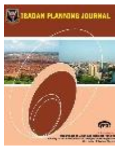
IPJ Ibadan Planning Journal
May 2025,
Vol.11, No. 1, 10-21

Ibadan Planning Journal
journal homepage: http://journals.ui.edu.ng/index.php/ipj/issue/view/7



# Spatio-Temporal Changes in Carbon Sequestration by Coastal Ecosystems in Ibeju Lekki, Lagos, Nigeria

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**Abstract**

*The rapid urbanisation of coastal areas presents significant challenges to the delicate balance between development and ecosystem conservation. This tension is particularly evident in Ibeju Lekki, Lagos, Nigeria, as the region undergoes a dramatic transformation. This study investigates spatio-temporal changes in carbon sequestration in coastal ecosystems in Ibeju-Lekki, Lagos, Nigeria, from 1986 to 2024. Employing a mixed-methods approach that combines geospatial analysis, field surveys, and stakeholder interviews, the research examines the impacts of rapid urbanisation on ecosystem health and carbon storage capacity. Landsat imagery and carbon pool data were analysed to quantify changes in land use and carbon stocks over the 38 years. The study reveals a substantial 22.57% reduction in total carbon storage, from approximately 23.25 million megagrams in 1986 to 18 million megagrams in 2024. This decline corresponds with significant land use changes, including a decrease in dense vegetation cover from 32.64% to 21.50% and an expansion of built-up areas from 14.25% to 19.73% of the total land area. Swamp forests and mangrove ecosystems experienced the most severe depletion, with urban development identified as the primary driver of change. The research highlights the lack of comprehensive ecosystem management strategies and proposes recommendations for sustainable development, including the implementation of Payment for Ecosystem Services models and stricter zoning regulations.*

**Keywords**
Carbon sequestration, Carbon stocks, Ecosystem conservation, Spatio-temporal, Urbanisation

**Article History**
Received 22 Jan. 2025
Accepted May 2025
Published online May 31, 2025

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**Declaration of Conflicting Interests**
The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

## 1. Introduction

Coastal ecosystems, which include estuaries, coastal waters, and lands located at the lower end of drainage basins, are unique habitats formed by plants and other organisms that can thrive at the borders between ocean and land, where they must live, adapt and flourish in saltwater and changing tides (Convertino, 2013). These ecosystems are among the most productive and ecologically significant habitats on Earth, particularly for global carbon cycling and climate regulation (Alongi, 2018). These ecosystems, including mangroves, salt marshes, and seagrass beds, are collectively known as "blue carbon" ecosystems due to their unique ability to sequester carbon in biomass and sediments for extended periods (Nellemann et al., 2009). Ecosystem services can be categorised into four functional groups: 'provisioning' (such as food and fibre, fuel, wood, construction materials, and medicinal resources), 'supporting' (including nutrient cycling, soil formation, primary production, and maintenance of genetic diversity), 'regulating' (covering climate regulation, flood and storm protection, and erosion prevention), and 'cultural' (encompassing recreation, tourism, and psychological benefits) services (Barbier, 2007).

The coastal ecosystems of Ibeju-Lekki play a critical role as natural carbon sinks in Nigeria. However, these ecosystems face significant threats from rapid urbanisation, industrial development, and climate change impacts (Adegoke et al., 2010). While economically promising, the Lagos State Government's initiative to develop Ibeju Lekki as a significant industrial and residential hub poses potential risks to these vital carbon-sequestering ecosystems (Ajibola et al., 2012). Climate change further complicates the scenario, with rising sea levels threatening to alter the delicate balance of freshwater and saltwater influences that define these coastal ecosystems (Ward et al., 2016). Changes in precipitation patterns and temperature regimes may also affect the distribution and composition of vegetation in these biomes, potentially impacting their carbon sequestration capacity (Osarodion et al., 2018).

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The spatial distribution and temporal changes in carbon sequestration across Ibeju Lekki's coastal landscape remain poorly documented. This knowledge gap makes it difficult to identify critical areas for conservation and to predict future carbon storage trends. The effects of changes in local land use, such as the conversion of mangroves for aquaculture or the draining of swamps for urban development, on carbon sequestration have not been quantified (Taiwo & Areola, 2009; Olajide et al., 2020; Olajide & Popoola, 2020). This lack of data hinders the development of targeted, ecosystem-specific management strategies, such as Payment for Ecosystem Services, that could enhance carbon sequestration while supporting sustainable development. Payment for ecosystem services can serve as a comprehensive framework for examining these services (Popoola et al., 2016). It is a mechanism that addresses the need for conservation and sustainable management of natural environments. In fact, payments for ecosystem services programs are being implemented globally to improve sustainability and conservation outcomes (Le et al., 2024). Payments for Ecosystem Services (PES) initiatives are advocated as a practical approach to advancing carbon offsetting, improving carbon sequestration, and alleviating poverty in ecologically vulnerable regions of developing nations (Hu et al., 2023). Carbon storage and sequestration mechanisms are needed to assess and quantify the extent of carbon stored in the Ibeju-Lekki landscape and to evaluate carbon sequestration over the years. The results can then be compared with the extent to which the payment-for-ecosystem-services framework has been adopted to conserve and sustain ecosystems, enabling informed decisions in Ibeju-Lekki.

The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) Carbon Storage and Sequestration Model is a tool designed to estimate the amount of carbon stored in a landscape or seascape and to value the amount of sequestered carbon over time. Developed by the Natural Capital Project, a partnership between Stanford University, the University of Minnesota, The Nature Conservancy, and the World Wildlife Fund, this model is part of a suite of ecosystem service models designed to inform decisions on natural resource management. The InVEST Carbon model operates on the principle that land use and land cover (LULC) types store different amounts of carbon in four main pools: aboveground biomass, belowground biomass, soil, and dead organic matter (Zhang et al., 2020). By mapping changes in LULC over time, the model can estimate changes in carbon storage and sequestration. This approach quantifies carbon stocks and the economic valuation of carbon sequestration services, providing valuable information for land use planning, climate change mitigation strategies, and ecosystem service assessments (Sharp et al., 2020).

As carbon is continually exchanged between the atmosphere, oceans, land, and living organisms, the model also considers carbon fluxes, which represent the movement of carbon between different pools and between the ecosystem and the atmosphere. Key fluxes include carbon uptake through photo-synthesis, release through respiration, transfer to soils through litterfall and root turnover, and export to adjacent ecosystems or the ocean. Findi and Wantim (2022) provided an in-depth review of carbon fluxes in mangrove ecosystems, emphasising the complexity of carbon cycling in these environments and the importance of considering all relevant fluxes for accurate carbon budgeting.

## 2. The Study Area

Lagos State is between latitudes $6^{0}24^{1}$ and $6^{0}42^{1}$ N and longitudes $2^{0}34^{1}$ and $3^{0}42^{1}$ E. This location is situated on Nigeria's southwest coast, extending from the Nigerian border with Benin to the east of the settlement of Agwerige, marking the beginning of the coastline's southerly bend (see Figure 1). The State borders the Atlantic Ocean on the south, the Benin Republic on the west, and Ogun State on the north and east. With a total land size of 3,577 sq. km and aquatic bodies covering roughly 256.26 sq. km, the State is still the smallest of the 36 states comprising the Federal Republic of Nigeria (Idiege et al., 2017).

