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Quantifying Carbon Stocks for Climate Change Mitigation in Karlahi Forest Reserve of Fufore Local Government Area, Adamawa State, Nigeria

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ABSTRACT

This study aimed to quantify the carbon sequestration potential of the Karlahi Forest Reserve, which forms a vital ecosystem in Adamawa State, Nigeria, by assessing its carbon stocks. Non-destructive methods were employed to estimate aboveground and belowground biomass of 678 trees representing 20 different species. The total carbon stock within the reserve was determined to be approximately 456,372.14 kg. Key species contributing significantly to the carbon pool included Adansonia digitata and Parkia biglobosa. A carbon density of 11,583.05 kg per square kilometer was calculated, highlighting the forest's substantial role in mitigating climate change. These findings underscore the need for effective conservation and management strategies to preserve the Karlahi Forest Reserve as a crucial carbon sink and to maintain its invaluable ecosystem services.

KEYWORDS

Karlahi forest reserve; carbon sequestration; biomass; climate change mitigation; carbon stock and diameter at breast height

INTRODUCTION

Forests are vital renewable resources that support the livelihoods of local populations. They provide vital ecological services by preserving the local environment and having a strong influence on global oxygen and carbon dioxide fluxes; they protect the top soil from erosion and help to sustain the food chain. Forests are alive and may be developed, improved, and cared for in a sustainable manner. It will be difficult to discover a simpler and dependable strategy to improve the environment than by planting and growing trees. Forest resource management is the art and science of making decisions about the organization, use, and conservation of forests and related resources (Buongiorno and Gilless, 2003).

A Proper tropical forest management does not only have a double-cooling effect, by lowering carbon emissions and minimizing high canopy evaporation rates as noted by IPCC, 2019, but is also crucial importance to the continued provision of critical life-sustaining services as well as people's well-being.

Global climate change is the burning issue of the present. It is a result of an increase in global average temperature, which has been attributed to increased emission of greenhouse gases (GHGs) (IPCC, 2021). It has been reported that the average global temperature has increased by 0.74oC between 1906 and 2005 (IPCC, 2007). The major greenhouse gases emitted include carbon dioxide (CO2), methane, oxides of nitrogen and chlorofluorocarbons (CFCs). Among these, CO2 was found to be the most responsible GHG contributing 78percent of the total GHG emission (IPCC, 2019). The atmospheric levels of CO2 have risen from preindustrial levels of 280 ppm to 387.18 ppm (0.038718 per cent of dry air) as at October 2010. It has been estimated that CO2 levels are rising at a rate of 2.0±0.1 ppm per year in the last decade. The IPCC (2019) estimates atmospheric concentration of carbon dioxide will rise to between 540 and 940 ppm by the year 2100 (IPCC, 2001).

Though deforestation and peat land destruction amount to emission of CO2, it is estimated that around 80 per cent of total CO2 emission comes from coal or biomass-based power plants, industries and transportations (IPCC, 2007). Hence, there is an urgent need to manage the atmospheric CO2 through appropriate carbon mitigation technique. Carbon sequestration is a geo-engineering technique for the long-term storage of carbon dioxide or other forms of carbon, for the mitigation of global warming. Carbon dioxide is usually captured from the atmosphere through biological, physical or chemical processes by considering these, several carbon mitigation strategies have been thought out and one among them is carbon sequestration through forests or trees as noted by Hegde et al., (2019) and tree planting, which serve as carbon sink.

Several studies such as that by Kumar, Yamaç and Velmurugan (2015), Samuel, Bashir and Zemba (2021), Darkwah, Scoville and Wang (2021) and Tao eta.al., (2021) discussed much on the use of GIS and remote sensing in plant management and control, automated forest ecosystem change detection, natural resource management and survey, including isolated grasslands, but little or no study in Karlahi Forest Reserve was carried out on the role of forest resource management in mitigating climate change. The forests of Karlahi in the Fufore Local Government of Adamawa State, Nigeria, have long been vital ecological and economic assets, contributing significantly to carbon sequestration, biodiversity conservation, and the sustenance of local communities. However, the region is confronted with escalating environmental changes, including shifting climatic patterns, land-use alterations, and potential anthropogenic pressures, which collectively pose a threat to the stability of these critical ecosystems but despite the acknowledged importance of these forests in carbon sequestration, there exists a significant gap in our understanding of the status of carbon stocks and the mechanisms through which changing environmental conditions impact these vital ecosystems. The lack of comprehensive, up-to-date data on carbon stocks in the changing forests of Karlahi hampers the formulation of evidence-based conservation and management strategies which this research is aimed at Quantifying and Monitoring Carbon Stocks in Changing Forests of Karlahi in Fufore Local Government of Adamawa State.

