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Research Article

Open-Source Remote Sensing Determination of Carbon Emissions From Tropical Deforestation Scenarios in Southeast Nigeria

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Remote Sensing of carbon forestry is the act and science of collecting and analyzing geographically referenced data on the biophysical characteristics of forest carbon fluxes without physical contact. Therefore, the overall objective of this paper is to quantify carbon emissions from tropical deforestation scenarios in Southeast Nigeria. Methodologically, tree cover gain-and-loss status, including rates of deforestation-related carbon emissions, was analyzed in the study area using the open-source remote sensing tool of the Global Forest Watch (GFW), managed by the World Resources Institute (WRI). From the results of the analysis, Nigeria's Southeastern region experienced forest-related greenhouse gas fluxes amounting to 1.20 megatons of CO_2 emissions (CO2-eq)/year during the period between 2001 and 2022. This is because the study area lost 39.3 kha of tree cover within the two decades, which is equivalent to a 12% decline since 2000. Bushfires were responsible for 0.13% of tree cover loss in the SE zone between 2001 and 2022. Specifically, the Southeast lost 52 hectares (ha) of tree cover due to bushfires between 2001 and 2022, and 39.2 kha from all other driving factors of deforestation such as logging, farming, and construction projects. Due to various tree cover loss scenarios, the Southeast region of Nigeria released 909 kt of carbon dioxide into the atmosphere annually on average between 2001 and 2022. Over the course of these two decades, 20.0 Mt of CO_2 gas was released into the environment. In conclusion, the Global Forest Watch platform is a viable open-source remote sensing tool for monitoring emissions from tropical deforestation scenarios in Southeast Nigeria. Based on the findings of this research, it is therefore recommended that there is a need for the subnational governments within the zone to intensify intervention policies on bamboo forestry towards mitigating the consequential impacts of carbon emissions resulting from tropical deforestation.

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1. Introduction

One of the most significant aspects of the natural world is forest resources. In general, forest tree covers contribute significantly to purifying the surrounding air and to the reduction in environmental hazards. Therefore, forest trees can affect the concentration of air pollutants, directly removing pollutants and emissions from the atmosphere (Ogbodo *et al.*, 2020). Ogbodo *et al.,* (2013) further expresses that tropical forest trees enable societies to become more resilient to the effects of climate change and contributes to mitigating erosion, improving air quality, and sequestering carbon dioxide within the context of the United Nations Framework on reducing emissions from deforestation and forest degradation (REDD+).

Nigeria has been a signatory to REDD+ since Year 2012 (FMoE, 2013). To effectively implement REDD+ objectives, however, requires not only funding but also clear metrics for measuring, reporting, and verifying (MRV) the effectiveness of measures taken. Unfortunately, Nigeria's forest vegetation is declining steadily due to the deliberate removal of forest trees to pave the way for mineral exploitation, agricultural expansion, and urban sprawling (Ogbodo *et al.*, 2020). Since the built environment accounts for around 40% of all energy-related CO_2 emissions worldwide, it has the potential to be a major player in a more sustainable future (UNEP, 2020). Worse still, the percentage reduction in forest cover of Nigeria has been on the increase since 2004 (Ogbodo et al., 2017). In the same direction, Nigeria's Nationally Determined Contributions (NDCs) annual decarbonisation index is slowing down (FME, 2021). Regrettably, however, reducing emissions from tropical deforestation and promotion of urban forestry both remain major areas that lack specific mitigation policies despite their importance to global CO_2 emissions (FME, 2021).

Hence, the need for provision of up-to-date forest cover information for Nigeria, especially the South-eastern part where there are relics of tropical primary forests.

According to Ogbodo and Okeke (2023), Nigeria's five Southeastern states of Abia, Anambra, Ebonyi, Enugu, and Imo have a total of forty-seven (47) government-owned protected forests. A total of 133,500 hectares of forest landmass is represented by these 47 forest reserves (**Annex 2**). According to the Nigerian National Bureau of Statistics (NBS, 2017), the official gazetted area of the Southeast (SE) Geopolitical Zone in Nigeria is 2,898,700 hectares. Consequently, 4.61% of this total is accounted for by forest reserves, as reported by Ogbodo and Okeke (2023).

