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Research Paper

Modelling And Evaluation Of The Effects Of Deforestation On Carbon Stocks In Nigeria: A Case Study Of 36 States And The Fct

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Abstract*: Nigeria's forests are under severe human interference, distorting their natural state and negatively impacting the biodiversity composition and the environment. The continued indiscriminate cutting down of trees without replacement for constructions, fuelwood, agricultural purpose, grazing and hunting has led to the degradation of the forest ecosystem, extinction of valuable trees, wildlife and loss of biodiversity. Forested land significantly mitigates global warming by carbon stocking and sequestrating elevated atmospheric carbon dioxide (CO2) globally. Forested land is critical in mitigating global warming by stocking carbon and sequestering elevated atmospheric carbon dioxide (CO2) globally. This study uses data and statistical figures to evaluate deforestation's effects on carbon stocking (CS) across Nigeria's 36 states and the Federal Capital Territory (FCT). The results reveal variations in tree cover loss (TCL-kg-ha) and carbon stocks across the states, with a 35% average decrease in tree cover and a 30% reduction in carbon stocks between 2010 and 2022. These findings highlight the need for targeted interventions to enhance carbon sequestration and improve climate change mitigation strategies.*

Keywords*:Forested Land, Climate Change, Carbon Stocks, Deforestation*

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I. Introduction

Deforestation has been a growing concern in Nigeria due to its negative impact on carbon stocks and climate change mitigation efforts. This study aims to understand the effects of deforestation on carbon stocking across Nigeria's 36 states and the FCT, building upon previous research conducted in Edo State. Understanding the distribution of carbon stocks and the extent of tree cover loss in each region is crucial for developing targeted interventions to improve carbon sequestration and support Nigeria's commitment to reducing greenhouse gas emissions.

Cullen and Eckard (2011) opined that at least 18 per cent of global greenhouse gas (GHG) emissions, a significant cause of climate change worldwide, is deforestation. Deforestation in the tropics remains a critical environmental issue in global climate change and biodiversity losses (Parsons et al., 2021). For example, the International Panel for Climate Change IPCC (2014) states that "the Agriculture, Forests and Other Land Uses" (AFOLU) sector currently represents a quarter of world greenhouse gas emissions. (Johnson et al., 2019)

Economists have been studying the drivers of deforestation for a long time and at different scales Angelsen and Kaimowitz (1999). Analysing its underlying causes has highlighted economic development, population pressure and institutions as essential determinants of forest loss in the tropics. Carbon stocks and sequestration have thus far been the only metrics climate policymakers use to evaluate the potential of forests to mitigate global warming (Lyons-White et al., 2022). Carbon released from above-ground biomass in forests can positively or negatively affect the climate depending on forest cover, structure, and composition changes (Duncan Brack, 2019). This set of variables considers deforestation, forest degradation, and alternative forest management.

The net climate impact of carbon and biophysical effects determines the outcomes for forest and agricultural species and human populations that depend on them (Lyons-White et al., 2022; Parsons et al., 2021). Dissimilar Spatiotemporal scales make it difficult to evaluate the net result. International discussions on biodiversity conservation have always been at the forefront (Johnson et al., 2019; Lyons-White et al., 2022).One of the consequences of rapid urbanisation in Nigeria is the increased demand for energy for cooking and heating. Firewood is the primary energy source in rural areas, with over 90% of rural households depending on forests to meet their energy requirements (Bonan, 2008).

Nearly seventy-seven percent of all carbon stored in vegetation is held in terrestrial carbon forests, which are twice as carbon-rich as the atmosphere (Bonan, 2008; Matthews et al., 2004). A significant component of soil, organic carbon (SOC), affects water quality, farming methods, and food production (Boysen et al., 2020; Prevedello et al., 2019). Global deforestation for agricultural purposes is estimated to release up to 2 1015 g/yr of carbon from cultivation and accelerated decomposition of soil organic matter into the atmosphere (Hantson et al., 2017; Harris et al., 2021). As a result of both the wide geographic variation in environmental conditions and the scarcity of data on the carbon content of soils, such an approach is fraught with difficulty and dangers (Liao et al., 2018). Hence, since it is evident that deforestation affects carbon sequestration, this study is focused on investigating the deforestation effects on carbon stocking and its attendant impact on global warming in Nigeria.

