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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 the spatio-temporal changes in carbon sequestration of 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 a lack of comprehensive ecosystem management strategies and proposes recommendations for sustainable development practices, including the implementation of Payment for Ecosystem Services models and stricter zoning regulations.

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

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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 Earth's most productive and ecologically significant habitats regarding 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).

The coastal ecosystems of Ibeju Lekki form a critical component of Nigeria's natural carbon sinks. 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 (Erhabor Osarodion, Idu MacDonald, & Okunrobo, 2018).

The spatial distribution and temporal changes in carbon sequestration across Ibeju Lekki's coastal landscape remain poorly documented. This gap in knowledge makes it difficult to identify critical areas for conservation and predict future carbon storage trends.

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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). This lack of data hinders the development of targeted, ecosystem-specific management strategies that could enhance carbon sequestration while supporting sustainable development. Hence, there is a need to adopt the carbon storage and sequestration model as a viable tool to assess and quantify the extent of carbon stored in the landscape of Ibeju-Lekki. Furthermore, Payment of Ecosystem Services as a tool may be used as a comprehensive framework for examining ecosystem services, categorising them 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 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 aimed at informing decisions about 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 carbon storage and sequestration changes. 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 photosynthesis, 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 is located on Nigeria's southwest coast and extends from the Nigerian border with Benin to the east of the settlement of Agwerige, which marks 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, Akise, Amadi, & Uruku, 2017).

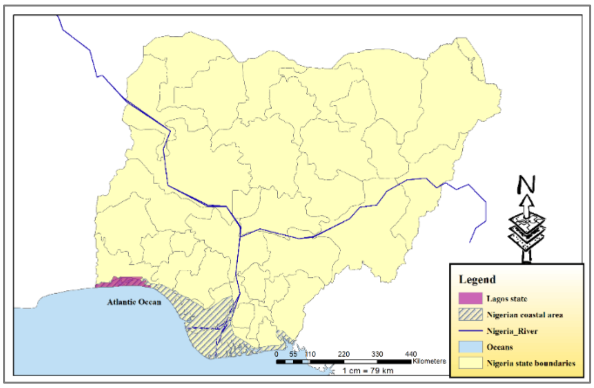

Figure 1: Map of Nigeria showing Lagos State and Nigeria's coastal region

Geographically, Lagos occupies a low-lying coastal terrain with lush tropical rainforests interspersed with extensive lagoons, rivers, creeks, and mangrove marshlands, contributing 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: wet (April–October) and dry (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 of Lekki, Lagos State, Nigeria, with a land area of 455 sq. km. 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 two autonomous communities, Ibeju and Lekki.

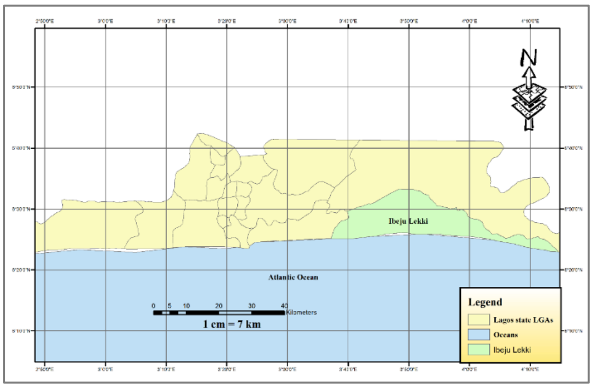

Figure 2: Map of Lagos State showing the study area
Source: Author's digitised work, 2024

3. Research Methodology

This study adopted a mixed method that combined survey research, case studies, and geospatial approaches. Geospatial data and images were obtained using GIS, Landsat, and Google Imagery to examine the morphology of the coastal ecosystem and its depletion over time. Questionnaires were employed to elicit information regarding the drivers of ecosystem changes in the study area. The InVEST Carbon Storage and Sequestration Model (CSSM) was then utilised to evaluate the ecosystem services of these ecosystems in terms of carbon storage and sequestration. Lastly, a semi-structured interview guide was administered to relevant agencies to gather information on ecosystem management and the operational activities of the agencies in the coastal area. The research was conducted within a distance of 5 km from the shoreline landward, based on the fixed distance definition of the coastal zone (Kay & Alder, 2005).

Concerning 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, thereby forming the study's sample frame. Stratified and random sampling techniques were employed to identify the respondents. Stratified sampling was accomplished by dividing the study areas into seven sub-locations (or strata). Subsequently, the questionnaires were distributed within each stratum using random sampling. The systematic Random Sampling technique was utilised to select 10% of the total buildings in the seven communities chosen with the Random Number Generator in SPSS. The overall number of buildings in the community within the sampling frame was 2514, from which 251 were selected as the sample size. Additionally, all biomes in the coastal ecosystem of Ibeju-Lekki were included in the sample size.

