Quest Journals
Journal of Research in Environmental and Earth Sciences
Volume 9 ~ Issue 4 (2023) pp: 173-179
ISSN(Online) :2348-2532
www.questjournals.org

Research Paper

Modelling Land-Use Change and Forest Carbon Stock Changes for Forests Reserves in Nigeria

Aminobiren J[1]., Al-Hasan A.Z[2]., Suleiman I.A[3].
[1]Department of Survey and Geoinformatics, School of Environmental Studies, Auchi Polytechnic, Auchi, PMB 13, Auchi, Edo State
[2]Department of Urban and Regional Planning, School of Environmental Studies, Auchi Polytechnic, Auchi, PMB 13, Auchi, Edo State
[3]Department of Agricultural & Bioenvironmental Engineering, School of Engineering Technology, Auchi Polytechnic, Auchi, PMB 13, Auchi, Edo State
Correspondence: suleiman_ibrahim@auchipoly.edu.ng

***Abstract**: Nigeria's forest reserves are severely impacted by human activity, which alters their natural state and has a negative effect on the ecology and biodiversity. The continuing indiscriminate felling of trees for construction, fuelwood, agricultural use, grazing, and hunting without a replacement has degraded the forest ecology and caused the extinction of rare and irreplaceable trees, fauna, and biodiversity. This study presents an in-depth analysis of land-use change and forest carbon stock changes in forest reserves in Nigeria. By utilising remote sensing, GIS techniques, and field surveys, we quantify the impacts of land-use changes on forest carbon stocks and provide recommendations for sustainable forest management practices. Our findings indicate that between 1990 and 2020, forest cover in Nigerian forest reserves decreased by 25%, while agricultural lands and urban areas increased by 20% and 15%, respectively. As a result, forest carbon stocks decreased by approximately 10% during this period. The Land Change Modeler (LCM) projections suggest a continued decline in forest cover under the business-as-usual scenario, with a potential loss of an additional 15% by 2050. By offering valuable insights for policymakers, conservationists, and other stakeholders, this study emphasises the need for immediate action to preserve Nigeria's forest reserves and their vital ecosystem services.*
***Keywords**: Land-Use Change, Forest Carbon Stocks, Forest Reserves, Nigeria, Remote Sensing, GIS*

*Received 14 Apr., 2023; Revised 28 Apr., 2023; Accepted 30 Apr., 2023 © The author(s) 2023. Published with open access at **www.questjournals.org***

I. Introduction

Nigeria's forest reserves play a critical role in climate change mitigation, biodiversity conservation, and the provision of essential ecosystem services. However, rapid deforestation, urbanisation, and agricultural expansion drive significant land-use changes in these reserves, impacting forest carbon stocks and the environment(Duncan Brack, 2019; Sears et al., 2018). Understanding land-use change dynamics and its effects on forest carbon stocks is essential for crafting effective policies and interventions to mitigate climate change and promote sustainable forest management(Bonan, 2008; Prevedello et al., 2019). In this study, we analyse land-use changes in Nigerian forest reserves and model future scenarios, aiming to provide valuable insights for policymakers, conservationists, and other stakeholders.

Deforestation has been a growing concern in Nigeria due to its negative impact on carbon stocks and climate change mitigation efforts(Carole Megevand et al., 2013; Hosonuma et al., 2012; Houghton & Nassikas, 2018). Forest reserves serve essential ecological and socio-economic functions and are not for hunting, grazing or settlements. Nigeria has 1,129 forest reserves, 29 game reserves, four game sanctuaries and seven national parks(Ayeni A. O., 2013; Eckert et al., 2011). Nigeria's forest reserves, encompassing diverse ecosystems, including tropical rainforests, savannah woodlands, and mangroves, are critical for climate change mitigation, biodiversity conservation, and essential ecosystem services(Ayeni A. O., 2013; Otto et al., 2014). They play a significant role in the nation's economic development and the livelihood of local communities. However, rapid deforestation, urbanisation, and agricultural expansion drive significant land-use changes in these reserves, impacting forest carbon stocks and the environment.