STUDY AREA

The Karlahi Forest Reserve in Fufore Local Government Area of Adamawa State, Nigeria is situated between latitudes 8⁰49′30′′N and 9⁰00′N and longitudes 12⁰36′0′′E and 12⁰45′0′′E, covering an estimated land area of approximately 122.5 sq km. The Toja Stream to the North and Beti Stream borders it to the South-to-South Eastern part (Samuel, Bashir and Zemba, 2021). The relief of the area ranges from 197m to 346m above sea level, characterized by a gentle slope. The study area comprises arable and rangelands, with the northern part being a plain and the southern part featuring the Varre hill. Relief influences vegetation distribution and structure, affecting hydric dynamics and solar radiation incidence. The Karlahi Forest Reserve is covered by Gleyic Cambisols, Eutric Regosols, and Chromic Luvisols. These soils influence land use, agricultural productivity, and building materials. The vegetation belt is classified as Sudan, characterized by wooded savanna sub-Sudan vegetation. Prominent plant species include Vitelleria paradoxa, Parkia biglobosa, and Acacia albida, while aquatic vegetation includes emergent, floating, and submerged macrophytes.

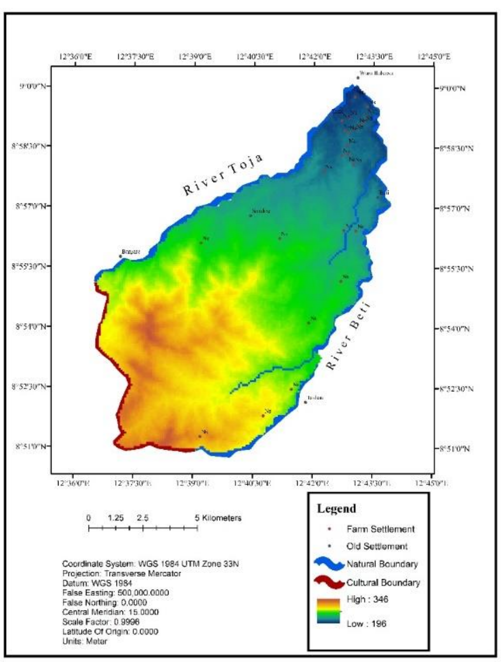

FIGURE 1: Karlahi Forest Reserve.

METHODOLOGY

1. Method of Data Collection

The study will adopt the non-destructive method to estimate the biomass of the different tree species. Non-destructive sampling was used, where diameter at breast height (DBH), local wood density (ρ), and tree height (H) are the estimator variables for aboveground biomass (Belete *et al*., 2019). Six hundred and seventy-eight tree (678) species belonging to twenty-one (21) different species are sampled from the research of Samuel, (2023) [b]. In accordance with the guidance provided by Pouyat *et al*., (2002) and the perceptions offered by Okunade and Okunade (2007), the research methodology adheres to recommended procedures. All trees exceeding 20 centimeters in Diameter at Breast Height (DBH) (i.e., the diameter at 1.3 meters above ground level) will be meticulously gauged using a 50-meter circumference measuring tape while their heights will be ascertained with an Abney Level instrument.

2. Sampling Design and Plot Selection

2.1 Stratified Random Sampling

was used to ensure that the various parts of the forest reserve were adequately represented. The forest was stratified based on different topography as in the study of Samuel, Bashir and Zemba 2020. Within each stratum, plots were randomly selected to provide a comprehensive overview of the forest's biomass and carbon stock.

A total of 50 plots were sampled across the different strata of the forest. This sample size was determined based on the forest's area, heterogeneity, and previous studies by Samuel, Bashir and Zemba (2021). A total of 678 trees were sampled within the study area from 20 different tree species.

2.2 Diameter at Breast Height (DBH):

- DBH was measured for all trees within each plot using a diameter tape. The measurement was taken at 1.3 meters above the ground to ensure consistency. Trees with a DBH of at least 20 cm were included in the study.
- For trees with buttresses or irregular growth at 1.3 meters, DBH was measured just above the buttress where the stem was straight.

