International Journal of Environment and Climate Change

Volume 15, Issue 1, Page 309-327, 2025; Article no.IJECC.130190
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Impacts of Mangrove Loss on Greenhouse Gas Emissions in the Niger Delta, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijecc/2025/v15i14694

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/130190

Original Research Article

Received: 16/11/2024
Accepted: 18/01/2025
Published: 25/01/2025

ABSTRACT

The mangrove vegetation within the Niger Delta region of Nigeria is ravaged by anthropogenic practices including but not limited to rapid urbanization, aquaculture expansion and oil exploration which penultimately distorts the biodiversity of both the mangrove and marine environments, culminating in the loss of structural and functional integrity of these ecosystems, specifically their role in climate change regulation. The study aimed at assessing the changes in mangrove covers from 1987 to 2022 in the study area as well as examining the changes in GHGs emissions resulting

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Cite as: *Jonah, Useh, Uwem, Magaji, J. I, Sunday Kpalo, Lay, U. S, and Useh, Mercy Uwem. 2025. "Impacts of Mangrove Loss on Greenhouse Gas Emissions in the Niger Delta, Nigeria". International Journal of Environment and Climate Change 15 (1):309-27. https://doi.org/10.9734/ijecc/2025/v15i14694.*

from the mangrove changes. The methodology adopted a remote sensing-based research design utilizing satellite imagery to analyze temporal changes in mangrove cover and evaluated their association with climate variables such as CO_2 emissions and LST of the study area. Each satellite image geo-referenced in ArcGIS 10.8 & LULC changes calculated using geometry module of ArcGIS 10.8. NDIR spectroscopy was used in examining the variation in GHGs emissions. The data obtained revealed mangrove reduction from 12,991 km^2 in 1987 to 9,089km^2 in 2022 resulting in the loss of 3,904.00 km^2 of mangrove forest. The reduction resulted in increased CO_2 emissions from 370.70 ppm to 403.29 ppm between 1987 and 2022. These results illustrate a clear link between mangrove cover change and CO_2 emissions, highlighting the critical role mangroves play in regulating climate change. The study was able to show that significant losses in mangrove cover have been closely associated with increased CO_2 emissions, thus reflecting the vital role these ecosystems play in carbon sequestration which underscores the importance of preserving these vital ecosystems to mitigate local and global climate impacts.

Keywords: Niger Delta; mangrove cover; greenhouse gases; urbanization.

1. INTRODUCTION

Mangroves are characterized by their high productivity (Komiyama et al., 2008) and capacity to store large amounts of organic carbon in its soils (Donato et al., 2011; Nellemann et al., 2009). “The carbon accumulation in its soils is a function of the inputs of organic carbon compounds, formed basically by photosynthetic processes sequestering atmospheric CO_2, and the losses caused by decomposition, erosion and leaching” (Stockmann et al., 2013). “The organic compounds enter the edaphic system as litter, decaying roots, root exudates, and microbial biomass, which are decomposed by the activity of micro and mesofauna” (Nelson and Oades, 1998).

“Mangroves play a crucial role in mitigating climate change by removing carbon dioxide from the atmosphere and storing it in their biomass and sediments. Protecting and restoring mangrove forests is therefore considered an important strategy for climate change mitigation. Mangroves have been identified as blue carbon ecosystems that are natural carbon sinks” (Donato et al., 2011; Lovelock et al., 2020; Murray et al., 2011). “These carbon rich ecosystems store carbon in both aboveground and belowground carbon pools and have a mean global ecosystem carbon stock of 939 Mg C ha^{-1} (range 856–1023 Mg C ha^{-1}) of which 49%–98% is stored in the soil” (Alongi, 2012; Donato et al., 2011; Kauffman et al., 2014; Sanderman et al., 2018). “Storage of carbon by coastal wetland ecosystems (such as mangroves) can be managed (e.g., conserved or restored) to assist in reducing atmospheric CO_2” (Pendleton et al., 2012; Windham-Myers et al., 2019).

“Emissions of carbon dioxide (CO_2) and methane (CH_4) by mangrove sediments are potential sources of greenhouse gas to the atmosphere and as such may contribute to global climate change” (Barnes et al., 2006). “On the other hand, the high primary production by mangrove trees, accretion and permanent storage of organic carbon in sediments point to the fact that many mangrove environments are actually sinks of atmospheric CO_2” (Alongi 2012). “There are, however, large geographical differences in published attempts to estimate mangrove carbon gas balance caused by variations in factors such as geomorphology, freshwater input and degree of eutrophication” (Alongi et al. 2014). Furthermore, it is important not only to consider the carbon balance in terms of CO_2 because CH_4 has about 20 times greater global warming potential than CO_2. CH_4 can be a major product of sediment carbon mineralization (Canfield, 2004) and as such a potential greenhouse gas emitted from mangrove ecosystems (Barnes et al. 2006).

