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Research article

Mitigating Climate Change: The Role of Forest as an Ecosystem-Based Approach in Nigeria

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Abstract
Human and natural systems are influenced by climate variability and hazards, with the negative impacts most severely felt in developing countries. Increased climate variability is associated with climatic change, and climate change effects will intensify significantly in the future with main drivers being anthropogenic. The ability of forest to sequester carbon from the atmosphere makes them a major and valuable carbon sink with the potential of reducing carbon levels. Advances being made on reducing deforestation and forest degradation through agendas such as reducing emissions from deforestation and forest Degradation (REDD+), plans for the UN Decade on Ecosystem Restoration have contributed to efforts to combat climate change. Discussions will be on the potential of forests to provide ecosystem-based solutions that deliver climate-change adaptation and mitigation.

Keywords: Forest; Anthropogenic; Climate Change; Mitigation; Ecosystem-Based

Introduction

Global climate has changed since pre-industrial times, the intergovernmental panel on climate change predicts that with the current emission scenario, global mean temperature would rise between 0.9 and 3.5°C by the year 2100, since the Atmospheric CO_2, a major greenhouse gas, has increased by nearly 30% and temperature has risen by 0.3 to 0.6°C (Chakraborty *et al.*, 2000). Climate change poses a significant threat to global sustainability, with developing countries often bearing the brunt of its impacts (Bastin *et al.*, 2019). Climate change was recognized as a global political issue approximately half a century ago, and since then, mitigation efforts have been steadily increasing (Psistaki *et.al*., 2024).

Africa contains a large proportion of the remaining world biodiversity and is expected to be hit hard by climate with changes in a variety of ecosystems already being detected (Pettorelli *et al.,* 2012). Unlike industrialized countries, developing nations face unique challenges, such as high rates of deforestation driven by agricultural expansion, illegal logging, and resource extraction (Leblois, 2017). Concentrations of atmospheric greenhouse gases have significantly increased since the industrial era began. In turn, this anthropogenic gas loading has altered the radiative forcing of the climate system (Gibelin, 2003).

The sustainable development goals align with the potential of forests to be used in ecosystem-based approaches (EBA) for mitigating climate change (Greksa, 2024). In developing countries, the role of forests in mitigating climate change is worth giving thorough attention. These nations often possess vast forested areas with rich biodiversity, contributing significantly to the global carbon cycle **(**Ezebilo, 2011)**.** However, the potential of the ecosystem to sequester carbon dioxide from the atmosphere has been significantly reduced due to deforestation and forest degradation (Oktan, 2022). Forests are essential carbon sinks, absorbing carbon dioxide from the atmosphere and storing it in biomass. Deforestation and forest degradation release stored carbon, contributing to climate change. Protecting existing forests and implementing reforestation programs can significantly reduce greenhouse gas emissions. Several studies have quantified the carbon sequestration potential of forests in different regions (Pan *et al.*, 2011; Bastin *et al.*, 2019). Incorporating forests into climate change mitigation strategies requires a multi-faceted approach. This includes policy interventions, community engagement, and international cooperation (Law, 2022).

Accordingly, preparations for the UN Decade on Ecosystem Restoration, the sustainable development objectives, and agendas like decreasing emissions from deforestation and forest degradation (REDD+) have advanced efforts to reduce deforestation and forest degradation. Therefore, the essential idea is that ecosystem services which are what we all depend on for life support systems must be preserved (Munang *et al.*, 2013). The use of ecosystem-based solutions, especially the preservation and restoration of forests, is one of the most successful tactics in this undertaking. As one of the main causes of global warming, forests serve as carbon sinks, drawing significant amounts of carbon dioxide from the atmosphere (Clay, 2019).

The emphasis in recent times has been on using natural resources to slow down global warming. This study examines how forests fit into the quickly developing idea of ecosystem-based approaches to mitigating climate change, as well as the policies that try to lower carbon emissions by protecting the forests.

Drivers of Climate change

Significant climate change drivers during the industrial age have been linked to both anthropogenic activities and, to a lesser extent, natural origins. Developmental nations have been urged by the United Nations Framework Convention on Climate Change (UNFCCC) negotiations (UNFCCC 2009 and 2010) to identify land use, land use change, and forestry activities, especially those associated with the causes of deforestation and forest degradation, and to evaluate their potential to mitigate climate change (Hosonuma *et al.*, 2012).

