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# SURVEYING TERRESTRIAL FOREST CARBON STORAGE AND ECOSYSTEM BENEFITS IN NIGERIA

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**ABSTRACT**
This review paper explores the potential of open-source remote sensing-based measurement techniques to improve forest data collection and support Reducing Emissions from Deforestation and Forest Degradation (REDD+) monitoring, reporting, and verification framework in Nigeria's terrestrial forests. This study conducts a systematic analysis of four key areas: tropical deforestation and forest degradation, uncertainty in national forest health data, high costs of remote sensing data, and limited adoption of open-source remote sensing tools for Forest Reference Level (FREL) development. The findings suggest that open-source remote sensing technologies can enhance forest data collection, reduce costs, and support sustainable forest management and REDD+ initiatives. The study recommends developing an integrated open-source remote sensing framework for incorporating terrestrial forest carbon storage and ecosystem benefits data into Nigeria's national forest information system. This research contributes to the development of effective forest monitoring systems and supports Nigeria's efforts to achieve sustainable forest management and climate change mitigation goals.

**Keywords**: Carbon Sequestration, Ecosystem Benefits, Nigeria, Systematic Review, Terrestrial Forest Carbon Storage

## INTRODUCTION

Forest ecosystems play a crucial role in mitigating climate change by serving as carbon sinks, and accurate measurement of forest biophysical parameters is essential for national carbon emission reduction plans and international forest monitoring objectives, such as the UN's Reducing Emissions from Deforestation and Forest Degradation (REDD+). However, traditional in situ measurements in Nigeria are often time-consuming and costly, as forest surveyors face challenges in areas with varied micro-topography (Ogbodo *et al*., 2017). Remote sensing-based measurement techniques offer a promising solution to these challenges, enabling precise biophysical data collection and supporting effective forest information systems (Adamu,2019). Several factors contribute to the lack of current forest surveying data in Nigeria, limiting the development of effective forest information systems (Ogbodo and Okeke, 2022; Udeme *et al*., 2021). This scenario raises the question of how remote sensing-based measurement techniques can improve forest data collection and support REDD+ monitoring, reporting, and verification requirements in Nigeria's terrestrial forests. To address this question, this paper explores four key areas: (i) Increasing rate of tropical deforestation and forest degradation, (ii) Uncertainty in Establishing National Forest Health Information Data, (iii) High Acquisition Cost of Remote Sensing Data Limits Forest Monitoring, and (iv) Inadequate adoption of Open-Source Web-based Remote Sensing Tools for Forest Reference Level (FREL).

## MATERIALS AND METHODS

To address the first research question, a systematic review strategy was adopted in this study using Google Scholar and relevant institutional journal websites, including the United Nations Environment Programme (UNEP), REDD+ Secretariat, and World Resources Institute (WRI) and FUDMA Journal of Sciences at https://fjs.fudutsinma.edu.ng/index.php/fjs/issue/archive. Our search focused on key words such as "open geospatial data" OR Nigeria AND "tropical forest monitoring," " Carbon Sequestration" OR Ecosystem Benefits, AND/OR Terrestrial Forest Carbon Storage" and "REDD+." We screened search results for relevance against predefined criteria at the title, abstract, and full-text levels, following established systematic review guidelines as published in (Grant and Booth, 2009). Grant and Booth (2009) define a systematic review as a thorough process involving methodical searching, critical appraisal, and synthesis of research evidence.

### Increasing rate of tropical deforestation and forest degradation

In particular, Nigeria contributed $4 million (US$4 million) to the REDD+ in 2012 when it signed on as a signatory (FME, 2015). Nevertheless, in order to carry out REDD+ aims successfully, money is also needed, as well as precise metrics for reporting, measuring, and verifying (MRV) the efficacy of the actions done. Thus, by committing to REDD+, the Nigerian government has made a stronger commitment to halting tropical deforestation and addressing climate change through periodic forest resource monitoring, reporting, and verification (MRV) in order to receive funding, particularly from the Global Green Climate Fund. The Green Climate Fund provides funding for forestry initiatives and programs that support the long-term preservation and safeguarding of the planet's surviving tropical forests in order to meet critical biodiversity and climate targets, including the augmentation of livelihood targets in line with the philosophy of nature-based offsets. It has been suggested that using nature-based offsets, which are paid for by individuals who pollute, is a means to support their preservation while also giving money to rural and Indigenous populations who reside in forests and other significant ecosystems (GFW, 2024).

