Original Research Article

Assessment of Changes in Mangrove Cover in the Niger Delta Region of Nigeria

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ABSTRACT

Nigeria has the third largest mangrove forest in the world, the largest in Africa and approximately 80% of Nigeria's mangrove vegetation spreads within the Niger Delta region of the Country. Unfortunately, unchecked land-use practices, including urbanization, oil exploration & exploitation, aquaculture expansion and agricultural development, have resulted in widespread mangrove loss, threatening both the integrity of these ecosystems and their climate regulatory functions.

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Aim: The study therefore assessed the impacts of mangrove cover changes on climate change in the Niger Delta Region of Nigeria with the aim of articulating sustainable mangrove management practices.

Place and Duration of Study: Mangrove covers from 1987 to 2022 in the study area which includes nine states of Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo, Rivers, and Abia, and encompasses significant mangrove forests.

Methodology: 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.

Commented [RoSa3]: Land surface temperature

Result: 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 within the pace of thirty-five (35) years.

Conclusion: There are significant losses in mangrove cover in the region resulting from unchecked land-use practices, including urbanization, oil exploration & exploitation, aquaculture expansion and agricultural development etc., thus underscoring the importance of preserving these vital ecosystems to mitigate local and global climate impacts.

Keywords: Niger Delta Region, Mangrove Cover, Change

1. INTRODUCTION

Nigeria hosts the world's third-largest mangrove forest and the largest in Africa (Adedeji *et al*., 2011). Approximately 80% of this mangrove vegetation is concentrated within the Niger Delta region of the country (James *et al*., 2013). However, Nigeria mangroves have been on the decline over the years. Feka *et al.,* (2011) acknowledged a reduction from 9,990km^2 in 1980 to 7,386km^2 in 2006. Also, Friess and Webb (2013) using trend estimated from data for 1977 and 1994, reported that Nigeria mangrove reduced at 92.09 km^2 per year. Again, studies have identified aquaculture, coastal erosion, salt extraction, crude oil exploration and exploitation activities, wetland dredging and reclamation, overharvesting of mangroves for fuel wood and charcoal, population growth, coastal urbanization, and high incidence of invasive alien species as primary threats to the mangroves and livelihoods of millions of vulnerable coastal households who depend on them for subsistence and income in Niger Delta (Feka *et al*., 2011). Amongst these factors, the unsustainable exploitation of mangrove resources as a means of livelihood has been identified as a major driver of mangrove deforestation in the Niger Delta. Feka and Ajonina (2011) noted that wood harvesting is the most perverse indirect driver of mangrove decline in West-Central Africa region. Irikana (2011) revealed that the increased demand for mangrove wood for building, traps, firewood, charcoal, etc., has resulted in widespread mangrove deforestation in the Niger Delta Region.

Against these threats to both the mangroves and coastal livelihoods, it is necessary to promote conservation practices that can adequately address these issues, without compromising the sustainable supply of ecosystem services. Several conservation strategies have been employed for the conservation and sustainable use of mangroves through the employment of policy, legislative and response options. Because mangrove ecosystems are dynamic both in space and time, Schmitt and Duke (2015) suggested that an understanding of historical changes in the extent of mangrove forests is therefore important in order to provide information required for management interventions. This can be used to provide spatial and temporal information on mangrove forest area and distribution, as well as on species differentiation. More so, Valiela *et al*., (2001) stated that forest conservation targets rely on an accurate baseline of historical data, and estimates of mangrove cover change are crucial inputs into national, regional and global estimations of change in mangrove cover.

