

Spatio-Temporal Analysis of Carbon Sequestration Potential and Biomass Loss in Selected Forest Reserves of Akwa Ibom State, Nigeria (1986–2019)

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Abstract

This study evaluates the carbon sequestration potential and biomass dynamics within three critical forest reserves in Akwa Ibom State, Nigeria, over a comprehensive thirty-two-year longitudinal period (1986–2019). Utilizing a robust mixed-method approach that integrates Geographic Information Systems (GIS) mapping with non-destructive field inventory techniques, tree diameters at breast height (DBH) were measured, ranging significantly from 4.14 cm to 197.45 cm across the study sites. The findings reveal a substantial average carbon density of 113,532.26 kg C ha⁻¹, while the mean regional sequestration potential was established at 206,333.126 kg C year⁻¹. However, the spatial-temporal analysis uncovers an alarming and persistent trend of carbon depletion; specifically, the Ogu Itu and Stubb Creek reserves suffered massive biomass losses exceeding 13 million and 6 million kg C, respectively, primarily driven by deforestation for local livelihoods. While the current sequestration potential remains higher than those identified in comparable regional studies, the accelerating rate of biomass loss threatens to transition these vital ecological sinks into active atmospheric emission sources. These results provide a critical empirical framework for localized conservation strategies aimed at enhancing sustainable forest management and mitigating the long-term impacts of climate change within the Niger Delta region.

Keywords: Carbon Sequestration, Biomass Density, Deforestation, GIS Mapping, Akwa Ibom State, Climate Mitigation, Forest Degradation, DBH Analysis.

Introduction

The assessment of carbon sequestration potential within existing forest covers is a critical endeavor for

understanding the ecological health and climate mitigation capacity of regional landscapes in the face of global warming. This study evaluates the complex carbon dynamics across three strategic Local Government Areas (LGAs) in Akwa Ibom State—Ikot Uso Akpan, Ogu Itu, and Stubb Creek utilizing detailed field data and spatial mapping spanning from 1986 to 2019. Measuring a wide variety of tree diameters ranging from 4.14 cm to 197.45 cm, the research identifies a mean carbon sequestration potential of 206,333.126 kg C year⁻¹ for the state's protected forest areas. However, a longitudinal comparison reveals a stark and worrying decline in total carbon stocks over the decades; for instance, the total storage in the Ogu Itu forest reserve plummeted from over 96 million kg C in 1986 to approximately 83.7 million kg C by 2018. This significant incidence of carbon loss, totaling millions of kilograms across the various study sites, is primarily attributed to heightened emissions stemming from systemic deforestation and forest degradation. Analyzing these shifts in biomass density and sequestration rates over a thirty-two-year period, this study provides a foundational framework for localized conservation strategies aimed at reversing carbon depletion.

Statement of Problem

The core problem addressed in this research is the significant and accelerating degradation of carbon sequestration capacity in Akwa Ibom State's forest reserves due to persistent and unmanaged deforestation. Despite the recorded mean sequestration potential of 206,333.126 kg C year⁻¹, the longitudinal data collected from 1986 to 2019 reveals a massive net loss of carbon stocks that undermines the region's environmental stability. Notably, the Ogu Itu and Stubb Creek reserves have suffered dramatic losses exceeding 13 million and 6 million kg C, respectively, within the study timeframe. This progressive decline transforms vital carbon sinks into active emission sources, thereby threatening regional climate stability and reducing the ecosystem's ability to buffer against environmental shocks. The current trajectory suggests that anthropogenic pressures driven by the need for timber, agricultural land, and fuel are outpacing the natural regenerative capacity of these forests. Without urgent and evidence-based intervention, the widening gap between natural sequestration and anthropogenic biomass loss will continue to erode the ecological integrity of these protected areas, eventually leading to a total collapse of their carbon storage functions and a subsequent rise in localized atmospheric carbon concentrations.