Geographically, Lagos is situated on a low-lying coastal terrain, characterised by lush tropical rainforests interspersed with extensive lagoons, rivers, creeks, and mangrove marshlands, which contribute to its rich biodiversity. The State's twofold rainfall pattern, which creates a wetland environment, influences the mangrove and freshwater swamp forests, which comprise most of the State's vegetation. The State typically has two distinct seasons: a wet season (April–October) and a dry season (November–March). A complex network of lagoons and canals characterises the region's drainage system, making up roughly 22% of the State's total area (787 sq. km). The Yewa, Ogun, Oshun, Kweme Rivers, and the Lagos and Lekki Lagoons are the main bodies of water (About Lagos, 2024). Lagos State remains susceptible to climate change-induced hazards, including sea-level rise and severe flooding from torrential precipitation.

Ibeju-Lekki (in Figure 2) is a local government area (LGA) in Lagos State, Nigeria, covering 455 square kilometres. The administrative centre was formerly at Akodo but was later moved to Igando Oloja due to the creation of the Lekki Council Development Area. The name of the Local government was derived from the two autonomous communities of Ibeju and Lekki.

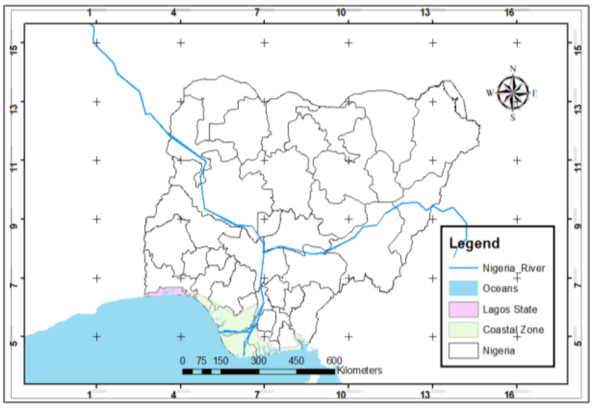


**Figure 1: Map of Nigeria showing Lagos State and Nigeria's coastal region**

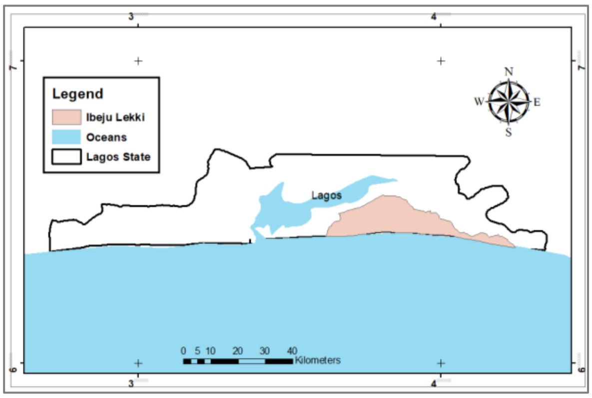


**Figure 2: Map of Lagos State showing Ibeju Lekki LGA**

Source: Author's digitised work, 2024

## 3. Research Methodology

This study employed a mixed-methods approach that combined survey research, case studies, and geospatial analysis. Geospatial data and imagery were obtained using GIS, Landsat, and Google Earth imagery to examine the morphology of the coastal ecosystem and its depletion over time. Questionnaires were used to gather information about the drivers of ecosystem changes in the study area. The InVEST Carbon Storage and Sequestration Model (CSSM) was then utilised to evaluate ecosystem services related to carbon storage and sequestration. Lastly, a semi-structured interview guide was administered to relevant agencies to gather information on ecosystem management and their operational activities in the coastal area. The research was conducted within a 5 km radius of the shoreline, based on the fixed-distance definition of the coastal zone (Kay & Alder, 2005).

Regarding the fixed-distance definition, seven communities (Imobido, Idasho, Ilekuru, Ilege, Oke-Segun, Magbon-Segun, and Idotun) were identified along the coastline of Ibeju-Lekki during the reconnaissance survey, forming the study's sample frame. Stratified and random sampling techniques were used to select respondents. Stratified sampling was conducted by dividing the study areas into seven (7) sub-locations (strata). Subsequently, the questionnaires were distributed within each stratum using random sampling. The systematic Random Sampling technique was used to select 10% of the total buildings in the seven chosen communities, using the Random Number Generator in SPSS. The overall number of buildings in the community within the sampling frame was 2514, of which 251 were selected as the sample. Additionally, all biomes in the Ibeju-Lekki coastal ecosystem were included in the sample.

The data collection and analysis procedure were conducted in two stages. The first stage involved delineating the study area, which was digitised into a polygon feature class using ArcGIS 10.7.1, and then overlaid on the spatially disaggregated carbon dataset and the historical Landsat datasets for 1986, 2016, and 2024. Additionally, the Landsat images were analysed to assess changes in land cover within the study area from 1986 to 2024. The Landsat dataset bands were stacked to produce a true-colour composite raster, which was then used to generate training samples in ArcMap 10.7.1 using the image classification tool. The resulting LULC maps and a .csv file containing information on the data pools (C_Above, C_Below, C_Soil, and C_Dead) of the area over the period under study were subsequently input into the InVEST CSS model. This was done to evaluate the amount and value of carbon stored in the study area for each year examined, as well as the rate of sequestration over time. The second stage involved using semi-structured interview guides to gather information on the conservation and sustainability of coastal ecosystems, the drivers of change, the extent of alterations, and their implications for the well-being of residents in Ibeju-Lekki. This information was obtained from the Local Planning Authorities, Agencies, and Ministries responsible for environmental and ecosystem management. It aims to examine existing regulations in relation to the principle of payment for ecosystem services, which supports carbon sequestration and guides development in the area to improve human well-being.

## 4. Findings and Discussions

This section presents data from a survey administered to 251 households in the Imobido, Idasho, Ilekuru, Ilege, Oke-Segun, Magbon-Segun, and Idotun communities, which were previously selected to represent the study area. It includes the analysis and discussion of findings from this research. The data covers the various ecosystem biomes in Ibeju Lekki, including rates of change and depletion over the years, and how these changes have subsequently affected the value of carbon stored and sequestered in the landscape. The analysis aimed to investigate spatiotemporal changes in carbon sequestration by coastal ecosystems in Ibeju-Lekki, using imagery and data spanning 38 years, with 1986, 2016, and 2024 as the reference years.

### 4.1 Spatial distribution and storage of carbon in Ibeju-Lekki between 1986 and 2024

The amount of carbon stored in any land area is primarily determined by the sizes of four carbon pools: aboveground biomass, belowground biomass, soil, and dead organic matter. This study mapped and quantified carbon storage in the landscapes of the Ibeju-Lekki LGA and subsequently examined changes in carbon sequestration in the study area between 1986 and 2024. As shown in Table 1, the amount of carbon stored in carbon pools was interpolated into the various LULC classifications for pre-modelled raster LULC maps of the study area for 1986, 2016, and 2024. To further enhance accuracy, the carbon pool data for three LULC classes – Water bodies, Built-up areas, and Beaches/Bare-grounds – were modified and assigned a value of zero (0) because these are non-carbon-storing land uses.

