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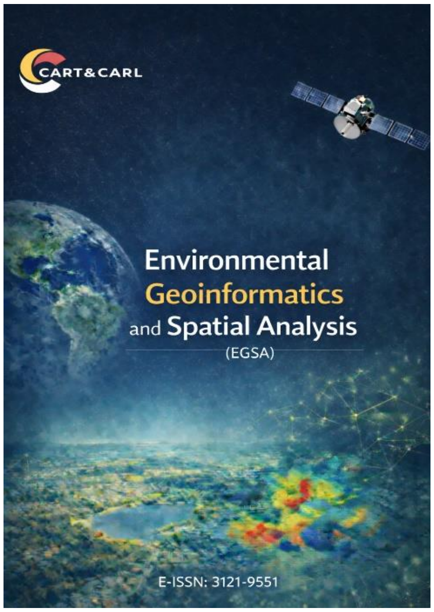

Geographic Information System (GIS) Assessment of Anthropogenic Impacts on Mangrove Forests in Parts of Rivers State, Nigeria

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Abstract

Mangrove forests are vital coastal ecosystems that provide a range of ecological, economic, and protective services. However, these ecosystems are increasingly threatened by anthropogenic activities, particularly in resource-rich regions like Rivers State, Nigeria. This study employed Geographic Information System (GIS) and remote sensing techniques to assess the spatio-temporal changes in mangrove forest cover in selected Local Government Areas (LGAs) Gokana, Andoni, Asari-Toru, and Degema from 1995 to 2024. Multi-temporal Landsat satellite images were analyzed using supervised classification to delineate land use/land cover (LULC) categories including mangroves, freshwater vegetation, built-up areas, and water bodies. The results revealed a significant and progressive decline in mangrove coverage across the LGAs, with Gokana and Andoni experiencing a 59.49% loss, and Asari-Toru and Degema a 42.67% loss over the study period. Conversely, built-up areas and freshwater vegetation expanded considerably, indicating growing urbanization and possible ecological succession. The findings strongly suggest that human-induced activities such as infrastructure development, oil exploration, and land reclamation are the primary drivers of mangrove degradation. This study underscores the urgent need for targeted conservation strategies, sustainable land-use planning, and strengthened environmental regulations to preserve the remaining mangrove forests and restore degraded areas.

Keywords : Geographic Information System (GIS), Anthropogenic Impacts, Mangrove Forests, Land Use/Land Cover Change, Environmental Degradation

Introduction

Mangrove forests are among the most productive and ecologically valuable ecosystems on the planet. Found within the intertidal zones of tropical and subtropical coastlines, they deliver critical ecosystem services such as shoreline protection, carbon sequestration, water purification, and habitat provision for diverse aquatic and terrestrial species (Huxham et al, 2017; Osland et al., 2022; Das et al, 2022). In Nigeria, particularly within the Niger Delta region, mangroves constitute an extensive and vital component of the coastal ecosystem (Onyena and Sam, 2020; Aransiola et al, 2024). The Niger Delta mangrove ecosystem is the largest in Africa and third largest mangrove globally (Nwobi et al, 2020; Uwadiae Oyegun et al, 2023). Rivers State, situated in this deltaic zone, is endowed with one of the densest mangroves covers in West Africa, making it a region of exceptional ecological significance (Numbere, 2018). However, the integrity of these ecosystems is increasingly compromised by a range of anthropogenic activities, including urban expansion, oil exploration, logging, aquaculture, and infrastructure development (Zabbey et al, 2019; Numbere et al, 2023).

Unregulated human activities have led to severe degradation of mangrove forests in Rivers State. One of the most persistent threats arises from crude oil exploration and exploitation. Oil spills, gas flaring, and pipeline vandalism have introduced toxic pollutants into the mangrove environment, disrupting plant physiology and causing widespread deforestation (Nduka et al., 2010; Olalekan et al., 2018). Additionally, the high demand for fuelwood and agricultural land has resulted in unsustainable harvesting and land conversion, further depleting forest cover (Udo & Iloeje, 2019). These cumulative pressures not only diminish biodiversity but also erode the vital ecosystem services mangroves provide, thereby heightening the vulnerability of coastal communities to flooding, erosion, and economic displacement (Ohwo, 2018). Given the growing threats to mangrove ecosystems, there is an urgent need for accurate, spatially explicit, and up-to-date assessments of anthropogenic impacts (Avtar et al, 2017; Maurya et al, 2021). Traditional field-based monitoring techniques, while valuable, are often constrained by limited accessibility, high costs, and time requirements. The integration of Geographic Information Systems (GIS) and Remote Sensing (RS) technologies presents a more efficient, comprehensive, and cost-effective approach to assessing changes in land use and land cover (Hamud et al, 2019; Singh & Bhadauria, 2024). These tools enable researchers and policymakers to visualize spatial patterns, detect temporal changes, and analyze the drivers of mangrove degradation with greater precision.

GIS-based approaches allow for the collection, storage, analysis, and visualization of geospatial data to estimate the extent of human-induced ecological impacts (Reddy, 2018; Bielecka, 2020). In the context of mangrove conservation, GIS facilitates the delineation of forest boundaries, quantification of forest loss, and identification of degradation hotspots. When combined with satellite imagery from sources such as Landsat or Sentinel, these techniques enable temporal analyses that reveal changes in mangrove cover over specific periods—providing empirical evidence for restoration planning and policy development (Giri et al., 2011). Furthermore, GIS allows for the integration of socioeconomic and environmental variables, promoting a more holistic understanding of the complex interactions between human activities and ecosystem dynamics (Xia et al, 2023; Maurya & Kumar, 2024).

Several studies have demonstrated the utility of GIS and RS in assessing mangrove degradation both globally and within the Niger Delta (Nwobi et al, 2020; Kwabe, 2021; Numbere, 2022) . Adedeji and Oyebanji (2012), for example, employed GIS to examine coastal erosion and land loss in the Niger Delta, underscoring the stabilizing role of mangroves. In Rivers State, GIS-based analyses have been applied to evaluate the environmental impacts of oil spills and to identify degraded areas requiring targeted restoration (Obida et al., 2018). Despite these contributions, significant gaps remain in the availability of localized, current, and policy-relevant data on the impacts of human activities on the mangrove forest conditions in Rivers State. Much of the existing research provides macro-level insights that fail to capture the spatial heterogeneity and site-specific drivers of mangrove loss. Moreover, the increasing complexity of land-use dynamics in the Niger Delta calls for an integrated analytical framework that combines spatial data, field validation, and community engagement.

This study therefore seeks to address these gaps by employing GIS-based methodologies to estimate and map the anthropogenic impacts on mangrove forests in Rivers State. Using multi-temporal satellite imagery, spatial analysis, and field data, the research will quantify mangrove cover change, identify areas of intense human pressure, and evaluate the contribution of different anthropogenic factors to forest degradation. This integrated approach aligns with international best practices for environmental monitoring and supports evidence-based strategies for sustainable mangrove management. Beyond its academic relevance, the study carries significant practical implications for environmental governance, biodiversity conservation, and climate change mitigation in the Niger Delta. As Nigeria strives to meet its commitments under global frameworks such as the United Nations Sustainable Development Goals (SDGs) and the Paris Agreement on Climate Change, understanding the status and dynamics of mangrove ecosystems becomes indispensable. Specifically, this research contributes to SDG 13 (Climate Action), SDG 14 (Life Below Water), and SDG 15 (Life on Land) by promoting data-driven decision-making and advocating for the conservation of critical coastal habitats.

Materials and Methods

The Study Area

The study was conducted in four coastal Local Government Areas in Rivers State (i.e. Gokana -Bodo Mangrove Forest, Andoni - Asarama mangrove forest, Asari-toru - Oproama mangrove forest and Degema - Bille mangrove forest) located at the core mangrove forest of Rivers State **(Figure 1).** These local government areas are predominantly the vast mangrove forest of Rivers State hence were purposefully chosen for the study. Amadi et al. (2014) identified the Central Niger Delta for its extensive and diverse mangrove vegetation cover, highlighting its ecological richness and importance. The economic activities of the people of these areas are mainly fishing, farming and sand mining (Obenade et al., 2020).