Previous studies have been conducted to assess the extent and rate of change in mangrove cover. For example, Cohen and Lara (2003) analyzed the temporal changes of mangrove vegetation boundaries in Amazonia, North Brazil using satellite and aerial images covering a 25-year period from 1972 to 1997. The aim of the investigation was to identify and quantify areas with vegetation coverage losses or gains in mangroves and elevated mudflats. Analysis of image time series showed that in 1972, the study area had mangrove vegetation coverage over an area of about 592 km^2, which progressively declined to 585, 583 and 573 km^2 in 1986, 1991 and 1997, respectively. Nguyen, *et al*., (2013) used change detection analysis to assess spatial-temporal changes in the extent and width of fringe mangroves, and changes in adjacent land use in Kien Giang Province, Vietnam, for the period 1989-2009. The result showed a significant decrease in mangrove extent for the periods 1989-1992 (-2.7% yr -1) and 2003-2006 (-2.1% yr -1), while a significant increase in mangrove extent was observed during 1992-2003 (0.7% yr -1). In general, the extent of fringe mangroves in study areas increased by 342 ha, with an average rate of increase 9.3% yr -1 over 17 years. However, the annual rate of loss in Kien Giang was higher than global annual rate of mangrove loss estimated at 2.07% yr-1 by Valiela *et al*, (2001). Dan *et al*, (2016) used change detection analysis to investigate the spatial and temporal change in mangrove from 1988 to 2014 in West and Central Africa and in the Sundarbans delta. The result shows that in the West and Central Africa, mangrove loss from 1988 to 2014 was approximately 16.9%, and only 2.5% was recovered or newly planted at the same time, while the overall change of mangrove in the Sundarbans delta increased approximately by 900 km^2 of total mangrove area.

For the Niger Delta area, Ayanlade (2012) used Landsat satellite data, remote sensing change detection and ecological services valuation methodologies to assess the impacts of environment change on the ecological services in Niger Delta. The result shows that mangrove area decreased from 13,396km^2 in 1987 to 12,838km^2 in 2001 and from 12,838km^2 in 2001 to 12,173km^2 in 2011. Wang *et al*, (2016) employed the change detection technique to assess long-term changes in mangrove landscape of the Niger Delta, Nigeria in the period 1984 -2007. The analysis showed that mangrove forest was the major land cover and its average proportion and area are 42.0% and 1444.7 km^2 respectively. The study noted a 4% decrease in mangrove area for the period under investigation. Nababa *et al*., (2020) incorporated image compositing techniques, spectral-temporal metrics, and machine learning classification algorithms into the 'traditional' remote sensing mapping method to carry out an assessment of land cover dynamics and estimate the extent of the degraded mangroves in Niger Delta between 1988 and 2013. The study observed that degraded mangrove area reduced from 1800.27km^2 in 1988 to 1169.07km^2 in 2000, and also reduced from 1169.07km^2 in 2000 to1158.61km^2 in 2013. Similar pattern was observed for mangrove area which reduced from 6897.15km^2 in 1988 to 5743.70km^2 in 2000, and also reduced from 5743.70km^2 in 2000 to 5529.72km^2 in 2013.

Despite the important role of analyzing historical changes in mangrove cover at regular intervals for use in conservation initiatives, accurate and reliable information regarding the impacts of mangrove depletion on climate change in the Niger Delta Region of Nigeria is very limited. Also, there is a need to identify location-specific annual extent and rate of change in order to correctly inform conservation policies designed to reduce such mangrove losses in Niger Delta. Several studies indicated that the original extent of mangrove forests in Niger Delta has declined considerably over time following the global trend. Niger Delta estimates of original mangrove cover lost varies, with the most losses occurring in recent decades due human activities. This research work therefore aims to assess the extent and rate of mangrove cover change in Niger Delta over the period 1987 –2023. This study is very significant in a number of ways. First, it can be used in building up regional, national and global estimates. In addition, the findings can be used as a decision support tool to inform policies on mangrove conservation. More so, it can contribute to climate change adaptation and mitigation efforts through the Land Use and Land Use Change and Forests (LULUCF) option.

2. 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).