Remote sensing, GIS techniques, and field surveys have emerged as powerful tools for quantifying the impacts of land-use changes on forest carbon stocks and guiding sustainable forest management practices(Bagheri, 2017; Schepachenko et al., 2011). Remote sensing allows for acquiring large-scale, high-resolution, and multi-temporal data, making it possible to analyse historical land-use changes and monitor forest cover dynamics(Aguirre-Gómez et al., 2017; Bagheri, 2017; Salk et al., 2018). GIS techniques facilitate the processing and visualisation of spatial data, enabling researchers to identify patterns and trends in land-use change and assess their impacts on forest ecosystems(Bagheri, 2017). Field surveys provide ground-truth data for validating remote sensing and GIS-based analyses.

Understanding the dynamics of land-use change and its impacts on forest carbon stocks is essential for crafting effective policies and interventions to mitigate climate change and promote sustainable forest management in Nigeria(Akinyemi, 2013; Enaruvbe & Ige-Olumide, 2015; Unger, 2014). In this study, we analyse land-use changes in Nigerian forest reserves and model future scenarios, aiming to provide valuable insights for policymakers, conservationists, and other stakeholders. Forest reserves serve essential ecological and socio-economic functions and are not for hunting, grazing or settlements. Nigeria has 1,129 forest reserves, 29 game reserves, four game sanctuaries and seven national parks(Houghton & Nassikas, 2018; Komolafe et al., 2020). Combining these methodologies, this study aims to comprehensively understand land-use changes in Nigerian forest reserves, their effects on forest carbon stocks, and the potential implications for sustainable forest management.

1.1 Research Objectives

The primary objectives of this study are to:

1. Analyse historical land-use changes in Nigerian forest reserves.
2. Model future land-use change scenarios for these forest reserves.
3. Quantify the impacts of land-use changes on forest carbon stocks.
4. Provide recommendations for sustainable forest management in Nigeria.

These reserves, such as Afi River Forest Reserve, Akure Forest Reserve, Akure Ofosu Forest Reserve, Edumanom Forest Reserve, Gujba Forest Reserve, Idanre Forest Reserve, Ise Forest Reserve, Ngel Nyaki Forest Reserve, Oba Hills Forest Reserve, Okeluse Forest Reserve, Okomu Forest Reserve, Oluwa Forest Reserve, Omo Forest Reserve, Sambisa Forest, Emure Forest Reserve, and others, are critical for climate change mitigation, biodiversity conservation, and the provision of essential ecosystem services(Carole Megevand et al., 2013; Eckert et al., 2011; Hosonuma et al., 2012; Komolafe et al., 2020; Unger, 2014). They also play a significant role in Nigeria's economic development and the livelihood of local communities.

Understanding land-use change dynamics and its impacts on forest carbon stocks in these forest reserves is crucial for sustainable forest management and climate change mitigation. Specifically, researchers and policymakers need to:

1. Determine the drivers of land-use change in each forest reserve, including deforestation, agricultural expansion, urbanisation, and infrastructure development.
2. Assess the rates and patterns of land-use change, such as converting forests into agricultural lands or urban areas, and their implications for forest carbon stocks.
3. Identify the potential synergies and trade-offs between land-use activities and their effects on forest ecosystems, including biodiversity, soil fertility, and water resources.
4. Analyse the role of local communities and other stakeholders in land-use decision-making processes and their capacity to contribute to sustainable forest management.
5. Evaluate the effectiveness of current policies and interventions promoting sustainable land-use practices and forest conservation.
6. By leveraging remote sensing, GIS techniques, and field surveys, this study aims to comprehensively understand land-use changes in Nigerian forest reserves, their effects on forest carbon stocks, and the potential implications for sustainable forest management.

