:

lnB = Natural logarithm of Biomas

DBH = Diameter at Breast Height (cm)

Carbon Content = 0.5 x Biomass .... *(2)*

Results and Discussion

Land Use-Land Cover Analysis

The entire forest reserve had a land mass total of 52.9 km^2, of which natural forests occupied about 9.72 km^2, grassland-cultivated-deforested lands covered about 33.8 km^2, and the planted forest (teak plantation) was about 9.4km^2 (Fig. 2 and Table 2).

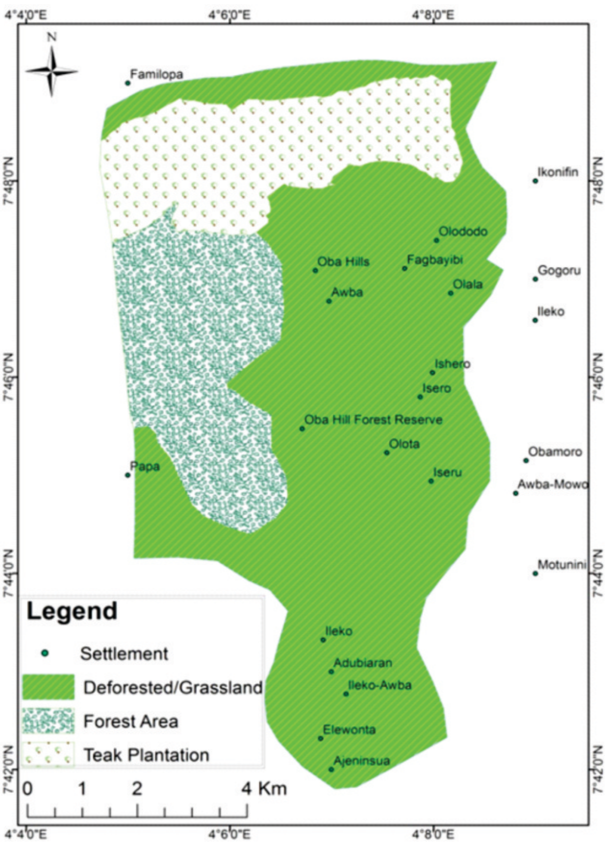

Figure 2: Land use/Land cover analysis of Oba Hill Forest Reserve

Table 2: Land use/Land cover analysis of Oba Hill Forest Reserve

Cover Classes	Area (km^2)	Percentage Cover (%)
Natural Forest	9.72	18.37
Teak Plantation	9.4	17.77
Grassland/Cultivated land/Deforested land	33.78	63.86
Total	**52.9**	**100**

Source: Analysis of Remotely Sensed and Map Data

The level of degradation of the forest reserve was evident by the expanse of the land cover converted to agricultural land within the reserve (64%). This was lumped together with deforested land which now has limited capacity to naturally replenish its forest resources. This is more worrisome as the forest reserve lies on the boundary of the tropical rain forest and the derived savannah ecological regions. The derived savannah was described by Clayton (1958) as a delicate zone that developed from the rain forest by the interplay of agricultural activities and recently, climate change and has since been expanding southwards. This is a phenomenon that developed over time with the weakening of the forest management system.

The Tree diameter at breast height (DBH) and Mean Biomass Estimates

The mean DBH of trees in Quadrat 1 was 16.70cm. A total of 24,832 trees were in the quadrat with an average biomass of 25.23kg per tree. A breakdown of derived DBH and biomass from each of the cells per Quadrat are presented in Table 4 while the mean values are in Fig. 3.

The plantation carbon estimates

The teak plantation had a total biomass of 2,533,584kg and a total carbon content of 1,266.79tCO_2e covering about 940 hectares and resulting to an average of 1.347t/ha. The distribution across the four quadrats is shown in Table 3.