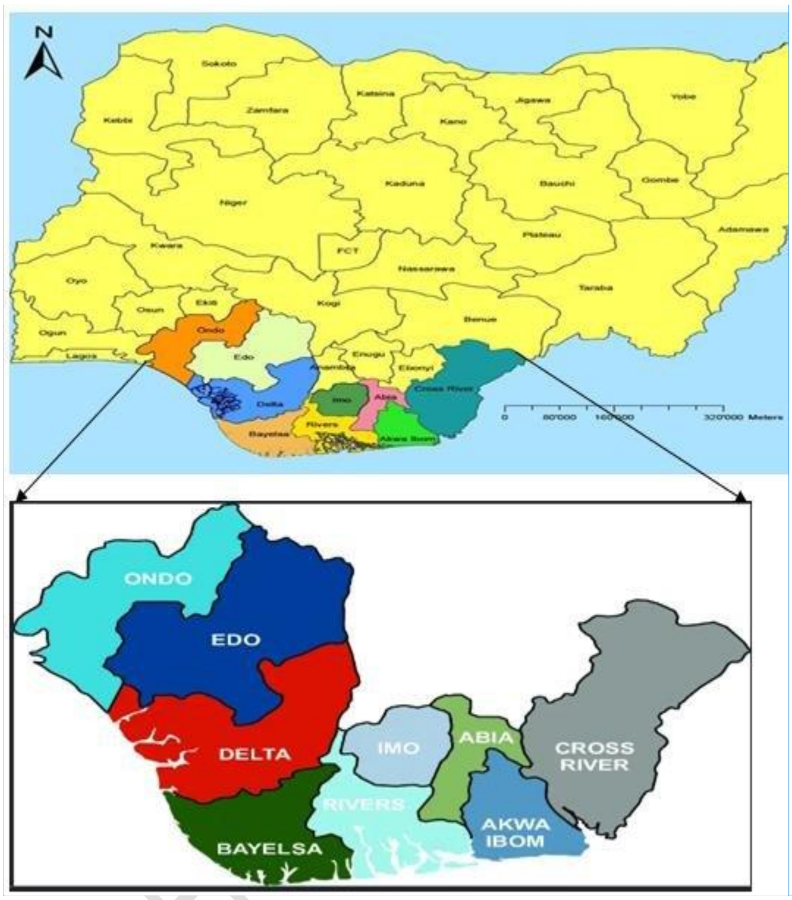

Fig. 1: Map of Nigeria Showing Niger Delta Region

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3. 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.

3.1 Data Types and Sources

Data was generated mostly from Secondary sources (satellite images downloads). However, primary data was also generated from directly from the impacted coastal communities, impacts of forest depletion on farming, impacts of Nypa palm invasion on the economy and livelihood, impacts of climate change on farming/agricultural pattern.

Table 1. Data acquisition, source and magnification

Data Type	Specific Data	Source	Resolution
Satellite Imagery	Landsat, Sentinel, MODIS	USGS, ESA, NASA	10m-30m (MODIS: 250m)
Climate Data	Temperature, Precipitation	ERA5, MODIS, Global Carbon Project	0.25° - 0.5° grid
Carbon Sequestration	Biomass, CO_2 concentrations	Global Mangrove Watch, Global Carbon Project	Variable
Socioeconomic Data	Population, land use, oil facilities	National Population Commission, World Bank, FAO	Variable

These data types and sources provided a robust foundation to examine the impacts of mangrove cover changes on climate variables, offering both spatial and temporal depth for meaningful analysis.

3.2 Population of the Study

For the study, population refers to the geographic area and environmental data points relevant to mangrove cover and climate change indicators within the Niger Delta Region. Thus, the population for the study comprises: Geographic Extent (all mangrove cover areas within the Niger Delta Region which includes nine states of Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo, Rivers, and Abia, and encompasses significant mangrove forests); Temporal Scope (annual or multi-year data from 1987 to 2022) as well as Data Variables (pixels or grid cells in satellite imagery representing mangrove areas, and associated climate data (temperature, carbon sequestration, precipitation) within these areas.

3.3 Sample technique and sample size

A combination of systematic sampling and stratified sampling techniques were used in order to allow for effective temporal and spatial analysis of mangrove cover changes and their climate impacts. Based on the study population and the sample technique used, the sample size for the study included:

- **Temporal Sample Size**: Approximately 20 time points across the 1987-2022 period.
- **Spatial Sample Size**: Around 1,500-3,000 pixels per image for mangrove areas (stratified by ecological zone), with a denser sampling in high-change zones using higher-resolution data where feasible.

3.4 Data acquisition and analysis

Land use/cover images of different periods in Niger Delta Region were captured from the Landsat Thematic Mapper (TM) imagery of 30m x 30m for 1987, 2002, 2012, and 2022. Each image was geo-referenced in ArcGIS 10.8 to Universal Transverse Mercator, Zone 32N (WGS 84). Composite analysis was carried out for the bands of each image in each period in order to produce a false composite imagery in ArcGIS 10.8.

Commented [RoSa5]: 2024 or at leat 2023

From the ground-truthing of the land use/cover types in the study area with additional information from the satellite imageries, an image classification analysis was carried out to classify the spectral reflectance into different major land use types as found during the reconnaissance survey. Six major classes namely vegetation, farmland, built-up area, bare land, water body and mangrove were identified and their descriptions tabulated. These classes are similar to the land use/cover categories in the Niger Delta acknowledged by Ayanlade (2012). The spatial coverage of each land use/cover type was determined in squared kilometers using the calculated geometry module of ArcGIS 10.8. These images were used to classify changes in mangrove extent.