2. Problem statement

Despite the availability of numerous national parks and forest reserves across Nigeria that are recognized under the NPAs of IUCN, Nigeria is yet to be compensated from the Global Climate Fund (Ogbodo, et al., 2024). For instance, an article published on 17 June, 2020, by the United Nations Framework Convention on Climate Change (UNFCCC) indicates that only four (4) countries have so far been granted REDD+ results-based payments worth USD229 million from the Green Climate Fund for emissions reductions, totalling approximately 45 Mt CO2eq (UNFCCC, 2020). The breakdown by the beneficiary countries shows that Brazil got USD 96.5 million while Ecuador (USD 18.6 million), Chile (USD 63.6 million), and Paraguay (USD 50 million).

The issue of the global COVID-19 pandemic added to Nigeria's carbon emission rises as the cost of acquiring commercial very high-resolution remote sensing imagery was beyond the reach of many forestry scientists in Nigeria. COVID-19 also impacted the rate of deforestation emissions from the illegal activities of log poachers during the lockdown period in 2020 as a result of the then ravaging COVID-19 pandemic (Ogbodo *et al.*, 2021). To buttress the foregoing, the World Bank (2023) attributes the worsening poverty line in Nigeria to rising inflation and the unprecedented impacts of the novel coronavirus (COVID-19) pandemic that shocked the world in 2020.

Most regrettably, geospatial scientists and researchers in underdeveloped countries like Nigeria often face challenges in obtaining remote sensing data for forest monitoring at the national and subnational levels due to the high cost of acquiring commercial high-resolution satellite imagery. Whereas many people in Nigeria are estimated to "live on less than US$1.90 per day" (UNSD, 2023).

Based on the foregoing justification, there is a dearth of information in the online scientific literature domains regarding the exact amount of carbon emissions from deforestation activities in Southeast Nigeria despite increasing deforestation activities (Ogbodo et al., 2022).

In view of the above, Nigerian geoscientists must embrace the application of open-source geospatial datasets, software, data platforms, and data-based tools to improve tropical forest carbon storage monitoring and eco-benefits valuation at national, subnational, and plot level scales in order to achieve the core REDD+ objectives by 2030 and beyond. Thus, testing the viability of such alternative open-source remote sensing data platforms and data-based applications is highly imperative.

Consequently, this paper considers it important to use high-speed and efficient open-source remote sensing platforms such as the Global Forest Watch (GFW) tool. Fortunately, highly expensive commercial satellite images are freely available for forest monitoring on the GFW open-source platform under the auspices of the World Resources Institute (WRI). Examples of these satellite imagery are Planetscope (3-m resolution), Sentinel-2 (10-m resolution) data, and Landsat (30-m resolution). However, the GFW tool has not been adequately utilized by researchers to quantify the exact amounts of forest-related carbon emissions in Southeast Nigeria. Therefore, the overall objective of this paper is to quantify carbon emissions from tropical deforestation scenarios in Southeast Nigeria.

3. Methodology

i. Study area

The Southeast region of Nigeria was the study's location. Nigeria is a country in West Africa that is essentially located between latitude 4° and longitude 14° North (N) and longitudes 3° and 14° East (E) (National Bureau of Statistics, 2010).

Southeast Nigeria **(Figure 1)** is naturally endowed with a more diverse vegetation cover of protected tropical forests and mangroves (Ogbodo et al., 2017).