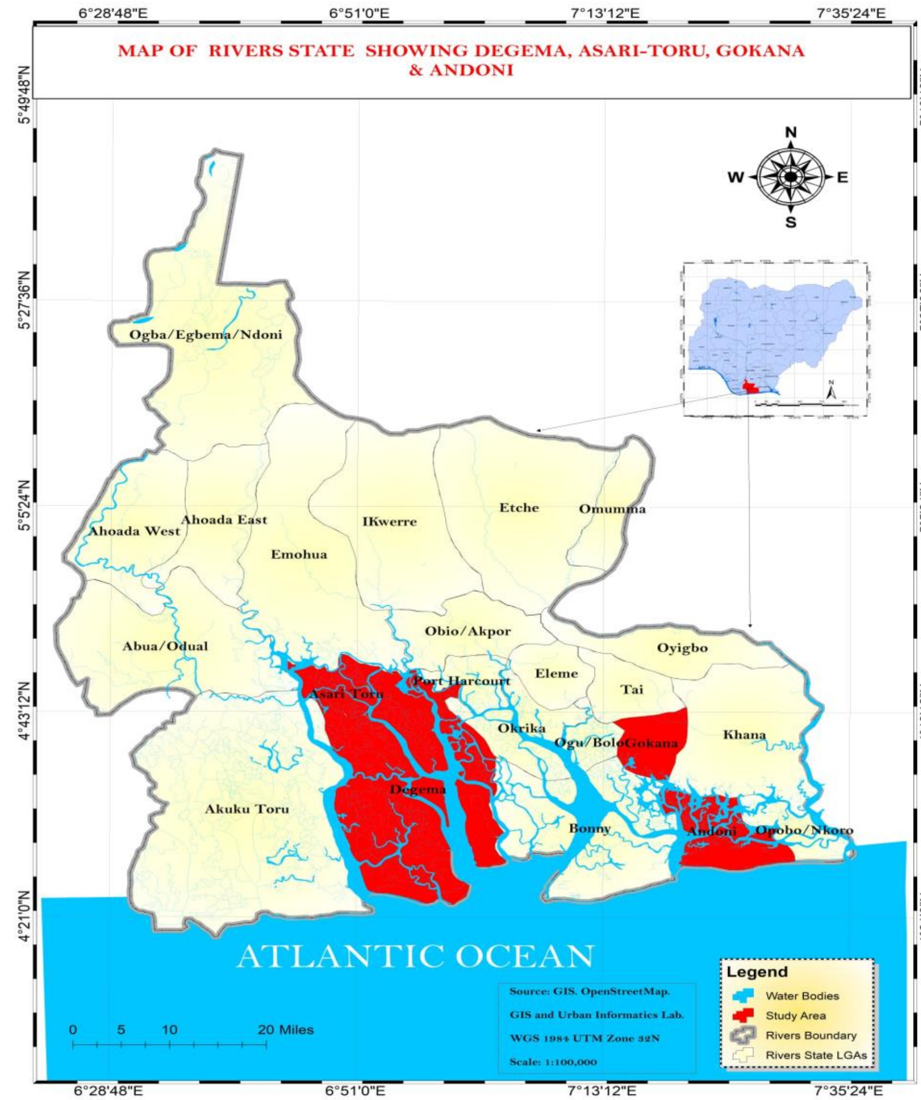

Figure 1: Map of Rivers State showing the study area
Source: Rivers State Ministry of Lands and Survey

Data Sources:
This study utilized both primary and secondary data sources to assess changes in land use and land cover (LULC) and to quantify mangrove loss in the region.

Primary Data: The primary data consisted mainly of spatial datasets and field observations. These included:

- **Landsat imagery** (30m × 30m resolution) of the Central Niger Delta obtained from the United States Geological Survey (USGS) Earth Explorer portal;
- **Satellite imagery** of the mangrove forests and surrounding landscapes;
- **Topographic maps** of the study area at a scale of 1:500,000, sourced from the Office of the Surveyor-General, Ministry of Lands and Survey, Rivers State; and

- **Soil maps** acquired from the Food and Agriculture Organization (FAO) database.

Secondary Data: Secondary sources comprised published and unpublished materials, including textbooks, journal articles, government reports, conference papers, magazines, and newspapers relevant to mangrove ecology and GIS-based land use studies.

Data Processing and Analysis:
This study employed spatial data acquisition, processing and analytical approaches from studies by Bill Donatien et al (2024), Onuegbu & Egbu (2024) and Adeoye et al (2025).

1. Image Acquisition: Landsat satellite images for the study area were acquired for four different temporal periods—specifically 1995, 2005, 2015, and 2024—to facilitate a multi-temporal analysis of mangrove cover dynamics.
2. Data Preprocessing: All images were preprocessed to ensure consistency and comparability. This included geometric correction, georeferencing to a common coordinate reference system, mosaicking, and subsetting to the boundaries of the study area.
3. Classification Method: A supervised classification approach using the Maximum Likelihood algorithm was employed. Distinct land use/land cover (LULC) categories were defined, including mangrove forest, built-up area, freshwater vegetation, and water bodies**.**
4. Training the Classifier: Representative training samples for each LULC class were selected from the imagery based on ground-truthing data and visual interpretation. These samples were used to train the classifier for accurate discrimination of spectral signatures.
5. Image Classification: The trained classifier was applied to the entire imagery dataset for each time period, producing classified LULC maps for 1995, 2005, 2015, and 2024.
6. Change Detection Analysis: Post-classification comparison was conducted using ArcGIS 10.4. The **Change Detection** tool and **Raster Calculator** were used to identify and quantify areas of change among the LULC classes between the four time periods.
7. Generation of Change Maps and Statistics: Change maps were generated to visually represent spatial patterns of mangrove loss and other land cover transformations. The **Tabulate Area** and **Zonal Statistics** tools were applied to calculate the area (in hectares) of each LULC category and the corresponding changes over time.
8. Trend and Trajectory Analysis: The spatial and temporal patterns revealed by the change maps were analyzed to determine the trajectory of mangrove degradation, identify hotspots of human activity, and infer potential drivers of change.
9. Visualization: ArcGIS 10.4 was used to produce thematic maps and graphical outputs that illustrate trends, patterns, and rates of mangrove loss across the study periods

Results

Extent of Anthropogenic Impacts on Mangrove in Gokana and Andoni LGAs using GIS-based methods

Table 1 shows the landuse/land cover pattern in Gokana and Andoni LGAs of Rivers State between 1995 and 2024. In 1995, it is revealed that mangrove vegetation covered 298860244.3m^2 (43.33%) of total spatial extent of the study area, freshwater vegetation had 339040697.9m^2 (49.15 %), dry lands/roads/built up area had 27316608.82m^2 (3.96 %), and water had 24520959.13 m^2 (3.56%) **(Figure 2)**. In 2005, the analysis showed that mangrove vegetation covered 150681133.8 m^2 (21.85%) of total spatial extent of the study area, freshwater vegetation had 464221016.8 m^2 (67.30 %), dry lands/roads/built up area had 51275601.38m^2 (7.43 %), and water had 23560758.12 m^2 (3.42%) **(Figure 3)**. In 2015, the analysis showed that mangrove vegetation covered 139683721.5m^2 (20.25 %) of total spatial extent of the study area, freshwater vegetation had 473407106.9 m^2 (68.64 %), dry lands/roads/built up area had 58126722.64m^2 (8.43 %), and water had 18520959.13 m^2 (2.69%) **(Figure 4)**. In 2024, the analysis revealed that mangrove vegetation covered 121075859.5 m^2 (17.55 %) of total spatial extent of the study area, freshwater vegetation had 486560178.6m^2 (70.54 %), dry lands/roads/built up area had 64581512.8 m^2 (9.36 %), and water had 17520959.13 m^2 (2.54%) **(Figure 5)**.

Thus, the landuse/land cover analysis has revealed that the mangrove and freshwater vegetation dominated Gokana and Andoni LGAs as they were higher than other landuse types in each of the years considered for this study. It is vividly shown also that mangrove vegetation continued to deplete while freshwater vegetation continued to increase. Similarly, dry lands/roads/built up area continued to increase from 1995 to 2024 but at a gradual and slow pace while waterbodies continued to decrease across the period of the study.