3.5 Image Processing and Classification

i. Supervised or unsupervised classification methods were used to categorize pixels in the satellite imagery into land cover classes, including mangrove forest, vegetation, farmland, built-up area, bare land and water body.
ii. Ancillary data and ground truthing were incorporated to improve classification accuracy and resolve class ambiguities.

3.6 Change detection analysis

Change detection analysis was performed using land use/cover map in 1987, 2002, 2012, and 2022. Change detection refers to the process of identifying differences in the state of land features by observing them at different times. In post-classification change detection, the images from each time period were classified using the same classification scheme into a number of discrete categories (i.e., land cover types) (Nguyen *et al*., 2013). Quantitative analysis of land use/cover between different dates was conducted to detect the change.

3.7 Annual rate of change in land use/cover

The percentage change in spatial coverage in percentage (%) for each land use type was calculated as a percentage increase or decrease in land use spatial coverage of the previous period for each land use type.

3.8 Formulas:

a. Annual Rate of Change (km^2 per Year) = Observed Land Use Change in km^2/No. of Yrs. Taken for the Change to Occur.
b. Percentage Change in Area (%) = New Value – Old Value/Old Value x 100

Where: New Value is the Current or Latest Land Cover Area,

Old Value is the Previous or Original Land Cover Area.

c. Total Change = New Value (km^2) – Old Value (km^2).
d. Annual Rate of Change = Total Change/Old Value/No. of Years x 100%.

Note: Negative result indicates mangrove loss or decline, while positive result indicates mangrove gain or increase.

4. RESULTS AND DISCUSSION

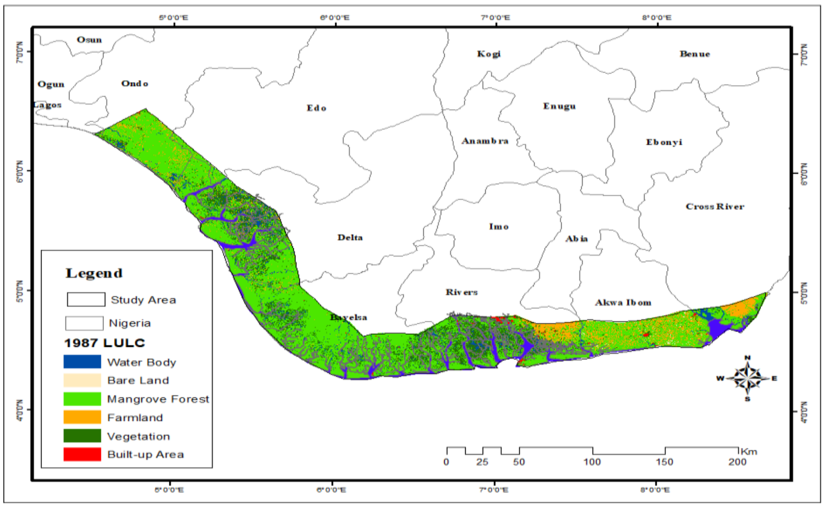

Figure 2: Land Use/Land Cover Satellite Map Category (1987)

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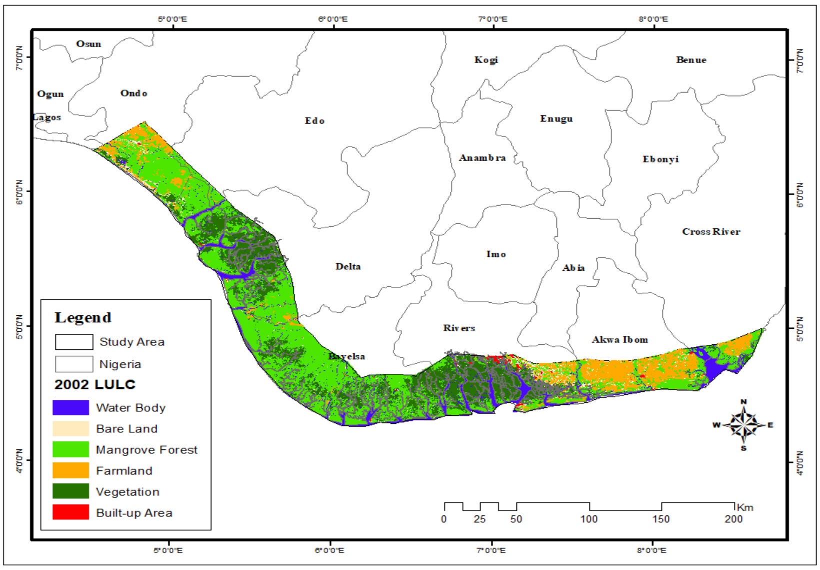