Mangroves within the Niger Delta community proffer an avenue to address and promote life on land in line with the sustainable development goals (SDG). They aid in offering protection towards land degradation, thwarting the effects of extreme weather including absorption of emissions. Mangroves possess highly established root systems that also promote sediment deposits, modulate water flow, filtration of essential cations, etc. Periodic assessment of the mangrove ecosystem also serves to protect the vast diversity of flora and fauna, thus meeting the call to action for the protection, restoration and promotion of sustainable land practices. Within the Niger Delta, mangroves can be seen as a bridge between life on land and climate change by virtue of its carbon sequestration ability. Also, mangroves in the Niger Delta protect such coastal communities from raising sea levels as well as the deleterious effects of storms, whilst sustaining the associated cities and communities, thereby addressing SDGs 1, 2, 6, 11, 15 and 16 (Bajaj et al*.,* 2024).

“Historic rates of mangrove deforestation posed a serious risk of significant GHG emissions and since the 1950’s it has been estimated that up to 50% of the world’s mangroves have been deforested, largely due to land-use change” (Alongi, 2002). Despite estimates of recent global mangrove loss slowing to 4.0% of global coverage between 1996 and 2016 (Richards et al., 2020), it has been estimated that > 300 million Mg of CO_2e were emitted as a result of mangrove deforestation between 2000 and 2012 (Hamilton and Friess, 2018). Between 2000 and 2016, 87% of mangrove loss in the West Coral triangle, where the vast majority of the world’s mangroves organic carbon is stored, was due to agriculture/aquaculture land-use conversion (Adame et al., 2021). Mangrove conservation and restoration programs on a national scale have been identified as an efficient means of offsetting GHG emissions (Murdiyarso et al., 2015; Taillardat et al., 2018; Cameron et al., 2019), although the prevention of further forest loss, by far, outweighs gains from restoration (Kauffman et al., 2017).

In mangroves, due to the frequent flooding event by seawater, organic matter decomposition occurs by reducing other electron acceptors substituting the O_2 (i.e., $O_2 \rightarrow NO_3{}^- \rightarrow$ Mn oxyhydroxides → Fe oxyhydroxides → $SO_4{}^{2-} \rightarrow CO_2$), decreasing the decomposition rate as a result of the lower energetic yield (Alongi et al., 2009). Because of the combination of high biomass production and low decomposition rates, mangroves, and other coastal wetlands have been denominated as “Blue Carbon sinks” emphasizing the important role that these ecosystems perform in sequestering atmospheric CO_2 (Duarte et al., 2005; Mcleod et al., 2011).

“CO_2 production in mangrove soils refers to microbial activity during organic matter degradation, mainly, and root respiration” (Lovelock et al., 2011). “The CO_2 flux to the atmosphere occurs when microorganisms oxidize the organic carbon using O_2, NO^{3-}, Mn^{4+}, Fe^{3+}, and $SO_4{}^{2-}$ as electron acceptors. On the other hand, CH_4 production occurs in flooded areas using CO_2 or other methyl compounds under extreme anoxic conditions” (Kristensen, 2007; Yu et al., 2009). “Besides, N_2O is produced by nitrification processes, converting ammonium to nitrate under aerobic conditions or by a denitrification process that involves anaerobic reduction of nitrate to N_2” (Chauhan et al., 2016). Since the GHG emission is performed through microbial processes, the edaphic and climatic factors (e.g., redox potential; organic carbon content; salinity and temperature) may affect these emissions (Chen et al., 2010).

“Despite its ecological importance, including its role in sequestering atmospheric CO_2, the mangrove forests are declining to extinction due to anthropogenic impacts that directly remove the vegetation, e.g., aquaculture, urbanization and coastal landfill” (Duke, 2016). “Globally, the mangroves occupy 0.7% of the tropical forest area, but their destruction currently adds 10% to global CO_2 release from tropical deforestations” (Alongi, 2014). “Other activities (i.e., shrimp farming and eutrophication) are related to nutrient-rich effluent release, which promotes changes in the soil characteristics and stimulates organic matter decomposition, increasing CO_2 fluxes” (Chen et al., 2010). In addition, mangroves can be an important source of CH_4 and N_2O to the atmosphere (Barnes et al., 2006; Kristensen, 2007) contributing to global climatic changes due to its warming potential (Chauhan et al., 2016).

While the potential for GHG emissions from mangrove deforestation are well documented (Lovelock et al., 2011; Kauffman et al., 2014; Lang’at et al., 2014; Atwood et al., 2017; Hamilton and Friess, 2018), the effects of climate change on global mangrove carbon stocks are less frequently addressed (Adame et al., 2021) and are therefore a priority research area for blue carbon science (Macreadie et al., 2019). Change in climatic regimes could also prove a significant factor in changing overall stocks in mangroves through altering forest biomass and productivity and its subsequent contribution to soil C stocks and soil sequestration rates (CSR).