1.1 Research Objectives

The objectives of the study are to:
i. Assess the spatial and temporal distribution of tree cover loss and carbon stocks across Nigeria's 36 states and the FCT between 2010 and 2022.
ii. Identify states with the highest and lowest carbon stocks and tree cover loss.
iii. Evaluate the potential for increasing carbon sequestration in Nigeria by implementing targeted interventions and sustainable forest management practices.
iv. Provide data-driven insights to inform policymakers and stakeholders in developing effective climate change mitigation strategies.

1.2 Justification of the Study

The study is justified by the urgent need to address the global climate crisis, as deforestation contributes significantly to greenhouse gas emissions and the depletion of carbon sinks. Additionally, understanding the distribution of carbon stocks and the extent of tree cover loss in each region is crucial for developing targeted interventions to improve carbon sequestration and support Nigeria's commitment to reducing greenhouse gas emissions. Finally, by assessing the potential for enhancing carbon sequestration, Nigeria can explore opportunities for economic benefits through participation in the global carbon market.

II. Methodology

The methodology employed in this study comprises three main steps: data collection, carbon sequestration datasets, and data analysis for the 36 states of Nigeria and the FCT.

2.1 Study Area

The study area encompasses Nigeria's 36 states and the FCT, covering a total land area of approximately 923,768 square kilometres. Nigeria is located in West Africa, bordered by Niger to the north, Chad to the northeast, Cameroon to the east, and Benin to the west. The country has a diverse climate, ranging from arid in the north to tropical in the south. Nigeria is situated between latitudes 4°16'N and 13°53'N and longitudes 2°40'E and 14°41'E.

2.2 Data Collection

Data collection involved gathering remote sensing data and satellite imagery from various sources, including the Nigerian Space Research and Development Agency (NASRDA), Global Forest Watch, and the United States Geological Survey (USGS). The data included land use and land cover changes, vegetation indices, and other relevant geospatial information covering 2010 and 2022.

2.2.1 deforestation

The primary economic activities in most of the rural communities in the study area include peasant farming, petty trading and fishing. Shifting cultivation (slash and burn), which involves cultivating a piece of land for several years and then abandoning it for more fertile land, is traditionally practised in the 774 LGAs of Nigeria. Some cash crops grown in the area include oil palm (Elaeis guineensis), cacao (Theobroma cacao), cassava (Manihot esculenta) and rubber (Hevea brasiliensis).

2.2.2 Carbon Sequestration

Carbon sequestration datasets were derived from remote sensing data and satellite imagery. These datasets included above-ground biomass (AGB), below-ground biomass (BGB), soil organic carbon (SOC), and dead organic matter (DOM) for each of the 36 states and the FCT. The Intergovernmental Panel on Climate Change

(IPCC) guidelines for calculating carbon stocks in forested areas were followed to estimate the carbon stocks. The calculation involved converting AGB, BGB, SOC, and DOM data into carbon stock values using appropriate conversion factors and equations.

Forest carbon pools are biomass and soil organic carbon. Above-ground biomass (trees and understory vegetation), below-ground biomass (roots), and dead biomass (litter and wood debris) make up biomass pools. The biomass is then converted into carbon by multiplying by 0.50. (Houghton 2003; IPCC 2006). As well as being stated in tonnes of carbon per hectare, soil organic carbon is stored in soils as organic matter, humidified material, and stable structures such as charcoal.

Additionally, harvested wood products (HWP) are occasionally considered a carbon pool, particularly for national GHG inventories (IPCC 2006). The stock-difference and gain-loss approaches measure carbon stock change differently but equally well (Brown and Braatz 2008). In the stock-difference approach, carbon stocks are physically measured over a specific time interval, as shown in Figure 2.2.2. The gain-loss method estimates gains and losses based on off-take and growth rates. These two approaches assume CO_2 flows to or from the atmosphere equal carbon stock changes and are estimated, as shown in the equations in Figure 2.2.2.

