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Land Use and Land Cover Dynamics of Gilli-Gilli Forest Reserve, Edo State, Nigeria from 1986 to 2023

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ABSTRACT: The rapid rate of land use and land cover (LULC) change has become a major concern, especially in tropical forests, where anthropogenic activities continue to strain natural resources. Forest degradation affects biodiversity, climate regulation, soil stability, and ecosystem balance. This study examined the spatial and temporal changes in land use and land cover within the Gilli-Gilli Forest Reserve, Edo State, Nigeria, over 37 years from 1986 to 2023. To assess these changes, Landsat satellite images from the United States Geological Survey (USGS) database for 1986, 2002, and 2023 were analyzed using Geographic Information System (GIS) and remote sensing techniques. Supervised classification using the Maximum Likelihood algorithm was applied to group the reserve into four major land-cover classes: dense forest, sparse vegetation, built-up areas, and water bodies. Post-classification change-detection analysis was conducted to determine the extent and rate of deforestation over the period. The analysis showed a decrease in dense forest cover over the study period. Dense forest cover decreased from 235.30 km² (72.73%) in 1986 to 156.12 km² (48.26%) in 2023, a net loss of approximately 79.18 km². Built-up areas increased significantly from 12.24 km² to 78.06 km², indicating rapid urban growth and increased demand for available forest resources. Sparse vegetation is also expected to increase by 2023 due to increased agricultural activities, logging, and forest clearing. NDVI analysis showed vegetation greenness and canopy density throughout the forest reserve over the study period. Results indicate that human activities, such as logging, farming, and urbanization, are the major causes of deforestation and degradation within the forest reserve. To address these challenges, the study recommends improved forest protection policies, continuous GIS-based monitoring systems, and applying forest management policies with the aim of stopping further forest degradation and encouraging the ecosystem reclamation.

Keywords: Forest, Georeferencing, Remote-sensing, Land-use, Land-cover.

Introduction

Forests rank among the earth's most valuable renewable resources, providing essential ecological and economic gains needed for both ecosystem survival and human existence (Singh *et al*., 2016). Tropical forests are central to conserving biodiversity, carbon sequestering, climate regulation, watersheds protection, and supporting livelihoods (FAO, 2020). However, rapid land use and land cover (LULC) changes caused by anthropogenic activities such as urbanization, agricultural expansion, logging, and industrialization have significantly altered forest ecosystems globally (Aghaesi *et al*., 2020; Lewis *et al*., 2015; Gbiri and Adeoye. 2019; Alo *et al*., 2020; Kpienbaareh *et al*., 2022). Recent global assessments have further shown that tropical forests continue to decline due to increasing demographic pressure and unsustainable exploitation of forest resources (Chunwate *et al*., 2025: Muhammad *et al*., 2026).

Nigeria possesses rich tropical rainforest ecosystems, yet it has experienced alarming rates of deforestation over the past decades. Between 1990 and 2020, Nigeria lost a substantial proportion of its natural forest cover due to population growth, agricultural expansion, illegal logging, and infrastructure development (FAO, 2020; Global Forest Watch, 2022).

Forest degradation (Global Forest Resources Assessment 2020) has become a major concern in Nigeria, especially in Edo State, where many forest reserves are already being degraded by urbanization and anthropogenic activities (Ukoba *et al*. 2023). Recent studies around Benin City and nearby forest ecosystems have shown that rapid urbanization is gradually replacing natural vegetation with settlements, resulting in habitat destruction and forest degradation (Adeyemi and Ibrahim, 2020; Aiguobarueghian *et al*., 2025).

The Gilli-Gilli Forest Reserve remains one of the important rainforest ecosystems in southern Nigeria with dense tropical vegetation, varied fauna, and timber species. Unfortunately, ever-increasing human activities within and around the reserve have increased deforestation and environmental disturbance. Continuous monitoring of these changes is necessary for conservation planning and viable forest management. Similar studies conducted in Okomu Forest Reserve and other protected forest ecosystems in southern Nigeria have reported increasing forest fragmentation and biodiversity decline linked to anthropogenic disturbances such as logging, agriculture expansion, and settlement development (Frank and Ureigho, 2021; Okoduwa *et al*., 2026).