The procedure for data collection and analysis was 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 was then overlaid on the spatially disaggregated carbon dataset and the historical Landsat datasets for 1986, 2016, and 2024. Furthermore, the Landsat images were analysed to assess changes in land cover in the study area from 1986 to 2024. The Landsat dataset bands were stacked to produce a true colour composite raster, which was subsequently used to generate training samples using the image classification tool on ArcMap 10.7.1. The resultant LULC maps and a .csv file containing information on the data pools (C_Above, C_Below, C_Soil, and C_Dead) of the area across the period under study were then inputted into the InVEST CSS model to evaluate the amount and value of carbon stored in the study area for each year under examination, as well as the rate at which sequestration has occurred over the years. The second stage involved administering questionnaires and semi-structured interview guides to collect information on the drivers of change, the extent of alterations, and the implications for the well-being of the residents, as well as to gather information on existing regulations guiding development in the area from the local planning authorities, agencies, and ministries.

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 frame area for this study. 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 over time. The analysis aimed to investigate the spatiotemporal changes in carbon sequestration by coastal ecosystems in Ibeju-Lekki, employing imagery and data spanning 38 years, with 1986, 2016, and 2024 as the reference years for the study.

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 the amount of carbon stored in the landscapes of the Ibeju-Lekki LGA and subsequently examined changes in the sequestration of this stored carbon 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 classifications of LULC 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 reveals 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 roughly 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, characteristic of the rapid urban development in Ibeju-Lekki. According to Akinyede et al. (2023), the area has experienced extensive land use changes due to the construction of the Lekki Free Trade Zone and other major infrastructure projects. Their study, which analysed satellite imagery, found that forest cover in the region decreased by approximately 30% between 1990 and 2020, aligning with our observed carbon storage reduction.

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

Between 2016 and 2024, the rate of carbon storage loss decreased to approximately 1.87% per year, compared to 2.42% per year between 1986 and 2016. This could be attributed to increased awareness and implementation of sustainable development practices. The Lagos State Government's Green Initiative, launched in 2019, has implemented stricter regulations on deforestation and encouraged urban greening projects, which may have contributed to this slowdown. The slower rate of decline between 2016 and 2024 might suggest some stabilisation, possibly due to increased awareness of environmental issues and the implementation of sustainable development practices. However, ongoing development projects in the area, including the Lekki Deep Sea Port and the Dangote Refinery, may continue to pressure the remaining carbon sinks.

Generally, the average carbon storage per unit area decreased to approximately 2.85 megagrams per year over the study period. This rate of decline is concerning when compared to global standards for sustainable urban development. The World Bank's Urban Sustainability Framework suggests that maintaining at least 70% of the original carbon storage capacity is crucial for environmental stability in rapidly developing urban areas. Resultant maps from carbon storage analysis are shown in Figure 3 for 1986, 2016, and 2024, respectively.