Research Question

How has forest degradation and deforestation in Akwa Ibom State affected the carbon storage and sequestration rates of the Ikot Uso Akpan, Ogu Itu, and Stubb Creek reserves between 1986 and 2019, and what is the current mean carbon sequestration potential of these forest covers for climate mitigation?

Study Area

The study area encompasses three distinct and ecologically significant Local Government Areas (LGAs) within Akwa Ibom State, Nigeria, specifically focusing on the Ikot Uso Akpan community forest, the Ogu Itu forest reserve, and the Stubb Creek forest reserve. These sites were strategically selected to represent the region's diverse forest cover types, ranging from coastal mangroves to inland tropical rainforests, and to capture the varying levels of ecological preservation and human interference present in the state. Geographically, the area is characterized by a significant but fluctuating biomass density, with tree diameters (DBH) showing a remarkable range from 4.14 cm in the Itu area to as large as 197.45 cm in the Ini LGA. This structural diversity indicates a forest system comprised of both young regrowth and ancient, high-biomass timber, each contributing differently to the overall carbon budget. The environmental profile of the study area is defined by its substantial historical carbon storage capacity, which averaged 113,532.26 kg ha⁻¹ across the monitored plots during the initial phases of the study, marking it as one of the most productive ecological zones in the southern Nigerian belt.

In addition to its ecological richness, the study area serves as a critical focal point for observing the intense anthropogenic pressures typical of the Niger Delta region. The documented carbon losses between 1986 and 2019 serve as a spatial testament to the impact of human settlement, subsistence farming, and industrial expansion on protected lands. While the landscape provides a critical baseline for calculating the state's mean carbon sequestration potential of 206,333.126 kg C year⁻¹, it also highlights the vulnerability of these "protected" reserves to illegal logging and land clearing. The Stubb Creek reserve, in particular, represents a unique coastal ecosystem that faces the dual threat of rising sea levels and intense biomass extraction for charcoal and building materials. This multifaceted landscape offers a unique opportunity to study the intersection of natural carbon cycles and human-driven environmental change. Focusing on these three specific LGAs, the research captures a representative cross-section of Akwa Ibom's natural heritage, providing data that is both locally relevant and broadly applicable to tropical forest management across West Africa, where similar socio-economic drivers often lead to rapid forest loss.

Materials and Methods

This research employed a rigorous mixed-method approach, seamlessly integrating primary fieldwork data analysis with advanced Geographic Information Systems (GIS) and remote sensing technologies to evaluate carbon dynamics across the three target LGAs. During the 2018/2019 field phase, a non-destructive sampling technique was strictly adhered to, allowing for the measurement of tree structural parameters without damaging the existing flora. The primary focus was on the diameter at breast height (DBH), with measurements spanning from 4.14 cm to 197.45 cm across various plots. These physical measurements were subsequently processed using standardized algometric equations to estimate carbon per

hectare and the total biomass storage of the reserves. To assess longitudinal changes over more than three decades, the researcher compiled and analyzed historical satellite imagery and field records from 1986, 2006, 2016, and 2019. Extrapolating the plot-level carbon density data to the total designated forest area, the study was able to calculate annual sequestration rates and accurately quantify the volume of carbon lost to the atmosphere. This spatial-temporal analysis allowed for a precise, year-by-year comparison of carbon sink capacities and the quantifiable impact of deforestation.

Results: Spatio-Temporal Analysis of Carbon Density

The figures below illustrate the spatial distribution of carbon per hectare for the years 1986, 2006, 2016, and 2019. These maps visualize the biomass density shifts resulting from land-use changes and forest successional stages.

