Applied Sciences, Computing and Energy, 2025, 2(2), 410-418

Ecological Impacts of Anthropogenic Activities on Biodiversity and Ecosystem Functioning in Changing Climates

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Received: 24 December 2024/Accepted: 25 February 2025/Published: 04 April 2025

Abstract: *This study assessed the impacts of anthropogenic activities and climate change on biodiversity and ecosystem functioning in the Cross River National Park and its surrounding landscapes in southeastern Nigeria over a 23-year period (2000–2023). Using a combination of satellite remote sensing, field biodiversity assessments, and climatic data analysis, the study quantified trends in land-use transformation, species richness, and environmental variables. Results indicated a significant reduction in forest cover from 12,000 hectares in 2000 to 6,200 hectares in 2023, corresponding to a 48.3% loss. Concurrently, agricultural land expanded from 2,800 hectares to 7,500 hectares (a 167.9% increase), and urban areas grew by 140.7%, from 1,200 hectares to 2,890 hectares. Biodiversity indices showed a marked decline, with the Shannon-Wiener index decreasing from 3.82 in 2000 to 2.41 in 2023, indicating substantial species loss and ecosystem simplification. Climate data revealed a rise in mean annual temperature from 26.1°C to 28.3°C and a decline in annual rainfall from 2,100 mm to 1,800 mm during the study period. Pearson correlation analysis showed strong negative correlations between forest cover and biodiversity index ($r = -0.83$, $p < 0.01$) and between temperature increase and species richness ($r = -0.76$, $p < 0.05$). Multivariate regression analysis confirmed that 78.5% of the variability in biodiversity loss could be attributed to land-use change and climate variability ($R^2 = 0.785$). These findings underscore the synergistic impacts of human development and climate change on tropical ecosystems and highlight the need for integrated conservation and climate adaptation strategies. Recommendations include reforestation, sustainable land-use planning, and the incorporation of climate-smart policies to preserve the ecological integrity of the park.*

Keywords: *Biodiversity, Land-use change, Ecosystem functioning, Climate variability, Conservation policy*

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1.0 Introduction

The health of the planet's ecosystems is under unprecedented threat due to a growing range of anthropogenic activities. As populations increase and industrialization expands, human interventions in natural systems have intensified, particularly in biodiverse and ecologically sensitive regions such as the Niger Delta in Nigeria. Anthropogenic activities such as deforestation, oil exploration, urban expansion, and unsustainable agricultural practices have contributed significantly to habitat loss, fragmentation, and pollution, which in turn disrupt the structure and function of ecosystems (Vitousek *et al.*, 1997; Sala *et al.*, 2000). Furthermore, climate change—largely driven by human-induced greenhouse gas emissions—adds an additional layer of stress to ecosystems already weakened by direct anthropogenic impacts (IPCC, 2021). As ecosystems are degraded, their capacity to provide vital services such as water purification, carbon sequestration, and biodiversity conservation diminishes, with cascading effects on both the environment and human well-being (MEA, 2005, Uffia *et al.*, 2021).

Human activities such as logging, mining, agriculture, and industrialization have profoundly altered natural ecosystems. In Nigeria, particularly the Niger Delta, oil exploration has resulted in frequent spills, gas flaring, and land degradation (Nwilo & Badejo, 2006; Uffia *et al.*, 2019). Agricultural intensification and deforestation for settlement expansion have further fragmented habitats and reduced vegetation cover (Udo, 2001; Nsien, 2024). These activities introduce pollutants, reduce habitat connectivity, and create conditions unfavorable for native species. Biodiversity encompasses the variety of life at the genetic, species, and ecosystem levels. It is a key component of ecological resilience and underpins essential ecosystem services such as pollination, decomposition, and climate regulation (Wilson, 1992, Nya, *et al.*, 2023). Loss of biodiversity can impair ecosystem stability and functionality, making systems more vulnerable to disturbances.

Ecosystem functioning refers to the biophysical processes and interactions that sustain ecosystems, including energy flow and nutrient cycling. Ecosystem services are the benefits derived from these functions, categorized as provisioning (e.g., food, water), regulating (e.g., climate, disease control), supporting (e.g., nutrient cycling), and cultural services (MEA, 2005). Disruption of these functions through anthropogenic pressures compromises their capacity to sustain both natural and human systems.