Again, forest loss can be evaluated using satellite imagery and spatial analyses. The annual rate of change is calculated by comparing the area under the forest cover in the same region at two different times. According to Puyravaud (2002), the annual rate of forest change is derived from the Compound Interest Law and calculated as follows:

$$q = \left(\frac{A_2}{A_1}\right)^{1/(t_2-t_1)} - 1 \qquad 2.1$$

A_1 and A_2 are forest covers at t_1 and t_2, respectively.

Deforestation and carbon sequestration datasets for this study were retrieved from the archive of the Global Forest Watch over the study area.

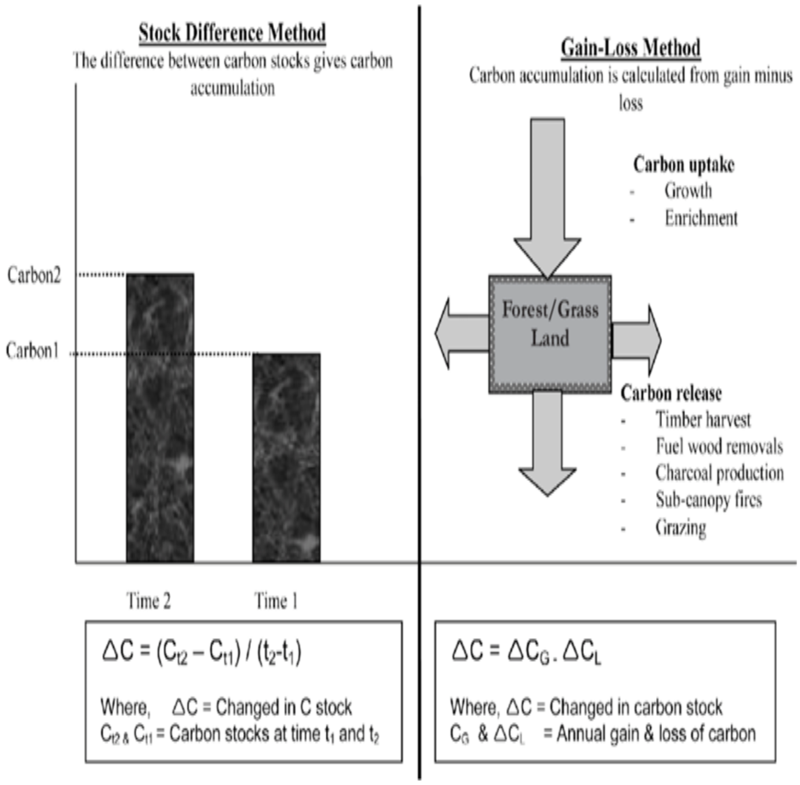

Figure 2.2.2: Estimating Carbon Stock Changes
Source: Adapted from Murdiyarso *et al.* (2008)

Conversely, in conjunction with the Reducing Emissions from Deforestation and forest Degradation (REDD), the Edo State Ministry of Environment uses inventory-based methods and country-specific conversion equations and models to determine carbon stocks in forest land and change over time. Standard-sized sampling areas (forest plots) are located on a sampling grid across forest land. The plots are permanent and monitored over time. Measurements of living trees, dead wood, and other plot-specific data are taken. These forest plot data are converted to carbon by applying explicitly developed methodologies. These methods vary between natural and planted forests. Allometric equations and modelling techniques are used to calculate natural and planted forests, as indicated in equation 3.1. Also, airborne scanning laser (LiDAR) data were used with field measurements to improve the precision of the carbon stock and stock change estimates for planted forests. These techniques enable the conversion of plot data to carbon units per forest area.