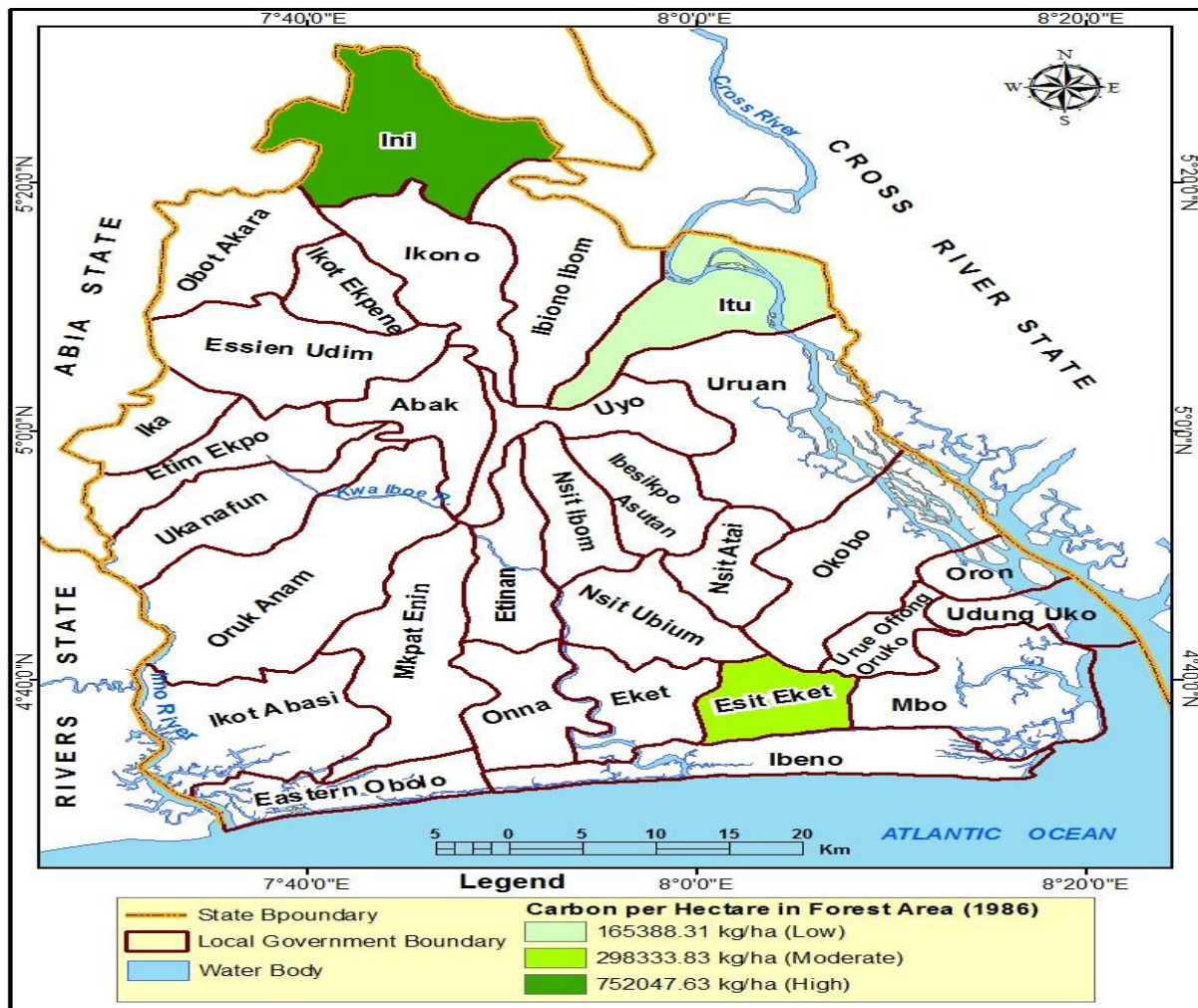


Figure 4.1: Carbon per hectare in forest area (1986)

Source: Compiled by the researcher using fieldwork data analysis (2019)

The 1986 baseline map illustrates the spatial distribution of carbon density across the study's focal Local Government Areas, revealing high initial storage levels prior to significant anthropogenic pressure. Ini LGA exhibited the highest carbon density at 752,047.63 kg/ha, while Esit Eket and Itu displayed moderate and low densities of 298,333.83 kg/ha and 165,388.31 kg/ha, respectively. This period represents a critical ecological benchmark, as subsequent years show a stark decline in these figures. The data confirms that during this era, the forest cover in these regions functioned as robust carbon sinks, possessing substantial biomass and sequestration potential before the onset of accelerated deforestation.