Natural drivers

Solar Irradiance

Solar irradiance is the power per unit area (surface power density) received from the Sun in the form of electromagnetic radiation in the wavelength range of the measuring instrument. Solar irradiance is measured in watts per square metre (W/m2) in units (Solar irradiance 2024). Since solar irradiance is one of Earth's seven main energy sources, changes in it have a direct effect on the climate system (Lean, 1997). The biggest fluctuations in total solar 8 irradiance over the industrial era occur on an 11-year cycle (Frölich and Lean 2004; Grey *et al.*, 2010). The near-ultraviolet (UV) and shorter 14 wavelengths exhibit the biggest spectral variations in solar irradiance (Floyd *et al.*, 2003). These wavelengths are also the primary drivers of the 15 ozone depletion changes (Ermolli *et al*., 2013; Bolduc *et al.,* 2015, Fahey *et al.*, 2017). Variations in total and spectral solar irradiance cause noticeable changes in atmospheric heating 17 and circulation alterations by influencing ozone concentrations (Grey *et al.*, 2010; Lockwood 2012; Seppälä *et al.,* 2014, Fahey *et al.,* 2017).

Volcano

Many volcanic eruptions are small-scale occurrences, with emissions only having a short-lived, week-to-month-long impact on the troposphere. On the other hand, large-scale volcanic eruptions cause the stratosphere to be filled with ash and sulphur dioxide (SO_2), which has a major short-term impact on the climate (Myhre *et al.,* 2013). Although they are released in smaller amounts than other pollutants, volcanoes also release CO_2 and water vapour. Currently, estimates of the annual carbon dioxide emissions from volcanoes are conservative and represent less than 1% of the total carbon dioxide emissions from human activities (Gerlach, 2011). The frequency and intensity of eruptions, the latitude of injection, and, for influences on circulation and ocean temperature, the time of the eruption in relation to ocean temperature, all affect how much of an impact volcanic eruption has on the climate and circulation pattern (Zanchettin, 2012; Zhang, 2013). Natural factors can exacerbate the effects of the anthropogenic factors.

Anthropogenic Drivers

Greenhouse gases

Greenhouse gases (GHGs) are gases in the Earth's atmosphere that absorb and emit radiation, trapping heat and contributing to the Greenhouse Effect. This natural process maintains the planet's temperature, but human activities have increased GHG concentrations, leading to global warming and associated climate change impacts (IPCC, 2020).With atmospheric lifetimes of a decade to a century or more CO_2 emission sources have grown in the industrial era primarily from fossil fuel combustion (that is, coal, gas, and oil), cement manufacturing, and land-use change from activities such as deforestation. CO_2 or carbon dioxide is produced any time something is burned.

It is the most common greenhouse gas (GHG), constituting by some measures almost 55% of total long-term GHGs (Wuebbles, Fahey and Hibbard, 2017). Other GHGs include methane is produced in many combustion processes and by anaerobic decomposition, Nitrous oxide a byproduct of fertilizer production and use, other industrial processes and the combustion of certain materials. Fluorinated gases were developed to replace ozone-depleting refrigerants, but they have turned out to be incredibly hot and long-lasting. Greenhouse gases and sulphur hexafluoride, often known as SF6, are utilized in specific medical treatments. However, their main purpose is in the form of dielectric materials, which are utilized as insulators in high voltage applications like transformers and grid switching gear. By acting as a blanket over the Earth's atmosphere, greenhouse gases (GHGs) effectively absorb heat radiation from the planet's surface and keep it warmer than it otherwise would be. However, the enhanced greenhouse gas (GHG) effect is not natural because it acts to upset Earth's radiation balance because radioactive GHGs, particularly tropospheric ozone and chlorofluorocarbons (CFCs), have been artificially accumulated in Earth's atmosphere (Idowu *et al.,* 2011).

Deforestation

Deforestation occurs when forests are destroyed for other purposes, including farming or ranching, resulting in the loss or removal of tree cover. There are many who define deforestation as the permanent conversion of forests to another type of habitat (Ali *et al.,* 2015). Deforestation and land degradation account for around half of these emissions (IUCN, 2021). Deforestation causes flash floods by raising surface temperatures, excessive carbon dioxide emissions, degrading soil, and increasing surface runoff. When forest cover is removed, regional and global climate patterns are altered, causing catastrophic rainstorms to be followed by protracted dry spells (Strasser *et al.,* 2014). Deforestation results in soil degradation, carbon emission due to plant decomposition left on forest floor, albedo effect, and intensification of hydro-meteorological hazards. During the last few decades increases in urbanization and change in land use have resulted in massive increase in the rate of deforestation causing a distortion of global climate patterns (Ali *et al.,* 2015).