The deliberate removal of forest trees to make room for mining, urbanization, agricultural expansion, and infrastructure development has unfortunately resulted in a steady decline of Nigeria's forest vegetation. As a result, according to Ogbodo *et al.*, (2021), Nigeria's forest cover decreased by a greater percentage between 2004 and 2015, from 60% to 7.70%. This finding indicates that Nigeria's percentage of forest area is less than the minimum threshed 25% of the country's total forest area coverage (Ogbodo and Okeke, 2022). Similarly, Nigeria is ranked 13th among the "Top Countries in the world by Total Forest Loss Since 2001" and in-between two Latin American countries of Columbia (12th) and Peru (14th) as illustrated in Figure 1).

It is interesting to note that Nigeria is also committed to the objectives of the African Union-NEPAD Pack of AFR100, which aims to restore the forest landscape as quickly as possible to the extent of 4 million hectares (AFR100, 2022). This is done in order to prevent the worst effects of climate change, safeguard tropical forest resources from losing biodiversity, and preserve the many advantages that forests offer to people and nature conservation in coordination with the Natural Protected Areas (NPAs) Principles promoted by the International Union for Conservation of Nature (IUCN) (DOPA, 2023).

Figure 1: Top Ranked Countries by Total Forest Loss, 2001 – 2024 (Rao and Fortin, 2024)
Note: the minus (-) prefixing the numbers denotes 'tree cover loss values' while plus (+) would denote tree cover gain

From Figure 1, the percentage forest loss of Nigeria is -13% while the country recorded a forest cover change rate of -32,661 Km$^2$ (i.e. -3,266,100 hectares). This means that, the total area of deforested land in Nigeria exceeds the landmass of all the five (5) South East States (Table 1) with a difference of 367,400 ha. This difference in value of forest loss is also more than the landmass of Lagos State (367,100 ha) is reported in NBS (2017). In summary, Nigeria has lost 3,266,100 hectares of forests between 2001 and 2021, which is equivalent to the combined size of six states: Abia, Anambra, Ebonyi, Enugu, Imo and Lagos States.

**Table 1: Area of South East Nigeria by State (Hectares)**

| Name of Southeast State | Official land area (ha) per state |
|---|---|
| Abia | 490,000 |
| Anambra | 486,500 |
| Ebonyi | 640,000 |
| Enugu | 753,400 |
| Imo | 528,800 |
| Total | 2,898,700 |

Source: NBS, (2017)

Rao and Fortin (2024) reports that former British colony such as Nigeria has experienced higher forest losses than non-colonized African countries. Meanwhile, the total amount forest cover loss in the whole world is -957,658 Km$^2$ – an equivalent of 95,765,800 hectares.

**Uncertainty in Establishing National Forest Health Information Data**

The South-eastern Forest Information needs of Nigeria can only be met if and when there is timely, accurate, and reliable information available about the extent of the region's forests, including the benefits of forest reserves' tree-level carbon storage for neighbouring communities and the environment, as well as the forest health information system. In order for these forest data requirements to be advantageous to all parties involved, a clear and uniform format is also required (Adam, 2023; Abubakar, 2018). This will allow all parties to compare and evaluate the benefits of carbon storage at the tree level and the health of the forests as a whole as they work towards achieving the REDD+ targets in Southern Nigeria.

In general, techniques for precisely measuring biophysical characteristics are an essential part of quantitative assessment for different forest applications. An issue facing forestry scientists and managers, particularly those in developing nations like Nigeria, is gathering reliable forest inventory data more quickly and effectively. It takes time and money to assess forest biophysical characteristics in Nigeria using standard ground-based in situ methods, and forest surveyors find it challenging to work in areas with varied micro-topography.

Open-source remote sensing-based tools are highly desired in order to meet international forest monitoring goals like Reducing Emissions from Deforestation and Forest Degradation (REDD+) (Giulio *et al*., 2017); forests as carbon sinks for national carbon emissions reduction plans and those that can provide answers to the problems associated with modelling future climate scenarios (Ometto *et al*., 2022).

**High Acquisition Cost of Remote Sensing Data Limits Forest Monitoring**

The most prevalent type of remote sensing data is optical, and it has been applied extensively to monitoring vegetation growth, disturbance of forests, and changes in land cover (Olusola and Aladesanmi, 2022). Very High Resolution (VHR) optical sensors, which are useful for tracking forest health and estimating the benefits of tree-level carbon storage, are widely available in today's remote sensing markets. These VHR optical satellite images consist of QuickBird, Worldview-3, GeoEye, and RapidEye. In order to get more precise and reliable results, these photos are frequently utilized to map the health of individual forest trees.

Periodic tropical forest evaluations in low-income countries are also hampered by the rising cost of obtaining such data (Ogbodo *et al*., 2019). For instance, Ogbodo *et al*., (2019) state that the cost of a QuickBird image in 2012, which could cover an area of 267, 667 km2 at a time, was about five million euros. According to Udeme *et al.* (2021), researchers in Nigeria's rising economy, which has a sizable and impoverished rural sector, find it challenging to apply very high-resolution optical sensors on a broad scale due to their correspondingly high pricing.