Trees in quadrat two had the highest mean biomass

Table 3: Distribution of biomass and carbon content across quadrats

Quadrat	Mean DBH (cm)	Mean Biomass (Kg)	Total No of Trees	Total Biomass (Kg)	Total Carbon (tCO_2e)	Total Carbon/ Hectare (t/ha)
Q1	16.7	25.2	24,832	626,637.4	313.3187	1.080
Q2	30.8	44.4	15,360	682,111.5	341.0557	1.894
Q3	24.7	34.9	16,128	609,544.0	304.772	1.604
Q4	17.3	25.8	23,808	615,291.7	307.6458	1.098
Overall	20.6	30.4	80,128	2,533,584.6	1,266.7922	5.676

Source: Field Surveys and Analysis

Table 4: The DBH and Biomass for the Cells for the Quadrats

Cell	Total Measured DBH (in cm)					Mean DBH (cm)					Mean Biomass (Kg)				
	Q1	Q2	Q3	Q4	Mean	Q1	Q2	Q3	Q4	Mean	Q1	Q2	Q3	Q4	Mean
1	413.3	764.7	560.9	428.8	541.9	15.9	29.4	21.6	16.5	20.8	24.4	41.9	30.7	25.0	30.5
2	440.9	776.4	546.6	425.7	547.4	17.0	29.9	21.0	16.4	21.1	25.5	42.7	30.0	24.9	30.8
3	429.6	760.4	697.5	448.8	584.1	16.5	29.3	26.8	17.3	22.5	25.1	41.7	37.8	25.8	32.6
4	417.5	763.8	674.7	407.3	565.8	16.1	29.4	26.0	15.7	21.8	24.6	41.9	36.5	24.2	31.8
5	433.5	818.6	664.7	482.5	599.8	16.7	31.5	25.6	18.6	23.1	25.2	45.6	36.0	27.2	33.5
6	447.2	829.5	665.6	459.5	600.5	17.2	31.9	25.6	17.7	23.1	25.7	46.3	36.0	26.2	33.6
7	439.7	790.5	627.5	448.0	576.4	16.9	30.4	24.1	17.2	22.2	25.4	43.6	34.0	25.8	32.2
8	440.5	823.5	659.6	420.6	586.1	16.9	31.7	25.4	16.2	22.5	25.5	45.9	35.7	24.7	32.9
9	416.6	845.0	646.3	460.5	592.1	16.0	32.5	24.9	17.7	22.8	24.6	47.5	35.0	26.3	33.3
10	472.4	853.9	681.0	461.0	617.1	18.2	32.8	26.2	17.7	23.7	26.8	48.1	36.9	26.3	34.5
11	418.8	793.1	695.1	437.6	586.2	16.1	30.5	26.7	16.8	22.5	24.6	43.8	37.7	25.4	32.9
12	434.1	793.3	652.6	431.6	577.9	16.7	30.5	25.1	16.6	22.2	25.2	43.8	35.3	25.1	32.4
13	432.8		590.7	460.7	494.7	16.7		22.7	17.7	19.0	25.2		32.1	26.3	27.8
14	427.0			447.2	437.1	16.4			17.2	16.8	25.0			25.7	25.3
15	445.6			445.2	445.4	17.1			17.1	17.1	25.7			25.7	25.7
16	461.3			425.9	443.6	17.7			16.4	17.1	26.3			24.9	25.6
17	412.5			464.3	438.4	15.9			17.9	16.9	24.4			26.4	25.4
18	426.1			518.7	472.4	16.4			20.0	18.2	24.9			28.7	26.8
19	441.0			465.5	453.3	17.0			17.9	17.4	25.5			26.5	
Min	**412.5**	**760.4**	**546.6**	**407.3**	**437.1**	**15.9**	**29.3**	**21.0**	**15.7**	**16.8**	**24.4**	**41.7**	**30.0**	**24.2**	**25.3**
Max	**472.4**	**853.9**	**697.5**	**518.7**	**617.1**	**18.2**	**32.8**	**26.8**	**20.0**	**23.7**	**26.8**	**48.1**	**37.8**	**28.7**	**34.5**
Avg	**434.2**	**801.1**	**643.3**	**449.4**	**534.7**	**16.7**	**30.8**	**24.7**	**17.3**	**20.6**	**25.23**	**44.40**	**34.9**	**25.8**	**30.4**
SD	**15.9**	**32.4**	**48.7**	**25.3**	**66.0**	**0.6**	**1.2**	**1.9**	**1.0**	**2.5**	**0.6**	**2.2**	**2.5**	**1.0**	**3.3**
Var	**239.2**	**1010.8**	**1922.5**	**649.3**	**4605.1**	**0.4**	**1.5**	**2.8**	**1.0**	**6.8**	**0.4**	**4.8**	**5.2**	**1.1**	**11.7**