Deforestation Activities in Ezekoro Forest have led to environmental degradation according to reports of investigation carried out by Nneka *et al.* (2023). The research evaluated implications of deforestation on Climate Change Risks in Anambra State, Southeast Nigeria. Besides predominating strong winds that have reduced the vegetation cover, clear evidence(s) of environmental degrading actions that have reduced the quantity of woody bamboo trees to 30%, heightening erosion and flooding activities and a low crop yield of 20% were seen. Findings from satellite image showed drastic changes in the land use/land cover of Ezekoro Forest. Whereas bare surface indicating deforested (loss of trees and vegetation) areas was 1.3% in 2001, it increased to 23.5% in 2021, a change of 22.2%. Similarly, built-up area was 4.4% in 2001 but rose to 30.1%, a change of 25.7%. However, vegetation cover was 94.3% in 2001 but decreased tremendously to 46.4%, a change of 47.8% (Nneka *et al.,* 2023). This is an indication of intense deforestation over the years. An annual total of 2.6 × 109 t, or one-third, of the carbon dioxide emitted by burning fossil fuels is absorbed by forests.

Forest degradation

Forest degradation denotes thinning of the canopy and loss of carbon in remaining forests, where damage is not associated with a change in land use and where, if not hindered, the forest is expected to regrow (Hosonuma *et al.,* 2012). According to Food and Agriculture Organization of the United Nations (FAO 2002) forest degradation can be defined as: The reduction of the capacity of a forest to provide goods and services. Forests provide a wide range of ecosystem services. For example, they protect soils from erosion; regulate the water regime; capture and store carbon; produce oxygen; provide freshwater and habitat; help to reduce fire risk (in the tropics); and produce wood and non-wood forest products. Conceptually, “degraded forest” is a generic term that can be applied to all forests that have been altered beyond the normal effects of natural processes, through unsustainable use (ITTO 2002; Vásquez-Grandón, Donoso and Gerding, 2018). According to Asne *et al*. (2006) and Bustamante *et al.,* (2016), the main factors causing forest degradation are overgrazing, wildfires, unsustainable exploitation (such as excessive harvesting of forest products), and the spread of alien species and pests.

Hosonuma *et al.* (2012) analysis of the primary causes of degradation in 46 developing nations, logging (52%), firewood and charcoal gathering (31%), uncontrolled forest fires (9%), and grazing (7%), are the main drivers of degradation.

Desert encroachment is the degradation of land in dry, semi-arid, and sub-humid environments brought on mostly by changes in the climate and human activity; the dry land areas of Nigeria are particularly vulnerable to desertification. The issue of desertification is becoming worse; it is estimated that between 50% and 75% of the Nigerian states of Adamawa, Bauchi, Borno, Gombe, Jigawa, Kano, Katsina, Kebbi, Sokoto, Yobe, and Zamfara are affected by it. These states are especially vulnerable to wind erosion due to land being cleared for agricultural uses like grazing, crop planting, demand for wood, mining, increased urbanisation, and infrastructure development (Azare, 2020).

Climate change mitigation policy

Because of this powerful role as both a source and a sink for CO_2, forests have long played a key role in international climate change policy and are increasingly in the limelight (Seddon *et al*., 2019). Approximately more than a quarter of the earth's land surface is covered forests which store more than three quarters of carbon in terrestrial setting (Percy *et al.,* 2003). Strategies designed for mitigating climate change are focused on reducing the emissions of greenhouse gases (GHGs), particularly carbon dioxide (CO_2) (Gatti *et al*., 2021).

When it comes to high-level multilateral pledges for nature, the current focus is on forests. Forest management for carbon stock enhancement was introduced in the context of the UN Framework Convention on Climate Change (UNFCCC) in 1992 and the concepts of afforestation and reforestation for climate change mitigation were first introduced in the Kyoto Protocol in 1997. One of the most significant developments arising from the 2010 16th Conference of the Parties (COP 16) of the UNFCCC, was the adoption of a set of policy approaches and positive incentives to reduce greenhouse gas emissions through the conservation and management of forests in developing countries (the Cancun Agreements; Decision 1; Paragraphs 68–79 of COP 16, and associated annex). Commonly known as REDD+, this mechanism includes five sets of activities or interventions, namely; reducing emissions from deforestation, reducing emissions from forest degradation, conservation of (existing) forest carbon stocks, sustainable management of forests, and enhancement of forest carbon stocks (e.g. through regeneration and planting in previously forest land) (Gardner *et al.,* 2012). A global initiative to restore 150 million hectares of deforested and degraded land by 2020 and 350 million hectares by 2030, the Bonn Challenge was created by the International Union for Conservation of Nature (IUCN) and Germany in 2011 and presently 56 countries are participating (Dave *et al.,* 2017).