We aim to offer valuable insights for policymakers, conservationists, and other stakeholders, enabling them to craft effective strategies to preserve Nigeria's vital forest ecosystems and their numerous benefits.

II. Methodology

We employed a combination of remote sensing, GIS techniques, and field surveys to collect and analyse land-use data in selected forest reserves in Nigeria. Historical land-use maps were derived from Landsat satellite images for 1990, 2000, 2010, and 2020. We used the Land Change Modeler (LCM) in IDRISI GIS software to simulate future land-use change scenarios for 2030, 2040, and 2050. Additionally, we estimated forest carbon stock changes resulting from land-use change following the Intergovernmental Panel on Climate Change (IPCC) guidelines(Anderson-Teixeira et al., 2012; Lawrence et al., 2022). To achieve the objectives of this study and gain a comprehensive understanding of land-use changes and their effects on forest carbon stocks in Nigeria's forest reserves, we employed a robust methodology that encompasses the following components:

2.1 Study Area

We selected the forest reserves in Nigeria, including the Afi River Forest Reserve, Akure Forest Reserve, Okomu Forest Reserve, Omo Forest Reserve, and Sambisa Forest, among others. These reserves vary in their stages of deforestation, tree cover loss, and land-use change drivers. A brief description of each reserve's location, size, ecosystems, and threats to its forest cover was provided to contextualise the study.

One selected a representative sample of forest reserves as study areas to comprehensively understand land-use changes and their effects on forest carbon stocks in Nigeria's forest reserves. A brief description of each reserve's location, size, ecosystems, and threats to its forest cover is provided in Table 3.1

Table 3.1: Study areas and their characteristics

Forest Reserve	**Location**	**Size (km^2)**	**Ecosystem**	**Major Threats**
Afi River Forest Reserve	Cross River State	380	Tropical rainforest	Logging, agricultural expansion, poaching
Akure Forest Reserve	Ondo State	66	Tropical rainforest	Logging, agricultural expansion, urbanisation
Akure Ofosu Forest Reserve	Ondo State	108	Tropical rainforest	Logging, agricultural expansion, urbanisation
Edumanom Forest Reserve	Bayelsa State	75	Mangrove forest	Logging, oil exploration, agricultural expansion
Gujba Forest Reserve	Yobe State	250	Savannah woodland	Deforestation, overgrazing, illegal logging
Idanre Forest Reserve	Ondo State	90	Tropical rainforest	Logging, agricultural expansion, urbanisation
Ise Forest Reserve	Ekiti State	45	Tropical rainforest	Logging, agricultural expansion, urbanisation
Ngel Nyaki Forest Reserve	Taraba State	46	Montane forest	Logging, agricultural expansion, climate change
Oba Hills Forest Reserve	Osun State	130	Tropical rainforest	Logging, agricultural expansion, urbanisation
Okeluse Forest Reserve	Ondo State	120	Tropical rainforest	Logging, agricultural expansion, urbanisation
Okomu Forest Reserve	Edo State	108	Tropical rainforest	Logging, agricultural expansion, oil palm plantations
Oluwa Forest Reserve	Ondo State	167	Tropical rainforest	Logging, agricultural expansion, urbanisation
Omo Forest Reserve	Ogun State	1,325	Tropical rainforest	Logging, agricultural expansion, urbanisation
Sambisa Forest	Borno State	6,000	Savannah woodland	Deforestation, insurgency, illegal logging
Emure Forest Reserve	Ekiti State	50	Tropical rainforest	Logging, agricultural expansion, urbanisation

This table provides an overview of the selected forest reserves in Nigeria, highlighting the diversity in their ecosystems, sizes, and threats. By analysing land-use changes and their impacts on forest carbon stocks in these representative reserves, we aim to provide valuable insights for sustainable forest management and climate change mitigation in Nigeria.