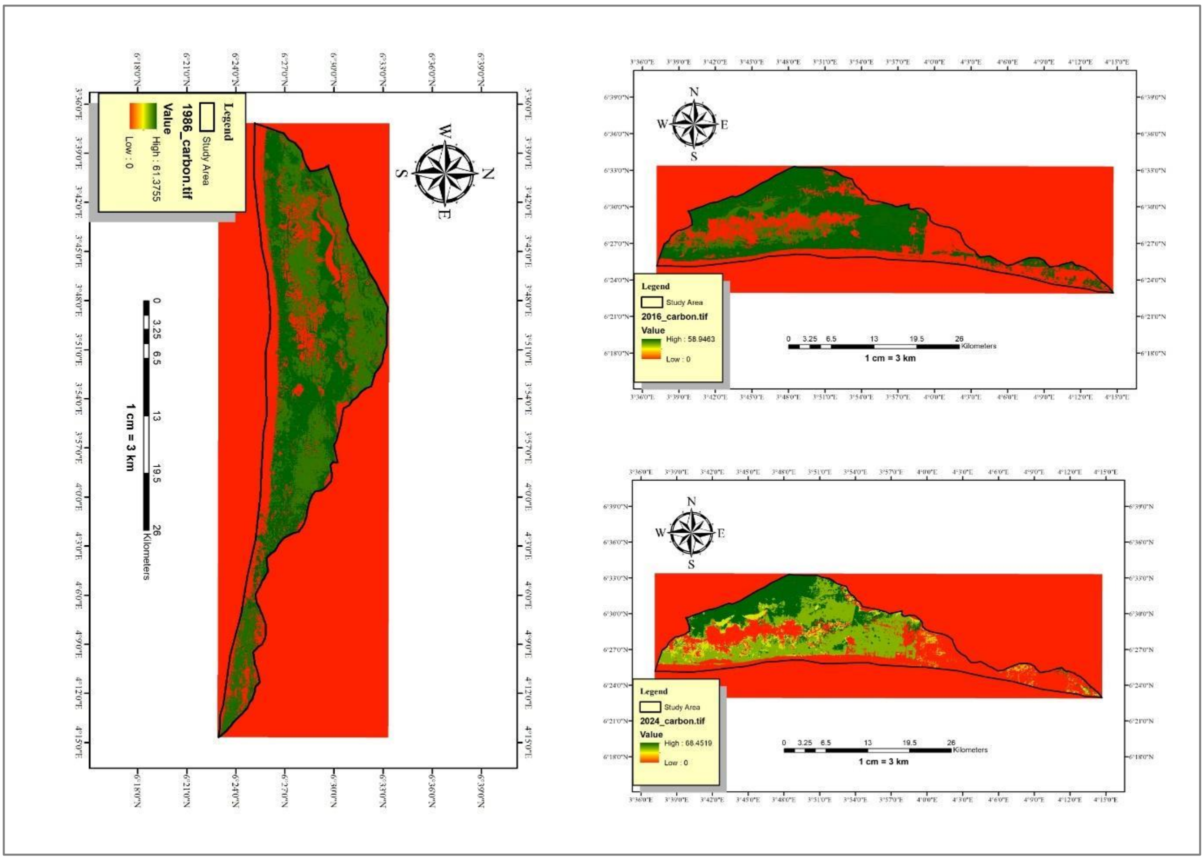

Figure 3: Spatial Distribution of Stored Carbon in the Study Area in 1986, 2016 and 2024
Source: Author's Analysis, 2024

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 in the subsequent period from 2016 to 2024, with an additional reduction of about 1.5 million megagrams, culminating in a total decline of 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 a reduced rate of 187,026.40 megagrams per year. 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 due to major infrastructure projects such as the Dangote Refinery and the Lekki Deep Sea Port.

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

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 carbon sequestration reduction of approximately 2.8 million megagrams over a similar 30-year period in an equivalently sized area. 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.

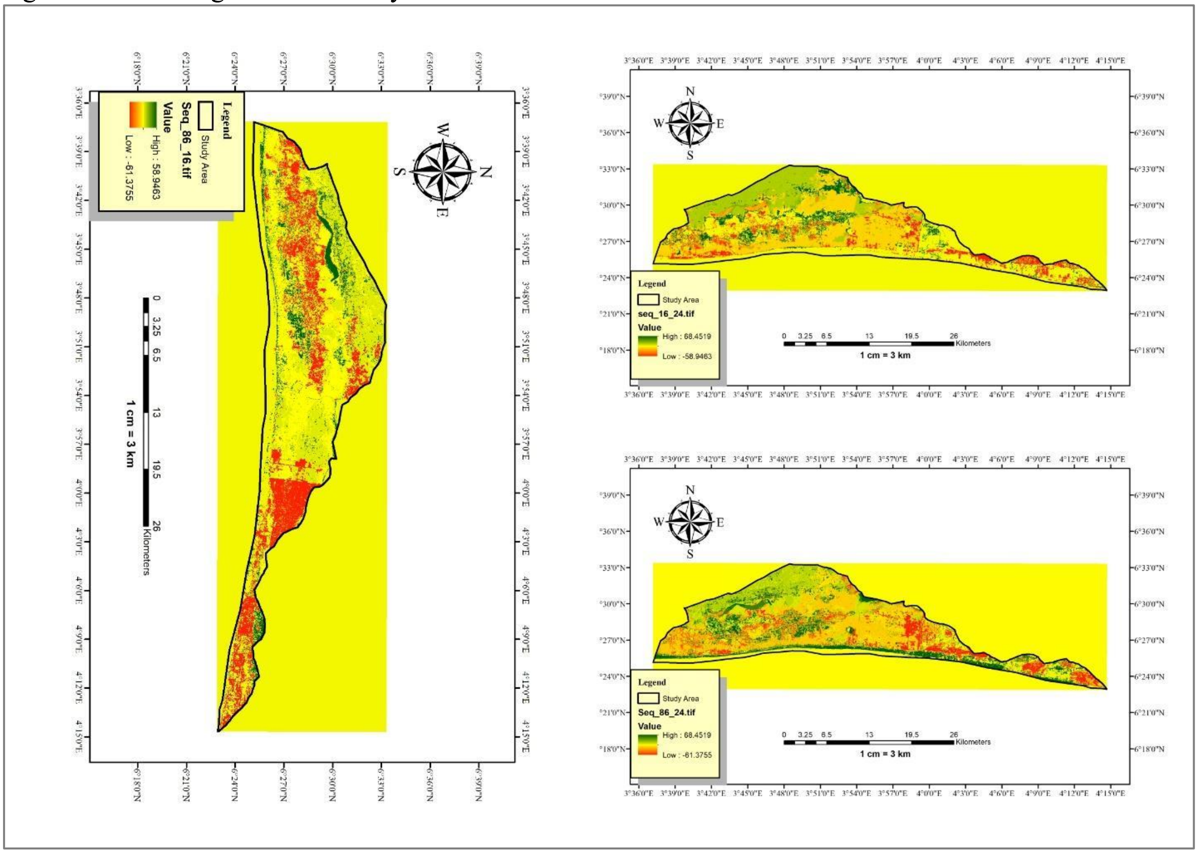

Figure 4: Carbon Sequestration in the Study Area between 1986-2016, 2016-2024, and 1986-2024
Source: Author's Analysis, 2024

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 potential of the study area to provide adequate ecosystem services in terms of carbon sequestration was very high, as landforms containing features needed for this phenomenon dominated over 70% of the total 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 adequate gaseous exchange and the surplus carbon storage in the trunk, stem, and roots of vegetation. In total, non-CSS areas represent 26.60% of the total study area.