**Table 1: Carbon pool data in aboveground biomass, belowground biomass, soil, and dead organic matter in the study area**

| Lucode | LULC_name | C_above | C_below | C_soil | C_dead |
|---|---|---|---|---|---|
| 1986 | | | | | |
| 1 | Water Body | 0.87789117 | 0.242517 | 203.252605 | 0 |
| 54 | Bare grounds/Beaches | 9.20996331 | 3.39631 | 710.536249 | 0 |
| 87 | Dense Vegetations | 52.6748323 | 12.987661 | 618.000931 | 0 |
| 147 | Sparse Vegetations | 30.6776634 | 7.881619 | 583.967646 | 0 |
| 182 | Built-Up Areas | 23.7303819 | 6.813488 | 632.441315 | 0 |
| 208 | Wetlands | 25.6254907 | 9.310676 | 615.913198 | 0 |
| 0 | Other | 0 | 0 | 0 | 0 |
| 2016 | | | | | |
| 204 | Water Body | 14.085054 | 3.360854 | 231.405318 | 0 |
| 239 | Bare grounds/Beaches | 23.008478 | 8.030796 | 681.730679 | 0 |
| 258 | Dense Vegetations | 46.916943 | 11.7723 | 597.915075 | 0 |
| 278 | Sparse Vegetations | 38.949856 | 9.682609 | 598.028058 | 0 |
| 205 | Built-Up Areas | 17.304478 | 5.091144 | 628.959081 | 0 |
| 257 | Wetlands | 23.501143 | 6.286286 | 567.5548 | 0 |
| 0 | Other | 0 | 0 | 0 | 0 |
| 2024 | | | | | |
| 1 | Water Body | 0.090811 | 0.076216 | 10 | 0 |
| 39 | Bare grounds/Beaches | 29.31222 | 8.554775 | 390 | 0 |
| 51 | Dense Vegetations | 50.106866 | 12.380117 | 700 | 0 |
| 70 | Sparse Vegetations | 36.426227 | 9.328491 | 510 | 0 |
| 87 | Built-Up Areas | 19.448575 | 5.943536 | 870 | 0 |
| 40 | Wetlands | 22.685745 | 6.314466 | 400 | 0 |
| 0 | Other | 0 | 0 | 0 | 0 |

Source: Author's Field survey, 2024

#### 4.1.1 Spatio-temporal assessment of carbon storage in Ibeju Lekki (1986 to 2024)

As shown in Table 2, the carbon storage data for Ibeju-Lekki Local Government Area reveal a significant declining trend over the 38 years from 1986 to 2024. In 1986, the total carbon storage was approximately 23.25 million megagrams, averaging 478.61 megagrams per unit area. By 2016, this had decreased to about 19.49 million megagrams (average 401.37 megagrams), representing a 16.14% reduction. The most recent data from 2024 shows a further decline to nearly 18 million megagrams (average 370.57 megagrams), marking a total decrease of 22.57% from the 1986 baseline. This substantial reduction in carbon storage capacity can be attributed to several factors that are characteristic of rapid urban development in Ibeju-Lekki. According to Popoola et al. (2025), Akinyede et al. (2023), and Popoola et al. (2022), the area has experienced extensive land use changes due to the construction of the Lekki Free Trade Zone and other major infrastructure projects. These studies show an extensive reduction in vegetation, ranging from 30% to 50%, between 1984 and 2024. This aligns with the findings in this research, which indicate that vegetation has been reduced by 51.34%, leading to a decrease in carbon storage.

**Table 2: Terrestrial Stored Carbon in Ibeju-Lekki in 1986, 2016, and 2024**

| Year | Total Land Area (Hectares) | Total Carbon (Mg of C) | Average Value Per Hectare (Mg of C) |
|---|---|---|---|
| **1986** | 48,569.04 | 23,245,658.05 | 478.61 |
| **2016** | 48,569.04 | 19,494,319.35 | 401.37 |
| **2024** | 48,569.04 | 17998108.13 | 370.57 |

Source: Author's digitised work, 2024

Results indicate that between 1986 and 2016, carbon stock decreased by 16.14%, representing an average annual decline of 0.54% over 30 years. However, by 2024, a further reduction of 7.68%, averaging 0.96% annually, was recorded. Factors responsible for this decline include urbanisation, demographic expansion, the conversion of vegetated land to residential and industrial uses, and climate change (Popoola et al., 2025; Popoola et al., 2022). According to field studies, the primary land conversion was driven by the Deep-Sea Port and Dangote Refinery, which transformed vegetated areas into industrial zones. Other uses included commercial centres, increased residential construction, road development, and various urban infrastructure projects. These changes have decreased the amount of carbon stored within the study area. Additionally, the Lagos State Government launched the Green Initiative, which imposes stricter regulations on deforestation and promotes urban greening, potentially helping mitigate forest loss in Ibeju-Lekki. Overall, the carbon loss over the 38 years amounts to 22.57%. This suggests that 77.43% of the carbon storage prior to 1986 remains preserved. However, if appropriate measures are not taken, carbon loss will exceed the 70% benchmark required for environmental sustainability in rapidly developing urban areas, as the World Bank's Urban Sustainability Framework (2018) suggests. The carbon storage analyses for this study are revealed in Figure 3.

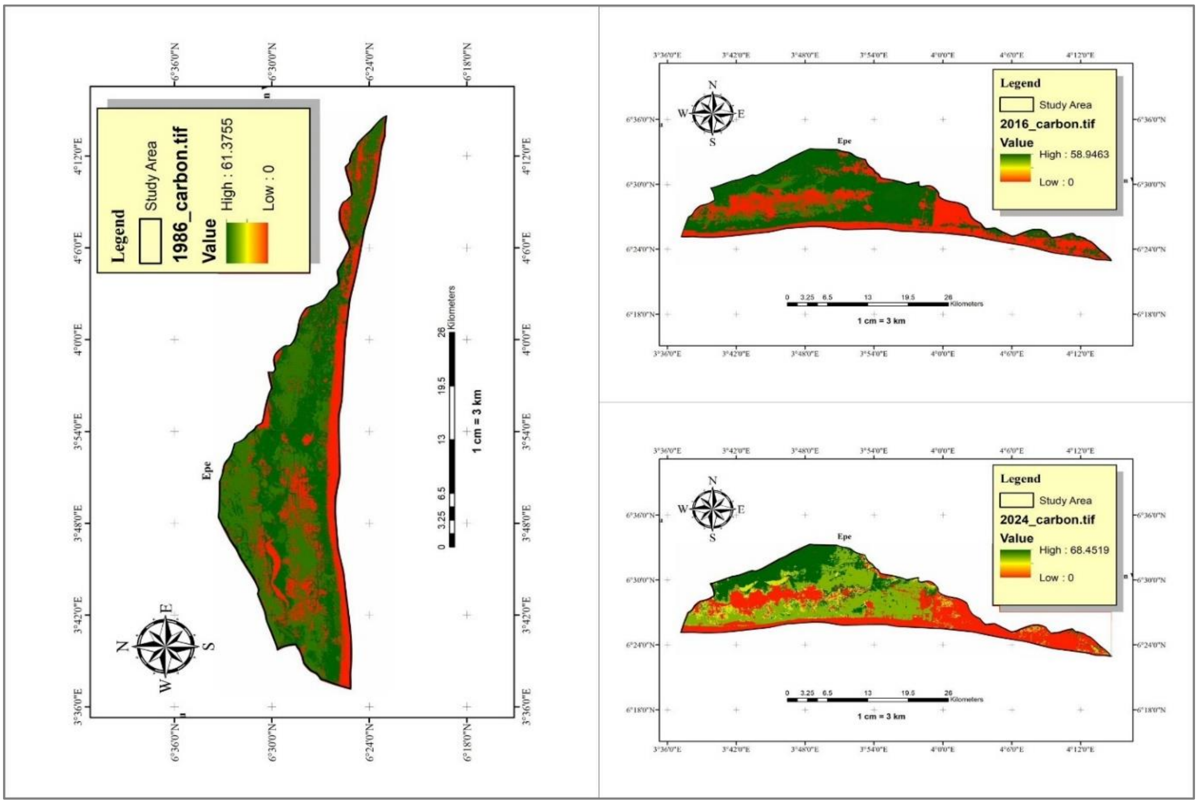


**Figure 3: Spatial Distribution of Stored Carbon in the Study Area in 1986, 2016 and 2024**
Source: Author's Analysis, 2024