Remote sensing and Geographic Information System (GIS) technologies have become valuable tools for assessing land use and land cover changes because they provide reliable, cost-effective, and spatially comprehensive information over time (Aliyu and Botai, 2018; Walker *et al*., 2021; Joshi *et al*., 2016). Landsat satellite imagery, in particular, has been widely used for long-term environmental monitoring and forest change detection. Recent studies in Nigeria have increasingly applied these techniques for forest monitoring and environmental management. For example, Okoduwa and Amaechi (2024) applied Google Earth Engine, GIS, and machine learning techniques to detect LULC change in Abuja and reported rapid vegetation decline and urban expansion. Previous studies have also highlighted the importance of remote sensing indices, such as NDVI, for monitoring vegetation changes and forest degradation. Yahaya *et al*. (2025) used these indices to assess canopy and non-canopy forest species in Taraba State and highlighted the impacts of deforestation and climate variability on vegetation health. Similarly, Aiguobarueghian *et al*. (2025) reported extensive vegetation decline associated with urban growth and land transformation in Benin City.

The present study aimed to assess the dynamics of land-use and land-cover changes within the Gilli-Gilli Forest Reserve between 1986 and 2023 using GIS and remote sensing techniques. The study seeks to create classified land cover maps for 1986, 2002, and 2023, determine the deforestation rate within the forest reserve, and assess changes in dense forest cover over time. The findings will contribute to forest management policies and strengthen sustainable forest conservation strategies in Nigeria, especially through improved GIS-based monitoring and land use planning.

Materials and methods

Study area: Gilli-Gilli Forest Reserve study area is located in the Ovia North-East Local Government Area of Edo State, Nigeria, between latitudes 5°55′N and longitude 6°09′E (Figure 1). The forest reserve was established in 1935 and covers approximately 324 km^2 of tropical rainforest and swamp forest. The area experiences a humid tropical climate with an average annual temperature of about 27 °C and annual rainfall between 1778 mm and 2286 mm. (Ayanlade, 2013). Relative humidity ranges from 60% in the dry season to nearly 100% in rainy seasons of the year (Aigbe *et al*., 2025). The reserve contains economically valuable tree species like *Milicia excelsa*, *Khaya ivorensis*, and *Triplochiton scleroxylon*, as well as other many flora and fauna that provide critical ecological services Ayanlade, 2016).

The map of the study area (Figure 1) illustrates the geographical location of Gilli-Gilli Forest Reserve within Edo State and Nigeria. The reserve lies within a strategically important ecological zone of the humid rainforest belt of southern Nigeria. Its location within the Niger Delta rainforest ecosystem makes it highly vulnerable to anthropogenic disturbances, including logging, farming, and urban expansion.

The reserve's spatial location also explains the increasing human pressure observed in the study, as nearby settlements and infrastructure continue to expand into forested areas. (Ayanlade, 2016). Similar spatial patterns have been reported in nearby forest reserves, such as Okomu and Oluwa Forest Reserves in southern Nigeria (Okoduwa *et al*., 2026; Adeniji *et al*., 2023).

Data collection: Landsat Collection 2 Level-2 satellite images for 1986, 2002, and 2023 were obtained from the United States Geological Survey (USGS). The datasets included: Landsat 4 Thematic Mapper (TM) for 1986, Landsat 7 Enhanced Thematic Mapper Plus (ETM+) for 2002, and Landsat 8 Operational Land Imager (OLI) for 2023 (Table 1).

The images were downloaded from https://earthexplorer.usgs.gov/ already processed for surface reflectance, geometric, radiometric corrections, and analysis-ready. Georeferencing was processed through the World Geodetic System 1984 and projected to Universal Transverse Mercator (UTM) Zone 32N.