Source: Field Surveys and Analysis

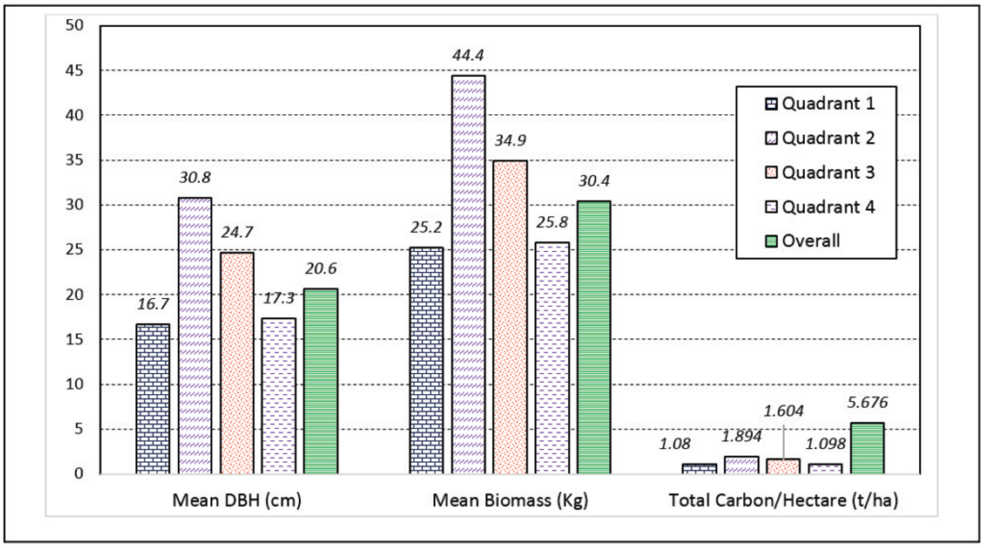

Figure 3: Mean DBH and Mean Biomass across quadrats

Source: Computed from Field Survey

(44.4kg) while those in quadrat one had the least biomass (25.2kg). This is connected to the average diameter of the trees in each quadrat with 30.8cm and 16.7cm in quadrat two and one respectively. Quadrat two invariably had the highest carbon content (341tCO_2e). Variations in tree biomass are usually related to the age of trees amongst others.

Mbaekwe and Mackenzie (2008) found that teak biomass increase with age but that the rate of accumulation begins to decline at some point in time. This was also consistent with the findings of Ouban *et al.,* (2016) in teak plantations of Thailand. To Olayode *et al.* (2015), the carbon stock in plantations of selected forest reserves in South-western Nigeria were most significant as they are yet to be exploited while only coppices of minimum of second or third rotation were left at the other sites. This study could neither confirm the ages of the tree species because they were noted to have been randomly planted without any records of the planting dates or their age differentials. However from the DBH measurements taken, the sample trees in quadrat two had the highest ranges which could serve as the pointers to the age differentials in the quadrats.

Conclusion

Forest carbon stock estimation is a critical step towards adequate measurement and monitoring of its specific contribution to the mitigation of greenhouse gas emissions. However, dearth of data for most Nigerian forests presents a basic challenge to achieving this aim. The development of specie-specific allometric equations for particular locations is imperative in view of large expanses of forest area. Beyond developing these equations is also the need for constant mapping and assessment of land use and land cover within and around forest reserves for adequate monitoring. Since forest conversion in the reserve is mostly to farmlands, engagement with the local community is necessary in order to develop an action plan that will facilitate gradual withdrawal and restoration of the forest. Furthermore, teak is an important tree species in the timber industry hence a demand and supply study will help to regulate the tree harvesting for regeneration purposes. Finally, a regulatory framework is also recommended to include current realities of forest management and staff management while also taking into account the need for appropriate political will to drive its implementation.

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