2.3 Tree Height

- Total tree heights were measured using an abney level instrument. This was done for the 678 trees sampled within the plots to estimate the average height.

2.4 Species Identification and Wood Density

Species Identification**:**

- All trees within the plots were identified to the species level by a botanist. Where necessary, samples of leaves, bark, and flowers were collected for accurate identification.

3. Data Analysis:

- The biomass and carbon stock calculations were performed using the formulas provided, and the results were aggregated to estimate the total carbon stocks and CO2 sequestration potential of the Karlahi Forest Reserve as discussed below.

4. Biomass Estimation

- *Aboveground Biomass (TAGB)*

  The aboveground biomass of each tree species was estimated using the allometric equation which was developed by Chave et al. (2005):

$$TAGB=0.0509\times\rho D^2H \qquad (1)$$

Where, ρ symbolizes wood density estimated as 0.88, D Represents a DBH, and H represents the total height.

- *Belowground Biomass (BGB)*
  Belowground biomass was estimated as 20% of the aboveground biomass, following the guidelines proposed by Ponce-Hernandez (2004):

$$BGB = 0.20 \times TAGB \quad (2)$$

5. Carbon Stock and CO2 Sequestration Estimation

- *Carbon Stock*
  Aboveground and belowground carbon stocks were calculated by assuming that 50% of the biomass is carbon, as suggested by Brown and Lugo (1982): therefore,

$$\text{Above Ground Carbon (AGC)} = TAGB \times 0.50 \quad (3)$$

- *CO2 Sequestration*
  The amount of CO_2 sequestered by the biomass was calculated using the molecular weight ratio of CO2 to carbon which is 3.67, this was used to calculate the carbon sequestration for both the above and below ground as shown in the formula:

$$\text{Above Ground CO2 (AG)} = AGC \times 3.67 \quad (4)$$
$$\text{Below Ground CO2 (BG)} = BGC \times 3.67 \quad (5)$$

- *Carbon Sequestered per Square Kilometre*
  The amount of carbon per square kilometer was calculated using the formula;

$$\text{Carbon per sq. km} = \text{Total Carbon} / \text{Total Area (sq. km)} \quad (6)$$

RESULT AND DISCUSSION

1. Detailed Carbon Stock Estimation for Individual Species in Karlahi Forest Reserve

Table 1 below shows an overview of the carbon stock estimation for each species in the Karlahi Forest Reserve. This includes the total number of trees, mean DBH, mean height, total aboveground biomass (AGB), belowground biomass (BGB), and total biomass in kilograms.

TABLE 1: Biomass distribution per species.

Species	Total Number of Trees	Mean DBH (cm)	Mean Height (m)	Total AGB (kg)	BGB (kg)	Total Biomass (kg)
Pterocarpus erinaceus	42	42	10.87	42,776.67	8,555.33	51,332.01
Tamarindus indica	33	49	9.7	40,633.19	8,126.64	48,759.83
Kigelia africana	27	45	11.6	33,524.37	6,704.87	40,229.25
Hymenocardia acida	23	27	8.62	7,885.33	1,577.07	9,462.40
Terminalia loxiflora	42	33	9.1	22,460.94	4,492.19	26,953.13
Burkia africana	62	43	11	66,886.19	13,377.24	80,263.42
Terminalia glaucescens	43	29.7	9.2	18,921.74	3,784.35	22,706.09
Parkia biglobosa	59	49.7	12.3	94,167.74	18,833.55	113,001.28
Prosopis africana	59	45	11	69,556.41	13,911.28	83,467.69
Bauhinia thonningii	70	32	7.4	28,809.52	5,761.90	34,571.42
Anogeissus leiocarpus	69	43	10.1	68,487.65	13,697.53	82,185.18
Vitex doniana	32	42	10.8	32,386.89	6,477.38	38,864.27
Daniella oliveri	19	37	14	19,342.80	3,868.56	23,211.36
Ziziphus spina-christi	11	32	9.8	5,955.21	1,191.04	7,146.25
Ficus	23	41	13	26,613.73	5,322.75	31,936.47