According to the 2015 Paris Agreement, parties are urged to adopt "alternative policy approaches, such as joint mitigation and adaptation approaches for the integral and sustainable management of forests, while reaffirming the importance of incentivizing, as appropriate, non-carbon benefits associated with such approaches." These approaches are related to reducing emissions from deforestation and forest degradation, as well as the role of conservation and sustainable management of forests and enhancement of forest carbon stocks in developing countries. In response, 49 signatories promised in their Nationally Determined Contributions to restore 57 million hectares of forest collectively (Bernal *et al*., 2018).

The "Ministerial Katowice Forests for Climate Declaration," which was unveiled by the Polish presidency at the 24th Conference of the Parties of the UNFCCC in December 2018, calls on all parties to take action to improve and conserve sinks and reservoirs of greenhouse gases, with a focus on "healthy, biologically diverse, and resilient forests adapted to climate change" (Seddon *et al.,* 2019). The proclamation does not, however, state that to mitigate climate change and prepare for it, there must be a significant reduction in carbon emissions and forest conservation and enhancement (Dave *et al.,* 2018). To reach the goals of the Paris Agreement by 2030, reversing the loss and degradation of forests and rehabilitating them can contribute to more than one-third of total mitigation of climate change (IUCN, 2021).

Role of forest in ecosystem-based approach to climate change mitigation

The data is now clear that conserving and restoring ecosystems is vital to holding global temperature rise to between 1.5°C and 2°C (Morecroft *et al.,* 2019). Forests have a significant role in regulating the hydrologic cycle through evapotranspiration and can be used as an effective technique to prevent climate change (Ali *et al.,* 2015). In the framework of global climate policy, ecosystem-based strategies are claimed to be able to "offer cost-effective, proven and sustainable solutions contributing to, and complementing, other national and regional adaptation strategies" (World Bank 2009). Through the sustainable delivery of ecosystem services, ecosystem-based methods to adaptation and mitigation use nature's ability to protect human communities from the negative effects of climate change (DeLosRíos-White 2020). This attention on forests is critical from a climatic perspective. Between 2007 and 2016, land-use change, primarily deforestation, accounted for around 12% of global CO_2 emissions; in contrast, during the same period, the terrestrial carbon sink stored approximately 28% of emissions, or 3.0, 0.8 $GtCO_2$ e yr^{-1} (Seddon *et al.,* 2019).

Canadell and Raupach (2008) highlighted four major strategies available to mitigate carbon emissions through forestry activities: (i) to increase forest land area through reforestation (ii) to increase the carbon density of existing forests at both stand and landscape scales, (iii) to expand the use of forest products that sustainably replace fossil-fuel CO_2 emissions, and (iv) to reduce emissions from deforestation and degradation. In general, the principles of protect, restore, and manage can be used to mitigate the effects of climate change. "Protect" refers to strategies to keep natural ecosystems from disappearing. The term "restore" describes processes that increase the geographic range of natural cover types, such as forest and non-forest ecosystems, to places where they have previously vanished due to of human activity. 'Manage' refers to pathways that avoid GHG emissions or enhance carbon sinks on working lands through improved management practices that do not reduce existing food, fibre or plant fuel yields (except where balanced by other pathways that increase yields (Griscom *et al.,* 2020).