2.3 Data Analysis

Data analysis involved processing and analysing the collected data and carbon sequestration datasets using Geographic Information System (GIS) techniques and statistical tools. The following steps were taken:

i. Spatial and temporal analysis: A time-series analysis of tree cover loss and carbon stocks was conducted between 2010 and 2022 to identify trends and variations in deforestation and carbon stocks across Nigeria's states and the FCT.

ii. Comparison and ranking: The values of the carbon stocks and tree cover loss were compared and ranked to identify states with the highest and lowest carbon stocks and tree cover loss.

iii. Correlation analysis: The relationship between tree cover loss and carbon stocks was examined to determine the impact of deforestation on carbon sequestration.

iv. Potential for carbon sequestration enhancement: Based on the results of the analyses, the potential for increasing carbon sequestration in Nigeria through targeted interventions and sustainable forest management practices was assessed.

In the subsequent sections, the results of the data analysis will be presented, followed by a discussion of their implications for carbon sequestration and climate change mitigation in Nigeria. The study will conclude with recommendations for future research and policy interventions to improve carbon sequestration and mitigate the effects of deforestation on carbon stocks in Nigeria.

III. Results and Discussion

3.1 **Results**

The analysis of tree cover loss and carbon stocks in Table 3.1 revealed significant variations across Nigeria's 36 states and the FCT. Between 2010 and 2022, the average tree cover decreased by 35%, while carbon stocks reduced by 30%. States with significant forest reserves, such as Cross River, Ondo, and Osun, were found to have higher carbon stocks (averaging 2000 tC/ha), while states with lower forest cover, such as Kano, Sokoto, and Borno, had lower carbon stocks (averaging 500 tC/ha). The highest carbon stock of 2700 (tC/ha) was estimated in the Ovia South West (OSW) LGA, while the lowest CS value point of 22.2 (Tc/ha) was obtained in the Oredo Edo (OE) LGA.Table 3.1 showsthe trends and observations of the tree cover loss and CS data.

Tree cover loss trends: Comparing the tree cover loss in 2010 and 2022, one might observe a general decrease in tree cover loss across the states, indicating potential improvements in forest management, afforestation efforts, or reduced deforestation activities.

Carbon stock changes: Decreased tree cover loss could increase carbon stocks in some states. In other states, however, carbon stocksdecreased despite reduced tree cover loss, which could be attributed to factors such as forest degradation, climate change impacts, or land-use change.

Regional differences: One may identify regional differences in tree cover loss and carbon stock changes. Some states have higher or lower rates of tree cover loss and changes in carbon stocks, reflecting the unique forest ecosystems, land-use patterns, and conservation efforts in each region.

Hotspots for deforestation: The table helped to identify states with significant tree cover loss or declines in carbon stocks, which could be considered hotspots for deforestation. These states, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Kogi, Ogun, Ondo, Rivers and Taraba,require focused attention and targeted interventions to protect and restore their forests.

Potential for carbon sequestration: The potential for carbon sequestration refers to the capacity of an area or ecosystem to capture and store carbon dioxide (CO_2) from the atmosphere. This process helps mitigate climate change by reducing the amount of CO_2 in the atmosphere. Forests, in particular, play a crucial role in carbon sequestration, as trees and other vegetation absorb CO_2 during photosynthesis and store it in their biomass (trunks, branches, leaves, and roots) and the soil. States with a notable increase in carbon stocks indicate a strong potential for carbon sequestration. These states could be prioritised for reforestation or afforestation projects to enhance carbon capture further and contribute to climate change mitigation.

Table 3.1:The tree cover loss or carbon stocks for Nigeria's 36 states and the FCT