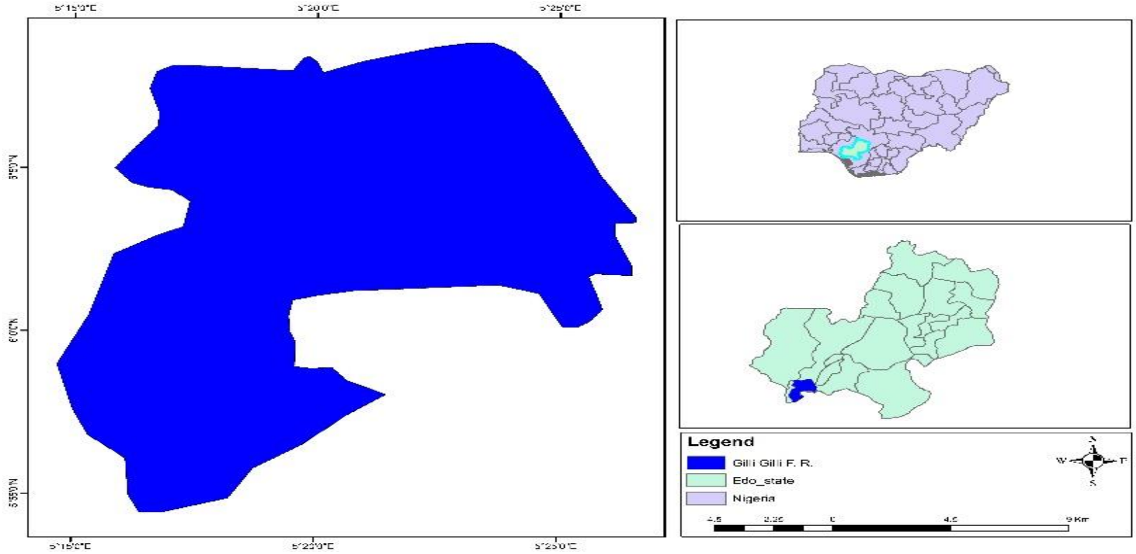

Figure 1: Map of Gilli-Gilli Forest Reserve in Edo State, Nigeria.

Table 1: Details of the Landsat imageries used for this study.

Collection 2 Level 2	Sensor	Acquisition Date	Path/ Row	Spatial Resolution (m)	Cloud Cover (%)
Landsat 8	OLI	2023/12/16	189/056	30	0
Landsat 7	ETM+	2002/12/30	189/056	30	0
Landsat 4	TM	1986/12/21	189/056	30	0

Image processing: Image processing was performed using ArcGIS 10.8 and ENVI software. Bands 4, 3, and 2 were combined for Landsat 4 TM and 7 ETM+ images, while bands 7, 5, and 4 were used for Landsat 8 OLI imagery to generate false-color composites (Figure 2). (NASA, 2025). Subsetting and delineation of the forest reserve boundaries were subsequently conducted for each study year. False-color composites were generated using appropriate spectral bands to improve land cover discrimination. The images were obtained in December to obtain images with zero cloud cover. This approach was successfully used by Temitope and Oyebamiji (2016).