Consequently, Chatting et al., (2022) conducted a study where they modelled the effects of climate change on future carbon stocks and soil sequestration rates (CSR) under two climate scenarios (“business as usual”: SSP245 and high-emissions: SSP585). Model results were contrasted with CO_2 equivalents (CO_2e) emissions from past, present and future rates of deforestation on a country specific scale. For carbon stocks, they found out that climate change will increase global stocks by ~7% under both climate scenarios and that this gain will exceed losses from deforestation by the end of the twenty-first century, largely due to shifts in rainfall. Major mangrove-holding countries Indonesia, Malaysia, Cuba, and Nigeria will increase national carbon stocks by > 10%. Under the high-end scenario, while a net global increase is still expected, elevated temperatures and wider temperature ranges are likely to increase the risk of countries' carbon stocks diminishing.

For CSR, Chatting et al., (2022) reported that "there will likely be a global reduction under both climate change scenarios such that 12 of the top 20 mangrove-rich countries will see a drop in CSR. Modelling of published country level mangrove deforestation rates showed that emissions have decreased from 141.4 to 6.4% of annual CSR since the 1980's. Projecting current mangrove deforestation rates into the future resulted in a total of 678.50 ± 151.32 Tg CO_2e emitted from 2012 to 2095. Reducing mangrove deforestation rates further would elevate the carbon benefit from climate change by 55–61%, to make the proposition of offsetting emissions through mangrove protection and restoration more attractive". These results according to Chatting et al., (2022) demonstrated "the positive benefits of mangrove conservation on national carbon budgets, and they identified the nations (e.g. Indonesia) where incorporating mangrove conservation into their Nationally Determined Contributions offers a particularly rewarding route toward meeting their Glasgow Agreement commitments".

The study aimed to evaluate factors influencing greenhouse gas (especially CO_2) emissions from Niger Delta Mangrove Forests in Southern Nigeria under different anthropogenic activities, in order to better comprehend the role of these endangered ecosystems for GHG emissions and carbon sequestration.

2. METHODOLOGY

The study adopted a remote sensing-based research design using satellite imagery to analyse temporal changes in mangrove cover and evaluated their association with climate variables such as variation in the CO_2 emissions and land surface temperature (LST) of the study area.

2.1 Study Area

Niger Delta Region is situated between longitude (5.05°E-7.17°E) and latitude (4.15° N-7.17°N) in the southern part of Nigeria and bordered to the south by the Atlantic Ocean and to the East by Cameroon. It occupies a total land area of 75,000 square kilometres, and it is the world's second largest delta with a coastline of about 450 km (Awosika, 1995). Niger Delta is composed of 9 out of 36 states in Nigeria, (Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Ondo, Imo and Rivers), and has 185 out of 774 local government areas. The predominant settlement type in the Niger Delta is small and scattered hamlets (Akpan et al., 2017). The vast majority of settlements comprise largely rural communities in dispersed village settlements. In total, there are 13,329 settlements in the Niger Delta Region (Enaruvbe and Atafo, 2014). Extrapolations from the 1991 National Population Census showed that at a growth rate of 2.9% the population of the Niger Delta Region by 2004 was about 30 million. There is an estimated population of about 41.5 million (about 22% of Nigeria's population of 200 million) and characterized by high ethnic and cultural diversity (NPC, 2023). The region has a maximum elevation of about 3m above mean sea level on the sandy barrier islands that border the sea and the Montana zone, is confined to the northeastern part of Cross River State being a high-altitude area approximately 900m to 1500m above sea-level (Dangana, 1981).

The study area is the Mangrove Forest in the Niger Delta Region, located along the Gulf of Guinea in the South-South Geopolitical Zone of Nigeria. It extends along the Gulf of Guinea, from the mouth of the Benin River for a distance of about 450 km, to its eastern flank at the Calabar Estuary in Cross River State. It lies between latitudes 4° 16′ 22″ and 5° 33′ 49″ N and longitudes 5°3′49″ E and 7° 35′ 27″ E (Fig. 1). The Niger Delta Mangrove Ecosystem is the third largest mangrove in the world, comprising some 36,000 km^2 in area (Wang et al., 2016). It is spread across Ondo, Edo, Delta, Bayelsa, Rivers, Akwa-Ibom and Cross Rivers (James et al., 2013). According to Ayanlade (2012) Niger Delta has four ecological zones namely the mangrove vegetation, freshwater swamp, rainforest, and derived savannah.