Figure 3: Land Use/Land Cover Category (2002)

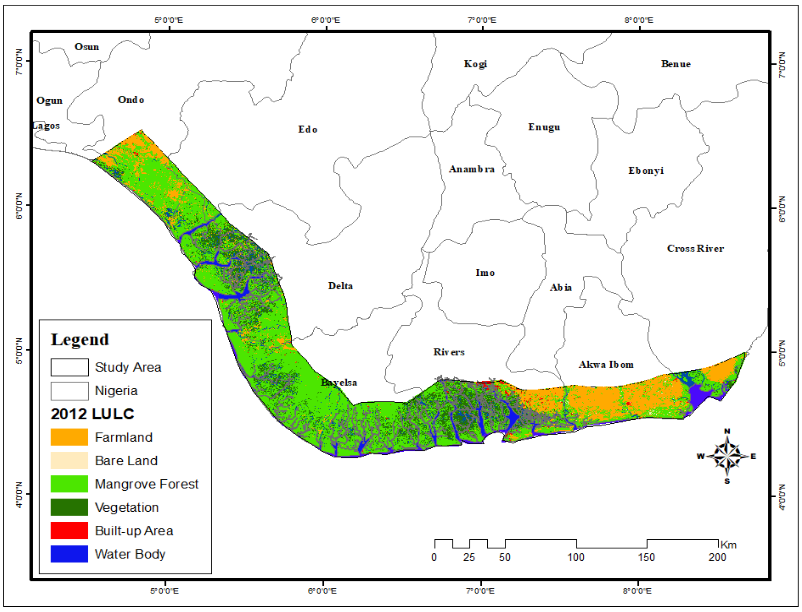


Figure 4: Land Use/Land Cover Category (2012)

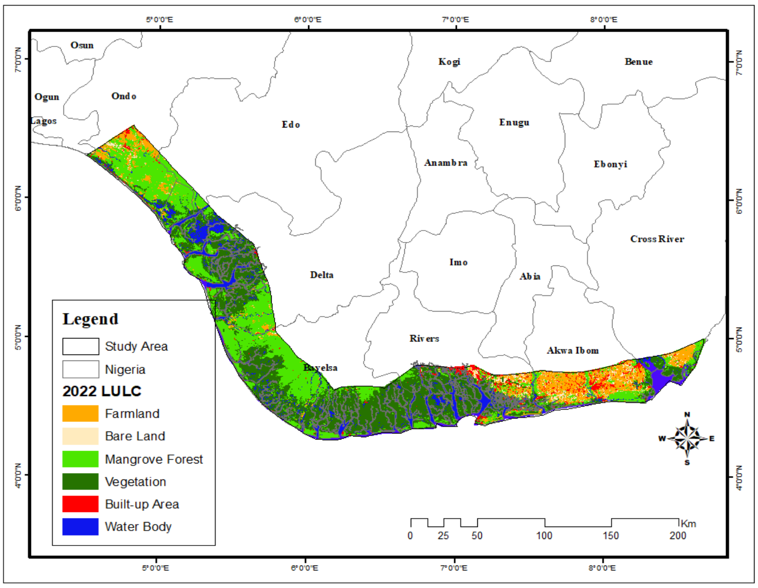


Figure 5: Land Use/Land Cover Category (2022)

Key: ***Mangrove (Light Green), Water bodies (Blue), Bare Land (Light Yellow), Farmland (Yellow), Vegetation (Dark Green) & Built-Up Area (Red).***