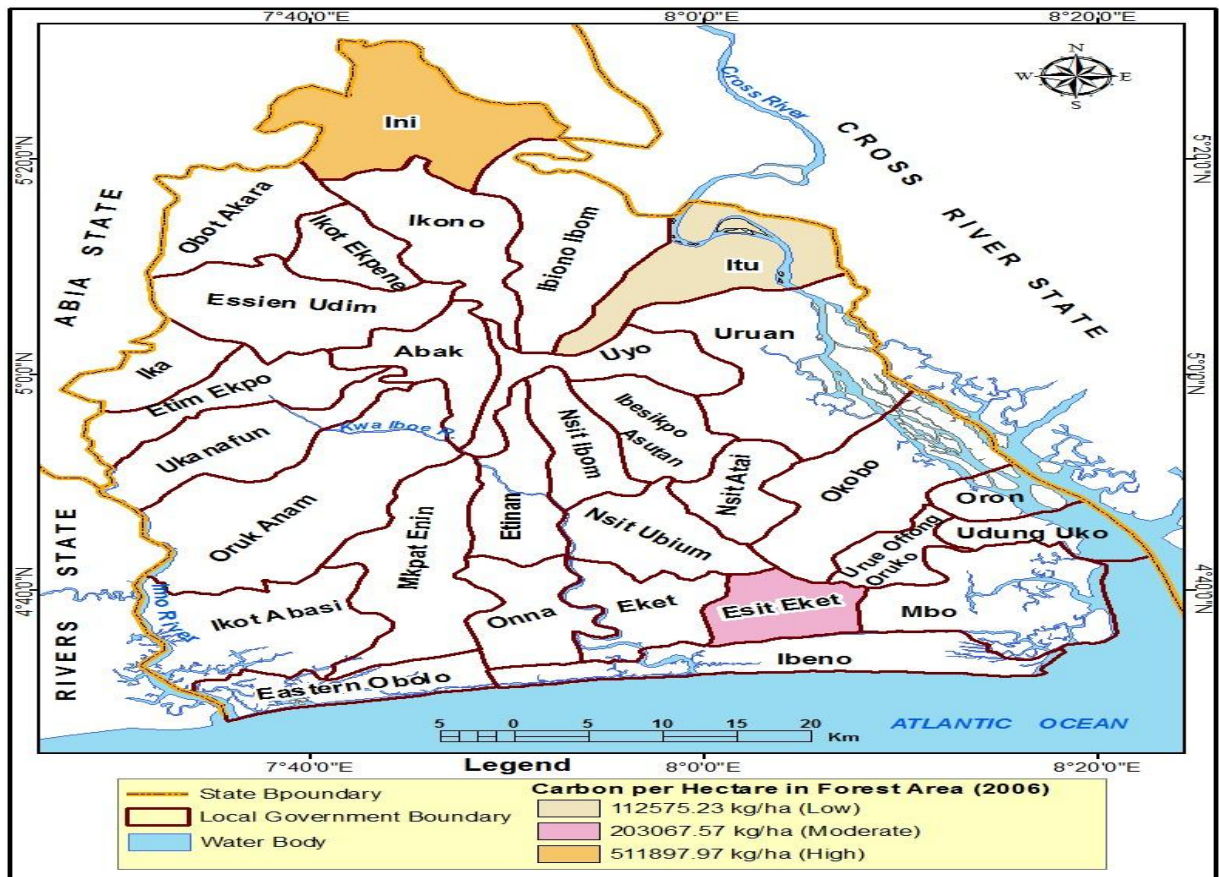


Figure 4.2: Carbon per hectare in forest area (2006)

Source: Compiled by the researcher using fieldwork data analysis (2019).