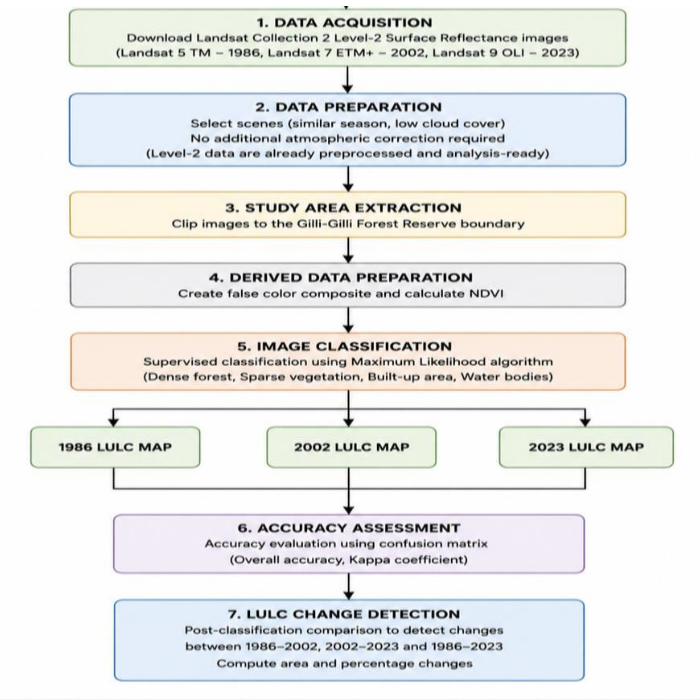

Figure 2: Workflow for land use and land cover change analysis

Land cover classification: Supervised classification using the maximum likelihood algorithm was applied to the imagery to classify it into four land cover categories: dense forest, sparse vegetation, built-up area, and water bodies (Bolstad, and Lillesand, 2007).
Change detection analysis: Post-classification change-detection analysis was conducted to evaluate temporal transitions in land cover classes. Land cover changes, including magnitude, percent, and rate of change, were assessed for 1986–2002, 2002–2023, and 1986–2023. This was done as described by Adesioye and Owoh (2016).

$$\text{Magnitude of Change} = \text{previous year} - \text{initial year}$$

$$\text{Percent of Change} = \frac{Magnitude\ of\ Change}{Sum\ of\ Change} * 100$$

Annual rate of deforestation (t) was calculated using the formula proposed by Puyravaud (2003).

$$r = \frac{1}{T2 - T1} * ln\frac{A2}{A1}$$

where A1 and A2 are the forest cover at time T1 and T2, respectively.
Normalized Difference Vegetation Index (NDVI) analysis was also performed to evaluate vegetation density and health across the study years (Ayanlade, 2016). NDVI was calculated for Landsat 5 TM (1986), Landsat 7 ETM+ (2002), and Landsat 9 OLI (2023) using the standard NDVI equation proposed by Rouse *et al*. (1974):

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

where NIR means near infrared reflectance, and Red is red light reflectance.
For Landsat 5 TM and Landsat 7 ETM+

$$NDVI_{Landsat\ 5\ TM\ and\ Landsat\ 7\ ETM+} = \frac{Band\ 4 - Band\ 3}{Band\ 4 + Band\ 3}$$

Bands used

- NIR = Band 4
- Red = Band 3

while for Landsat 9 OLI,

$$NDVI_{Landsat\ 8\ OLI} = \frac{Band\ 5 - Band\ 4}{Band\ 5 + Band\ 4}$$

Bands used

- NIR = Band 5
- Red = Band 4 (USGS, 2024; Lillesand *et al*., 2015).

Minimum, maximum, and mean NDVI values were computed for each study year to evaluate vegetation greenness and canopy density changes across the Gilli-Gilli Forest Reserve.

Results

Spatial distribution of land cover types classified land cover map for 1986: The 1986 classified map showed that dense forest was the dominant land cover type within the Gilli-Gilli Forest Reserve. Most parts of the reserve were covered by continuous forest vegetation, with extensive green cover. Sparse vegetation occurred mainly at the forest edges and areas with minor human disturbance, while built-up areas and water bodies occupied relatively small proportions of the reserve (Figure 3).
The dominance of dense forest in 1986 indicates that the reserve was still relatively intact and less disturbed at that time. The low extent of built-up areas indicates limited urban encroachment and lower anthropogenic pressure on the forest ecosystem at the time.