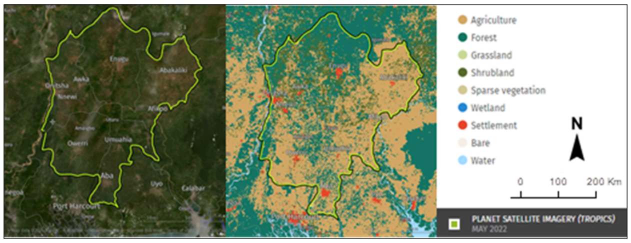

Figure 1. Overview of land cover types in Southeastern Nigeria based on Global Forest Watch data analysis

According to Global Forest Watch (2020), the Guinean forest-savanna and Cross-Niger transition forests are two of the various ecosystems that make up Nigeria's Southeast geopolitical zone. There is not an intact forest in this geopolitical region at the moment. The climate in the region is primarily equatorial, with dry seasons. Tropical and Subtropical Moist Broadleaf Forests cover most of the region. Savannas, shrublands, and portions of tropical and subtropical grasslands are also available. The location consists primarily of 2.85 million hectares (Mha) of land on a lowland terrain.

There are two distinct seasons in the inland areas: the rainy season, which runs from April to October, has a lower temperature, and the dry season, which runs from November to March, has afternoon temperatures that reach 38°C (100°F) but are generally cooler at night (NBS, 2017). Everywhere in the nation typically experiences nonstop rain throughout the month of August, following which a brief dry season known as the "August break" begins. Nonetheless, the South receives more rain than any other region, particularly in the South-East, which receives 2000–3000 mm annually (NBS, 2017). With some deviations, Table 3 summarizes the yearly rainfall rates per state that were observed in the South-East of Nigeria between 2012 and 2016.

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SN	Southeastern State	*Rainfall (mm) Rates In South-Eastern Nigeria*									
		2012		2013		2014		2015		2016	
		mm	^oC	mm	^oC	mm	^oC	mm	^oC	mm	^oC
1.	Abia	136	19.8	144	-	2,161	21.9	2,268	22.8	1,980	23.9
2.	Anambra	2,027	23.8	2,057	24.1	1,545	22.4	1,790	23.2	2,273	24.3
3.	Ebonyi	-	-	-	-	1,230	-	1,349	-	-	-
4.	Enugu	1,911	-	1,738	-	1,839	-	1,610	-	1,757	
5.	Imo	2,362	-	2,818	-	2,386	-	2,117	-	2,738	

Table 1. Annual rainfall (in millimetres - mm) in South-eastern Nigeria from 2012-2016

Note: NiMET (Nigerian Meteorological Agency) rainfall data as adapted from NBS, (2017). The report indicates no recording at the NiMET station in Ebonyi State for rainfall in the period 2012, 2013, and 2016 (Ogbodo and Okeke, 2020).

Table 1's observed reduced rainfall levels may be explained by the fact that the last five years' world temperatures were among the six highest since the middle of the 1800s (Ogbodo et al., 2021). Meanwhile, Okechukwu and Mbajiorgu (2020) provide a comprehensive and current spatial distribution of rainfall and reference evapotranspiration for the Southeast region of Nigeria. The South experiences generally stable temperatures and humidity throughout the year due to the gradual decrease in rainfall away from the coast, while the North experiences significant seasonal variations during the dry season. According to Olutoyin *et al.,* (2017), the average temperature in Southeastern Nigeria is roughly 27°C, with minor daily and seasonal variations. The zone experiences 3,810 mm of annual rainfall on average, with the most of it falling between March and November, during the rainy season (Olutoyin et al., 2017).

ii. Field data collection procedures

Field data were used to validate the processed remotely sensed data. Before the field trip, the Mamu River Forest Reserve shapefile (ArcToolbox—Data Management Tools) was processed using a random sample technique in ArcGIS 10.7, producing the output in (Figure 2).

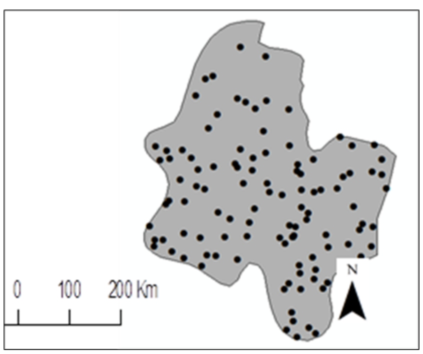

Figure 2. Distribution of the 54 randomly sampled points (black dots) at the study site