Table 1: Landuse/Land cover of Gokana and Andoni LGAs LGA between 1995 and 2024

Landuse	1995		2005		2015		2024	
	Areal coverage (m^2)	Percentage (%)	Areal coverage (m^2)	Percentage (%)	Areal coverage (m^2)	Percentage (%)	Areal coverage (m^2)	Percentage (%)
Mangrove Vegetation	298860244.3	43.33	150681133.8	21.85	139683721.5	20.25	121075859.5	17.55
Freshwater Vegetation	339040697.9	49.15	464221016.8	67.30	473407106.9	68.64	486560178.6	70.54
Dry Land/Roads/Built-up Area	27316608.82	3.96	51275601.38	7.43	58126722.64	8.43	64581512.8	9.36
Water	24520959.13	3.56	23560758.12	3.42	18520959.13	2.69	17520959.13	2.54
Total	689738510.1	100.00	689738510.1	100.00	689738510.1	100.00	689738510	100.00

Source: Researcher's Computation, 2025

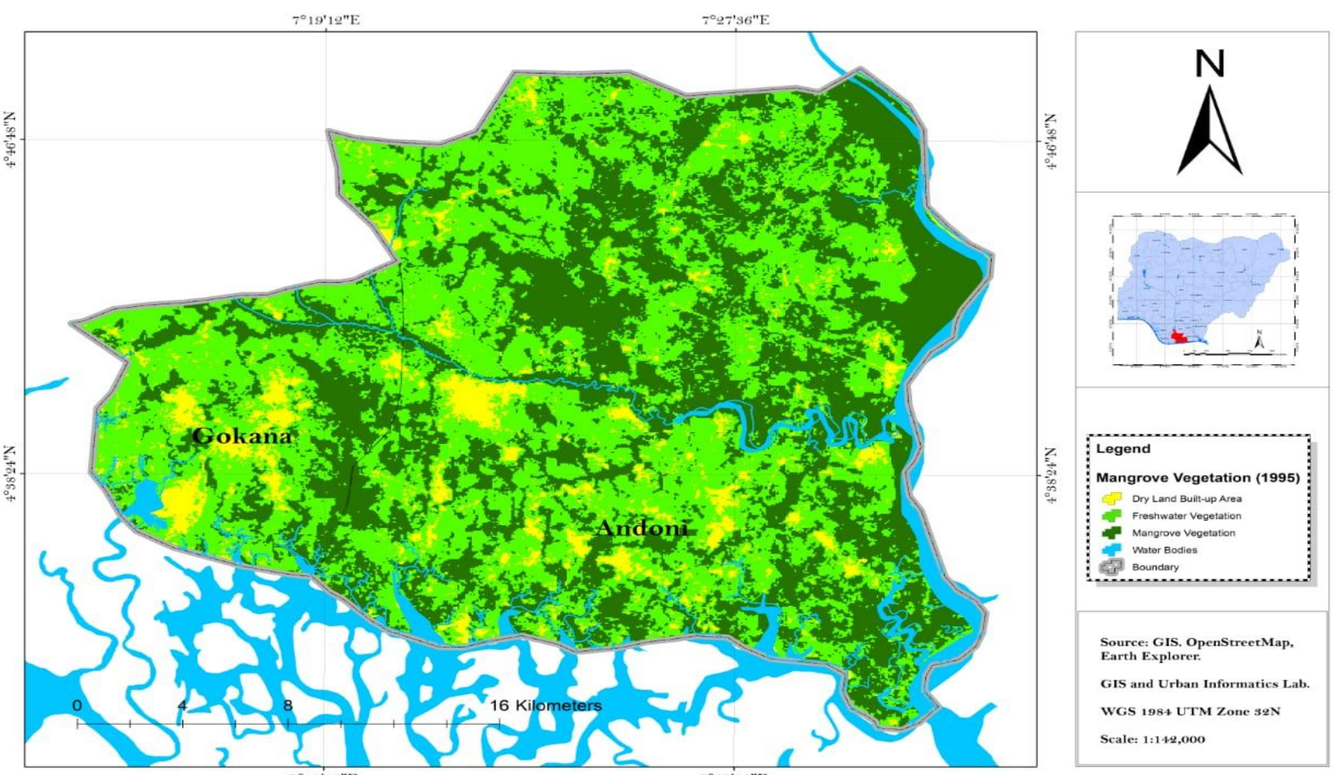

Figure 2: Landuse/Land cover of Gokana and Andoni LGAs of 1995

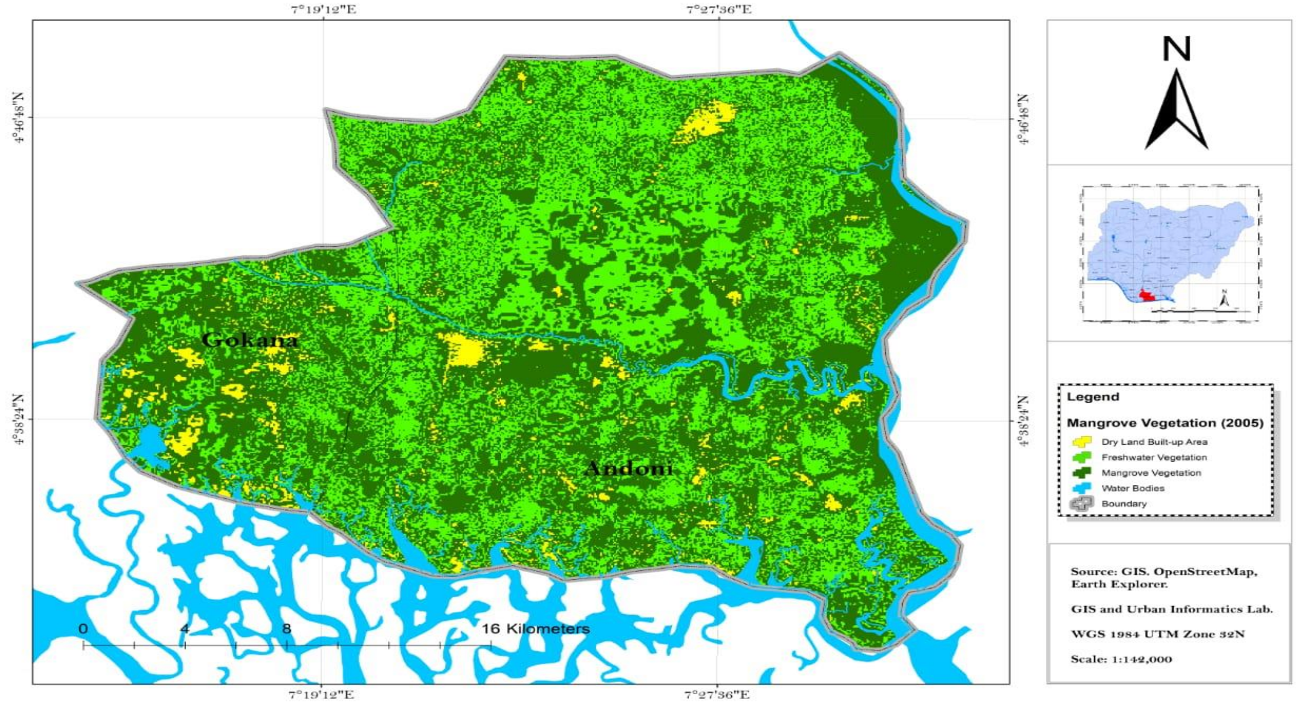

Figure 3: Landuse/Land cover of Gokana and Andoni LGAs of 2005

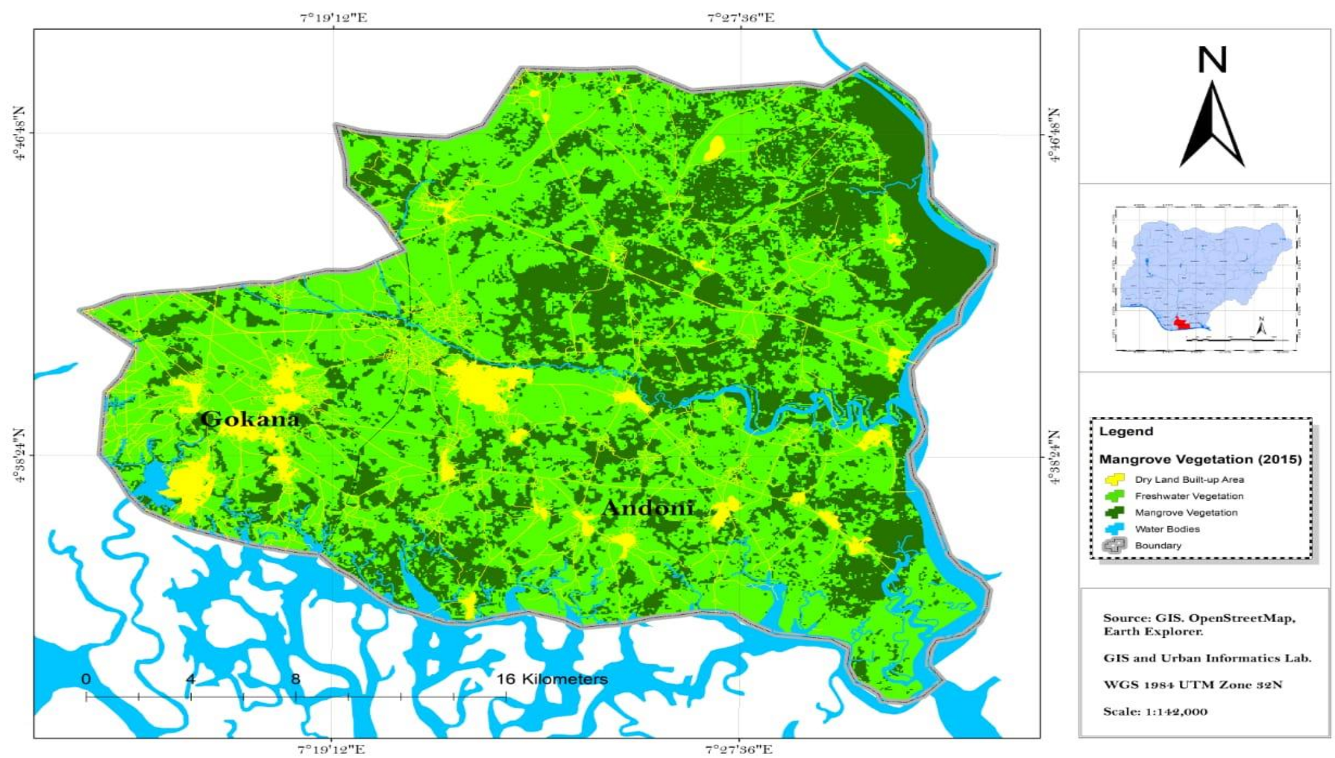

Figure 4: Landuse/Land cover of Gokana and Andoni LGAs of 2015

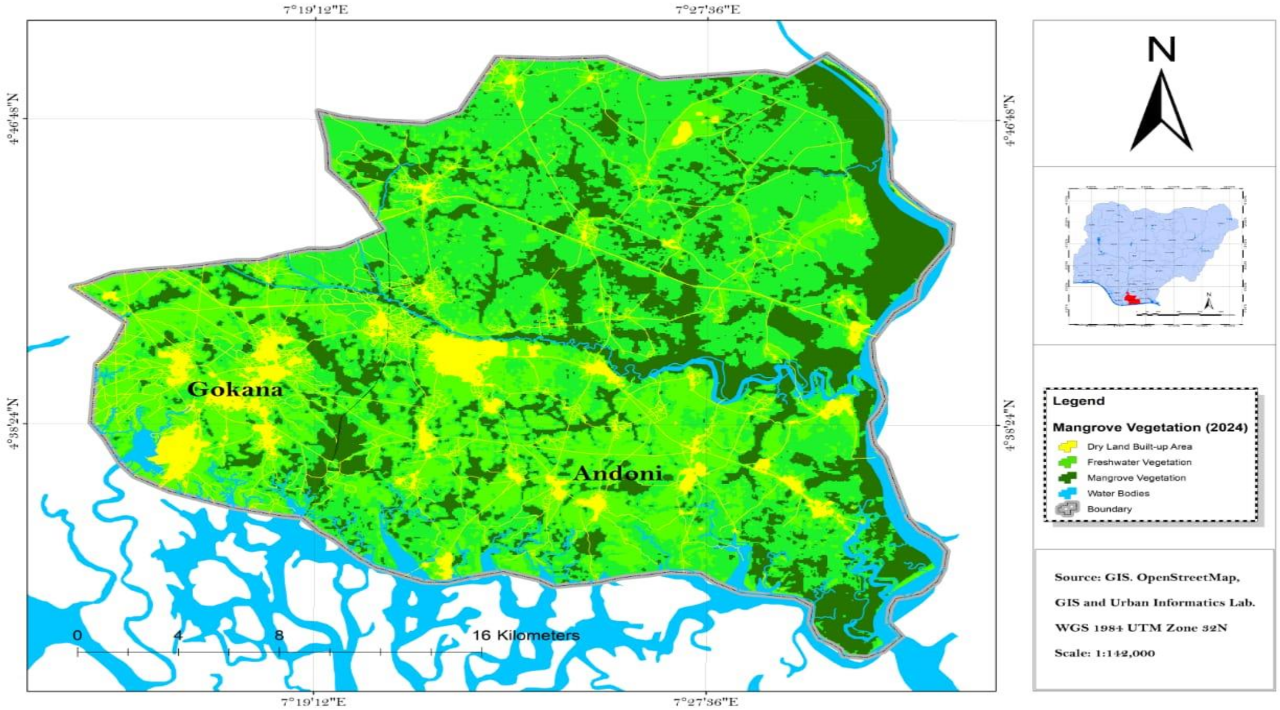

Figure 5: Landuse/Land cover of Gokana and Andoni LGAs of 2024

The land-use change and percentage change of Gokana and Andoni LGAs is presented in **Table 2**. From 1995 to 2005, the analysis showed that mangroves reduced by 148179110.5 m^2 (49.58%), freshwater vegetation increased by 125180318.9 m^2 (22.80%), dry lands/roads/built-up area increased by 23958992.56 m^2 (87.71%) and water increased by 960201.01 m^2 (3.92%). From 2005 to 2015, it is revealed that mangrove decreased by 10997412.33 m^2 (7.30%), freshwater vegetation increased by 9186090.07 m^2 (1.98%), dry lands/roads/built-up area increased by 6851121.26 m^2 (13.36%) and water decreased by 5039798.99 m^2 (21.39%). From 2015 to 2024, it is shown that mangrove decreased by 18607861.97 m^2 (13.32%), freshwater vegetation increased by 13153071.72 m^2 (2.78%), dry lands/roads/built up area increased by 6454790.16 m^2 (11.10%) and water decreased by -1000000 m^2 (5.40%). Generally, from 1995 to 2024, it is shown that mangrove decreased by 177784384.8 m^2 (59.49%), freshwater vegetation increased by 147519480.7 m^2 (43.51%), dry lands/roads/built up area increased by 37264903.98 m^2 (136.42%) and water decreased by 7000000 m^2 (28.55%) **(Figure 6).**