#### 4.1.2 Spatio-temporal assessment of carbon sequestration in Ibeju Lekki (1986-2024)

In Table 3, the carbon sequestration analysis for the Ibeju-Lekki Local Government Area reveals a consistent decline in carbon capture capacity over the studied timeframe, with distinct periods showing varying rates of change. Between 1986 and 2016, the area experienced a substantial decrease in carbon sequestration of approximately 3.75 million megagrams. This trend continued from 2016 to 2024, with an additional reduction of about 1.5 million megagrams, bringing the total decline to 5.25 million megagrams over the entire 38-year period. The annual rate of decline between 1986 and 2016 was approximately 125,044.62 megagrams per year, while the period from 2016 to 2024 showed an increased rate of decline at 187,026.40 megagrams per year.

**Table 3: Terrestrial carbon sequestered in Ibeju-Lekki between 1986 and 2024**

| Year | Total Land Area (Hectares) | Changes in Carbon (Mg of C) |
|---|---|---|
| **1986 - 2016** | 48,569.04 | -3,751,338.70 |
| **2016 - 2024** | 48,569.04 | -1496211.22 |
| **1986 - 2024** | 48,569.04 | -5,247,549.92 |

Source: Author's Analysis, 2024

This acceleration in the loss rate is particularly concerning and may indicate intensified land use changes in recent years. Research by Ademola and Sajor (2022) corroborates this finding, noting that the pace of urban development in Ibeju-Lekki accelerated significantly after 2015, driven by major infrastructure projects such as the Dangote Refinery and the Lekki Deep Sea Port.

The implications of this declining carbon sequestration capacity are far-reaching. On a local scale, reduced carbon capture ability can lead to decreased air quality and potential changes in microclimate. Ibrahim and Adebayo (2024) found that areas in Ibeju-Lekki with significant vegetation loss experienced average temperature increases of 1.5-2.0°C compared to areas where natural vegetation was preserved. Their study also noted a correlation between reduced carbon sequestration and increased respiratory issues among residents. Comparing these results with those of similar coastal urban areas in West Africa, the rate of carbon sequestration loss in Ibeju-Lekki appears to be higher than average. Research by Mensah et al. (2022) in coastal Ghana found a reduction in carbon sequestration of approximately 2.8 million megagrams over a similar 30-year period in an area of a similar size. The higher loss rate in Ibeju-Lekki may be attributed to its more rapid urbanisation and industrial development. Figure 4 displays sequestered carbon changes between 1986-2016, 2016-2024 and 1986-2024.

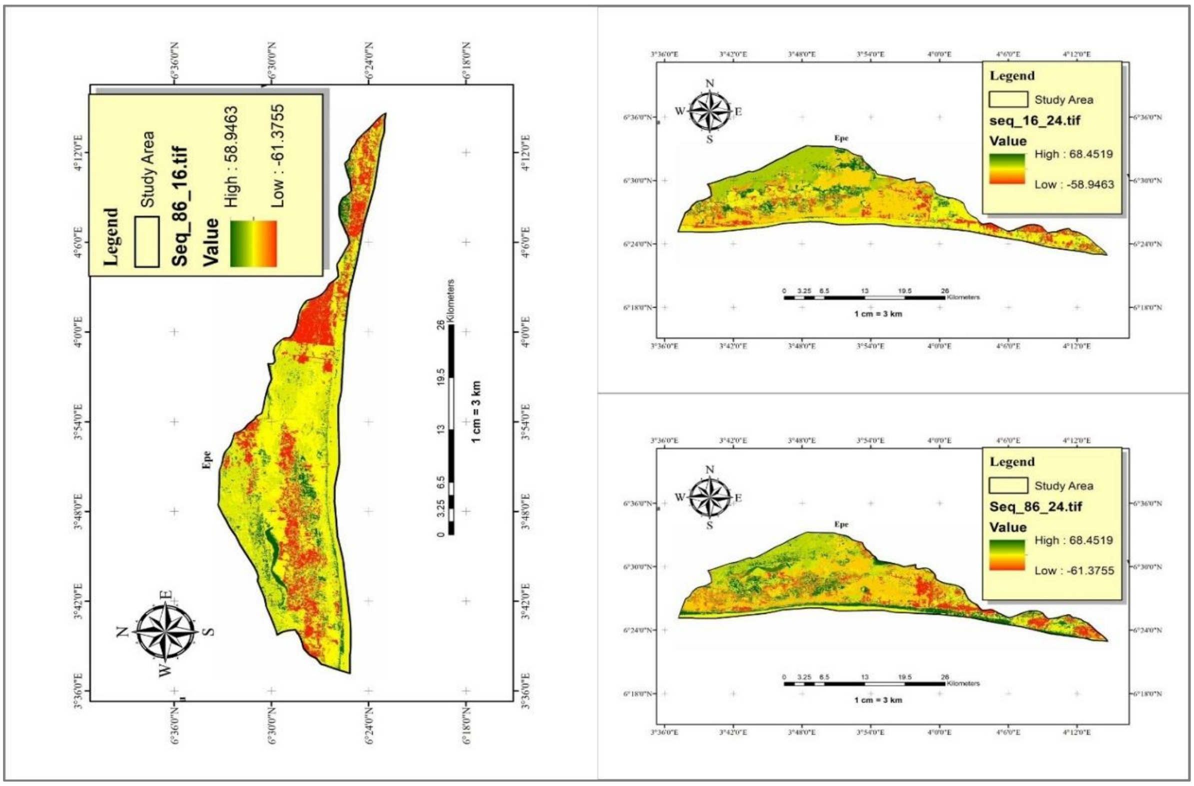


**Figure 4: Carbon Sequestration in the Study Area between 1986-2016, 2016-2024, and 1986-2024**
Source: Author's Analysis, 2024

### 4.1.3 Carbon Storage and Sequestration Threshold

The study analysed carbon storage and sequestration (CSS) characteristics in Ibeju-Lekki, Lagos State, Nigeria, over 38 years from 1986 to 2024. CSS maps were created by combining three LULC layers: built-up areas, bare surfaces, and water bodies. The maps were created to differentiate between CSS-prone and non-CSS areas. Table 4 shows that in 1986, the study area had a high potential to provide adequate ecosystem services, particularly carbon sequestration, as landforms with features necessary for this process dominated over 70% of the study area.