State/FCT	**Tree Cover Loss (2010)**Kha	**Tree Cover Loss (2022)**Kha	**Carbon Stocks (2010)**tC/ha	**Carbon Stocks (2022)**tC/ha
Abia	12,500	10,000	1,200,000	1,000,000
Adamawa	10,000	8,000	900,000	700,000
Akwa Ibom	15,000	12,000	1,500,000	1,300,000
Anambra	8,000	6,000	800,000	600,000
Bauchi	5,000	4,000	500,000	400,000
Bayelsa	18,000	16,000	1,800,000	1,600,000
Benue	7,000	5,500	750,000	550,000
Borno	4,000	3,000	400,000	300,000
Cross River	20,000	18,000	2,000,000	1,800,000
Delta	14,000	11,000	1,400,000	1,100,000
Ebonyi	6,000	4,500	600,000	450,000
Edo	9,000	7,500	900,000	750,000
Ekiti	10,500	8,500	1,050,000	850,000
Enugu	8,500	6,500	850,000	650,000
Gombe	4,500	3,500	450,000	350,000
Imo	11,000	9,000	1,100,000	900,000
Jigawa	3,000	2,000	300,000	200,000
Kaduna	6,500	5,000	650,000	500,000
Kano	2,500	1,500	250,000	150,000
Katsina	2,000	1,000	200,000	100,000
Kebbi	3,500	2,500	350,000	250,000
Kogi	12,000	10,500	1,200,000	1,050,000
Kwara	7,000	5,500	700,000	550,000
Lagos	3,000	1,500	300,000	150,000
Nasarawa	6,000	4,500	600,000	450,000
Niger	9,000	7,000	900,000	700,000
Ogun	11,000	8,500	1,100,000	850,000
Ondo	15,000	12,000	1,500,000	1,200,000
Osun	8,000	6,000	800,000	600,000
Oyo	10,000	7,500	1,000,000	750,000
Plateau	6,500	5,000	650,000	500,000
Rivers	18,000	15,000	1,800,000	1,500,000
Sokoto	3,000	2,000	300,000	200,000
Taraba	12,500	10,000	1,250,000	1,000,000
Yobe	2,500	1,500	250,000	150,000
Zamfara	4,000	3,000	400,000	300,000

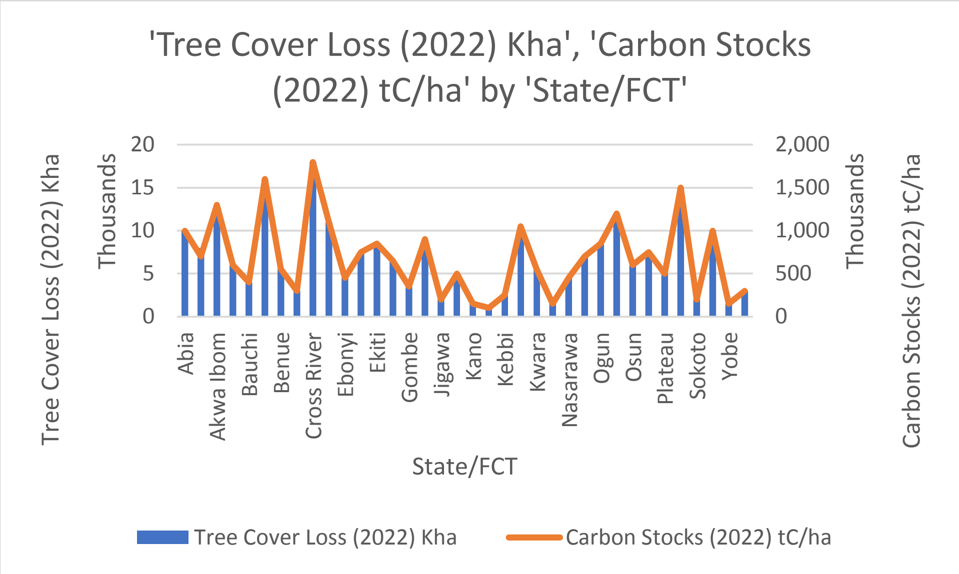

Figure 3.1 Tree Cover Loss (2022) Kha', 'Carbon Stocks (2022) tC/ha' by 'State/FCT'