The analysis on the rate of change and percentage change of landuse/land cover revealed that the decrease of mangrove vegetation in Gokana and Andoni LGAs was more pronounced between 1995 and 2005 (49.58) than other epochs while the least change of mangrove vegetation as found between 2005 and 2015. In a related development, dry lands/roads/built up area experienced highest change of increase between 1995 and 2005 with 87.71%.

Extent of Anthropogenic Impacts on Mangrove in Asari Toru and Degema LGAs using GIS-based methods

Table 3 shows the landuse/land cover pattern in Asari Toru and Degema LGAs of Rivers State between 1995 and 2024. In 1995, it is revealed that mangrove vegetation covered 763273907.00 m^2 (69.65%) of total spatial extent of the study area, freshwater vegetation had 128764631 m^2 (11.75 %), dry lands/roads/built up area had 8376295.72m^2 (076 %), and water had 195482076 m^2 (17.84%) **(Figure 7)**. In 2005, the analysis showed that mangrove vegetation covered 726967807.1 m^2 (66.34%) of total spatial extent of the study area, freshwater vegetation had 185455509 m^2 (16.92 %), dry lands/roads/built up area had 8662507.66 m^2 (0.79 %), and water had 174811086.2 m^2 (15.95%) **(Figure 8)**. In 2015, the analysis showed that mangrove vegetation covered 585754866.8 m^2 (53.45 %) of total spatial extent of the study area, freshwater vegetation had 301366160 m^2 (27.50 %), dry lands/roads/built up area had

39863786.43 m² (3.64 %), and water had 168912097.4 m² (15.40%) **(Figure 9)**. In 2024, the analysis revealed that mangrove vegetation covered 437596951.9 m² (39.93 %) of total spatial extent of the study area, freshwater vegetation had 450506725.4 m² (41.11 %), dry lands/roads/built up area had 45881135.74 m² (4.19 %), and water had 161912097.4 m² (14.77%) **(Figure 10)**.