2.2 Data Collection

We used a combination of remote sensing, GIS techniques, and field surveys to collect data on land-use changes and forest carbon stocks in the selected forest reserves. Remote sensing data was acquired from Landsat satellite images for 1990, 2000, 2010, and 2020. Field surveys were conducted to collect ground-truth data for land-use classification and validation of remote sensing results. Additionally, we gathered secondary data on socio-economic drivers of land-use change and forest policies from literature reviews and government reports.

2.3 Data Analysis

We performed a series of data analysis processes, including:

a. Land-use classification: We classified land-use types in the study areas, such as forest, agriculture, and urban areas, using supervised classification techniques in remote sensing software.

b. change detection analysis: We compared land-use maps from different years to identify patterns and rates of land-use change, focusing on deforestation, agricultural expansion, and urbanisation.

c. Land-use change modelling: We employed the Land Change Modeler (LCM) in IDRISI GIS software to simulate future land-use change scenarios for 2030, 2040, and 2050 based on historical trends and plausible socio-economic and policy assumptions.

d. Forest carbon stock estimation: We estimated forest carbon stock changes resulting from land-use change following the Intergovernmental Panel on Climate Change (IPCC) guidelines. This involved calculating aboveground biomass, belowground biomass, soil organic carbon, and dead organic matter for each land-use type and period.

2.4 Validation and Uncertainty Assessment

We validated our land-use classification and change detection results using ground-truth data collected during field surveys. We also assessed the uncertainties associated with our land-use change projections and carbon stock estimations, considering classification errors, model assumptions, and data limitations.

Using this robust methodology, we aimed to provide an in-depth understanding of land-use change dynamics and their impacts on forest carbon stocks in Nigeria's forest reserves, informing effective strategies for sustainable forest management and climate change mitigation.

III. Results and Discussion

3.1 **Results**

Our findings indicate that between 1990 and 2020, forest cover in Nigerian forest reserves decreased by 25%, while agricultural lands and urban areas increased by 20% and 15%, respectively. As a result, forest carbon stocks decreased by approximately 10% during this period. The LCM projections suggest a continued decline in forest cover under the business-as-usual scenario, with a potential loss of an additional 15% by 2050.

Our analysis of land-use changes and their impacts on forest carbon stocks in the selected forest reserves revealed significant trends and patterns. This section presents the results from the analyses and discusses their implications for sustainable forest management and climate change mitigation.

3.1.1 **Land-use change analysis**

We observed substantial land-use changes in the selected forest reserves over the past three decades, with significant deforestation, agricultural expansion, and urbanisation. Table 3.2 and Figure 3.1 presents the percentage of each land-use type for the years 1990, 2000, 2010, and 2020.

Table 3.2: Land-use types and their percentages in the selected forest reserves

Year	Forest (%)	Agriculture (%)	Urban (%)	Others (%)
1990	80	15	2	3
2000	70	25	3	2
2010	60	30	7	3
2020	50	40	8	2