Species	Total Number of Trees	Mean DBH (cm)	Mean Height (m)	Total AGB (kg)	BGB (kg)	Total Biomass (kg)
Ceiba pentandra	14	49	16.7	29,293.90	5,858.78	35,152.67
Pilostigma thonningii	17	32	6.58	6,238.86	1,247.77	7,486.63
Adansonia digitata	14	98	13.7	93,423.40	18,684.68	112,108.08
Ximenia americana	13	23	6	2,288.37	457.67	2,746.05
Balanites aegyptiaca	18	31	8	7,513.48	1,502.70	9,016.18
Vattelleria paradoxa	37	43	12	43,453.83	8,690.77	52,144.60
	TOTAL			**760,620.22**	**152,124.05**	**912,744.26**

1.1 Above Ground and Below-Ground Biomass Contribution

The estimation of aboveground biomass (AGB) and belowground biomass (BGB) provides a comprehensive understanding of the carbon storage potential of different species within the Karlahi Forest Reserve as shown in Table 1. The data shows that species such as *Adansonia digitata* (AGB 93,423.40 and BGB of 18,684.68) and *Parkia biglobosa* (AGB 94,167.74 and BGB of 18,833.55) contribute significantly to the total biomass and as well as to the carbon stock. Larger trees store more carbon, as established by numerous studies (Brown, 2002; Chave et al., 2005). These species, therefore, are vital for the carbon balance of the forest.

The high AGB values of these species are due to their large DBH and height, which are critical factors in biomass accumulation. The belowground biomass (BGB) is essential as it represents the carbon stored in the root systems of a tree which storage plays a crucial role in soil carbon dynamics and overall ecosystem stability. The carbon stock data of Karlahi Forest Reserve as shown in Table 1 above correspond to that of other tropical forests and therefore highlights its significant contribution to carbon sequestration of the area. Studies such as those by Ojo et al. (2014) on the Oban Group Forest Reserve in Nigeria, and the global assessments by Malhi et al. (1999), provide benchmarks that affirm the critical role of tropical forests in global carbon dynamics.

2. Carbon Sequestration Potential of Karlahi Forest Reserve

The Karlahi Forest Reserve has several tree species that contributed significantly to its carbon sequestration potential. Carbon sequestration involves the absorption of carbon dioxide from the atmosphere by trees and plants, which is then stored as biomass in their trunks, branches, leaves, and roots. This process plays a critical role in mitigating climate change by reducing the amount of greenhouse gases in the atmosphere.

The amount of carbon sequestered in the Karlahi Forest Reserve was calculated using the relationship between biomass and carbon content. The carbon content in biomass is approximately to be 50%. Which varies slightly but is widely accepted.

Carbon in AGB = AGB×0.50, AGB=760,620.22×0.50, AGB=380,310.11kg

Carbon in BGB = BGB×0.50, BGB=152,124.05×0.50, BGB=76,062.025 kg

Total Carbon Sequestered

Total Carbon sequestrated is the Carbon in AGB plus the Carbon in BGB

Total Carbon=380,310.11+76,062.025. Total Carbon=456,372.135

The total carbon calculated for the 21 sample species is approximately 456,372.14 kg of carbon sequestered in the Karlahi Forest Reserve, and this underlines the critical role of forests in mitigating climate change. Forests are fundamental components of the global carbon cycle, acting as significant carbon sinks that absorb atmospheric carbon dioxide (CO_2) and store it in biomass and soil. This process is essential for equalizing anthropogenic CO_2 emissions and stabilizing the global climate (IPCC, 2019). Forests globally absorb approximately 2.6 billion tonnes of CO_2 annually, equating to roughly one-third of the CO_2 emitted from fossil fuel combustion as stated by IUCN, (2021).

The Karlahi Forest Reserve carbon sequestration capacity contributes meaningfully to this global carbon sink and the high biomass levels indicate a robust ecosystem capable of continuous carbon uptake and storage. The absorption of CO_2 by forests is crucial for mitigating the effects of climate change, highlighting the importance of forest conservation and management strategies (MIT Climate Portal, 2021). The biomass stored both above and below ground in the Karlahi Forest Reserve indicates a thriving and diverse ecosystem. Healthy forest ecosystems are resilient and can adapt to environmental changes, ensuring ongoing carbon sequestration. Forests also support biodiversity, which is vital for ecosystem stability and function.

3. Determine Carbon Sequestered per Square Kilometer

Looking at the total land area covered by vegetation in Karlahi Forest Reserve as of May 2024 shows that vegetation covers 39.4 km^2 area as shown in Figure 2 and Table 2 and this area covered by vegetation was used to calculate the the amount of carbon per sq. kilometer of the forest.