The Field Assistants collected data on the species names (both English/local and scientific) of each sampled tree in the study site. They also recorded the GPS coordinates of each sampled tree and, following the methods described by Oliver Phillips *et al.,* (2009) and Assefa *et al.,* (2013), the research team measured the diameter at breast height (dbh) of trees that were ≥1.3 m using a diameter tape (d-tape). **Figure 3** illustrates how one research assistant measures the tree's dbh, another marks the tree using a white chalk, a third GPS device bearer obtains the point coordinates of sampled trees, and a fourth typically records field notes describing the plot and photo number(s). During the forest field survey, the designated research assistants were always in charge of tagging trees for inventory. In this study, **274** tree stems were tagged, identified, and documented.

Figure 3. Research assistants marking DBH points with white chalk and taking measurements

Using an Excel spreadsheet and the formula d = Girth/π (π = 3.14), the stem girth measurements (in centimetres) were further translated to a diameter (d, in centimetres) (Oliver Phillips *et al.*, 2009). It is crucial to emphasize as follows: The dbh value was measured at 1.3 m above the soil surface on the upland side of the tree. If more than 50% of the tree's roots were found inside the plot, the tree was sampled. If not, the tree was tagged systematically, going around each plot, with the last tree tagged near the beginning of the next mapped plot.

iii. Assessments of Forest Cover Variables Using GFW Tool

The Green Forest Watch (GFW) Tool (**Figure 4**) displays yearly tree cover loss/gain, defined as the stand-level replacement of vegetation greater than 5 meters, within the selected area. The GFW's tree cover loss dataset was made available through a collaboration between the University of Maryland in the USA, Google, USGS, and NASA, and uses Landsat satellite images to map annual tree cover loss/gains at a 30 × 30-meter resolution (GFW, 2023).

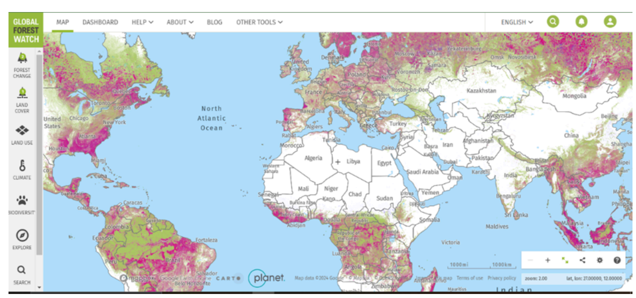

Figure 4. Overview of the GFW portal

For the analysis on the Green Forest Watch platform, after every GIS shapefile of the AOI was uploaded unto the GFW's version 1.10 portal, forest variables such as tree cover gain and loss, tree cover height, deforestation rates, forest carbon removals, forest greenhouse gas emissions, forest greenhouse gas net flux, tree biomass density, and potential carbon sequestration rate were analyzed on the GFW portal. The percentage tree cover gains and losses within Southeastern Nigeria during the period 2000 – 2020 were extracted from the Global Forest Watcher (GFW) Tool. Afterwards, the results were compared using descriptive statistics and the generated GIS maps snipped from the GFW portal.

4. Presentation of Results

i. Spatial Areal Extent of Southeastern Forest Reserves in Nigeria

In terms of national forestry comparison in **Figure 5**, Southeastern Nigeria accounts for 2.42%, whereas the South-South region accounts for 26.71%, the Southwestern region accounts for 24.63%, the North Central region accounts for 20.76%, the Northwest region accounts for 9.03%, and the Northeast region accounts for 16.45%.