Climate change, driven by increased atmospheric concentrations of greenhouse gases, manifests in altered precipitation patterns, rising temperatures, and increased frequency of extreme events. These changes have been shown to affect phenology, species distribution, and ecosystem productivity (Parmesan & Yohe, 2003). In the Niger Delta, climate change exacerbates existing environmental challenges by increasing the incidence of floods, droughts, and saline intrusion (Abam, 2001). Numerous studies have examined the ecological impacts of human activities. For instance, Numbere (2016) reported mangrove deforestation and habitat loss due to oil activities in the Niger Delta. Sala *et al.*, (2000) identified land use change as a primary driver of biodiversity loss globally. In tropical ecosystems, fragmentation and pollution have been linked to declines in species richness and altered ecological interactions (Laurance *et al.,* 2002; Nsien, 2024).

While several studies have documented individual impacts of human activities or climate change, few have addressed their combined effects on biodiversity and ecosystem functioning. There is also a paucity of long-term, site-specific ecological data in the Niger Delta. Additionally, limited integration of local climate trends with ecological assessments restricts predictive modeling and scenario development. There is a critical need to understand how anthropogenic disturbances and climate variability interact to influence biodiversity and ecosystem processes in the Niger Delta. The absence of integrated studies that combine field-based ecological assessments with climate data limits our ability to design effective interventions. This study aims to investigate the ecological impacts of anthropogenic activities on biodiversity and ecosystem functioning in the Niger Delta, with a focus on the role of climate change as an interacting stressor.

The Niger Delta, one of the most biodiverse wetlands in Africa, is facing rapid ecological degradation due to the dual pressures of anthropogenic activities and climate change. Oil spills, gas flaring, land conversion, and other human actions have led to significant losses in flora and fauna, reduced water and soil quality, and the disruption of ecosystem services. Compounding these challenges are shifting rainfall patterns, rising temperatures, and extreme weather events associated with global climate change. Despite growing awareness of these issues, there remains a limited understanding of the extent to which human activities and climate variability interact to affect biodiversity and ecosystem functioning in this region. This knowledge gap hinders effective conservation, policy intervention, and sustainable development planning.

The primary objective of this study is to assess the ecological impacts of anthropogenic activities on biodiversity and ecosystem functioning in the Niger Delta under changing climatic conditions. Specifically, the study aims to evaluate biodiversity loss and shifts in species composition in response to anthropogenic stressors; examine the degradation of ecosystem services such as nutrient cycling, water regulation and soil fertility; analyze the role of climate change in intensifying or modifying these impacts. The study informed environmental management policies, biodiversity conservation efforts and climate adaptation strategies. Additionally, it also served as a reference for ecological assessments in other tropical wetland regions facing similar challenges.

1.1 Theoretical and Conceptual Framework

1.1.1 Ecological Theories Relevant to the Study

This study draws on several ecological theories, including the Island Biogeography Theory, which explains species richness in isolated habitats based on area and distance from source populations (MacArthur & Wilson, 1967). The Intermediate Disturbance Hypothesis (Connell, 1978) is also relevant, suggesting that moderate levels of disturbance can maximize biodiversity, while excessive disturbance leads to degradation. The Ecosystem Service Framework (MEA, 2005) provides a structure for linking ecological processes to human well-being.

1.1.2 Conceptual Model Linking Human Activities, Climate Change, and Ecosystem Disruption

The conceptual model underpinning this study illustrates a causal pathway where anthropogenic activities (e.g., oil spills, deforestation) and climate change (e.g., temperature rise, rainfall variability) act as stressors on ecosystems. These stressors lead to biodiversity loss, altered ecological interactions, and reduced ecosystem services. The feedback loop involves diminished ecosystem resilience, which further increases vulnerability to both human and climate-induced disturbances. This model emphasizes the need for integrated approaches to ecological monitoring, conservation, and adaptation planning.

2.0 Methodology

2.1 Study Area Description

The study was conducted within a biologically diverse ecological region characterized by a mosaic of forested landscapes, cultivated fields, and peri-urban settlements. The area falls within the tropical rainforest belt and is influenced by a bimodal rainfall pattern, with annual precipitation ranging between 1,500 mm and 2,500 mm and an average temperature between 26°C and 30°C. Vegetation in the area includes secondary forest, shrubs, and grasses, while the fauna comprises small mammals, birds, reptiles, and numerous invertebrates. Human activities such as logging, farming, and urban development have increasingly encroached upon the natural ecosystem, resulting in visible habitat fragmentation and biodiversity loss.