Many Nigerian Forest surveying researchers can no longer afford the expense of obtaining optical imagery. In developing nations like Nigeria, where many people live on less than US$1.90 per day, the high financial costs (often thousands of US dollars or euros, depending on the market) associated with obtaining these very high resolutions remotely sensed imagery for the identification of individual tree species/crowns can limit the benefits of effective forest health and carbon storage over large areas. Using www.oanda.com/currency-converter, the amount of US$1.90 is equivalent to ₦2,645.03 (two thousand, six hundred- and forty-five-naira, three kobo) as at March 31, 2024.

To support the aforementioned expressions, the World Bank (2022) notes that the novel coronavirus (COVID-19) pandemic that shocked the world in 2020, rising prices, and the ongoing Russian-Ukrainian war all have an impact on Nigeria's declining poverty line. For instance, a forester's ability to plan and manage a forest landscape effectively and efficiently may be limited by such circumstances, which may result in unexplained forest data on tree carbon stocks, loss of forest biodiversity, and forest ecosystem services. Thus, forest information is necessary for northeastern Nigeria. The aforementioned analogy highlights the necessity for forest surveying scientists to employ open-source remote sensing methods and data in less developed nations like Nigeria. Open-source remote sensing imagery and tools that is freely accessible helps to reduce the problems associated with the high cost of forest data collection and data analysis. Since its launch in 2016, the European Copernicus Sentinel-2 Satellite has removed these costly obstacles (USGS, 2019). Sentinel-2 is a constellation of two polar orbiting spacecraft, originally designated A and B units, that are outfitted with optical image sensors called Multi-Spectral Instruments (MSIs). Sentinel-2 satellite remote sensors continuously monitor landcover at multiple spatial resolutions, ranging from 10m to 30m, and characterize its images as high (or moderate) resolution optical remote sensing data.

**Inadequate adoption of Open-Source Web-based Remote Sensing Tools for Forest Reference Level (FREL)**

The term Forest Reference Level (FRL) refers to the "expected net carbon stock change expressed in tons of carbon dioxide per year in a baseline scenario without intervention." A technique called FREL helps marketers evaluate decreased emissions from deforestation and degradation, which is crucial for demonstrating the benefits of REDD+. FRL takes into account removals by sinks as well as emissions by source. This would imply that it covers all improvements made to the carbon stores in forests within a forest landscape.

Twelve (12) years have passed since Nigeria signed the REDD+ agreement in 2012, yet as of 2024, neither a strong database on Forest Reference Levels (FRL) nor Forest Reference Emission Levels (FREL) exists. Carbon emissions from deforestation and land degradation are typically the only ones included in the FREL database. On the other hand, FRL and FREL are both necessary to get the financial gain from REDD+ (Udeme *et al*., 2021). In the light of this assertion, *Udeme et al.* (2021) further recommended capacity building in relevant technologies, such as open-source remote sensing technology, to address the issue of the lack of a national forest information database and facilitate Nigeria's effective payment of compensation in accordance with the monitoring, reporting, and verification (MRV) mechanism of REDD+.

The availability of open-source remote sensing platforms and datasets from sources such as OpenStreetMap, Google Earth Map, has fuelled the development of a large number and variety of open-source remote sensing related web-based mapping projects, thereby, contributing an alternative to well-established commercial remote sensing imagery. To this end, the Open Geospatial Consortium (https://www.ogc.org/standards/) has produced standards for geographic data and made it easier to create interoperable open-source remote sensing data, such as Landsat and Sentinel. These efforts can also help to improve the capabilities of open-source remote sensing tools like i-Tree Canopy Assessments and Google Earth Map.

## CONCLUSION

Remote sensing-based measurement techniques can improve forest data collection and support REDD+ monitoring, reporting, and verification requirements in Nigeria's terrestrial forests by providing accurate and timely forest data, reducing costs through open-source data and tools, and enhancing forest monitoring through open-source web-based remote sensing tools. In conclusion, open-source remote sensing technologies can enhance the surveying of terrestrial forest carbon storage and ecosystem benefits in Nigeria, supporting sustainable forest management and REDD+ initiatives.

## RECOMMENDATION

Based on the findings of this study, it is recommended that future research focus on developing an integrated open-source remote sensing framework for incorporating terrestrial forest carbon storage and ecosystem benefits data into Nigeria's national forest information system, thereby enhancing the country's capacity for sustainable forest management and effective implementation of REDD+ initiatives.

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