The Nigerian coastal zones have a tropical climate with rainy and dry seasons (Nwilo and Badejo, 2006). The Niger Delta areas generally have an equatorial climate on its southern coast and subequatorial climate in the north. The monthly mean temperature ranges between 25 °C and 29 °C, while the annual precipitation ranges between 2000 mm and 4000 mm, with relative humidity being above 70%. The rainy season in the Niger Delta lasts from March to October, with a little dry spell experience during the August break due to monsoon winds from the southwest that carries moisture from the ocean into the hinterland. The dry season lasts from November to February with harmattan experienced between December and February that is caused by tropical continental air mass from the north (Ohwo, 2015). The coastline is generally classified into four geomorphological units viz: The Strand coast, the Mud coast, the Barrier Lagoon coast and the Niger Delta (Agumagu, 2015). Creeks, estuaries, and rivers cover an estimated 2370 km^2 of the Niger Delta land; stagnant swamps cover approximately 8600 km^2, while the mangrove swamp with about 1900 km^2 is considered Africa's largest (Uyigue and Agho, 2007).

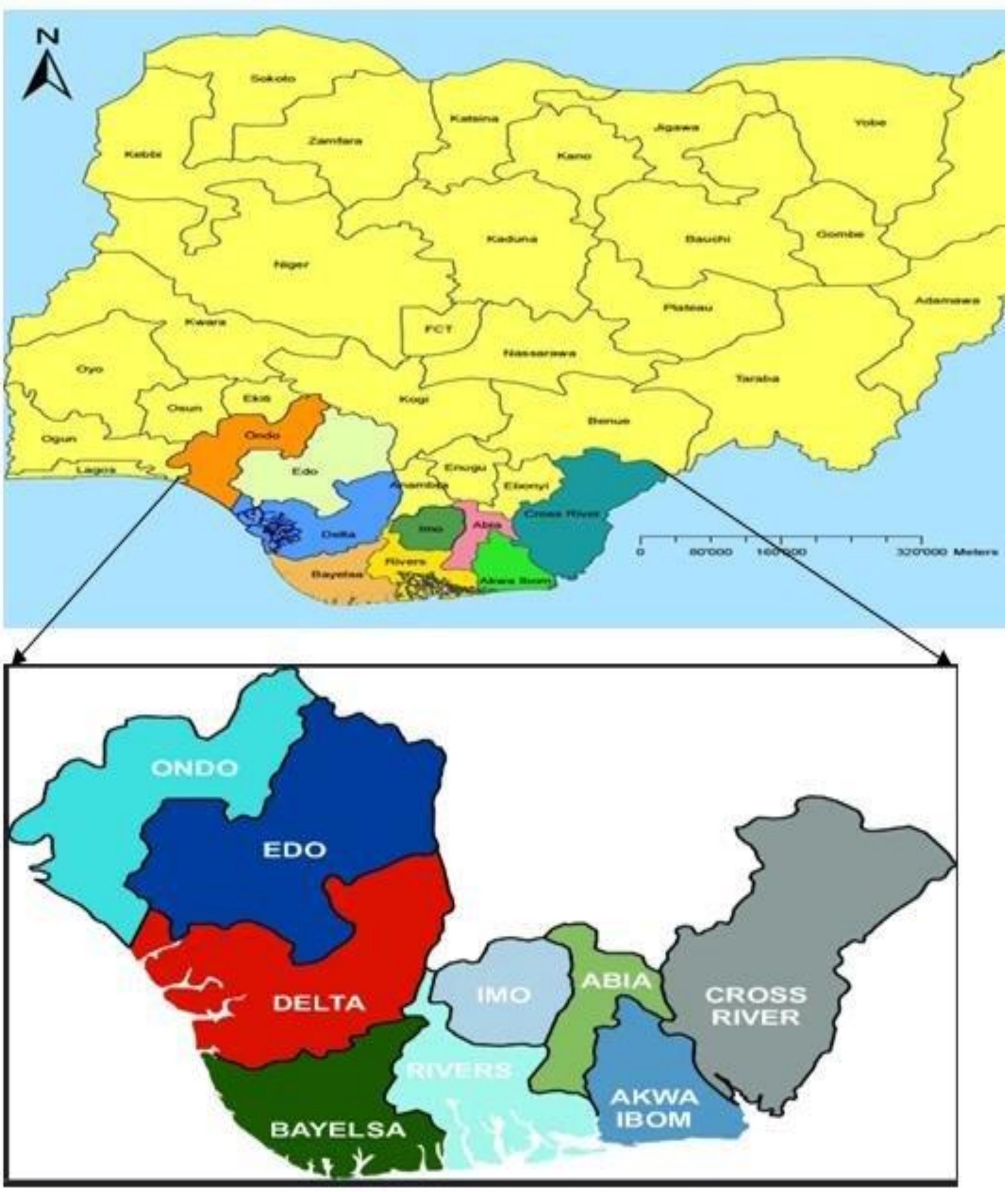

Fig. 1. Map of Nigeria showing Niger Delta Region