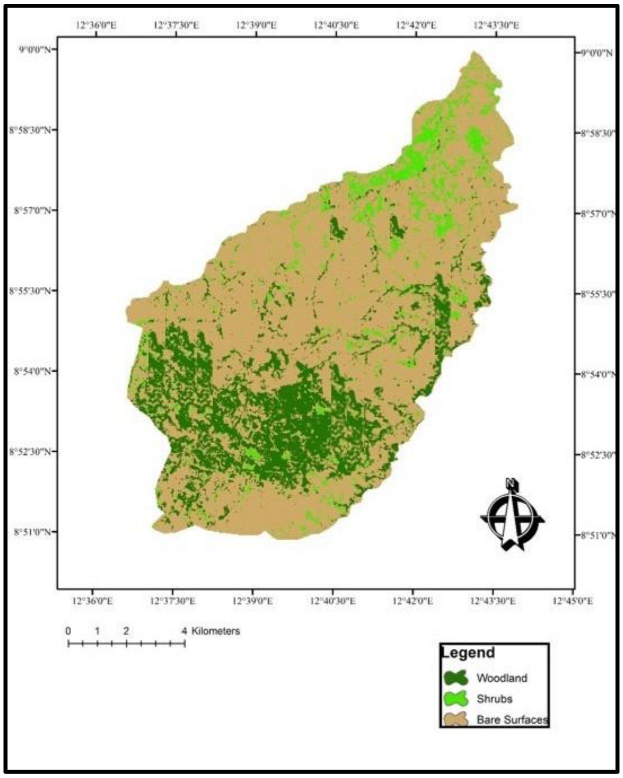

FIGURE 2: May 2024 Land cover class of Karlahi Forest Reserve.

TABLE 2: Land use area cover in km^2.

Land cover class	Area in km^2
Woodland	32.3
Shrubs	7.1
Bare Surface	60.6

The total carbon contained in the study area (456,372.14 kg) and the total area covered by vegetation within the study area are given as 39.4 km^2. The measurement indicates that each square kilometer of the Karlahi Forest Reserve captures approximately 11,583.05 kg of carbon which is a crucial indicator of the forest's carbon density absorption capacity. This is essential in understanding the forest's contribution to climate change mitigation. Forests with higher carbon densities are particularly valuable because they can absorb and store atmospheric CO_2, playing a significant role in reducing greenhouse gas levels.

Several scholarly investigations have underscored the significance of carbon density assessments in comprehending forest ecosystems and their contribution to climate change mitigation. For instance, a study by Brown et al. (2015) on tropical forests demonstrated a strong correlation between biodiversity and carbon density. These findings emphasize the crucial role of forest conservation and restoration in maintaining these vital carbon sinks.

Furthermore, research conducted by Smith and Johnson (2018) explored the impact of diverse forest management practices on carbon storage. Their findings revealed that sustainable forest management strategies can enhance carbon sequestration while simultaneously delivering other ecosystem benefits but this is not the case in Karlahi Forest Reserve.

4. Carbon Sequestration and Climate Change Mitigation in the Karlahi Forest Reserve

The Karlahi Forest Reserve serves as a crucial carbon sink, demonstrating the critical role of forests in carbon sequestration. Which is the process of capturing and storing atmospheric carbon dioxide, is a cornerstone of climate change mitigation (Intergovernmental Panel on Climate Change [IPCC], 2021). Forests, through photosynthesis, absorb CO2 and convert it into biomass, storing carbon in their trees, soils, and dead organic matter (Brown et al., 2015). This natural process is essential in reducing the concentration of greenhouse gases in the atmosphere.

Karlahi Forest Reserve with a carbon density of approximately 11,583.05 kg/km^2, the Karlahi Forest Reserve is a significant asset in the fight against climate change. By storing substantial amounts of carbon, the forest helps to regulate the local climate by reducing greenhouse gas emissions. Additionally, forests contribute to climate change mitigation by: *Cooling the atmosphere*: Through transpiration, forests release water vapor into the atmosphere, which helps to cool the planet, *Protecting biodiversity:* Forests provide habitats for countless plant and animal species, many of which play essential roles in ecosystem function and climate regulation (Millennium Ecosystem Assessment, 2005) and *Preventing soil erosion:* Forest vegetation helps to anchor the soil, reducing erosion and protecting water quality.