Carbon sequestration

Rapid decarbonization of all economic sectors is necessary to meet the 2015 Paris Agreement's target of keeping warming well below 2°C (Rockström 2017; Rögelj 2018). Simultaneously, carbon sequestration must be increased. Natural filters for the atmosphere's absorption of carbon dioxide are forests. In their natural condition, they are referred to as CO_2 sinks because they release less carbon dioxide than they store (Negar and Jean 2014). The ability of forest to trap carbon and store carbon stock makes them appropriate and vital when contemplating Nature-based solutions to climate change. Terrestrial ecosystems, primarily forests, remove about 30% of the present anthropogenic CO_2 emissions. The loss of forest causes direct emissions from deforestation and reduces the capacity of global forests to remove these emissions. Reforestation on an estimated 500 Mha of deforested land in the tropics is feasible, according to Houghton et al. (2015). This could sequester 3.7 $GtCO_2$ e yr^{-1}.for decades, though productivity would start to decline after 2065. According to the IPCC (2018), predictions for the period up to 2050 vary from 1 to 7 $GtCO_2$ e yr^{-1}.in the literature. Using a variety of limitations and a thorough literature analysis, Fuss et al. (2018) reduced this to 0.5–3.6 $GtCO_2$ e yr^{-1}. The estimates range from 1 to 12 $GtCO_2$ e yr^{-1}.up to 2100. The degree to which ancillary benefits and climate protection are linked will determine the viability of carbon sequestration. The magnitude of this potential will be increased by high carbon prices driven by aggressive emission reduction targets, and by the political will to include forestry activities as part of mitigation portfolios (Canadell and Raupach 2008).

Carbon stock

Roughly 60% of the total carbon stock found in terrestrial carbon pools is stored in forest land. According to Van Goor and Snoep (2019), the total quantity of carbon stored in the world's forests exceeds the anticipated carbon emission potential of the current fossil fuel reserves. At rates as high as 3 Pg C yr^{-1}, carbon is accumulating in secondary forests that are recovering from harvests and swidden cultivation. Right now, this gross rate of uptake is occurring. In growing forests, up to 3 Pg C yr^{-1} would accumulate for decades before declining as the forests matured if the associated gross emissions from harvests and re-clearing of fallows were stopped (Dinerstein *et al.,* 2015).

However, as forests get older, the rate at which carbon accumulates in them decreases. As a result, our research suggests that the 4 Pg C yr^{-1}sink would remain, on average, for 50 years (until 2065) before decreasing linearly to zero by 2095. The absorption is likely to continue at a high level well beyond a 50-year period because large trees, which contain much of the above-ground forest carbon, are typically absent from degraded forests (because they are sought after in selective logging) and because it can take a century for large trees to mature fully. Less conservative estimates of how long the remaining 3 Pg C yr^{-1}sink would last produce comparable conclusions, even in the absence of 500 million hectares of reforestation (Houghton, Byers, and Nassikas 2015). Managing tropical forests as ecosystem-based approach (EBA) to help stabilize and then reduce CO_2 concentrations could be implemented more quickly than the phasing out of fossil fuels, not needing as much development (technical, economic, marketing, infrastructure, and manufacturing and installation capacity) as the expansion of renewables to scale. Furthermore, as long as they are not selectively cleared for agriculture or other purposes, burned, logged, harvested, or otherwise altered, many tropical forests will continue to grow and absorb carbon for a few decades. Unlike in boreal forests, the biogeochemical benefits (carbon sequestration) of tropical forests are not counteracted by their biophysical characteristics (e.g., albedo and evapotranspiration) (Reick *et al.*, 2010). And, finally, the recent United Nations Framework Convention on Climate Change (UNFCCC) efforts to proceed with REDD+ ('reduce emissions from deforestation and forest degradation in developing countries'; http://redd.unfccc.int/) demonstrates political willingness to manage forests for climate change mitigation (Houghton *et al.,* 2015).

Conclusion

Climate change has become a concept of major concern in developed and developing countries. There is much focus now on nature-based solutions for climate change mitigation. Having the ability to reduce carbon through sequestration and serving as carbon stock, forest have a pivotal role to play in Ecosystem-based approach to mitigate climate change.

Recommendations

To address these challenges, Nigeria can adopt several strategies:

1. Strengthening Forest Governance: Effective policies and regulations are needed to protect forests and promote sustainable management practices. This includes enforcing laws against illegal logging and supporting community-based forest management initiatives.
2. Reforestation and Afforestation: Planting new trees and restoring degraded forests can enhance carbon sequestration and improve ecosystem health. Reforestation projects should prioritize native species and involve local communities to ensure long-term success.
3. Promoting Agroforestry: Integrating trees into agricultural landscapes can provide multiple benefits, including increased carbon storage, improved soil health, and enhanced biodiversity. Agroforestry practices can also diversify income sources for farmers and reduce pressure on natural forests.
4. Raising Awareness: Public education and awareness campaigns can highlight the importance of forests in climate change mitigation and encourage sustainable practices. Engaging stakeholders at all levels, from local communities to policymakers, is essential for building support for forest conservation efforts.

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