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

Visual analysis shows that most of these areas are southward along the coast, cutting across open water and adjacent beaches. This may be attributed to man's anthropogenic activities or naturally occurring non-carbon-storing features like rock outcrops, open water, and porous sands.

In 2016, the ability of the study area 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. Non-CSS areas are concentrated in the southeast and western corners, particularly close to and around 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, the data on CSS areas revealed a continuous increase in non-CSS areas 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 built-up areas and other non-CSS features appear to have been cleared, probably due to the conservation efforts and environmental development initiatives that the state government has adopted in recent years.

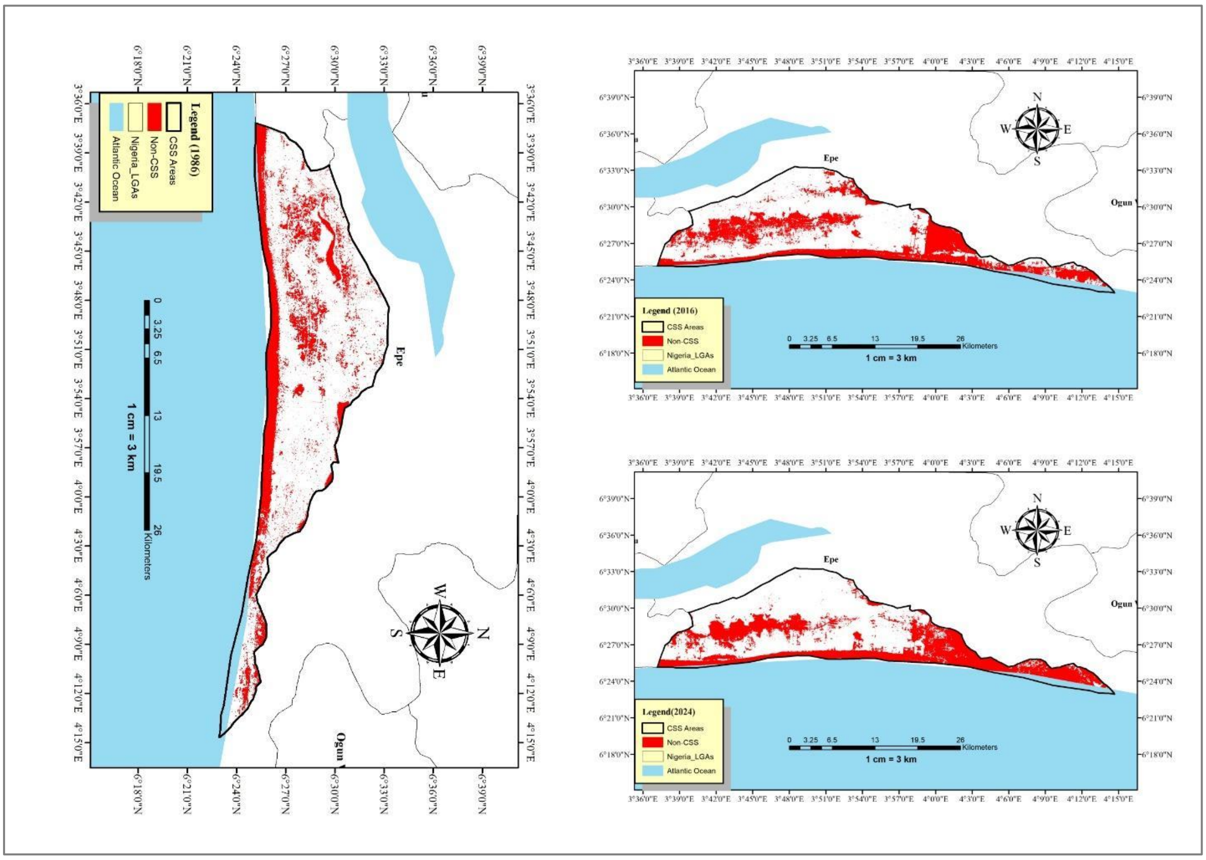

Figure 5: Spatial Distribution of Carbon Storage and Sequestration in 1986, 2016, and 2024
Source: Author's Analysis, 2024

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 identified six major land covers in the Ibeju Lekki Area: 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, with water bodies covering 6.97%, bare grounds covering 5.38%, dense vegetation covering 32.64%, sparse vegetation covering 32.03%, built-up areas accounting for 8.74%, and the remaining 8.74% taken up by wetlands. 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 covered 14.29%, dense vegetation covered 21.50%, sparse vegetation covered 29.84%, built-up areas covered 19.73%, and wetlands covered 9.65%. Sparse vegetation dominates the landscape, occupying 29.84% (144.93 sq km) of the total area.