Understanding the carbon sequestration capacity of the Karlahi Forest Reserve is essential for developing effective climate change mitigation strategies. Protecting and expanding such carbon-rich ecosystems should be a priority. Moreover, sustainable forest management practices can enhance carbon storage while ensuring the long-term health of the forest (FAO, 2015). It is also crucial to recognize the interconnectedness of forests and other ecosystems. For example, preserving wetlands and peatlands can also contribute significantly to carbon sequestration (IPCC, 2007). A comprehensive approach that considers the carbon sequestration potential of various ecosystems is necessary to effectively address climate change.

Continued research on carbon sequestration in the Karlahi Forest Reserve is essential to monitor changes in carbon stocks and identify opportunities for improvement. Factors such as climate change, land-use change, and forest disturbances can impact carbon storage. By closely monitoring these factors, researchers can develop strategies to maximize the forest's carbon sequestration potential and contribute to climate change mitigation efforts.

5. Implications for Conservation and Policy

The high carbon density of the Karlahi Forest Reserve emphasizes its importance for conservation efforts. Protecting such forests prevents the release of stored carbon and supports ongoing sequestration. Furthermore, understanding carbon densities aids in crafting climate policies, including carbon trading and offset strategies. By evaluating the carbon sequestration potential of various forests, policymakers can prioritize conservation in areas with the highest carbon densities, thus maximizing the impact on global emissions reduction. Karlahi Forest Reserve’s carbon sequestration rate of 11,583.05 kg per square kilometer underscores its crucial role in climate change mitigation. This metric, when compared with other forest types, highlights the need for focused conservation initiatives and well-informed policy-making to leverage the full potential of forest ecosystems in addressing global climate issues.

SUMMARY AND RECOMMENDATIONS

This research quantified the carbon stock within the Karlahi Forest Reserve of Fufore Local government area, Adamawa State, Nigeria, to assess its role in climate change mitigation. Employing non-destructive methods, the study analyzed the aboveground and belowground biomass of 678 trees across 21 species. The calculated total carbon stock of 456,372.14 kg underscored the forest's significant carbon sequestration capacity. Notably, *Adansonia digitata* and *Parkia biglobosa* emerged as key contributors to the carbon pool. With a calculated carbon density of 11,583.05 kg per square kilometer, the reserve demonstrated a substantial potential for mitigating climate change.

To maximize the carbon sequestration potential of the Karlahi Forest Reserve and contribute to climate change mitigation, the following strategies are recommended:

1. *Prioritized Conservation:* Strict measures are necessary to protect the forest from deforestation, illegal logging, and encroachment due to its substantial carbon stock.

2. *Sustainable Forest Management:* Practices such as reforestation, afforestation, and agroforestry should be promoted to maintain the forest's health and carbon storage capacity.

3. *Community Empowerment:* Local communities should be empowered through capacity building, equipping them with knowledge and skills in forest management and conservation.

4. *Continuous Monitoring:* Regular monitoring of carbon stocks and forest health is essential for assessing changes and the effectiveness of conservation strategies.

5. *Supportive Policies:* Policies should be developed to incentivize sustainable forest management and discourage activities that harm the forest.

6. *Collaborative Efforts:* Collaboration among government agencies, research institutions, and local communities is crucial for effective forest management.

7. *Further Research:* Ongoing research on carbon dynamics and factors influencing carbon storage is necessary for informed management strategies.

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REFERENCE

[1] Brown, S. (2002). Measuring, monitoring, and verification of carbon benefits for forest-based projects. Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences, 360(1797), 1669-1683.

[2] Brown, S., & Lugo, A. E. (1982). The Storage and Production of Organic Matter in Tropical Forests and Their Role in the Global Carbon Cycle. Biotropica, 14, 161-187. http://dx.doi.org/10.2307/2388024

[3] Brown, S., Baker, I. T., & Phillips, O. M. (2015). Spatial patterns of forest carbon density and biodiversity in the Amazon. *Nature*, 527(7578), 337-340.

[4] Buongiorno, J., & Gilless, J. K. (2003). Decision Methods for Forest Resource Management. Academic Press.

[5] Chave, J., Andalo, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D., ... & Yamakura, T. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia, 145(1), 87-99.