Table 2: Rate of Change and Percentage Change of Landuse/Land cover of Gokana and Andoni LGAs (1995- 2024)

Landuse/Land cover	1995	2024	Rate of Change (m²)	Percentage of Change
Mangrove Vegetation	298860244.3	150681133.8	-148179110.5	-49.58
Freshwater Vegetation	339040697.9	464221016.8	125180318.9	36.92
Dry Land/Roads/Built-up Area	27316608.82	51275601.38	23958992.56	87.71
Water	24520959.13	23560758.12	-960201.01	-3.92
Total	689738510.1	689738510.1		
Mangrove Vegetation	150681133.8	139683721.5	-10997412.33	-7.30
Freshwater Vegetation	464221016.8	473407106.9	9186090.07	1.98
Dry Land/Roads/Built-up Area	51275601.38	58126722.64	6851121.26	13.36
Water	23560758.12	18520959.13	-5039798.99	-21.39
Total	689738510.1	689738510.1		
Mangrove Vegetation	139683721.5	121075859.5	-18607861.97	-13.32
Freshwater Vegetation	473407106.9	486560178.6	13153071.72	2.78
Dry Land/Roads/Built-up Area	58126722.64	64581512.8	6454790.16	11.10
Water	18520959.13	17520959.13	-1000000	-5.40
Total	689738510.1	689738510		
Mangrove Vegetation	298860244.3	121075859.5	-177784384.8	-59.49
Freshwater Vegetation	339040697.9	486560178.6	147519480.7	43.51
Dry Land/Roads/Built-up Area	27316608.82	64581512.8	37264903.98	136.42
Water	24520959.13	17520959.13	-7000000	-28.55
Total	689738510.1	689738510		

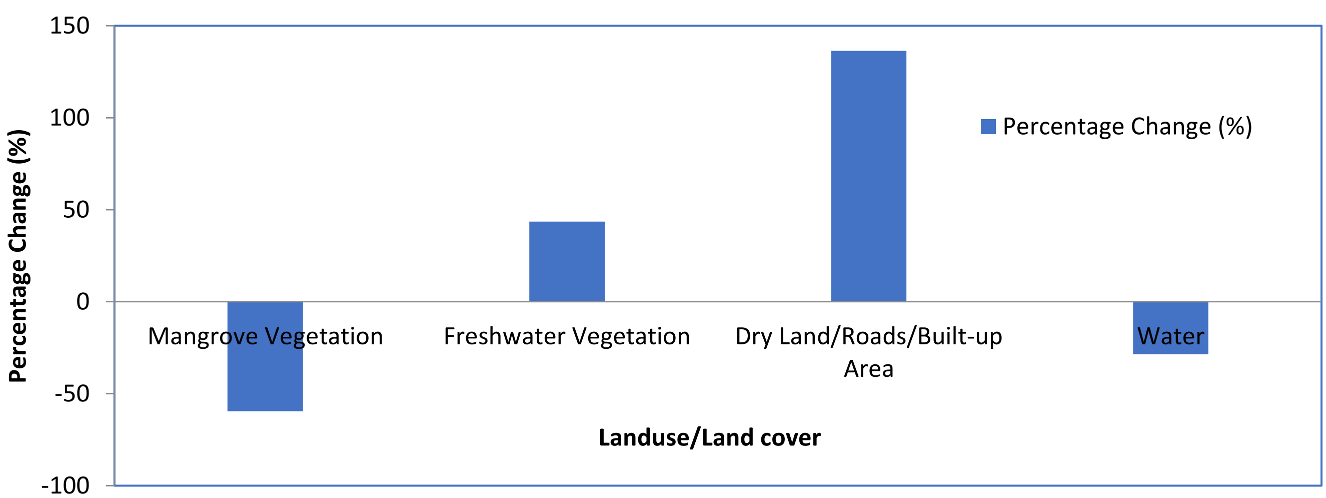

Figure 6: Percentage Change of Landuse/Land cover in Gokana and Andoni LGAs from 1995 to 2024

Table 3: Landuse/Land cover of Asari Toru and Degema LGAs LGA between 1995 and 2024

Landuse	1995		2005		2015		2024	
	Areal coverage (m^2)	Percentage (%)	Areal coverage (m^2)	Percentage (%)	Areal coverage (m^2)	Percentage (%)	Areal coverage (m^2)	Percentage (%)
Mangrove Vegetation	763273907	69.65	726967807.1	66.34	585754866.8	53.45	437596951.9	39.93
Freshwater Vegetation	128764631	11.75	185455509	16.92	301366160	27.50	450506725.4	41.11
Dry Land/Roads/ Built-up Area	8376295.72	0.76	8662507.66	0.79	39863786.43	3.64	45881135.74	4.19
Water	195482076	17.84	174811086.2	15.95	168912097.4	15.41	161912097.4	14.77
Total	1095896910	100.00	1095896910	100.00	1095896911	100.00	1095896910	100.00