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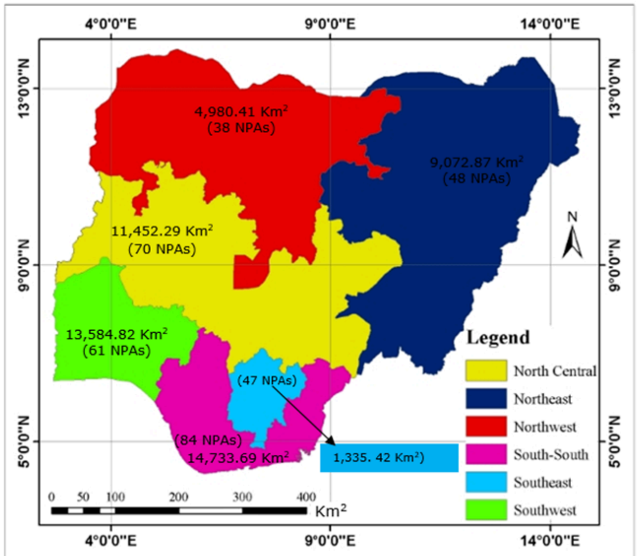

Figure 5. Total land (Km2) Map of Nature Protected Areas Available in the Six (6) Geopolitical Zone of Nigeria. Source: This Doctoral Research (Analysis based on Nigeria's NPAs shapefiles downloaded from IUCN database accessible at https://www.protectedplanet.net)

ii. Aggregate Tree Cover Loss Trend In Southeastern Nigeria

This subsection presents information on tree cover loss in southeast Nigeria from 2000 to 2022 according to the availability of data in the Global Forest Watch Remote Sensing Tool.

In 2000, more than thirty percent of the 325 kha (i.e., 325 thousand hectares), representing 11% of the Southeast landmass, was covered by trees. The other land cover categories occupied the remaining 2.53 Mha (i.e., 2.53 million hectares). The Southeast (SE) Geopolitical Zone of Nigeria lost 39.3 kha of tree cover between 2001 and 2022 (**Figure 6**), which is a 12% decline since 2000. Bushfires were responsible for 0.13% of tree cover loss in the SE zone between 2001 and 2022. Specifically, the Southeast lost 52 hectares (ha) of tree cover due to bushfires between 2001 and 2022, and 39.2 kha from all other loss factors such as logging, farming, and construction projects. During this time, 2001 saw the greatest loss of tree cover due to bushfires, with 22 hectares lost to flames, meaning an equivalent of 0.38% of all tree cover losses for the year 2001.

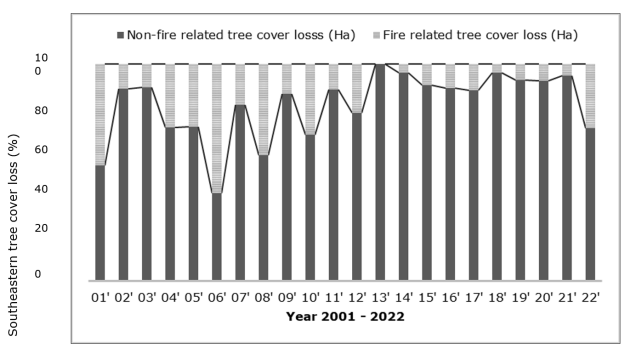

Figure 6. Percentage tree cover loss in Southeastern Nigeria, 2001 – 2022

In Southeast Nigeria, between 2001 and 2022, forest-related greenhouse gas fluxes amount to 1.20 megatons[1] of CO_2 emissions (CO_2-eq)/year. According to the European Environment Agency - Glossary, based on: IPCC Third Assessment Report (2001), CO_2-eq is defined as a carbon dioxide equivalent (CO_2-eq) is a metric measure used to compare the emissions from various greenhouse gases on the basis of their global-warming potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming.

Due to various tree cover loss scenarios, the Southeast region of Nigeria released 909 kt of carbon dioxide into the atmosphere annually on average between 2001 and 2022. Over the course of these two decades, 20.0 Mt of CO_2 gas was released into the environment.

iii. Trend of Nigeria's Southeastern Tree Cover Gains, 2000 - 2022

This subsection presents the findings of a tree cover gain analysis conducted for the southeast region of Nigeria between 2000 and 2020 as part of this PhD thesis, in a similar approach to the above-reported tree cover loss. Southeastern Nigeria gained 81.3 kilometres of hectares (kha) of tree cover, which is an equivalent of 2.8% of its total landmass, between 2000 and 2020 (**Figure 7**). Forest trees absorb 3.58 MtCO2eq/year of carbon emissions from tropical deforestation scenarios throughout the same time period. This corresponds to a net carbon sink of -2.38 MtCO2e/year in the region.