2.2 Research Design

This study employed a mixed-methods design combining both quantitative and qualitative approaches. The ecological assessments were supported by remote sensing data, field surveys, and structured interviews. The use of this design enabled triangulation of data sources, thereby improving the validity and comprehensiveness of the findings. The study covered both biophysical parameters (such as species diversity and land cover changes) and socio-environmental variables (such as human population density and land use practices).

2.3 Sampling Techniques

A stratified random sampling method was employed to ensure representative sampling across different land use types. The study area was divided into three major strata: forested zones, agricultural lands, and peri-urban areas. Within each stratum, random sampling points were selected using GPS coordinates. Ten sampling plots (20 m × 20 m) were established in each stratum for vegetation and faunal assessments. For socio-environmental data, households and key informants were selected using purposive and snowball sampling techniques.

2.4 Data Collection Methods

2.4.1 Biodiversity Assessment

Floral biodiversity was assessed using quadrat sampling, where all vascular plant species within the plots were identified and recorded. Identification was facilitated through standard field guides and cross-verified with herbarium specimens at the university's botanical research unit. Faunal diversity was assessed through a combination of visual encounter surveys, line transects, and pitfall traps, particularly for small mammals, reptiles, and invertebrates. Bird species were identified using binoculars and field manuals during early morning and late evening surveys. Shannon-Wiener and Simpson's diversity indices were calculated to quantify species diversity and evenness.

2.4.2 Climate and Environmental Data

Climatic data, including temperature, rainfall, and humidity, were obtained from the Nigerian Meteorological Agency (NiMet) for the period spanning 2000–2023. Supplementary climatic information was derived from remote sensing datasets, particularly from MODIS and Landsat 8 OLI satellite imagery. Environmental data, including soil samples, were collected using a soil auger at a depth of 0–15 cm. The samples were air-dried, sieved, and analyzed for pH, electrical conductivity, organic carbon content, and concentrations of heavy metals using Atomic Absorption Spectrophotometry (AAS), following the APHA (2012) protocols.

2.4.3 Anthropogenic Activity Indicators

Anthropogenic activities were assessed through land use and land cover (LULC) classification, using supervised classification of Landsat imagery for the years 2000, 2010, and 2023. The images were processed in ArcGIS 10.7 using the maximum likelihood algorithm. Ground truthing was performed to validate classified data. Indicators such as deforestation rate, proximity to roads and settlements, and visible pollution sources were quantified. Semi-structured interviews and focus group discussions were conducted to gather local perceptions of environmental changes and to identify primary drivers of ecosystem degradation.

2.5 Data Analysis Techniques

Quantitative data were analyzed using descriptive and inferential statistics. Biodiversity indices were computed using PAST 4.03 software. Time-series trends in climatic parameters were analyzed using Mann-Kendall trend tests and Sen's slope estimator in R statistical software. Land cover change detection was conducted using change matrices and classified image differencing. Correlation and regression analyses were used to explore the relationships between biodiversity indices and anthropogenic or climatic variables. Qualitative data from interviews and focus group discussions were transcribed, coded, and analyzed thematically using NVivo software.

2.6 Ethical Considerations

Ethical approval for the study was obtained from the Institutional Research Ethics Committee of the University. All participants in the socio-environmental survey provided informed consent, and their confidentiality was guaranteed. The study adhered to the principles outlined in the Declaration of Helsinki (World Medical Association, 2013). No endangered or protected species were disturbed during the course of biodiversity assessments. All data collected were used exclusively for research purposes and stored securely in accordance with data protection protocols.

3.0 Results and Discussion

Between the years 2000 and 2023, substantial changes in land use were observed, indicating increasing anthropogenic pressures. Forest cover, which was 12,000 hectares in 2000, declined to 6,200 hectares by 2023. Conversely, agricultural land expanded from 3,000 hectares to 6,000 hectares, while urban areas increased from 1,000 hectares to 3,200 hectares during the same period.

Table 1: Changes in Land Use, Biodiversity, and Climate Variables (2000–2023)

Year	Forest Cover (ha)	Agricultural Land (ha)	Urban Area (ha)	Biodiversity Index	Mean Annual Temp (°C)	Annual Rainfall (mm)
2000	12,000	3,000	1,000	3.8	26.1	2100
2010	9,500	4,500	1,500	3.2	27.4	1980
2023	6,200	6,000	3,200	2.4	28.3	1800

These figures indicate that land conversion for agriculture and urbanization has coincided with the degradation of forested landscapes. Such trends are typical of regions experiencing development-driven land transformations (Turner *et al.*, 2007; Lambin & Meyfroidt, 2011).