This is due to the predominance of vegetation coverage, which at the time covered 314.07 sq.km, accounting for 64.67% of the area. This allowed for adequate gaseous exchange and the storage of surplus carbon in the vegetation's trunk, stem, and roots. In total, non-CSS areas account for 26.60% of the study area. Visual analysis shows that most of these areas are southward along the coast, cutting across open water and adjacent beaches. This is attributed to anthropogenic activities in coastal areas. In these areas, there are newly constructed residential estates such as the Amen Estate, Emerald Estate, and Oakwood Estate, among others. Likewise, various industries are springing up along the coast in response to the Deep Seaport and the Dangote Refinery. Furthermore, naturally occurring non-carbon-storing features, such as rock outcrops, open water, and porous sands, are present in Ibeju Lekki.

**Table 4: Carbon Storage Characteristics in 1986, 2016, and 2024**

| Classification | Area in sq. km | Percentages |
|---|---|---|
| ***1986*** | | |
| Non-CSS | 129.19 | 26.60 |
| CSS | 356.50 | 73.40 |
| ***2016*** | | |
| Non-CSS | 183.33 | 37.75 |
| CSS | 302.36 | 62.25 |
| ***2024*** | | |
| Non-CSS | 189.46 | 39.01 |
| CSS | 296.23 | 60.99 |
| **Total** | **485.69** | **100.00** |

Source: Author's Analysis, 2024

In 2016, as shown in Figure 5, the study area's ability to capture and store carbon decreased significantly, with affected areas expanding to 183.33 sq. km and CSS areas decreasing to 302.36 sq. km. The non-CSS areas are concentrated in the southeast and western corners, particularly near water bodies. Fewer non-CSS areas were scattered evenly in the north, suggesting surface exposures were more common and closer to the ocean due to increased human and natural activities along the coast. By 2024, data on CSS areas showed a continuous increase from 183.33 sq. km to 189.46 sq. km, while CSS areas decreased from 302.36 sq. km in 2016 to 296.23 sq. km. At this point, almost all of the southeastern region shows signs of land-use modifications due to continuous urban development. However, some areas in the northern quadrant of the study area, previously occupied by shanty-built-up areas and other non-CSS features, appear to have been cleared, likely due to the conservation efforts and environmental development initiatives adopted by the state government in recent years.

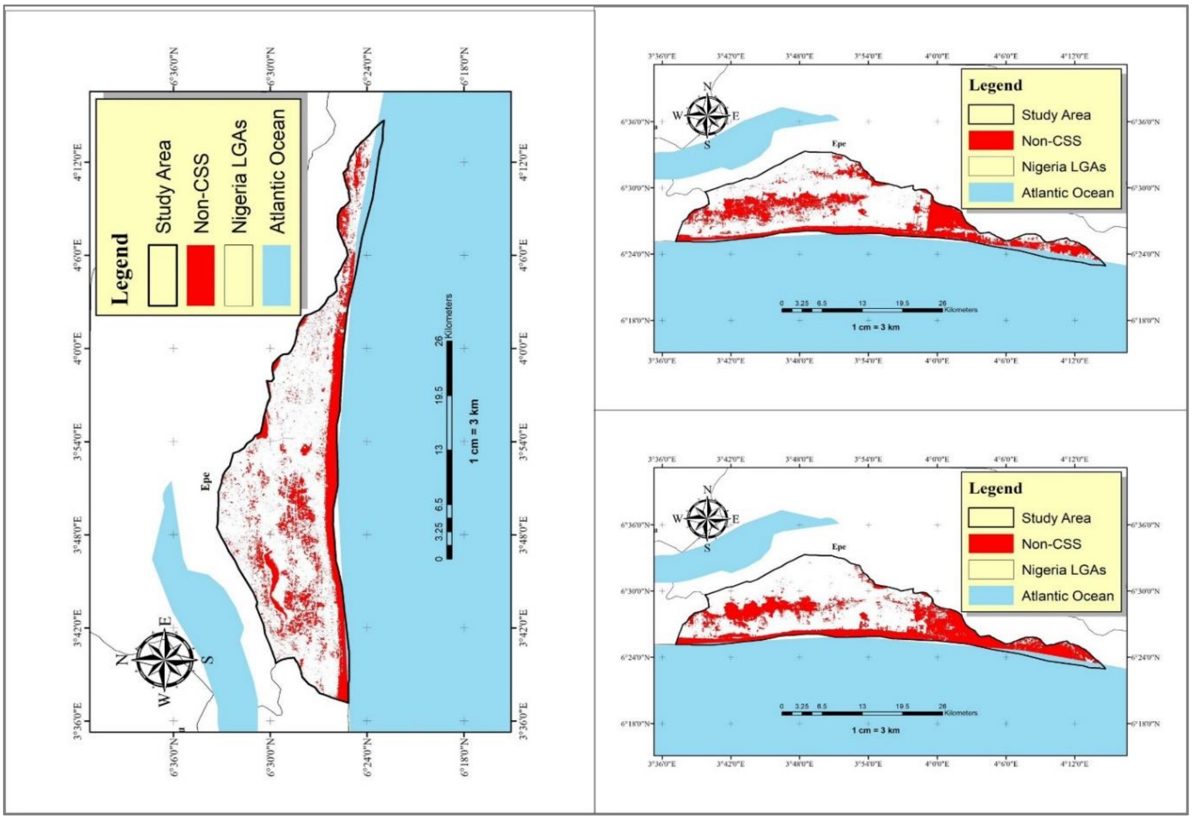


**Figure 5: Spatial Distribution of Carbon Storage and Sequestration in 1986, 2016, and 2024**
Source: Author's Analysis, 2024

### 4.2 Spatiotemporal Analysis of Mangroves, Rainforests, and Swamps in Ibeju Lekki (1986-2024)

#### 4.2.1 Land cover dynamics to carbon storage of Ibeju Lekki, Lagos, from 1986 to 2024

The study, as shown in Table 5 and Figure 6, identified six major land cover types in Ibeju Lekki. They include water bodies, Bare grounds/Beaches, dense vegetation, Sparse Vegetation, Built-up Areas, and Wetlands. The 1986 LULC analysis of Ibeju-Lekki reveals a largely natural landscape with minimal urbanisation. Water bodies cover 6.97%, bare grounds 5.38%, dense vegetation 32.64%, sparse vegetation 32.03%, built-up areas 8.74%, and wetlands occupy the remaining 8.74%. In 2016, water bodies showed no significant increase, occupying 6.97% of the total land area; bare grounds/beaches occupied 11.42%; dense vegetation had the highest percentage of land cover at 44.93%, while sparse vegetation occupied 6.80%, built-up areas occupied 19.43%, and wetlands covered 10.52% of the study area. By 2024, water bodies covered 4.98%, bare grounds 14.29%, dense vegetation 21.50%, sparse vegetation 29.84%, built-up areas 19.73%, and wetlands 9.65%. Sparse vegetation dominates the landscape, occupying 29.84% (144.93 sq.km) of the total area.