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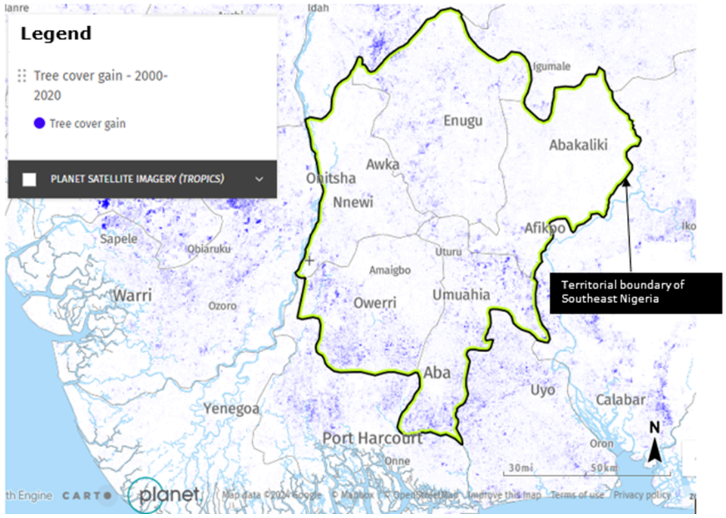

Figure 7. Spatial distribution of tree cover gains (bluish colour) in Southeast Nigeria, 2001-2020

5. Discussion

A report by the World Resources Institute (WRI, 2023) recently confirmed that deforestation in the tropical countries has a direct effect on local climate, making temperatures more extreme and increasing the risk of heat-related deaths. For instance, in January 2023, the United States National Oceanic and Atmospheric Administration (NOAA) reported that year 2022 was the hottest year ever on record in joint ranking with 2015, since the pre-industrial era (NASA, 2023). Similarly, the European Union's Copernicus Climate Change Service (Copernicus, 2023), also confirms that NASA's report indicated that year 2022 was a year of climate extremes, with record high temperatures and rising concentrations of greenhouse gases (GHGs) in the atmosphere.

Accordingly, the World Meteorological Organization (WMO) reported on 16th April, 2023, that the month of March 2023 was Earth's second warmest March on record. Meanwhile, before 2013, scientists had never recorded three consecutive years of such high CO_2 growth. But lately, they are reporting that atmospheric CO_2 is now 50% higher than pre-industrial levels. According to Swallow et al., (2007), global-level studies of the economics of climate change mitigation indicate that afforestation and avoided deforestation are among the most attractive investments for reducing net greenhouse gas emissions (i.e., total emissions less total sequestration).

Literature asserts that a large amount of the Southeast's forests has been destroyed due to increasing human activity brought on by the majority of the rural population's reliance on agriculture for food security and their use of fuelwood for cooking (Ogbodo, et al., 2024; World Bank, 2012), in addition to growing urban sprawl (Ogbodo *et al.*,, 2020). According to the World Bank, up to four (4) out of ten (10) Nigerians are estimated to be living below the $1.90 daily national poverty threshold (World Bank, 2022; World Bank, 2020). Again, because it is extremely expensive to obtain high-resolution commercial remote sensing data in US dollars (USD) or euros rather than the unstable Naira (N) currency of Nigeria, many young remote sensing scientists are unable to purchase this satellite imagery for even plot-level forest monitoring. The official Naira equivalent of $1.90 on January 1, 2024, is N896.80 (https://www.oanda.com/currency-converter/en/), lending credence to the preceding assertion.

Optical remote sensing data are the most abundant and have been widely used in land cover change, forest disturbance, and vegetation growth monitoring (Jiang *et al.*,, 2022). Modern remote sensing markets offer multiple sources of Very High Resolution (VHR) Optical Sensors suitable for monitoring forest health and valuing tree-level carbon storage benefits. Such VHR optical satellite imagery includes GeoEye, RapidEye, WorldView-3, and QuickBird. These images are widely used in mapping forest carbon monitoring to obtain more accurate and precise results.