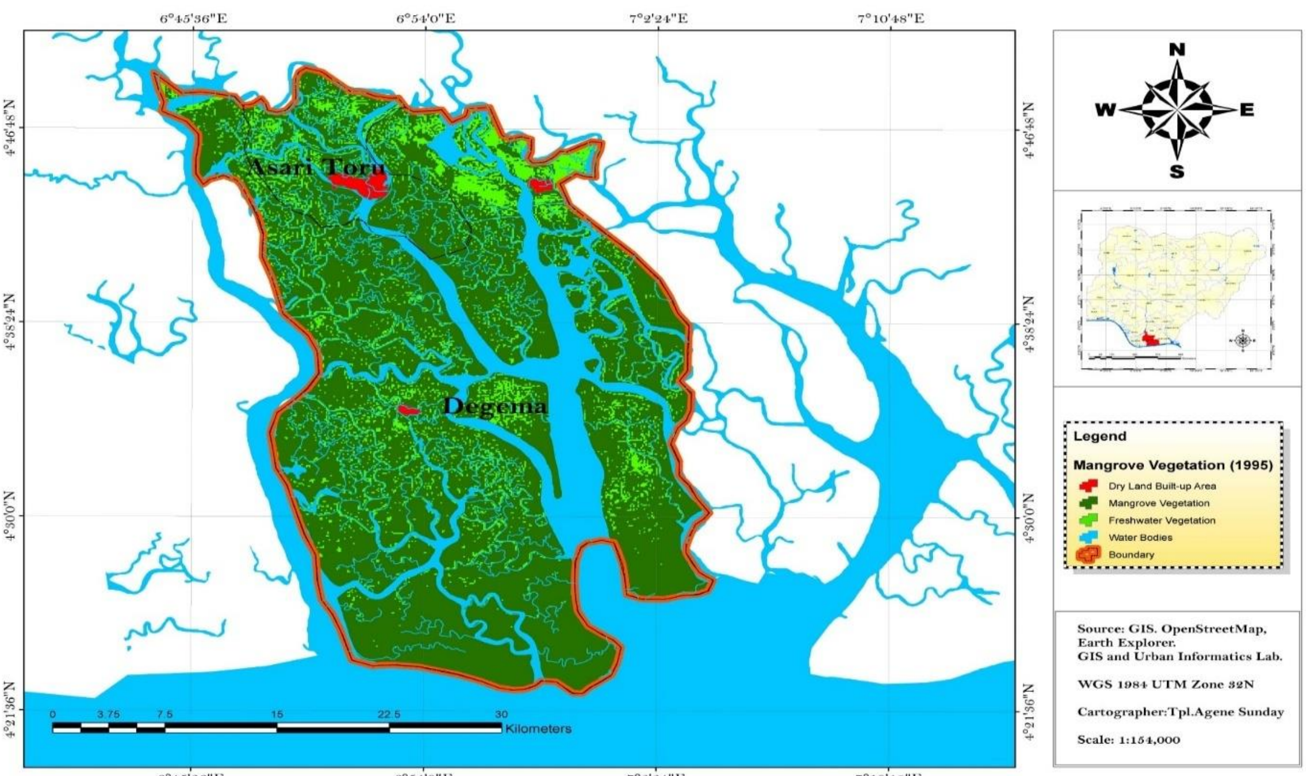

Figure 7: Landuse/Land cover of Degema and Asari Toru LGAs of 1995

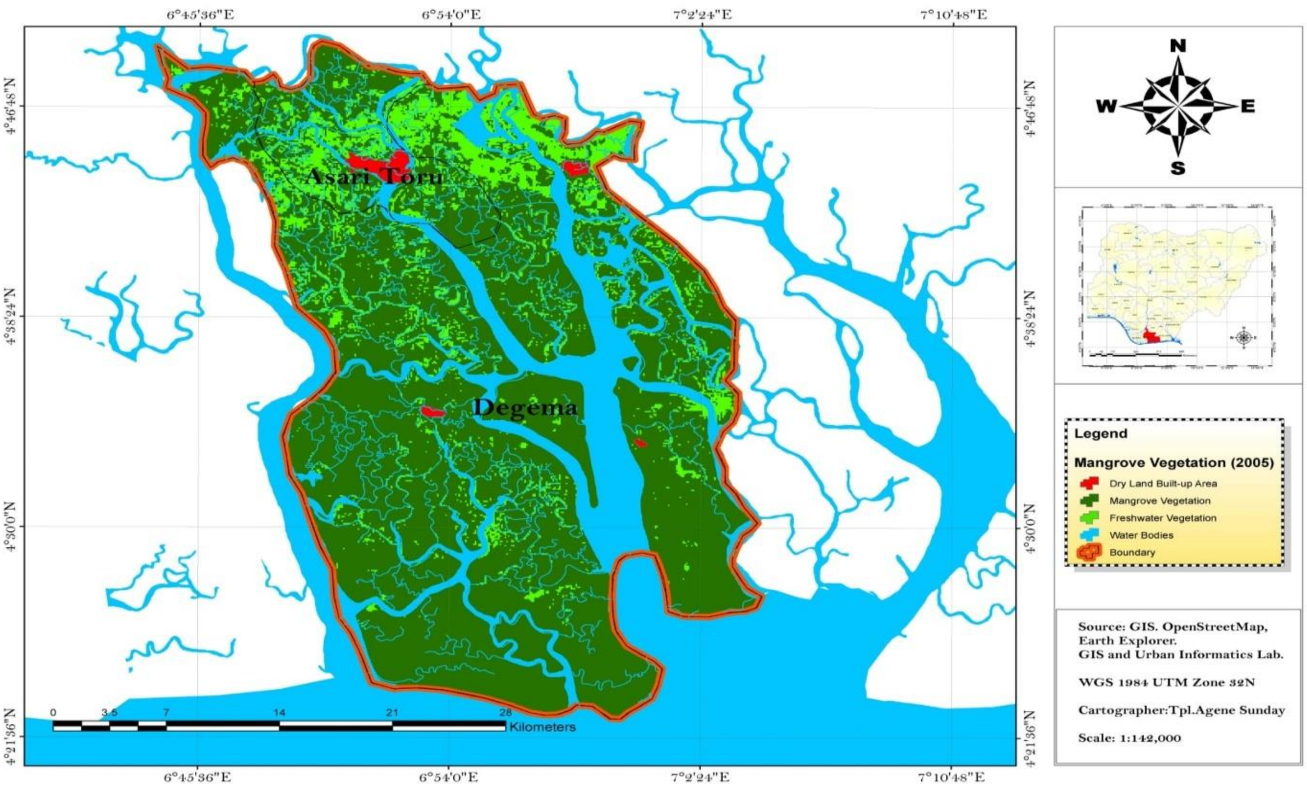

Figure 8: Landuse/Land cover of Degema and Asari Toru LGAs of 2005

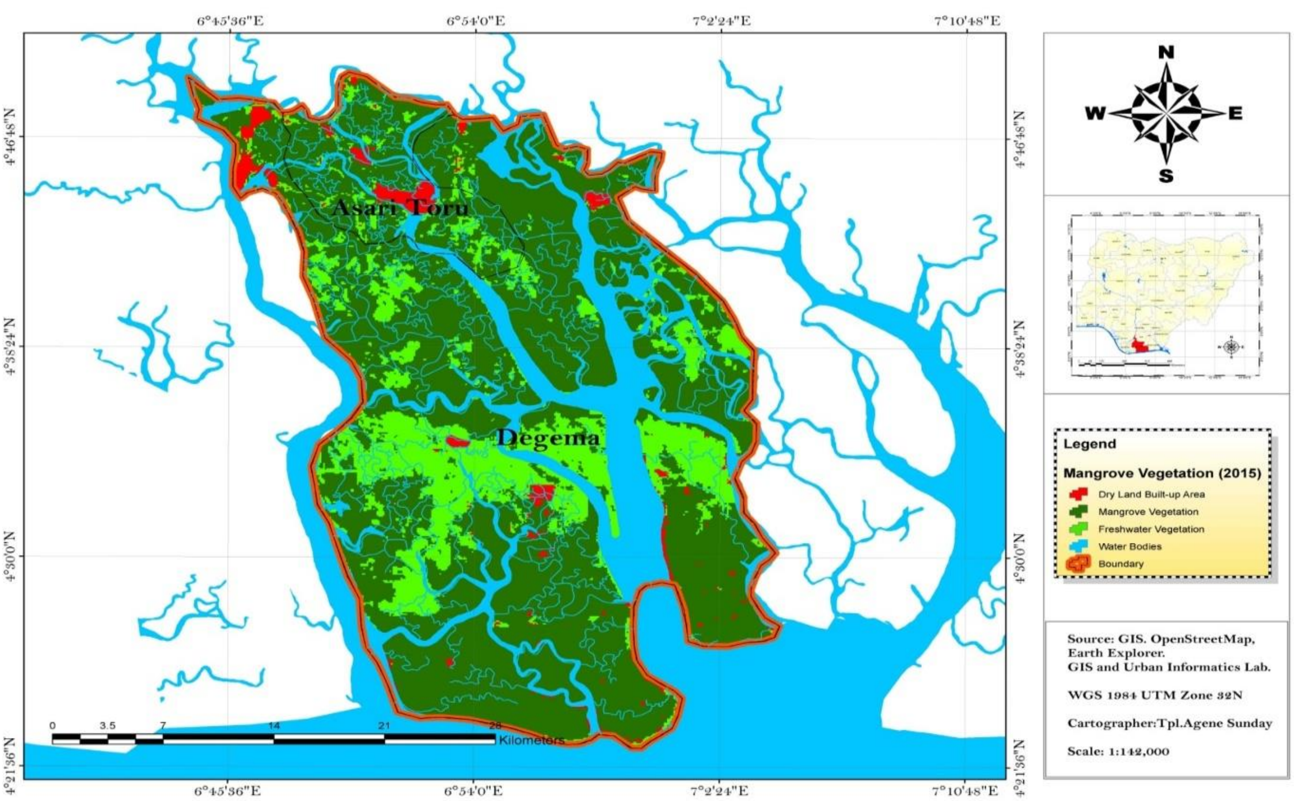

Figure 9: Landuse/Land cover of Degema and Asari Toru LGAs of 2015

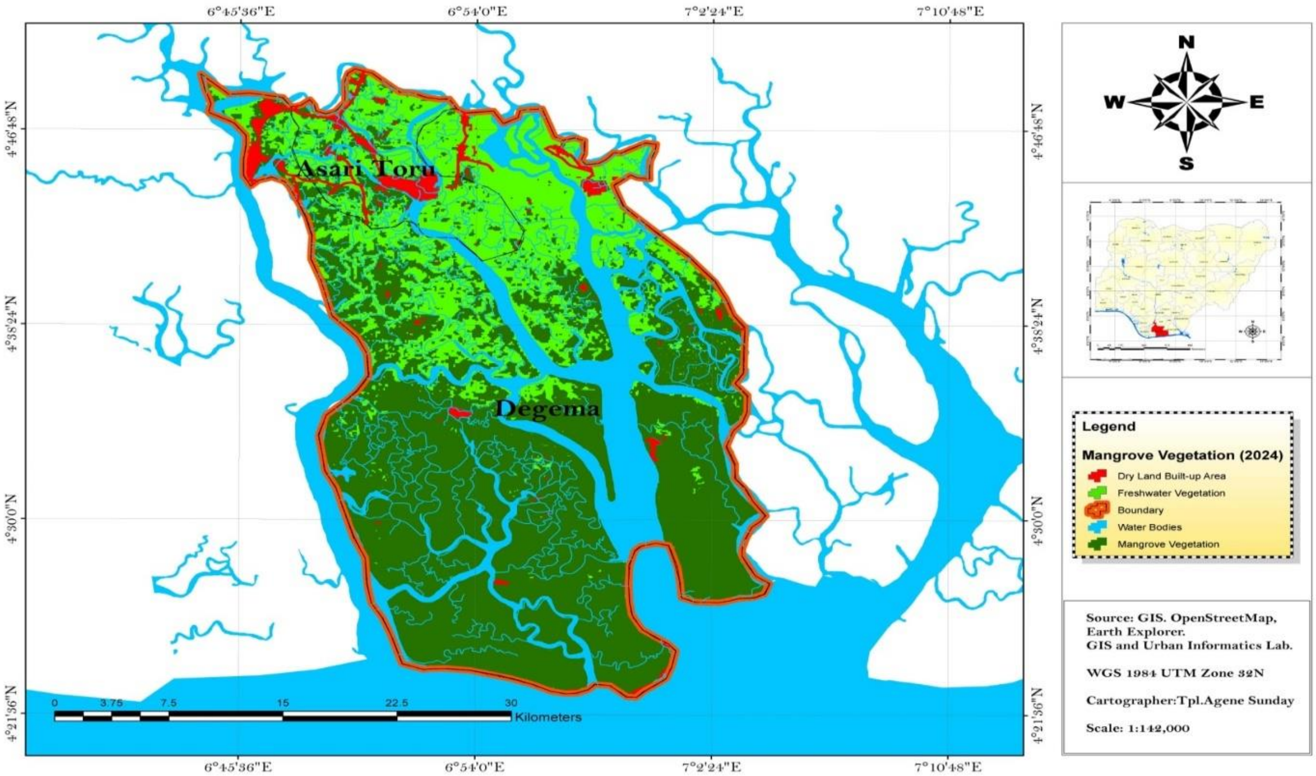

Figure 10: Landuse/Land cover of Degema and Asari Tori LGAs of 2024

Thus, the landuse/land cover analysis in Asari Toru and Degema LGAs has revealed that the mangrove and freshwater vegetation dominated as they were higher than other land use types in each of the years considered for this study. Unfortunately, as freshwater vegetation was increasing with time, mangrove was decreasing. This shows that some part of mangrove must have been lost to freshwater vegetation through some human activities that must have disrupted the survival of mangrove in the area. Moreover, it is clearly shown that dry lands/roads/built up area which could be termed as the real antropogenic activities were increasing over the time considered for this study. Thus, more of the land cover especially the mangrove must have been tampered with for various purposes, consequently leading to the depletion of the abundance of mangrove vegetation in the study area. Water bodies did not have any regular pattern from 1995 to 2024.

The landuse change and percentage change of Asari Toru and Degema LGAs is presented in **Table 4**. From 1995 to 2005, the results showed that mangrove reduced by 36306099.84 m^2 (4.76%), freshwater vegetation increased by 56690877.91 m^2 (44.03%), dry lands/roads/built up area increased by 286211.94 m^2 (3.42%) and water decreased by 20670990.1 m^2 (10.57%). From 2005 to 2015, it is revealed that mangrove decreased by 141212940.3 m^2 (19.42%), freshwater vegetation increased by 115910651 m^2 (62.50%), dry lands/roads/built up area increased by 31201278.77 m^2 (360.19%) and water decreased by 5039798.99 m^2 (21.39%). From 2015 to 2024, it is shown that mangrove decreased by 148157914.9 m^2 (25.29%), freshwater vegetation increased by 149140565.4 m^2 (49.49%), dry lands/roads/built up area increased by 6017349.31 m^2 (15.09%) and water decreased by 7000000 m^2 (4.14%). In a nutshell, from 1995 to 2024, it is shown that mangrove decreased by 325676955.1 m^2 (42.67%), freshwater vegetation increased by 321742094.3 m^2 (249.87%), dry lands/roads/built up area increased by 37504840.02 m^2 (447.75%) and water decreased by 33569978.86 m^2 (17.17%) **(Figure 11)**.