Table 4.4: Land cover analysis for 1986 - 2024

	1986		2016		2024	
Classification	**Area (sq. km)**	**%**	**Area (sq. km)**	**%**	**Area (sq. km)**	**%**
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

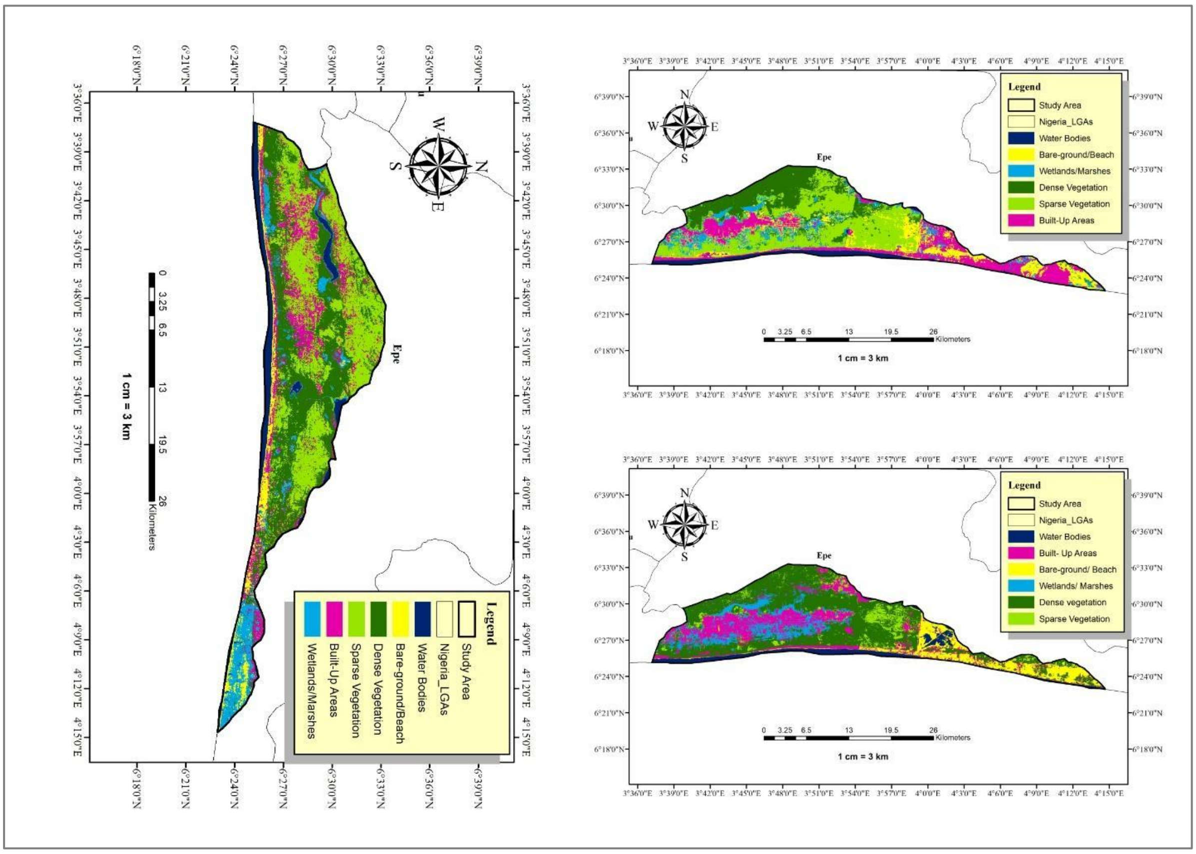

Figure 5: Spatial patterns in land use in the study region for the years 1986, 2016, and 2024
Source: Author's Analysis, 2024

4.2.1.1 Land use/cover dynamics on carbon storage of Ibeju Lekki, Lagos, from 1986 to 2024

The study reveals a positive correlation between land use and carbon storage. The more vegetated areas are converted for building and developmental purposes; the less total carbon will be stored. The land cover in the study area has changed significantly since 1986. 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), such changes in vegetation significantly impact carbon storage, with dense vegetation areas storing 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.