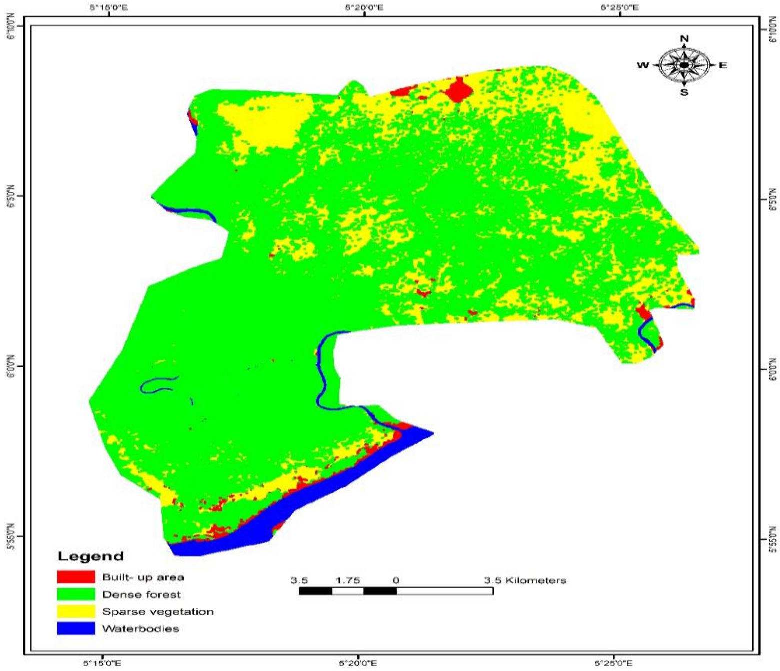

Figure 3: Land-use/land-cover classification map of Gilli-Gilli Forest Reserve for 1986

Classified land cover map for 2002: The 2002 land cover map revealed moderate changes in forest distribution compared to 1986. Dense forest was dominant but showed evidence of forest fragmentation in certain parts of the reserve. Built-up areas increased slightly, while sparse vegetation increased in some areas previously occupied by dense forest (Figure 3).

The increase in sparse vegetation indicates forest degradation from farming, logging, and clearing. However, dense forest still remained high in 2002. This indicates vegetation regeneration or periods of lower exploitation. Several forest recovery patterns have also been reported in tropical forest ecosystems undergoing fluctuating land-use intensity (Yahaya *et al*., 2025; Bruno *et al*., 2006).