It is shown that in Asari Toru and Degema LGAs, mangrove was mostly reduced between 2015 and 2024 with 25.29%. It continued to decrease with increasing time or periods. The percentage change between 1995 and 2005 was 4.76% and increased to 19.42% between 2005 and 2015. Although, freshwater vegetation increase was increasing until the periods between 2015 and 2024 when the percentage change reduced to 49.49% from its initial

62.50% between 2005 and 2015. Having known this, the dry lands/roads/built up area was increasing in each epoch but the highest was experienced between 2005 and 2015 having 360.19% increase. The reduction of mangrove could be vividly attributed to the anthropogenic activities which continued to increase overtime.

Table 4: Rate of Change and Percentage Change of Landuse/Land cover of Asari Toru and Degema LGAs (1995-2024)

Landuse/Land cover	1995	2024	Rate of Change (m^2)	Percentage of Change
Mangrove Vegetation	763273906.9	726967807.1	-36306099.84	-4.76
Freshwater Vegetation	128764631.1	185455509	56690877.91	44.03
Dry Land/Roads/Built-up Area	8376295.72	8662507.66	286211.94	3.42
Water	195482076.3	174811086.2	-20670990.1	-10.57
Total	1095896910	1095896910		
Landuse/Land cover	2005	2015		
Mangrove Vegetation	726967807.1	585754866.8	-141212940.3	-19.42
Freshwater Vegetation	185455509	301366160	115910651	62.50
Dry Land/Roads/Built-up Area	8662507.66	39863786.43	31201278.77	360.19
Water	174811086.2	168912097.4	-5898988.76	-3.37
Total	1095896910	1095896911		
Landuse/Land cover	2015	2024		
Mangrove Vegetation	585754866.8	437596951.9	-148157914.9	-25.29
Freshwater Vegetation	301366160	450506725.4	149140565.4	49.49
Dry Land/Roads/Built-up Area	39863786.43	45881135.74	6017349.31	15.09
Water	168912097.4	161912097.4	-7000000	-4.14
Total	1095896911	1095896910		
Landuse/Land cover	1995	2024		
Mangrove Vegetation	763273906.9	437596951.9	-325676955.1	-42.67
Freshwater Vegetation	128764631.1	450506725.4	321742094.3	249.87
Dry Land/Roads/Built-up Area	8376295.72	45881135.74	37504840.02	447.75
Water	195482076.3	161912097.4	-33569978.86	-17.17
Total	1095896910	1095896910		

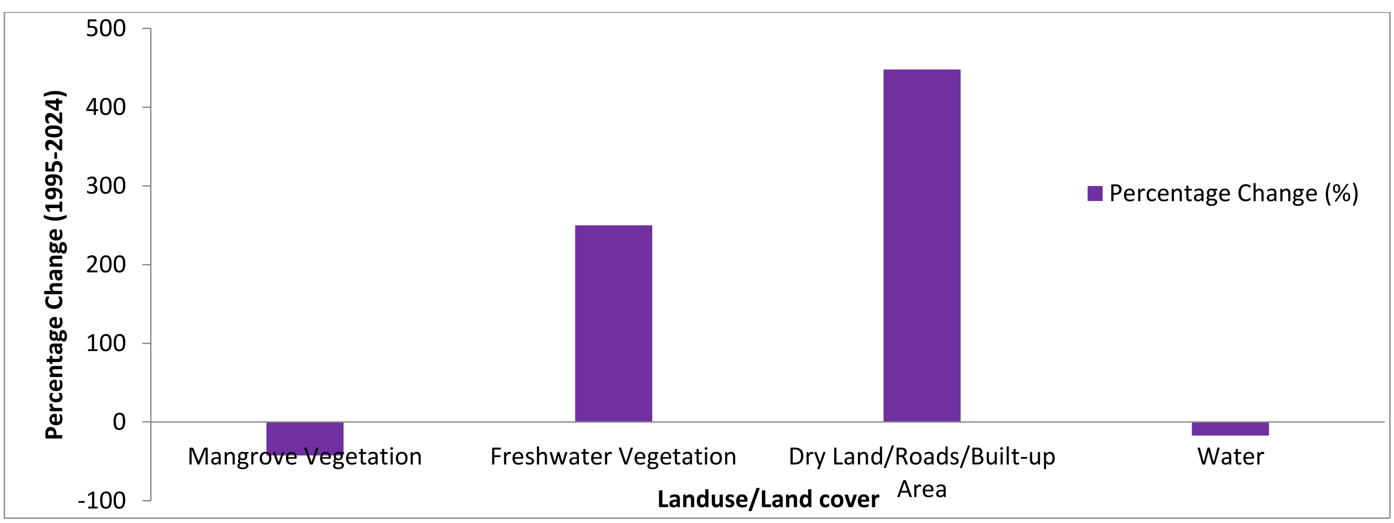

Figure 11: Percentage change of Landuse/Land cover in Asari Toru and Degema LGAs from 1995 to 2024