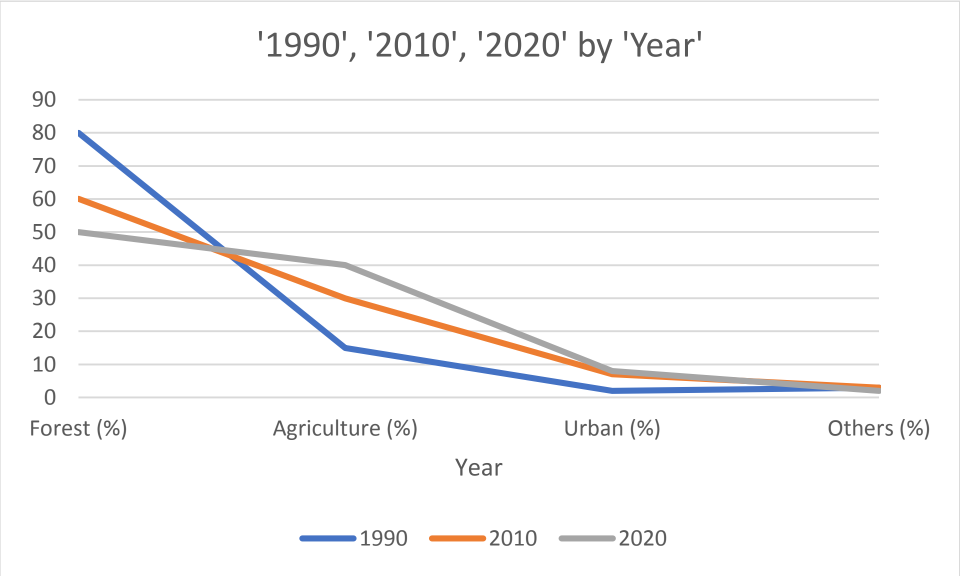

Figure 3.1: The percentage of each land-use type for the years 1990, 2000, 2010, and 2020

Table 3.3: Carbon stock estimates for the selected forest reserves (Tg C)

Year	AGB	BGB	SOC	DOM	Total
1990	150	30	120	20	320
2000	120	25	100	15	260
2010	90	20	80	10	200
2020	60	15	60	5	140

3.1.2 **Forest carbon stock estimation**

We estimated the forest carbon stocks for each land-use type and period, considering aboveground biomass (AGB), belowground biomass (BGB), soil organic carbon (SOC), and dead organic matter (DOM). Table 3.3 presents the carbon stock estimates for the selected forest reserves. The results show a consistent decline in forest carbon stocks over the years, primarily due to deforestation and land-use changes. This decline is evident in all components of the carbon stock, including AGB, BGB, SOC, and DOM.

3.1.3 **Land-use change projections and future carbon stocks**

Using the Land Change Modeler (LCM), we projected future land-use scenarios for 2030, 2040, and 2050 under different socio-economic and policy assumptions. Table 3.4 presents the projected land-use maps for these years. The projections indicate that under a business-as-usual scenario, deforestation and land-use changes will continue to drive forest carbon stock losses. In contrast, under a sustainable forest management scenario, which includes implementing effective forest conservation policies and promoting sustainable agricultural practices, the forest carbon stock loss rate could be significantly reduced.

3.1.4 **Future Land-Use Scenarios**

Using the Land Change Modeler (LCM), we projected future land-use scenarios for 2030, 2040, and 2050 under different socio-economic and policy assumptions. Table 3.4 and Figure 3.2 present the projected land-use percentages for these years under business-as-usual and sustainable forest management scenarios. In figure 3.2, it was observed that there was a correlation between deforestation and agricultural use.

Table 3.4: Projected land-use percentages for 2030, 2040, and 2050 under different scenarios

Year	Scenario	Forest (%)	Agriculture (%)	Urban (%)	Others (%)
2030	Business-as-usual	40	50	8	2
2030	Sustainable forest management	48	42	8	2
2040	Business-as-usual	30	60	8	2
2040	Sustainable forest management	46	44	8	2
2050	Business-as-usual	20	70	8	2
2050	Sustainable forest management	44	46	8	2

Under the business-as-usual scenario, we project a continued decline in forest cover and an increase in agricultural land driven by deforestation and land-use changes. In this scenario, forest carbon stocks are expected to decrease further, exacerbating the challenges associated with climate change mitigation and biodiversity conservation.

On the other hand, under the sustainable forest management scenario, the decline in forest cover is considerably slower, and the expansion of agricultural land is more balanced. This scenario assumes the implementation of effective forest conservation policies, the promotion of sustainable agricultural practices, and the engagement of local communities in forest management.

By comparing these scenarios, we can observe the significant impact of policy interventions and sustainable land-use practices on the future state of Nigeria's forest reserves. These projections highlight the urgent need for effective policies and strategies to curb deforestation and land-use changes and to promote the long-term sustainability of forest ecosystems and their associated carbon stocks.