**Table 5: Land cover analysis for 1986 - 2024**

| Classification | 1986 Area (sq. km) | 1986 % | 2016 Area (sq. km) | 2016 % | 2024 Area (sq. km) | 2024 % |
|---|---|---|---|---|---|---|
| Water Body | 33.85 | 6.97 | 33.507 | 6.90 | 24.21 | 4.98 |
| Bare grounds/Beaches | 26.13 | 5.38 | 55.4661 | 11.42 | 69.42 | 14.29 |
| Dense Vegetations | 158.52 | 32.64 | 218.205 | 44.93 | 104.41 | 21.50 |
| Sparse Vegetations | 155.55 | 32.03 | 33.039 | 6.80 | 144.93 | 29.84 |
| Built-Up Areas | 69.20 | 14.25 | 94.356 | 19.43 | 95.84 | 19.73 |
| Wetlands | 42.43 | 8.74 | 51.1173 | 10.52 | 46.89 | 9.65 |
| **Grand Total** | **485.69** | **100.00** | **485.6904** | **100.00** | **485.69** | **100.00** |

Source: Author's fieldwork, 2024

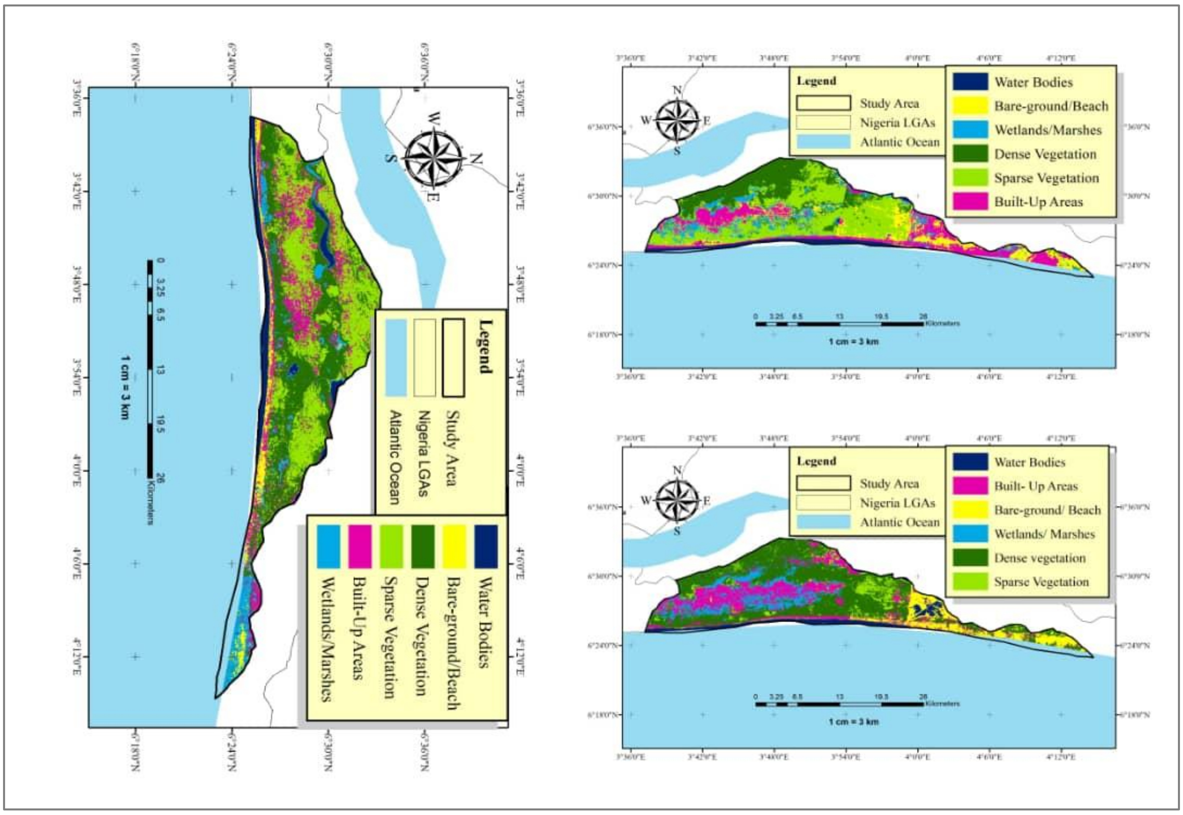


**Figure 6: Spatial patterns in land use in the study region for the years 1986, 2016 and 2024**
Source: Author's Analysis, 2024

#### 4.2.1.1 Land use/cover dynamics on carbon storage of Ibeju Lekki, Lagos (1986-2024)

The study reveals a positive correlation between land use and carbon storage. As more vegetated areas are converted for development, the total carbon stored will decrease. The land cover in the study area has undergone significant changes since 1986 (Figure 7). Before 1986, it was dominated by dense vegetation, sparse vegetation, and built-up surfaces. The most dramatic changes have occurred in vegetation coverage, with dense vegetation initially increasing from 32.64% (158.52 sq. km) in 1986 to 44.93% (218.205 sq. km) in 2016, but then declining sharply to 21.50% (104.41 sq. km) by 2024. Conversely, sparse vegetation decreased from 32.03% (155.55 sq. km) in 1986 to 6.80% (33.04 sq. km) in 2016 before rebounding to 29.84% (144.93 sq. km) in 2024. According to research by Adeniyi et al. (2018), vegetation changes significantly affect carbon storage: dense vegetation areas store approximately 243 tons of carbon per hectare, while sparse vegetation areas store only about 67 tons per hectare. This aligns with findings by Ogunsanwo et al. (2021), who documented a 40% reduction in carbon sequestration potential in rapidly urbanising coastal areas of Lagos between 2015 and 2022.