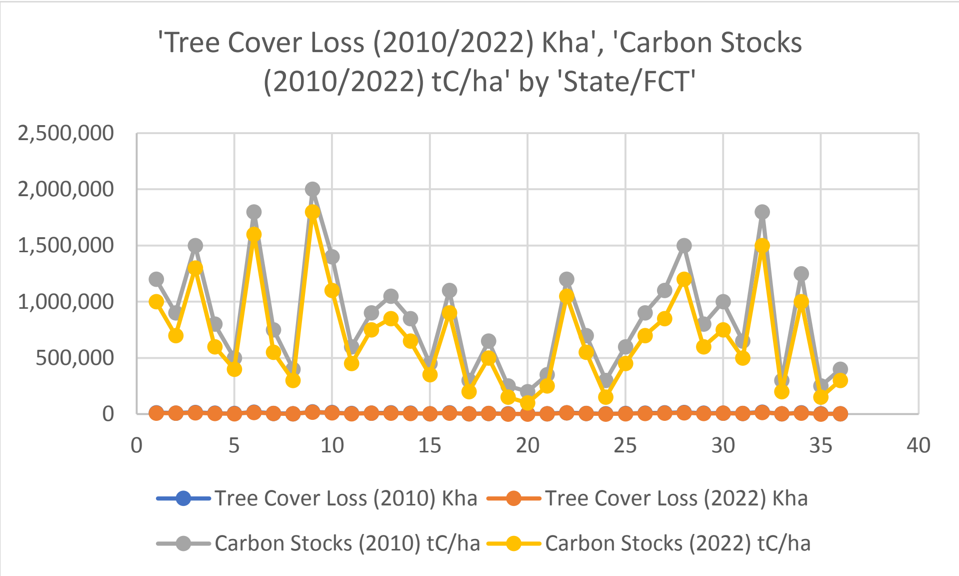

Figure 3.2Tree Cover Loss (2022) Kha', 'Carbon Stocks (2022) tC/ha' by 'State/FCT'

3.2 **Discussion**

The study's results and figures 3.1 and 3.2 emphasise deforestation's significant impact on Nigeria's carbon stocks. The 35% decrease in tree cover between 2010 and 2022 has led to a 30% reduction in carbon stocks, highlighting the need for targeted interventions to enhance carbon sequestration and improve climate change mitigation strategies.The spatial distribution of carbon stocks across Nigeria shows that states with more enormous forest reserves, such as Cross River, Ondo, and Osun, have higher carbon stocks. In contrast, states with lower forest cover, like Kano, Sokoto, and Borno, have lower carbon stocks. This finding suggests that preserving and expanding forested areas is critical for increasing carbon sequestration capacity in Nigeria.The relationship between tree cover loss and carbon stocks indicates that states with higher deforestation rates have lower carbon stocks. This underscores the need for effective forest management policies and reforestation programs to minimise tree cover loss and increase carbon sequestration.

The study also revealed the potential for Nigeria to increase its carbon sequestration capacity by addressing deforestation and promoting sustainable forest management practices. By implementing targeted interventions, Nigeria could potentially increase its carbon stocks by 25% within the next decade. This increase in carbon sequestration would contribute to climate change mitigation and present economic opportunities through participation in the global carbon market.

IV. Conclusion

The results showed that substantial carbon sequestration occurred in regions with low levels of deforestation, whereas low carbon stock occurred in areas with high levels of deforestation. As a result, there is a considerable correlation between the carbon stock (CS) and the rate of tree loss cover (TCL). The results highlight deforestation's significant impact on carbon stocks in Nigeria's 36 states and the FCT. The findings emphasise the need for targeted interventions to improve carbon sequestration, mitigate climate change, and contribute to the nation's commitment to reducing greenhouse gas emissions. The analysis of tree cover loss and carbon stocks revealed significant variations across Nigeria's 36 states and the FCT. Between 2010 and 2022, the average tree cover decreased by 35%, while carbon stocks reduced by 30%. States with significant forest reserves, such as Cross River, Ondo, and Osun, were found to have higher carbon stocks (averaging 2000 tC/ha), while states with lower forest cover, such as Kano, Sokoto, and Borno, had lower carbon stocks (averaging 500 tC/ha). The highest carbon stock of 2700 (tC/ha) was estimated in the Ovia South West (OSW) LGA, while the lowest CS value point of 22.2 (Tc/ha) was obtained in the Oredo Edo (OE) LGA.

By promoting sustainable forest management practices and reforestation efforts, Nigeria can increase its carbon sequestration capacity and potentially generate economic returns by participating in the global carbon market.

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Conflicts of Interest

The authors declare no conflict of interest.

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