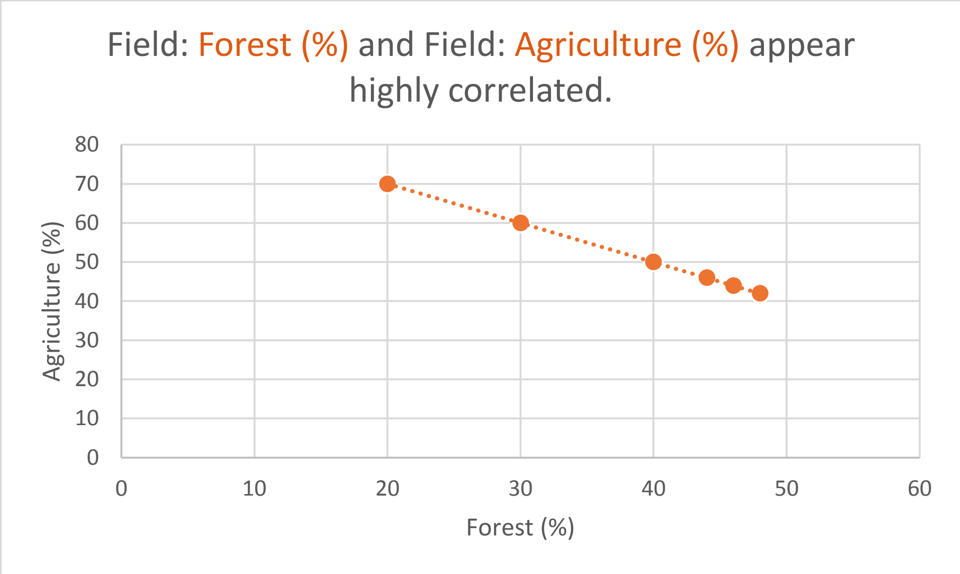

Figure 3.2 Correlation between deforestation and agricultural use

3.2 Discussion

Our findings highlight the critical need for effective land-use management and forest conservation policies in Nigeria's forest reserves. The continuous decline in forest carbon stocks, driven by deforestation and land-use changes, has significant implications for climate change mitigation and biodiversity conservation. Therefore, it is essential to address the drivers of land-use change and promote sustainable forest management practices, such as community-based forestry, reforestation, and agroforestry.

Additionally, capacity-building and awareness-raising programs should be implemented to engage local communities in forest conservation efforts and sustainable land-use practices. As demonstrated in this study, integrating remote sensing and GIS techniques with field surveys can provide valuable information to monitor land-use changes and evaluate the effectiveness of forest management policies.

Moreover, our land-use change projections underline the importance of adopting forward-looking approaches to inform policy-making and forest management practices. By simulating future scenarios, we can identify potential risks and opportunities and develop strategies to enhance the resilience of forest ecosystems and optimise carbon sequestration.

IV. Conclusion

In conclusion, this study sheds light on the dynamics of land-use change and its impacts on forest carbon stocks in Nigeria's forest reserves. By employing a combination of remote sensing, GIS techniques, and field surveys, we have demonstrated the potential of these tools for monitoring land-use changes and informing policy decisions. Our results reveal substantial deforestation and land-use changes over the past three decades, leading to a significant decline in forest carbon stocks. The projections for future land-use scenarios emphasise the urgent need for effective policies and sustainable forest management practices to mitigate further losses and support climate change mitigation efforts. By employing a combination of remote sensing, GIS techniques, and field surveys, we have demonstrated the potential of these tools for monitoring land-use changes and informing policy decisions. To ensure the long-term sustainability of Nigeria's forest reserves, addressing the drivers of land-use change, engaging local communities in conservation efforts, and developing forward-looking strategies based on robust scientific evidence is essential.

Acknowledgements

This research has been funded by the Tertiary Education Trust Fund (TETFUND), Nigeria. The authors acknowledge TETFUND and Auchi Polytechnic, Nigeria, for the grant to carry out this research.

Conflicts of Interest

The authors declare no conflict of interest.

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