The spatial distribution of carbon density across Akwa Ibom State underwent a significant decline between 1986 and 2006, as illustrated by the comparative mapping of the three study

areas. In 1986, Ini LGA maintained a high carbon density of 752,047.63 kg/ha, which plummeted to 511,897.97 kg/ha by 2006. Similarly, Esit Eket dropped from 298,333.83 kg/ha to 203,067.57 kg/ha, while Itu decreased from 165,388.31 kg/ha to 112,575.23 kg/ha. This downward trend highlights a substantial reduction in biomass, directly attributed to anthropogenic pressures and deforestation, which weakened the region's overall carbon sequestration potential and ecological stability over the twenty-year period.

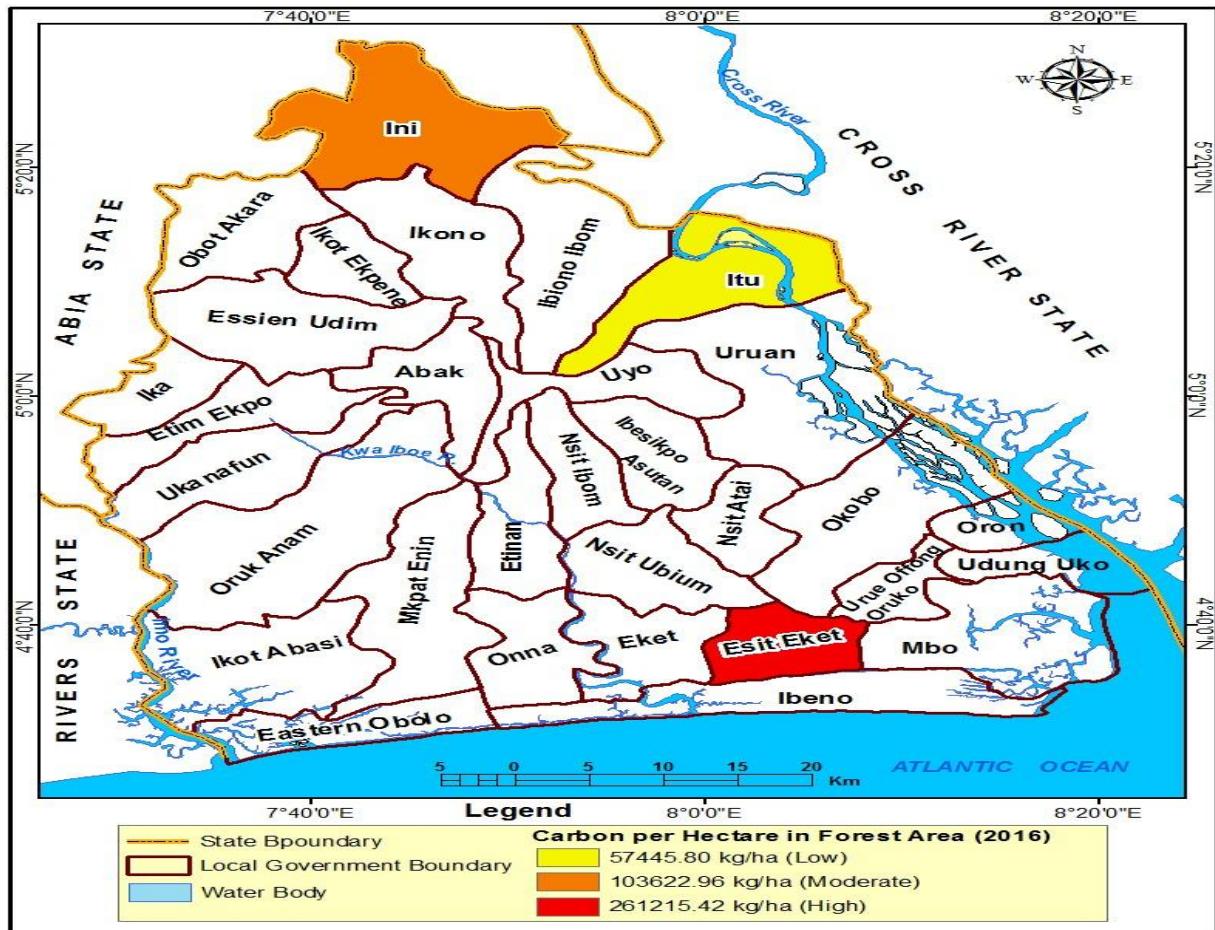


Figure 4.3: Carbon per hectare in forest area (2016)

Source: Compiled by the researcher using fieldwork data analysis (2019)

The longitudinal spatial analysis of carbon density across Akwa Ibom State from 1986 to 2016 reveals a progressive and alarming decline in forest carbon stocks. In 1986, Ini LGA recorded a "High" density of 752,047.63 kg/ha, which dropped significantly to 511,897.97 kg/ha by 2006 and reached a "Moderate" status of 103,622.96 kg/ha in 2016. Similarly, Itu and Esit Eket LGAs experienced sharp reductions, with Itu falling to just 57,445.80 kg/ha by 2016. This spatial-temporal trend underscores a severe erosion of the region's carbon sequestration capacity, primarily driven by sustained anthropogenic pressures and deforestation over the thirty-year period.