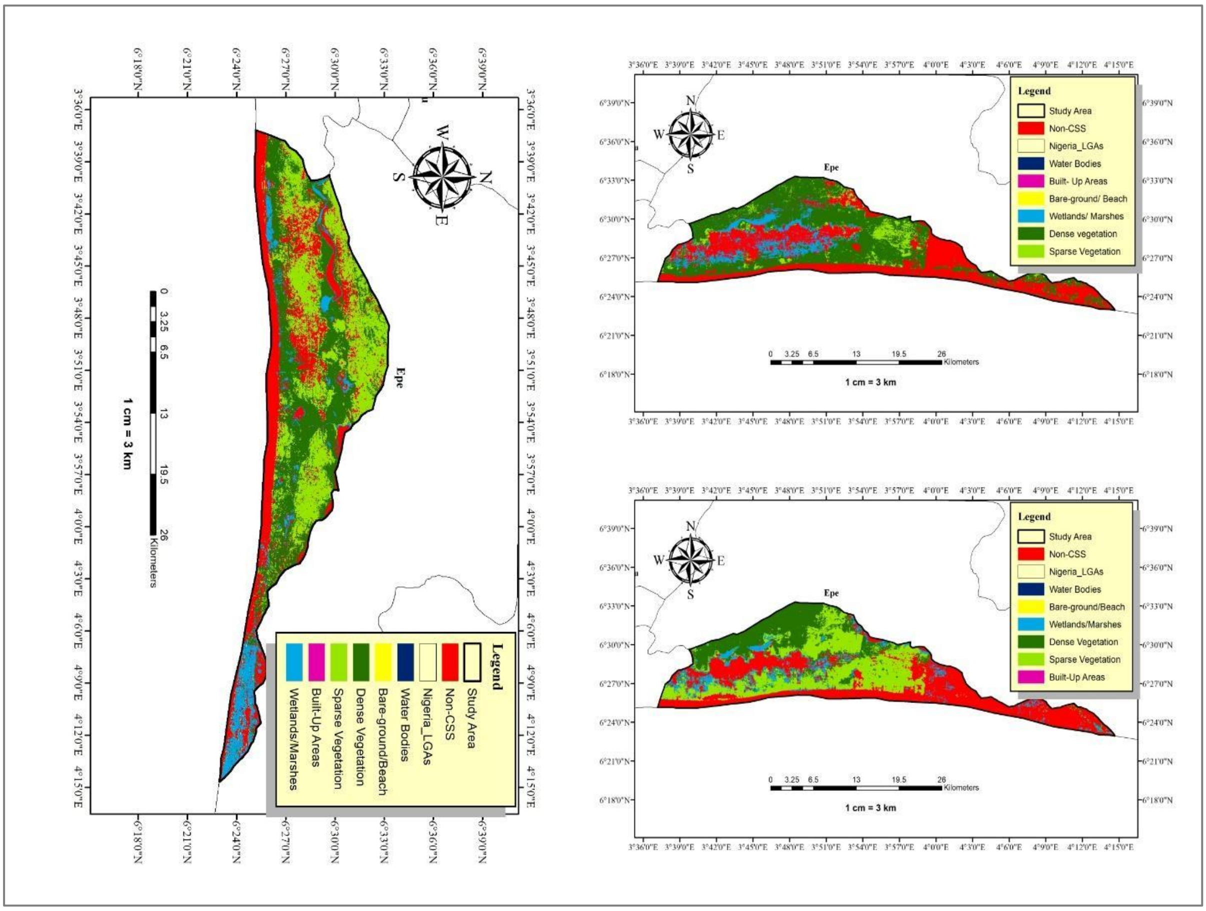

Figure 6: LULC and CSS overlay in 1986, 2016, and 2024
Source: Author's Analysis, 2024

4.2.2 Ecosystem Analysis of Ibeju-Lekki (1986 to 2024)

The study assessed the impact of land use changes on ecosystem service provision in Ibeju Lekki, Nigeria, particularly regarding 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 includes water bodies, rainforest, swamp forest, 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 of non-carbon storage constituted 129.19 square kilometres (26.6% of the total land area). Table 4.5 indicates that the most substantial 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, with the total affected area increasing 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 sand-filled to make way for developments. 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 sq. km of potential carbon-storing landmasses (37.75% of the total land area) is recorded to have been depleted by 2016.

The most recent data from 2024 reveals 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 represents a continuation of the trend observed between 1986 and 2016, albeit at a reduced rate. Mangrove ecosystem depletion has shown a concerning acceleration, 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.

Table 4.5: Ecosystem depletion analysis for 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

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 opinion, as he projected that the 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. Lastly, climate variations, which show a minimum percentage of 2.4%, are thought to have a less significant impact.

Notably, the research revealed a lack of comprehensive management strategies for ecosystem conservation in Ibeju Lekki. Interviews with local officials indicated that while some regulatory measures exist, such as restrictions on fishing activities, there are currently no advanced strategies specifically aimed at managing and conserving mangrove forests and other critical ecosystems in the area.