4.1 Land use/cover change analysis

The land use/cover maps of the study area for 1987, 2002, 2012 and 2022 are shown in Figures 2, 3, 4 and 5 above respectively. The spatial extent of land use/land cover types for the study area (1987 – 2022) is shown in Tables 2 to 8. The tables indicate that mangrove was 12,991km^2 in 1987; 11,044km^2 in 2002; 9,250km^2 in 2012 and 9,087km^2 in 2022. This shows a decrease of 3,904km^2 (30.05%) or (2.00% per year) between 1987 and 2022. Water bodies category was 5,146km^2 in 1987; 5,150 km^2 in 2002; 4,419km^2 in 2012; and 4,300km^2 in 2022. This shows an increase of 846km^2 (16.44%) or (2.39% per year) between 1987 and 2022. Bare land category was 356km^2 in 1987; 344km^2 in 2002; 481km^2 in 2012 and 450km^2 in 2022. This shows a decrease of -94km^2 (26.40%) or (3.61% per year) between 1986 and 2022. Farmland category was 342km^2 in 1987; 436km^2 in 2002; 495km^2 in 2012 and 400km^2 in 2022. This shows a decrease of -58km^2 (16.96%) or (3.34% per year) between 1986 and 2022. Vegetation was 2,965km^2 in 1987; 4,738km^2 in 2002; 6,965km^2 in 2012 and 7,046km^2 in 2022. This shows a decrease of -4,081km^2 (137.64%) or (6.79% per year) between 1986 and 2022. Built-up area was 68km^2 in 1987; 156km^2 in 2002; 258km^2 in 2012 and 495km^2 in 2022. This shows an increase of 427km^2 (627.94%) or (20.80% per year) between 1986 and 2022.

Table 2: Spatial extent of land use/land cover types for the study area (1987 – 2022)

Land use/Land Cover Category	Extent (Km^2) 1987	Extent (Km^2) 2002	Extent (Km^2) 2012	Extent (Km^2) 2022	Total Change in Area				
					1987-2002 (km^2)	2002-2012 (km^2)	2012-2022 (km^2)	1987-2022 (km^2)	1987-2022 (%)
Mangrove	12,991	11,044	9,250	9,087	1,947	1,794	163	3,904	30.05
Water Bodies	5,146	5,150	4,419	4,300	-4	731	119	846	16.44
Bare land	356	344	481	450	12	-137	31	-94	-26.40
Farmland	342	436	495	400	-94	-59	95	-58	-16.96
Vegetation	2,965	4,738	6,965	7,046	-1,773	-2,227	-81	-4,081	-137.64
Built-up Area	68	156	258	495	-88	-102	-237	-427	-627.94
Total	21,868	21,868	21,868	21,868					

Table 3: Extent and rate of mangrove cover change (1987–2022)

Period	**Extent of Change (km^2)**	**Annual Rate of Change (km^2 per Year)**	**Percentage Change in Area (%)**	**Percentage of Original Area Lost per Year (% per Year)**
1987-2002	1,947.00	129.80	-14.99	-1.00
2002-2012	1,794.00	179.40	-16.24	-1.62
2012-2022	163.00	16.30	-1.76	-0.18
1987-2022	3,904.00	111.54	-69.95	-2.00

Table 4: Extent and rate of water bodies change (1987–2022)

Period	Extent of Change (km^2)	Annual Rate of Change (km^2 per Year)	Percentage Change in Area (%)	Percentage of Original Area Lost per Year (% per Year)
1987-2002	-4.00	-0.27	0.08	0.01
2002-2012	731.00	73.10	-14.19	-1.42
2012-2022	119.00	11.90	-2.69	-0.27
1987-2022	846.00	24.17	-83.56	-2.39

Table 5: Extent and rate of bare land change (1987–2022)

Period	Extent of Change (km^2)	Annual Rate of Change (km^2 per Year)	Percentage Change in Area (%)	Percentage of Original Area Lost per Year (% per Year)
1987-2002	12.00	0.80	-3.37	-0.22
2002-2012	-137.00	-13.70	39.83	3.98
2012-2022	31.00	3.10	-6.44	-0.64
1987-2022	-94.00	-2.69	-126.40	-3.61

Table 6: Extent and rate of farmland change (1987–2022)