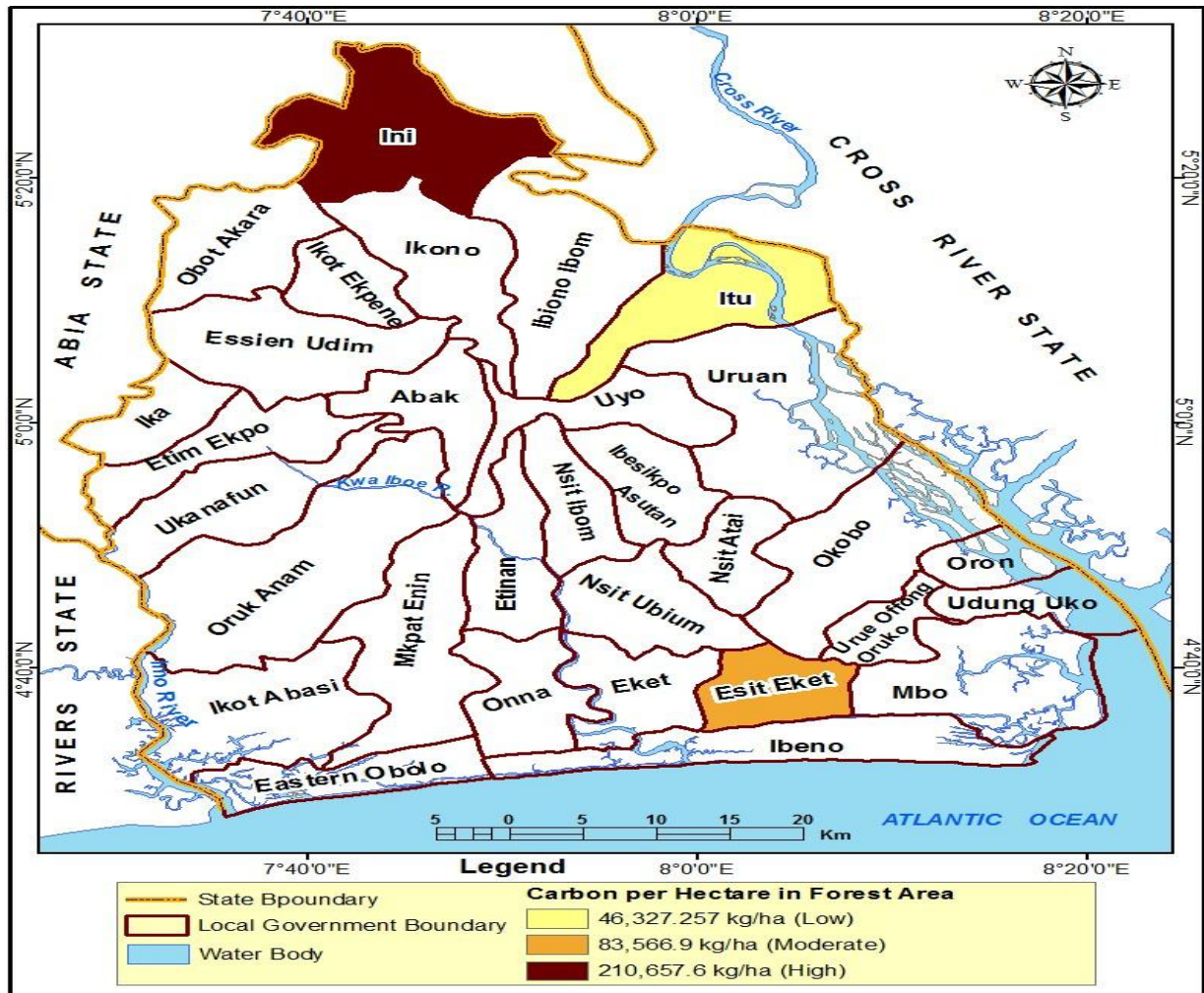


Figure 4.4: Carbon per hectare in forest area (2019)

Source: Compiled by the researcher using fieldwork data analysis (2019).

The 2019 spatial analysis represents the final assessment period, revealing that carbon density reached its lowest historical levels across the monitored LGAs. Ini LGA, formerly a high-density stronghold, declined to 210,657.6 kg/ha, while Esit Eket and Itu fell to 83,566.9 kg/ha and 46,327.257 kg/ha respectively. This concluding data point confirms a persistent 33-year trend of biomass erosion. Although these areas still maintain a mean sequestration potential of 206,333.126 kg C year⁻¹, the significant shift toward the "Low" and "Moderate" classifications underscores a critical ecological transition, necessitating immediate conservation interventions to prevent further atmospheric carbon release.

Discussion of Findings

Spatio-Temporal Analysis of Carbon Sequestration Potential and Biomass Loss in Selected Forest Reserves of Akwa Ibom State, Nigeria (1986–2019)

The findings from this thirty-two-year analysis reveal that the average carbon sequestration potential for forest areas in Akwa Ibom State currently stands at a robust 206,333.126 kg C year⁻¹. However, this figure is overshadowed by a sharp and continuous decline in carbon density across all studied reserves when viewed through a spatio-temporal lens. For instance, the Ini LGA, which served as the high-density ecological benchmark in 1986 with a storage of 752,047.63 kg/ha, saw its carbon density plummet to a mere 210,657.6 kg/ha by 2019. Similar alarming trends were observed in the Esit Eket and Itu reserves, which reached historical lows of 83,566.9 kg/ha and 46,327.257 kg/ha, respectively, by the end of the study period. This severe erosion of biomass is primarily attributed to heightened anthropogenic pressures, including the expansion of agricultural peripheries and the clearing of forest land for local livelihood support. Interestingly, the data suggests that forest areas located closer to the state capital or major urban centers appeared more conservative or stable in their later years; this is likely because their most accessible natural resources had been previously impacted, whereas more distant, "pristine" areas experienced much higher rates of recent degradation.