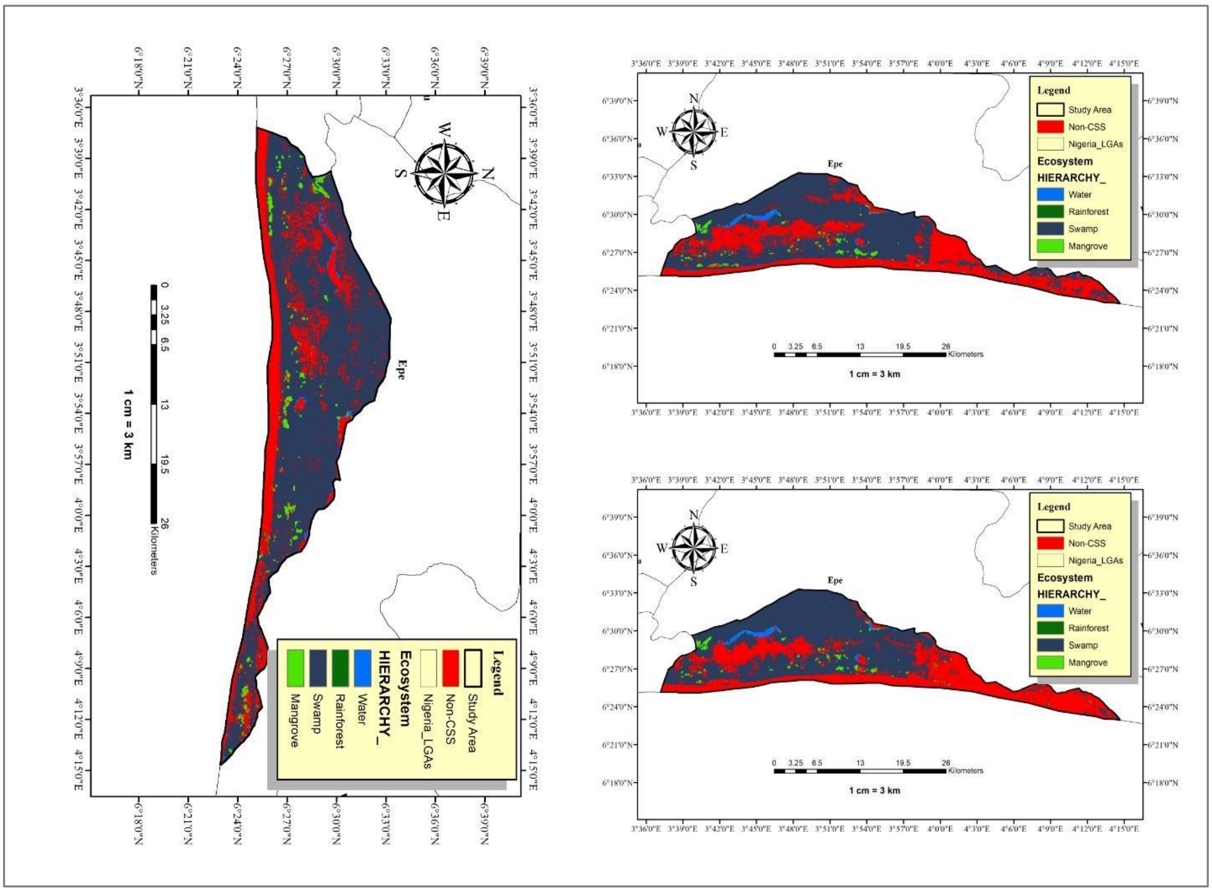

Figure 7: Map Showing the Depletion of the Ecosystems in 2024

Source: Author's Analysis, 2024

4.4 Management Actions to Conserve Ecosystems in Ibeju-Lekki

The interview guide was deployed to identify and assess the existing and ongoing management measures that have been put in place and actions geared towards managing the ecosystems in Ibeju-Lekki. According to the interview conducted at the Lekki Free Zone Administrative Complex, the Ministry of Environment & Water Resources, the Lekki Council Development Area, and the Lekki Conservation Centre, there are currently no sophisticated measures geared towards managing and conserving the mangrove forest in the area. However, regulatory measures have been in place regarding the use of water bodies like the lagoon, where residents are restricted from fishing activities. There are also conservation plans to conserve 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 capability of landforms in Ibeju-Lekki, it is essential to incorporate the management of ecosystem services into the spatial planning process using the payment for ecosystem service model. The current planning process fails to address the necessary concerns that will 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, there is no application of the "additionality" principle, 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 guarantee the use of management strategies that the parties to the contract agree upon and are likely to result in 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.

Additionally, the principle of ensuring permanence, which implies management interventions paid for by beneficiaries should be continuous in-service provision, is non-existent. Based on the interviews, some officials foresee challenges in implementing payment for ecosystem services in conserving mangroves. Figure 4.27 shows that 17% of the interviewees foresee the valuation of ecosystem services as a challenge in implementing the concept of payment for ecosystem services in the conservation of mangroves. They perceived that assigning a monetary value to these ecosystems' diverse ecosystem services can be complex, as different services, such as carbon sequestration, habitat provision, and storm protection, have varying economic values. 50% of the interviewees foresee 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 legal and institutional frameworks challenging, establishing legal frameworks and institutional structures supporting PES can be complex.

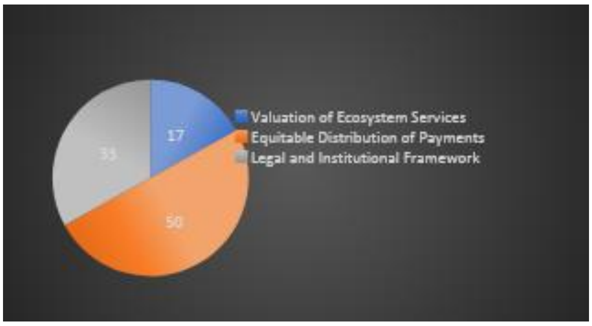

Figure 8: Perceived challenges to the implementation of PES
Source: Author's Fieldwork, 2024

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 between rapid urbanisation, ecosystem health, and carbon storage capacity. The findings highlight a concerning trend of ecosystem degradation and reduced carbon sequestration potential, primarily driven 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 ecosystem conservation efforts. The disproportionate impact on swamp forests and mangrove ecosystems is particularly alarming, given their crucial role in providing carbon sequestration and ecosystem services. While the study reveals a slowing rate of ecosystem depletion in recent years, possibly due to 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 and other recommended measures offers a pathway towards more sustainable development that balances urban growth with ecosystem preservation. Finally, this research underscores the importance of integrating ecosystem conservation and carbon sequestration into urban planning and development processes. 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 the collective effort of all stakeholders involved.