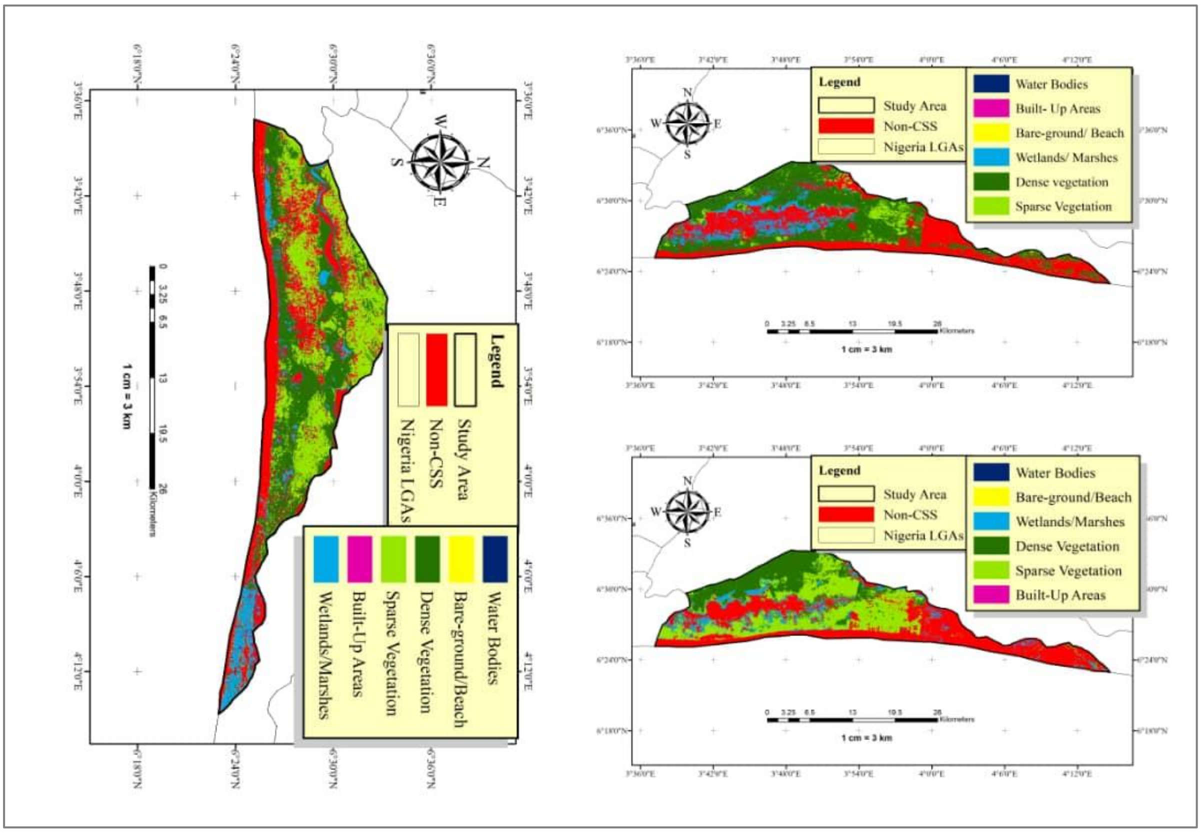


**Figure 7: LULC and CSS overlay in 1986, 2016, and 2024**
Source: Author's Analysis, 2024

### 4.2.2 Ecosystem Analysis of Ibeju-Lekki between 1986 and 2024

The study assessed the impact of land-use changes on ecosystem service provision in Ibeju Lekki, Nigeria, with a particular focus on carbon storage. The baseline analysis was conducted for 1986, with two other reference years (2016 and 2024) utilised to compare the depletion rate with the increasing physical development rate of the study area's ecosystem. The ecosystem, which encompasses water bodies, rainforests, swamp forests, and mangroves, spans approximately 485.69 square kilometres and has undergone significant changes since 1986. In 1986, urbanisation was in its early stages, and areas without carbon storage covered 129.19 square kilometres (26.6% of the total land area). Table 6 indicates that the most significant loss occurred in swamp forest ecosystems, accounting for 84.40 square kilometres, or 65.58% of the total depleted area. Water bodies were the second most affected, with 29.09 square kilometres (22.60%) lost, followed by mangrove ecosystems at 9.25 square kilometres (7.19%) and rainforests at 5.96 square kilometres (4.63%).

In 2016, a significant escalation in ecosystem loss occurred in the study area. The total affected area increased from 128.70 square kilometres to 185.50 square kilometres, representing a 44.13% increase in total ecosystem depletion over the 30 years, with varying impacts across different biomes. At this time, many previously vegetated regions had been cleared and swamps filled with sand to make way for development. This pressure on the environment resulted in the loss of valuable biomes and reduced the study area's ability to store carbon. A total of 183.33 square kilometres of potential carbon-storing landmasses (37.75% of the total land area) were recorded as depleted by 2016.

**Table 4.5: Ecosystem depletion analysis (1986-2022)**

| Classification | 1986 | | 2016 | | 2024 | |
|---|---|---|---|---|---|---|
| | Area (sq. km) | % | Area (sq. km) | % | Area (sq. km) | % |
| **Water** | 29.09 | 22.60 | 24.86 | 13.40 | 24.54 | 12.80 |
| **Rainforest** | 5.96 | 4.63 | 5.96 | 3.21 | 5.87 | 3.06 |
| **Swamp forest** | 84.40 | 65.58 | 142.01 | 76.55 | 147.26 | 76.82 |
| **Mangrove** | 9.25 | 7.19 | 12.68 | 6.83 | 14.04 | 7.32 |
| **Total** | **128.70** | **100.00** | **185.50** | **100.00** | **191.70** | **100.00** |

Source: Author's fieldwork, 2024

Results, as depicted in Figure 8, show a continuing trend of ecosystem depletion in the Ibeju-Lekki Local Government Area, with the total affected area increasing from 185.50 square kilometres in 2016 to 191.70 square kilometres in 2024. Swamp forest ecosystems remain the most severely impacted, with depleted areas increasing from 142.01 square kilometres in 2016 to 147.26 square kilometres in 2024. This additional loss of 5.25 square kilometres of swamp forest continues the trend observed between 1986 and 2016, albeit at a reduced rate. Depletion of the mangrove ecosystem has accelerated, with an additional 1.36 square kilometres lost between 2016 and 2024, bringing the total depleted area to 14.04 square kilometres. This represents a 10.73% increase in mangrove loss over just eight years. Waterbody depletion slightly decreased, from 24.86 square kilometres in 2016 to 24.54 square kilometres in 2024. Rainforest areas showed a minimal additional loss, decreasing from 5.96 to 5.87 square kilometres.