When placed in a broader academic context, the carbon sequestration potential and total stocks recorded in Akwa Ibom State exceed those reported in many prominent regional and international studies. For example, research by Behnaz (2016) in Iran and Olufunke et al. (2015) in other parts of Nigeria reported significantly lower carbon storage values. Specifically, Olufunke et al. identified carbon stocks ranging from 14.84 t to 29.36 t per hectare, whereas the average for the Akwa Ibom study sites remains significantly higher at 113,532.26 kg/ha. Despite these relatively superior baseline figures, the visible field evidence of rapid depletion suggests that the integrity of the state's forest reserves is highly vulnerable and currently in a state of crisis. The study's results align with the prevailing ecological theory that reduced anthropogenic activity is the primary driver for increased carbon sequestration. The stark difference between the 1986 "High" density classifications and the 2019 "Low" classifications serves as a visual and mathematical warning of the consequences of unmanaged land use. If the current deforestation trends are not curtailed, the state risks losing its status as a high-biomass region, leading to a permanent shift in the local carbon balance.

The final stage of the discussion emphasizes the critical ecological transition currently taking place within the Niger Delta's forest systems. The transition of these reserves from robust carbon sinks to potential net emission sources is not merely a local concern but a significant contributor to the global climate crisis. The massive loss of over 13 million kg C in Ogu Itu and 6 million kg C in Stubb Creek represents a significant release of stored carbon back into the atmosphere, which directly counteracts regional efforts at climate change mitigation. This study highlights a clear pattern: as the human population grows and economic dependency on

forest resources increases, the natural capacity of the environment to sequester carbon is being outpaced. The finding that even protected reserves are experiencing such dramatic declines suggests a failure in current conservation enforcement and management protocols. Consequently, the data underscores that the "status quo" is no longer a viable option for forest management in Akwa Ibom. Immediate and aggressive conservation interventions are required to maintain existing sequestration potential and to prevent these vital ecosystems from reaching a tipping point where they can no longer recover their former biomass density.

Conclusion

In conclusion, this study demonstrates that while the forest reserves of Akwa Ibom State—specifically Ikot Uso Akpan, Ogu Itu, and Stubb Creek—possess a significant mean carbon sequestration potential of 206,333.126 kg C year⁻¹, this capacity is being rapidly and dangerously undermined. The 32-year longitudinal analysis provides undeniable evidence of a stark decline in carbon stocks, with total biomass losses exceeding millions of kilograms due to persistent deforestation and anthropogenic encroachment. The transition of these areas from high-density carbon sinks in 1986 to much lower density levels by 2019 indicates a severe ecological regression. These findings suggest that the current management of these protected areas is insufficient to combat the drivers of forest degradation. Without a shift toward more sustainable practices, these critical carbon sinks will inevitably become net atmospheric emission sources, thereby exacerbating the very climate challenges they are meant to mitigate. The research confirms that the ecological health of Akwa Ibom's forests is at a crossroads, where the preservation of remaining biomass is essential for maintaining regional biodiversity, protecting local watersheds, and ensuring the continued sequestration of greenhouse gases for the benefit of future generations.

Recommendation

Based on the findings of this study, it is urgently recommended that the Akwa Ibom State Government, in collaboration with environmental NGOs and local communities, implement a more rigorous and technologically driven forest management framework. First, there must be a shift toward "community-based conservation" where local residents are provided with alternative livelihood options to reduce their economic dependence on timber extraction and land clearing. Second, the state should utilize the GIS mapping data generated in this study to establish "High-Priority Recovery Zones" in areas like Ogu Itu and Stubb Creek, where carbon loss has been most severe. These zones should be subject to strict reforestation programs using indigenous, high-biomass tree species. Third, there is a need for enhanced legal enforcement of existing forest reserve boundaries to curb illegal logging. Finally, the state should explore participation in international carbon credit markets, such as REDD+, to generate revenue from preserved forest stocks, which can then be reinvested into forest protection and local development. Valuing the forests as active carbon-capturing assets rather

than just sources of timber, Akwa Ibom can secure both its ecological future and its climate resilience.

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