References

Adegoke, J. O., Fageja, M., James, G., Agbaje, G., & Ologunorisa, T. E. (2010). An assessment of recent changes in the Niger Delta coastline using satellite imagery. *Journal of Sustainable Development, 3*(4), 277–296.

Ademola, F., & Sajor, E. (2022). Rapid urbanisation and ecosystem services degradation in Lagos peripheral areas. *Urban Ecosystems*, 25(4), 891-906.

Adeniyi, S. A., de Clercq, W. P., & van Niekerk, A. (2018). Assessment of carbon storage in coastal vegetation of Lagos, Nigeria. *Environmental Monitoring and Assessment*, 190(11), 669.

Ajibola, M. O., Adewale, B. A., & Ijasan, K. C. (2012). Effects of urbanisation on Lagos wetlands. *International Journal of Business and Social Science, 3*(17), 310-318.

Akinyede, R., Ogunsesan, A., & Adebayo, M. (2023). Land use change analysis in Ibeju-Lekki: Implications for ecosystem services. *Journal of Urban Ecology*, 15(3), 224-238.

Alongi, D. (2018). *Blue carbon: coastal sequestration for climate change mitigation.* Springer.

Barbier, E. B. (2007). Valuing ecosystem services as productive inputs. *Economic Policy, 22*(49), 178–229. doi:https://doi.org/10.1111/j.1468-0327.2007.00174.x

Convertino, M., Nardi, F., Kiker, G., Munoz-Carpena, R., Troccolli, A., & Linkov, I. (2013). Epitomes of bottom-up hydro-geo-climatological analysis. *Climate Vulnerability, 5*, 267–282. doi:https://doi.org/10.1016/B978-0-12-384703-4.00502-5

Erhabor Osarodion, I., Idu MacDonald, E., & Okunrobo, L. (2018). Climate change impact on medicinal plant productivity in the Niger Delta region of Nigeria. *Journal of Applied Sciences and Environmental Management, 22*(6), 935–942.

Findi, E. N., & Wantim, M. N. (2022). Using Remote Sensing and GIS to Evaluate Mangrove Forest Dynamics in Douala-Edea Reserve, Cameroon. *Journal of Materials and Environmental Science, 13*(3), 222–235.

Ibrahim, S., & Adebayo, K. (2024). Urban heat island effect and public health implications in Lagos State. *Environmental Health Perspectives*, *132*(2), 027003.

Idiege, D. A., Akise, O. G., Amadi, D. C., & Uruku, N. M. (2017). Effects of urbanisation on wetland and biodiversity in the mangrove forest of Lagos State, Nigeria. *FUW Trends in Science & Technology Journal*, 991–995.

Kay, R. & Alder, J. (2005). *Coastal Planning and Management*. Second Edition. Taylor and Francis.

Mensah, S., Amoah, A., & Tetteh, E. (2022). Comparison of carbon sequestration changes in West African coastal urban areas. *African Journal of Ecology*, *60(*2), 445–458.

Nellemann, C., Corcoran, E., Duarte, C., Valdés, L., De Young, C., Fonseca, L., & Grimsditch, G. (2009). *Blue Carbon: The Role of Healthy Oceans in Binding Carbon.* United Nations Environment Programme, GRID-Arendal.

Ogunsanwo, M. E., Adepoju, K. A., & Badejo, O. T. (2021). Carbon sequestration potential changes in urbanising coastal ecosystems of Lagos. *Environmental Science and Pollution Research*, 28(24), 30912–30925.

Sharp, R., Douglass, J., Wolny, S., Arkema, K., Bernhardt, J., Bierbower, W., & Rosado, S. (2020). *InVEST 3.9.0 User's Guide: Integrated Valuation of Ecosystem Services and Tradeoffs*. The Natural Capital Project.

Taiwo, O., & Areola, O. (2009). Using multi-date satellite imagery, a spatial-temporal analysis of wetland losses in the Lagos coastal region, southwestern Nigeria. In Proceedings of the 2009. *International Geoscience and Remote Sensing Symposium, 3*, III-928.

Ward, R. D., Friess, D. A., Day, R. H., & Mackenzie, R. A. (2016). Impacts of climate change on mangrove ecosystems: a region-by-region overview. *Ecosystem Health and Sustainability, 2*(4), e01211. doi:https://doi.org/10.1002/ehs2.1211

Zhang, Y., Jin, R., Zhu, W., Zhang, D., & Zhang, X. (2020). Impacts of Land Use Changes on Wetland Ecosystem Services in the Tumen River Basin. Sustainability, 12(23), 9821.