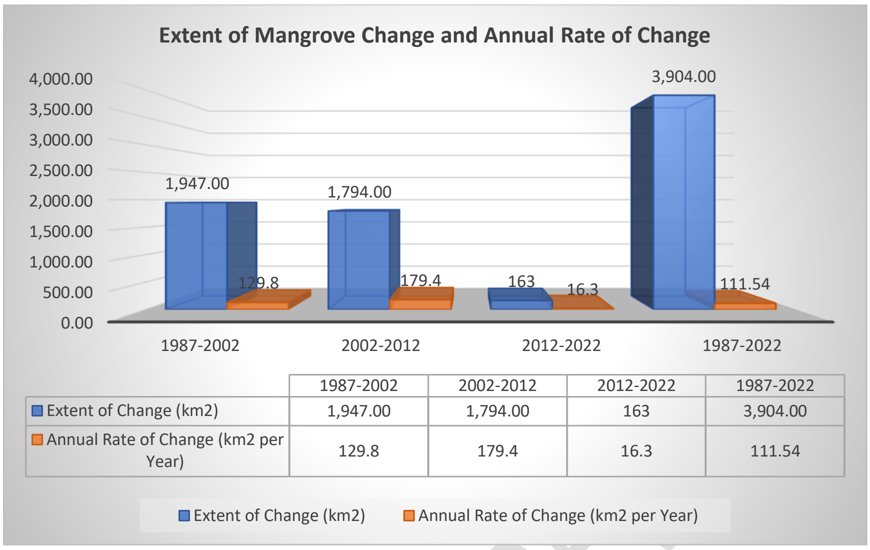
Period	Extent of Change (km^2)	Annual Rate of Change (km^2 per Year)	Percentage Change in Area (%)	Percentage of Original Area Lost per Year (% per Year)
1987-2002	-94.00	-6.27	27.49	1.83
2002-2012	-59.00	-5.90	13.53	1.35
2012-2022	95.00	9.50	-19.19	-1.92
1987-2022	-58.00	-1.66	-116.96	-3.34

Table 7: Extent and rate of Vegetation change (1987–2022)

Period	Extent of Change (km^2)	Annual Rate of Change (km^2 per Year)	Percentage Change in Area (%)	Percentage of Original Area Lost per Year (% per Year)
1987-2002	-1,773	-118.20	59.80	3.99
2002-2012	-2,227	-222.70	47.00	4.70
2012-2022	-81	-8.10	1.16	0.12
1987-2022	-4081	-116.60	-237.64	-6.79

Table 8: Extent and rate of "Built Up Area" change (1987–2022)

Period	Extent of Change (km^2)	Annual Rate of Change (km^2 per Year)	Percentage Change in Area (%)	Percentage of Original Area Lost per Year (% per Year)
1987-2002	-88.00	-5.87	129.41	8.63
2002-2012	-102.00	-10.2	65.38	6.54
2012-2022	-237.00	-23.7	91.86	9.19
1987-2022	-427.00	-12.2	-727.94	-20.80



	1987-2002	2002-2012	2012-2022	1987-2022
Extent of Change (km2)	1,947.00	1,794.00	163	3,904.00
Annual Rate of Change (km2 per Year)	129.8	179.4	16.3	111.54

Figure 6: Chart Showing Extent of Mangrove Change and Annual Rate of Change

The extent and rate of mangrove cover change (table 3, figure 6) reveals that spatial-temporal changes in mangrove extent have been decreasing over the past 35 years. The period 1987 – 2002 recorded a loss of 1,947.00km^2 at an annual rate of 129.80km^2 per year. Percentage of original area lost per year was 1.00% per year. For the period 2002 – 2012, a loss of 1,794.00km^2 was recorded at an annual rate of 179.40km^2 per year and the percentage of original area lost per year was 1.62% per year. Again, for the period 2012 – 2022, a loss of 163.00km^2 was recorded at an annual rate of 16.30km^2 per year. The percentage of original area lost per year was 0.18% per year. Overall, for the period of 1987-2022, the change analysis indicates that the total mangrove area reduced from 12,991 km^2 (59.41%) in 1987 to 9,089km^2 (41.55%) in 2022. This change observed from 1987 to 2022 (35 years) resulted in the loss of 3,904.00 km^2 of mangrove forest to other land use/cover types in the study area. This implies that the mangrove forest extent decreased at the rate of 111.54 km^2 per year. The annual average rate of mangrove cover decrease was 2.00 % per year.

4.2 Conversion of mangroves forest in Niger Delta

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Several factors contribute to the conversion of mangroves to other land use types. Unchecked land use practices (especially coastal urbanization, agriculture development, aquaculture expansion etc.) is recognized as one of the most significant factors that reduce the extent of mangrove areas in Niger Delta. Based on this study, the Niger Delta has lost 3,904.00 km^2 of the original mangrove area between

1987 and 2022 to other land use/cover types including water bodies, farmlands, built-up areas for rapid urbanization like oil & gas exploration/exploitation, cleared land, and bare land.