Generally, in Nigeria, conventional ground-based in situ measurements of forest biophysical parameters take time and are expensive, and personnel involved do encounter difficulties at locations with heterogeneous micro-topography. To obtain precise biophysical data in such situations, there is a high demand for adoption of improved remote sensing-based measurement methods towards achieving international forest monitoring objectives, including the United Nations' Reducing Emissions from Deforestation and Forest Degradation (REDD+); forests as carbon sinks for national carbon emissions reduction plans; and forest health data that can proffer solutions to the challenges surrounding future modelling of climate and ecosystem benefits scenarios (Udeme *et al.*,, 2021; Ogbodo et al., 2017).

In the light of the above, ecosystem restoration can greatly support environmental, social, and economic services. Restoring degraded ecosystems entails growing trees to transform farms, forests, and pastures into more productive and resilient ecosystems (WRI, 2022b). One approach for ecosystem restoration in the world is forest landscape restoration (FLR), which supports forest conservation. WRI (2021) opines that forest conservation through forest landscape restoration could account for over 30% of the solution needed to slow down the rate of climate change towards enhancing environmental sustainability. WRI (2021) further asserts that any forestry project that targets the restoration of at least 100 million hectares could contribute to reducing up to 0.49 $GtCO_2e$ annually.

Nigeria is also committed to the goals of the African Union-NEPAD Pack of AFR100 in order to accelerate forest landscape restoration up to the tune of 4 million hectares (WRI, 2022a) in order to avert the worst impacts of climate change, protect tropical forest resources against biodiversity loss, and safeguard the many benefits of forests to people and the conservation of nature in tandem with the Natural Protected Areas (NPAs) Principles championed by the International Union for Conservation of Nature (IUCN) (Dudley, 2013). As such, the federal government has put in place some national greening policies that support efforts to prevent deforestation, stop forest degradation, restore forests (reforestation), plant new forests (afforestation), and manage existing forests at both national and subnational levels in Nigeria.

Hence, bamboo forestry has the potential to become a promising part of the solution to climate change, increase forest biodiversity, and supplement the requirements for timber, paper, and bioenergy in Nigeria (Ogbodo and Odey, 2023). Bamboo also has the potential to supply high yields of fibre and bamboo shoots for food in a relatively small area. Bamboos provide ecosystem services like carbon sequestration, erosion control, including support for rural development and livelihoods enhancement (Ogbodo, 2023a; Olorunnisola, 2023). The market for the bamboo value chain looks set to grow as rapidly as the plant itself grows in the wild (Ogbodo, 2023b). By this assertion, any bamboo enterprise could be the primary source of subsistence livelihoods and the source of economic upliftment for both the poor and underprivileged people. Thus, while raw material supply from tropical forests is decreasing, bamboo can meet demands for raw materials at both the domestic and international forest products marketplaces.

Interestingly, Nigeria has established the first-ever university-based institute known as the Sahelian Institute for Bamboo Research and Entrepreneurship Development (SIBRED) at Nnamdi Azikiwe University, Awka, Southeast Nigeria (Ogbodo, 2023c). SIBRED can help to catalyse bamboo clean energy transitions and research towards contributing to advancing SDG-7 implementation in Nigeria (Ogbodo, 2023d).

6. Conclusion and Recommendation

Due to various tree cover loss scenarios, the Southeast region of Nigeria released 909 kt of carbon dioxide into the atmosphere annually on average between 2001 and 2022. Over the course of these two decades, 20.0 Mt of CO_2 gas was released into the environment. In conclusion, this study has proven the potential of open-source remote sensing platforms such as the Global Forest Watch of the World Resources Institute (WRI) in quantifying the emissions rates from tropical deforestation scenarios in Southeastern Nigeria.

It is therefore recommended in this paper that there is a need for subnational governments in the southeast to adopt bamboo for forest ecosystem restoration towards contributing to attaining the United Nations Decade on Ecosystem Restoration and REDD objectives in Nigeria.

Footnotes

[1] = one million tons.

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