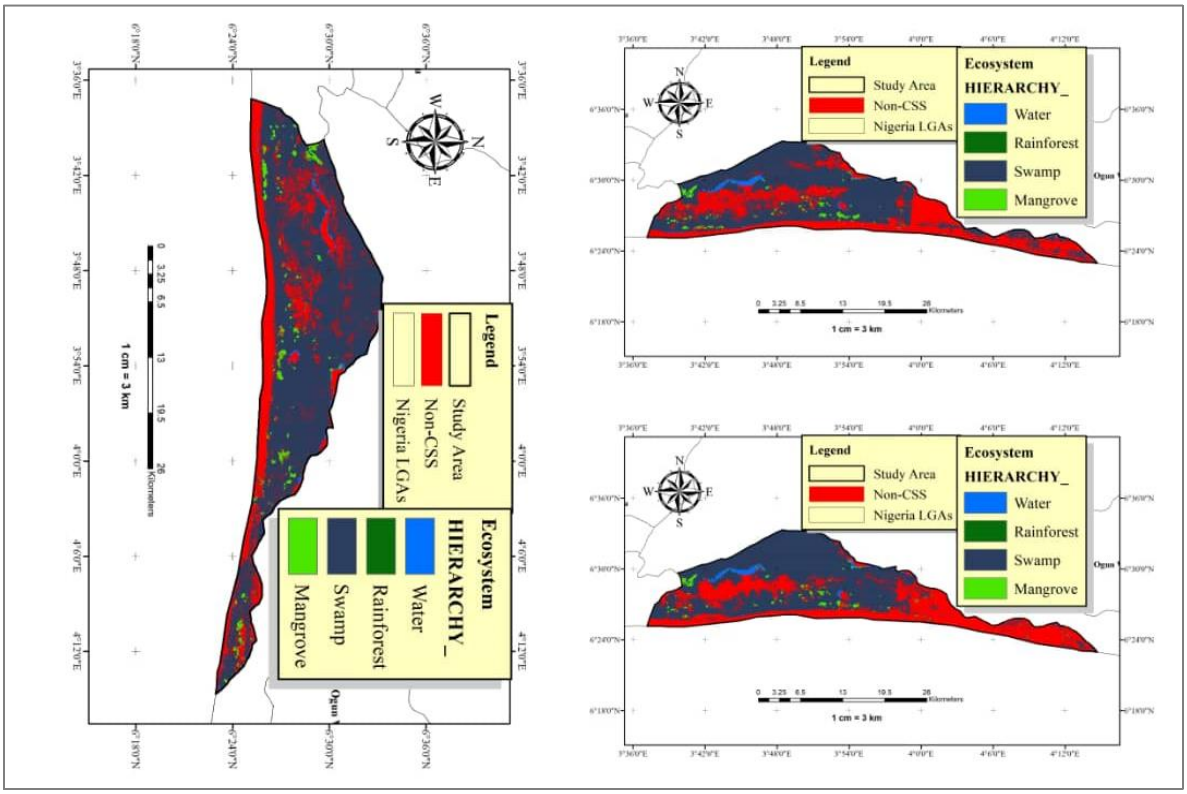


**Figure 8: Map Showing the Depletion of the Ecosystems in 2024**
Source: Author's Analysis, 2024

### 4.3 Drivers of Changes in the Ecosystems in Ibeju Lekki

The study identified urban development as the primary driver of these changes, with 86.1% of survey respondents attributing ecosystem alterations to urbanisation processes. The observed expansion of built-up areas and infrastructure projects, such as the Lekki Free Trade Zone, corroborates this finding. Anthropogenic activities and climate variations were also identified as contributing factors, albeit to a lesser extent. An interview with the head of planning and construction in the Lekki Free Trade Zone further supports this view, with projections indicating that mangrove forests in the northeast quadrant of the study area will be cleared and developed within 3-4 years. This clearance will result in the loss of mangroves, which have previously served as important carbon sinks in Ibeju-Lekki. Furthermore, climate variations, which range from 2.4% to 4.8%, significantly reduce carbon sequestration capacity during fluctuating and extreme climate events, especially in tropical regions. This is mainly due to anthropogenic activities, such as vegetation removal and land-use conversion. Indeed, a 1 °C increase in temperature can lead to a 20% decrease in precipitation, thereby affecting the carbon sequestration potential of ecosystems (Zhou et al., 2022). As reported by Popoola et al. (2025), the average increase in temperature variation is 2.2 °C, leading to increased precipitation loss and lower carbon sequestration potential in Ibeju-Lekki.

### 4.4 Management Actions to Conserve Ecosystems in Ibeju-Lekki

The study identified and assessed the existing and ongoing management measures implemented, as well as actions aimed at managing the ecosystems in Ibeju-Lekki. The results of the analysis of the interview conducted at the Lekki Free Zone Administrative Complex, involving representatives from the Ministry of Environment & Water Resources, the Lekki Council Development Area, and the Lekki Conservation Centre, indicate that there are currently no sophisticated measures in place to manage and conserve the mangrove forest in the area. However, regulatory measures have been implemented regarding the use of water bodies, such as the lagoon, prohibiting residents from fishing. There are also conservation plans in place to protect the flora and fauna at Ibeju-Lekki.

### 4.4 Payment for Ecosystem Service Model to Enhance Carbon Storage in Ibeju-Lekki

To conserve and further enhance the carbon storage capacity of landforms in Ibeju-Lekki, it is essential to incorporate the management of ecosystem services into the spatial planning process through the payment-for-ecosystem-services model. The current planning process fails to address the concerns necessary to meet the management requirements of the existing ecosystem, especially the mangroves. Based on the interviews and surveys, no systems exist to conserve and manage the mangrove ecosystem throughout Ibeju-Lekki. There are no voluntary agreements regarding stakeholders' involvement in PES programmes. The beneficiaries, which include individuals, communities, businesses, and government agencies, do not pay for these services. Moreover, no intermediaries or brokers ensure that direct and adequate payments for the services are made. In Ibeju-Lekki, the "additionality" principle is not applied, which suggests that resource managers should be compensated for efforts beyond what is typically expected of them. The interviews confirm that there is no mechanism in place to ensure the use of management strategies agreed upon by the parties to the contract, which are likely to yield ecosystem benefits. There is no scheme to ensure that securing an ecosystem service in one location does not lead to the loss or degradation of ecosystem services elsewhere in Ibeju-Lekki. The responses regarding the application of the payment for ecosystem services mirror the findings of Popoola et al. (2018), who found that the concept has not been adopted to alleviate poverty in the coastal area of Ondo State, Nigeria.

Additionally, the principle of permanence, which requires that management interventions funded by beneficiaries be sustained, is absent. Based on the interviews, some officials foresee challenges in implementing payment-for-ecosystem-services to conserve mangroves. Figure 9 illustrates that 17% of the interviewees perceive the valuation of ecosystem services as a challenge in implementing the concept of payment for ecosystem services for mangrove conservation. They recognised that assigning monetary values to diverse ecosystem services can be complex, as services such as carbon sequestration, habitat provision, and storm protection have varying economic values. Fifty per cent of the interviewees foresee an equitable distribution of payment as a challenge. They believed it could be challenging to ensure payments reach all stakeholders involved in mangrove conservation, including local communities and marginalised groups. While 33% of the interviewees consider the legal and institutional frameworks challenging, establishing structures that support PES can be complex.

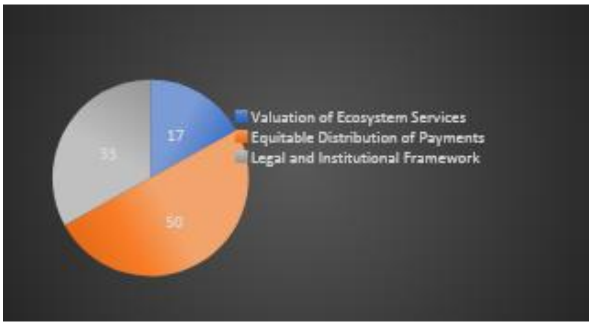


**Figure 9: Perceived challenges to the implementation of PES**
Source: Author's Fieldwork, 2024

### 5. Conclusion and Recommendations

The study of spatio-temporal changes in carbon sequestration by coastal ecosystems in Ibeju-Lekki, Lagos, Nigeria, from 1986 to 2024 has revealed a complex interplay among rapid urbanisation, ecosystem health, and carbon storage capacity. The findings highlight a concerning trend of ecosystem degradation and reduced carbon sequestration potential, driven primarily by urban development and land-use changes. The significant reduction in carbon storage capacity — from approximately 23.25 million megagrams in 1986 to roughly 18 million megagrams in 2024 — underscores the urgent need for sustainable development practices and conservation efforts for ecosystems. The disproportionate impact on swamp forests and mangrove ecosystems is particularly alarming, given their crucial role in carbon sequestration and ecosystem services, amid the high rate of ecosystem depletion in recent years. However, with increased awareness and some conservation efforts, the overall trend remains concerning. The lack of comprehensive management strategies for ecosystem conservation further exacerbates the challenges.

However, the findings also present opportunities for positive intervention. Identifying key drivers of change and assessing existing management measures provides a foundation for developing targeted and effective conservation strategies. The potential for implementing a Payment for Ecosystem Services model, along with other recommended measures, offers a pathway towards more sustainable development that balances urban growth with the preservation of ecosystems. Ultimately, this research highlights the importance of integrating ecosystem conservation and carbon sequestration into urban planning and development. The future of Ibeju Lekki's coastal ecosystems and their capacity to provide vital environmental services will depend on the successful implementation of sustainable management practices and on the collective efforts of all stakeholders.

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