From the data obtained (Figure 6), this study observed that the total area of Niger Delta mangrove has decreased from 1987 to 2022 resulting in the loss of 3,904.00 km^2 of mangrove forest to other land use/cover types. This trend is similar to the findings of previous studies which also suggested a general decline in mangrove area in the Niger Delta. Afiesimama *et al*, (2021) revealed that mangrove area decreased from 5037.48km^2 in 1986 to 1831.23km^2 in 2018. Also, Ayanlade (2012) reported that mangrove area decreased from 13,396 km^2 in 1987 to 12,173 km^2 in 2011. Again, Nababa *et al*. (2020) observed that degraded mangrove area was reducing from 1800.27km^2 in 1988 and 1169.07km^2 in 2000, and to 1158.61km^2 in 2013. Furthermore, Wang *et al*. (2016) reported a 4% decrease in mangrove landscape from 1984 to 2007. A similar pattern was observed for mangrove area which reduced from 6897.15km^2 in 1988 and 5743.70km^2 in 2000, and to 5529.72km^2 in 2013. The finding implies that the mangrove forest extent decreased at the rate of 111.54 km^2 per year. The annual average rate of mangrove extent decrease was 2.00% per year. However, the annual rate of loss in Niger Delta is close to the global annual rate of mangrove deforestation. Valiela *et al*. (2001) estimated the global annual rate of loss at 2.07% per year over 17 years. Although this study provides an estimate of spatial-temporal changes in mangrove cover extent in Niger Delta over the last 35 years, earlier findings have shown that there is variability in estimates of mangrove extent as noted by Friess (2013). Therefore, regular long-term assessment of changes in mangrove covers as provided by this study is required.

5. CONCLUSION

The study utilized Landsat data to assess the spatio-temporal dynamics of mangrove cover change in Niger Delta for the period 1987 – 2022 and the result reveals that between 1987 and 2022 (35years), the mangrove cover decreased by 63.7% (3,206.25 km^2) at a rate of 100.20km^2 /yr or 1.99% yr^{-1}. The findings thus has provided useful information and understanding of Niger Delta's mangrove extent and the rate of deforestation compared to the global situation. This result will go a long way in supporting policies and regulations associated with the conservation and rehabilitation of fringe mangroves. Also, it will be useful to conservationists, resource managers and other stakeholders involve in advocating for sustainable utilization of mangrove resources in Niger Delta region. Assessing the changes in the extent of mangrove cover at regular intervals will also help in understanding their status (decrease or increase) for better implementation of conservation initiatives.

6. RECOMMENDATION

The findings of the study underscore the urgent need for concerted efforts to address both anthropogenic and natural drivers of mangrove depletion in the Niger Delta and as such, the following key policy recommendations are proposed for the sustainable management of mangroves in the Niger Delta region:

i. Strengthening legal and policy frameworks by enacting comprehensive, stand-alone federal legislation for mangrove conservation and management, incorporating modern environmental principles and international best practices as well as revising and harmonizing outdated state and federal forestry laws to address the unique challenges of mangrove ecosystems.
ii. Enhancing governance and institutional capacity by strengthening enforcement mechanisms and building institutional capacity to enforce mangrove protection laws, including monitoring illegal logging, oil pollution, and urban encroachment including ensuring community participation by involving local communities in decision-making and mangrove restoration projects to foster stewardship and compliance.
iii. Restoration and rehabilitation of mangrove ecosystems by embarking on reforestation Programs like implementing large-scale mangrove reforestation projects using native species to restore degraded areas and controlling of invasive species by developing strategies to manage and reduce the spread of Nypa fruticans (Nipa palm), which displaces native mangroves.
iv. Strengthening of pollution control measures focusing on oil spill management by enforcing stricter regulations on oil companies for pollution control and remediation, ensuring prompt cleanup of spills including monitoring and regulating coastal industries to minimize waste discharge into mangrove areas.
v. Promoting sustainable livelihoods through alternative livelihood programs by providing training and support for sustainable income-generating activities, such as eco-tourism, aquaculture, and sustainable harvesting of mangrove resources.

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Commented [RoSa8]: References must be up date and at least 30.
Presentation must be in accordance with the citation style in the manuscript.

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