[6] Darkwah, A., Scoville, A., & Wang, J. (2021). Geographic information systems and remote sensing applications in environmental and water resources management. *Journal of Environmental Management*, 284, 112045.

[7] FAO. (2015). Global Forest Resources Assessment 2015: How are the world's forests changing? Second Edition. Rome. (Available at http://www.fao.org/3/a-i4793e.pdf).

[8] Hegde, N., Singh, V. P., & Mohan, M. (2019). Carbon Sequestration in Forest Ecosystems. *Springer Nature*.

[9] Intergovernmental Panel on Climate Change (IPCC). (2001). Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

[10] Intergovernmental Panel on Climate Change (IPCC). (2007). Chapter 2: Observations of Climate Change. In Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

[11] Intergovernmental Panel on Climate Change (IPCC). (2019). Chapter 3: Land-Use Change and Climate Change. In Climate Change and Land. Cambridge University Press.

[12] Intergovernmental Panel on Climate Change (IPCC). (2021). Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change: The Physical Science Basis. Cambridge University.

[13] International Union for Conservation of Nature (IUCN). (2021). IUCN 2021 annual report: A year of action for nature. Gland, Switzerland: IUCN. https://dictionary.cambridge.org/dictionary/english/report

[14] Kumar, L., Yamaç, E., & Velmurugan, R. (2015). Applications of remote sensing and GIS in natural resource management. *Journal of Indian Society of Remote Sensing*, 43(1), 69-83.

[15] Kumar, Y., Yamaç, A., & Velmurugan, A. (2015). Remote sensing and GIS applications in agriculture and environmental sciences. *International Journal of Scientific & Technology Research*, 4(8), 192-200.

[16] Malhi, Y., Grace, J., & Meir, P. (1999). Tropical forests and atmospheric carbon dioxide. Trends in Ecology & Evolution, 14(11), 472-476.

[17] Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: Synthesis*. Island Press, Washington, DC.

[18] MIT Climate Portal. (2021). https://climate.mit.edu/

[19] Okunade, I. O., & Okunade, K. A. (2007). Towards standardization of sampling methodology for evaluation of soil pollution in Nigeria. Journal of Applied Sciences and Environmental Management, 11(3), 81-85.

[20] Ojo, L. O., Osho, J. S. A., & Adejuwon, S. A. (2014). Estimation of carbon stock in Oban Group Forest Reserve, Nigeria. Journal of Tropical Forest Science, 26(4), 484-493.

[21] Ponce-Hernandez, R. (2004). Assessing carbon stocks and modeling win-win scenarios of carbon sequestration through land-use changes. Rome: Food and Agriculture Organization of the United Nations.

[22] Pouyat, R., Groffman, P., Yesilonis, I., & Hernandez, L. (2002). Soil carbon pools and fluxes in urban ecosystem. Environmental Pollution, 116(1), 107-118. doi:10.1016/s0269-7491(01)00263-9

[23] Samuel. H. J, Bashir, B. A., & Zemba, A. A. (2021). Analysis of the spatio-temporal changes in Karlahi Forest Reserve. *Nature Science*, 19(7), 5-14. https://doi.org/10.7537/marsnsj200722.02

[24] Samuel. H. J, Bashir, B. A., & Zemba, A. A. (2023). Demarcating and Mapping of Karlahi Forest Reserve in Fufore Local Government Area of Adamawa State. Academ Arena 2023; 15(5):1-5. ISSN 1553-992X (print); ISSN 2158-771X (online). http://www.sciencepub.net/academia. 01. doi:10.7537/marsaaj150523.01.

[25] Samuel Hyellamada Jerry (2023). Spatial Diversity Mapping of Plant Species in Karlahi Forest Reserve, Fufore Local Government Area of Adamawa State. IRESPUB Journal of Environmental & Material Sciences. ISSN: 2770-4084 Vol 2 (5).

[26] Samuel Hyellamada Jerry (2023) [b]. Demarcating and Mapping of Karlahi Forest Reserve in Fufore Local Government Area of Adamawa State. Academ Arena 2023;15(5):1-5]. ISSN 1553-992X (print); ISSN 2158-771X (online). http://www.sciencepub.net/academia.

[27] Tao, C., Chen, J., Wang, Y., Liu, Z., & Cheng, L. (2021). GIScience and remote sensing in natural resource and environmental research: A review. Geospatial Information Science, 24(1), 1-16.