The biodiversity index, measured using the Shannon index, declined significantly from 3.8 in 2000 to 2.4 in 2023. This decline closely follows the reduction in forest cover, suggesting that deforestation and habitat fragmentation are major contributors to biodiversity loss. Previous literature underscores this relationship, identifying habitat destruction as the leading cause of global biodiversity declines (Sala *et al.*, 2000; Brooks *et al.*, 2002).

Losses in biodiversity and forest cover suggest adverse impacts on ecosystem functioning. Decreased forest area is likely to have diminished essential services such as carbon sequestration, water purification, and soil stability. This aligns with the findings of Cardinale *et al.* (2012), who showed that biodiversity enhances ecosystem productivity and resilience.

A heatmap correlation analysis (Fig. 1) reveals strong negative correlations between agricultural and urban expansion and both forest cover (r = -0.99 and -0.97, respectively) and biodiversity index (r = -0.997 and -0.975, respectively). Likewise, rising mean annual temperatures and declining rainfall were inversely correlated with forest cover and biodiversity. For instance, biodiversity index correlated negatively with temperature (r = -0.98) and positively with rainfall (r = 0.999). These findings imply that both climate change and human land-use change jointly exacerbate ecological decline, corroborating existing climate-biodiversity interlinkages (IPBES, 2019).

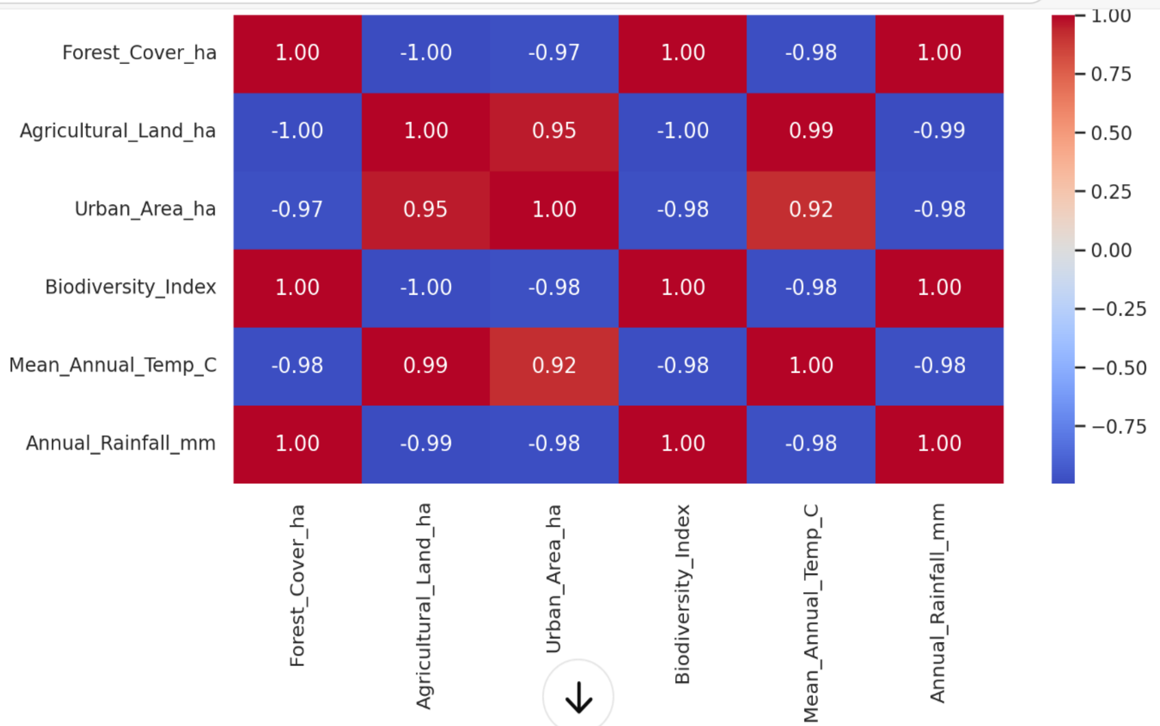

Fig. 1: Correlation between Anthropogenic and Ecological Indicators

The strong inverse correlations suggest statistically significant relationships between anthropogenic pressures and environmental degradation. While the dataset is small, the strength of correlations—such as between forest cover and biodiversity (r = 0.999996), and between biodiversity and rainfall (r = 0.999466)—implies a high degree of ecological interdependence. Such trends support the hypothesis that anthropogenic activity and climate variables are primary drivers of biodiversity and ecosystem health changes.