Discussion

The land use/land cover (LULC) analysis of Gokana and Andoni Local Government Areas in Rivers State between 1995 and 2024 reveals significant temporal changes, particularly in the spatial distribution of mangrove vegetation. The results show a consistent decline in mangrove cover from 43.33% in 1995 to 17.55% in 2024, indicating a significant loss of this critical coastal ecosystem. This pattern aligns with global and regional trends where mangrove forests are increasingly threatened by anthropogenic activities such as oil exploration, urban encroachment, and land reclamation (Numbere et al., 2023; Giri et al., 2011; Nwobi et al, 2020). The sharp decrease in mangrove areas suggests persistent environmental pressure, especially from industrial pollution and infrastructural development characteristic of the Niger Delta region (Nduka et al., 2010; Obida et al., 2018).

In contrast, freshwater vegetation expanded from 49.15% in 1995 to 70.54% in 2024, possibly due to the conversion of degraded mangrove areas and changes in hydrological patterns induced by climate and human activity, a position underscored by Gitau et al. (2023). While freshwater ecosystems provide valuable services, their expansion at the expense of mangroves could indicate ecological imbalance and reduced salinity resilience in coastal zones (White & Kaplan, 2017; Chow, 2018; Middleton & Boudell, 2023).

Moreover, dry lands/roads/built-up areas increased steadily from 3.96% in 1995 to 9.36% in 2024, reflecting ongoing urbanization and land development in the study area. This trend underscores the gradual transformation of natural landscapes into anthropogenic land uses, contributing to habitat fragmentation and biodiversity loss (Scanes, 2018). The decline in water bodies from 3.56% to 2.54% further suggests ecosystem shrinkage and increased sedimentation, often linked to deforestation and construction (Castello & Macedo, 2016; Bhowmik, 2022)

The temporal land-use change analysis of Gokana and Andoni LGAs from 1995 to 2024 reveals significant anthropogenic pressure on mangrove ecosystems. The most substantial loss of mangrove cover occurred between 1995 and 2005, with a decline of 49.58%, primarily due to intensified oil exploration, logging, and land reclamation activities characteristic of the Niger Delta (Adewuyi & Badejo, 2014; Obida et al., 2018). This trend aligns with broader regional observations where mangroves are converted for industrial infrastructure and urban expansion (Giri et al., 2011, Onyena & Sam, 2020; Numbere, 2020).

Freshwater vegetation increased steadily across the study period, particularly 22.80% from 1995 to 2005, suggesting either ecological succession in degraded mangrove areas or increased freshwater inflow from altered hydrology. The significant 87.71% rise in dry lands/roads/built-up areas between 1995 and 2005 reflects expanding human settlements and infrastructural developments (Gitau et al., 2023). Water bodies fluctuated but experienced an overall 28.55% reduction, likely due to siltation and land encroachment (Ayalew, 2021).

The land use/land cover (LULC) dynamics in Asari Toru and Degema LGAs from 1995 to 2024 reveal significant ecological shifts, particularly a steady decline in mangrove cover. Mangrove vegetation reduced from 69.65% in 1995 to 39.93% in 2024, a loss of nearly 30%, reflecting intense anthropogenic pressure and environmental degradation. This trend mirrors findings across the Niger Delta, where oil exploration, canal dredging, and infrastructural expansion have undermined mangrove ecosystems (Adewuyi & Badejo, 2014; Numbere, 2018; Numbere, 2020).

Conversely, freshwater vegetation expanded markedly from 11.75% to 41.11%, likely due to hydrological alterations and succession in degraded mangrove zones. This shift suggests a potential replacement of saline-tolerant mangroves by freshwater species, possibly driven by pollution, reduced salinity, or blocked tidal flows (Giri et al., 2011; Park et al., 2019).

The increase in dry lands/roads/built-up areas from 0.76% to 4.19% over the study period highlights growing urban and infrastructural encroachment. This form of land conversion is a key driver of mangrove loss and coastal ecosystem fragmentation (Gitau et al., 2023).

Water bodies showed no consistent trend, indicating a complex interplay of land reclamation and hydrological changes.

The land-use change analysis from 1995 to 2024 in Asari Toru and Degema LGAs demonstrates an alarming reduction in mangrove cover by 42.67%, primarily due to escalating anthropogenic pressures. The most significant decline occurred between 2015 and 2024 (25.29%), indicating recent intensification of threats such as oil exploration, sand mining, and urban encroachment (Giri et al., 2011; Aransiola et al., 2024). This pattern underscores the vulnerability of mangrove ecosystems in the Niger Delta, which are often sacrificed for development and energy infrastructure (UNEP, 2011).

Freshwater vegetation showed a remarkable increase of 249.87% over the entire period, possibly due to ecological succession following mangrove degradation, hydrological alterations, or sediment accumulation (Pérez et al., 2021). However, the rate of increase slowed between 2015 and 2024, suggesting saturation or a shift in land conversion priorities.

Dry lands/roads/built-up areas rose drastically, particularly between 2005 and 2015 (360.19%), reflecting rapid infrastructural growth. The reduction in water bodies (17.17%) further illustrates the impact of land reclamation and construction activities.

Overall, the results confirm a consistent trend of mangrove loss driven by anthropogenic expansion, necessitating urgent policy intervention, sustainable land-use planning, and environmental restoration measures to curb environmental degradation in coastal Rivers State.

Conclusion

The study examined the impacts of human activities on mangrove forests, especially the long-term land use and land cover changes in some parts of Rivers State using GIS and found a consistent decline in mangrove vegetation across the study period. This decline occurred alongside an expansion of freshwater vegetation and a notable increase in dry lands, roads, and built-up areas, indicating growing human influence on the landscape. Water bodies also showed a general reduction over time. Overall, the findings suggest that anthropogenic activities have played a significant role in transforming the natural environment, particularly through the depletion of mangrove ecosystems. The extent of mangrove loss was more severe in Gokana and Andoni LGAs compared to Asari Toru and Degema LGAs, highlighting spatial variations in the intensity of environmental change within the region. These findings necessitate urgent policy intervention, sustainable land-use planning, and environmental restoration measures to curb environmental degradation in coastal Rivers State.

Recommendations

1. Institutionalize GIS-based Monitoring Systems: The government of Rivers State and relevant environmental agencies (e.g., NESREA, NOSDRA) should adopt and institutionalize GIS and remote sensing technologies as standard tools for continuous monitoring of mangrove forests. Regular spatial assessments can detect changes early, enabling timely policy responses and restoration efforts.
2. Develop and Enforce Stronger Environmental Regulations: Stricter enforcement of environmental laws regulating oil exploration, logging, and land reclamation within mangrove zones is crucial. Penalties for illegal encroachment or pollution should be significantly increased, and environmental compliance must be mandatory for all industrial operations near sensitive ecosystems.
3. Integrate Mangrove Management into Coastal Development Planning: Urban planning and infrastructure development in Rivers State should integrate mangrove protection measures. Environmental Impact Assessments (EIAs) must incorporate up-to-date GIS-based mangrove maps to prevent projects from encroaching into protected zones.
4. Rehabilitation and Reforestation of Degraded Areas: Based on the GIS-identified hotspots of degradation, targeted mangrove reforestation programs should be initiated. These efforts should involve native mangrove species and be guided by scientific assessments to ensure ecological compatibility and sustainability.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Credit Authorship Contribution Statement

Etuk, E. E.: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Visualisation, Project administration, Writing - original draft, Review & Editing. **Agbagwa, I. O. & Ochekwu, E. B.**: Supervision, Methodology, Validation, Formal analysis, Data curation, Review & Editing, Visualisation.

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