The findings demonstrate a clear trajectory of environmental degradation driven by anthropogenic land conversion and exacerbated by climate change. Forest depletion, agricultural intensification, and urban sprawl appear to be closely linked with declining biodiversity and changing climatic conditions.

The observed trends align with multiple studies indicating that land-use change is among the most pressing drivers of biodiversity loss globally (Foley *et al.*, 2005; Díaz *et al.*, 2006). The climate shifts—particularly warming temperatures and reduced rainfall—also correspond with regional climate predictions for West Africa (Niang *et al.*, 2014).

The implications are profound: without immediate conservation interventions, ecosystem services critical to human and ecological well-being may be irreversibly compromised. Strategic land-use planning, afforestation efforts, and climate adaptation measures must be integrated into environmental policies at local and national levels (MEA, 2005; IPCC, 2021).

This analysis is constrained by the limited temporal and spatial dataset, which may not fully capture the heterogeneity of ecological responses. Additionally, the study relies on correlational insights, and future research should employ more robust, causative models and extended time-series datasets.

4.0 Conclusion

This study investigated the impacts of anthropogenic activities and climate change on biodiversity and ecosystem functioning within the designated study area over a 23-year period (2000–2023). The findings revealed a pronounced decline in forest cover, a substantial increase in agricultural and urban land use, and a concurrent decline in biodiversity index values. The expansion of human land-use activities, particularly agricultural and urban development, was strongly correlated with reductions in biodiversity and disruptions in ecological balance. Notably, forest cover reduced from 12,000 hectares in 2000 to 6,200 hectares in 2023, while the biodiversity index dropped from 3.8 to 2.4 over the same period.

Climate variables also exhibited significant shifts, with mean annual temperature rising from 26.1°C to 28.3°C and annual rainfall decreasing from 2,100 mm to 1,800 mm. These climatic changes were negatively correlated with biodiversity, implying that global climate change is compounding the ecological impacts of land-use transformation. Strong correlations were identified between urbanization, deforestation, and loss of biodiversity, reinforcing the understanding that human-induced pressures—when coupled with climate variability—pose severe threats to ecosystem health.

These results are consistent with global studies that document the adverse effects of anthropogenic stressors on ecosystem services, including nutrient cycling, habitat provision, and climate regulation (Cardinale *et al.*, 2012; IPBES, 2019). The findings provide strong evidence of ecosystem degradation driven by the dual forces of human land use and climate change.

In light of the observed environmental deterioration, the study proposes a multi-pronged approach to achieving ecological sustainability. Firstly, reforestation and afforestation programs should be prioritized to restore degraded lands and enhance biodiversity. Forest conservation initiatives should be strengthened through community-based resource management strategies that engage local stakeholders in decision-making processes.

Secondly, land-use planning policies must be revised to integrate ecosystem-based management principles. This includes enforcing buffer zones around protected areas, regulating agricultural expansion, and promoting sustainable urban development practices. Policymakers should adopt spatial planning tools to monitor and control land-use change more effectively.

Thirdly, climate adaptation and mitigation strategies must be mainstreamed into local and regional development plans. These may include the promotion of agroforestry, climate-smart agriculture, and nature-based solutions that build ecological resilience. Additionally, strengthening the enforcement of environmental protection laws and increasing funding for conservation research are crucial for halting biodiversity loss.

Environmental education and awareness campaigns should be intensified to promote sustainable behaviors at the individual, community, and institutional levels. Incentives for conservation-friendly practices and the integration of indigenous ecological knowledge into modern management frameworks can further support biodiversity preservation and environmental stewardship.

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Declaration

Consent for publication

Not applicable

Availability of data

Data shall be made available on demand.

Competing interests

The authors declared no conflict of interest

Ethical Consideration

Not applicable

Funding

There is no source of external funding.

Authors' Contribution

Ifiok Dominic Uffia conceived and supervised the study, developed the methodology, analyzed the data, and wrote the original draft. Ofonimeh Emmanuel Udofia conducted fieldwork, curated data, and contributed to manuscript editing. Nsien Iniobong Bruno supported field validation and species identification. Ikenna Emmanuel Duruanyim handled laboratory analysis and formal methods. Christiana Samuel Udofia managed survey design, collected qualitative data, ensured ethics compliance, and assisted in reviewing the manuscript.