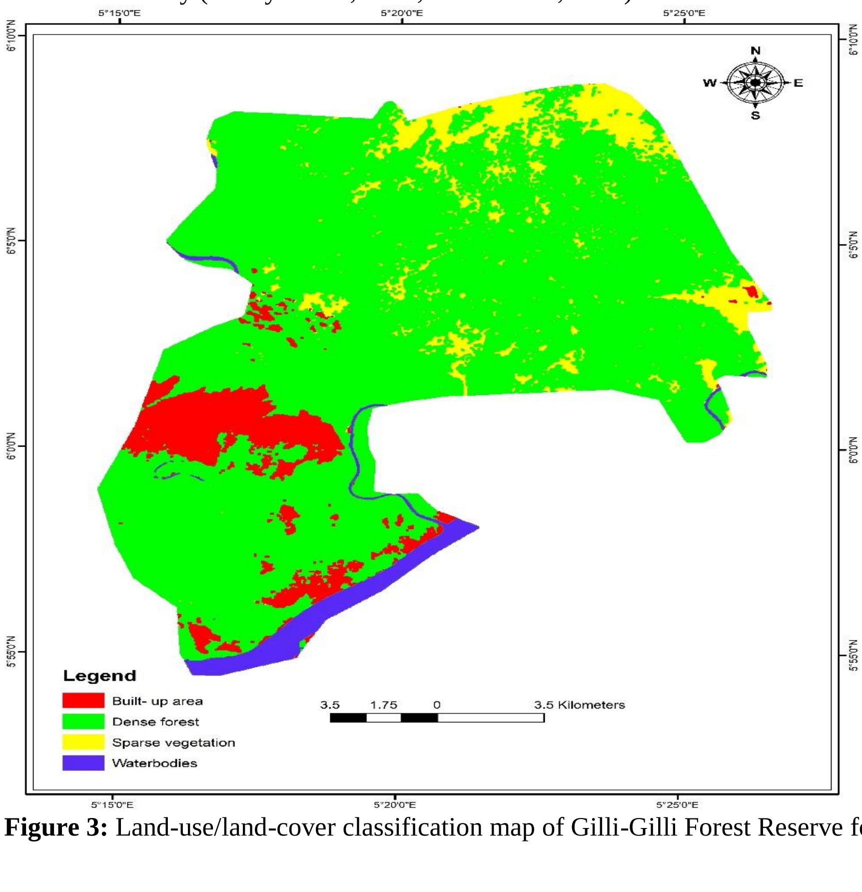

Figure 3: Land-use/land-cover classification map of Gilli-Gilli Forest Reserve for 2002

Classified land cover map for 2023: The classified land cover map for 2023 showed a clear reduction in dense forest compared to 1986. Built-up areas and sparse vegetation increased, indicating urbanization, agricultural encroachment, and increased anthropogenic activity (Figure 4).

The loss of dense forest areas suggests severe forest degradation and habitat disturbance. The increase in the area of sparse vegetation indicates the conversion of forest land into degraded forest, farmland, and partially cleared areas. This pattern indicates a faster rate of deforestation between 2002 and 2023.

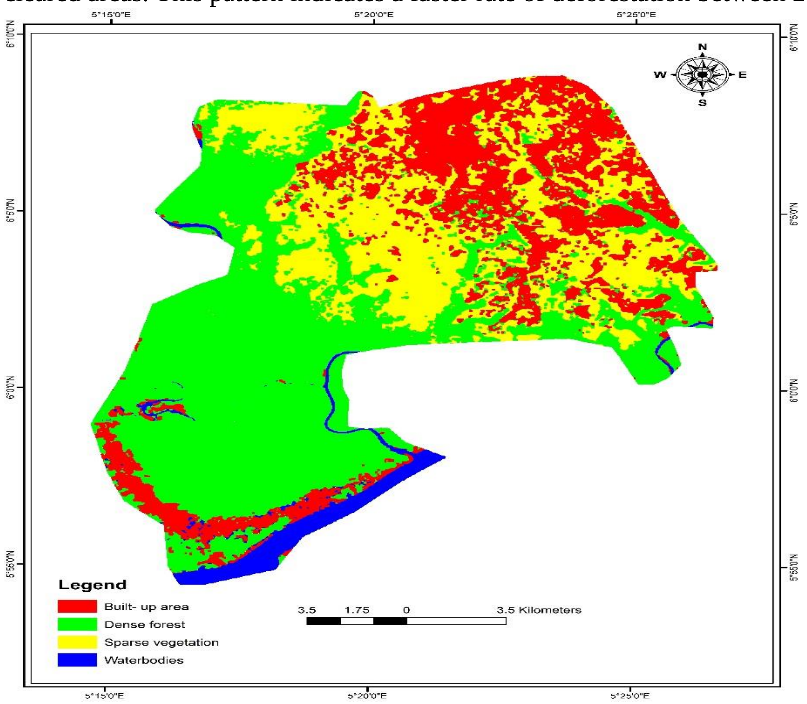

Figure 4: Land-use/land-cover classification map of Gilli-Gilli Forest Reserve for 2023

Annual deforestation rate: The annual deforestation analysis showed temporal changes in the Gilli-Gilli forest reserve over the study period. Between 1986 and 2002, the forest reserve recorded an annual gain of 0.43%, evincing a period of forest regeneration or reduced anthropogenic activity. However, between 2002 and 2023, the forest reserve recorded an annual loss of 2.23%. Overall, between 1986 and 2023, the annual loss rate was 1.11% (Figure 5).

The increase in deforestation after 2002 displays increased urbanization, population growth, agricultural activities, and logging activities within the forest reserve. The data show that the degradation of the Gilli-Gilli forest reserve accelerated in recent decades.

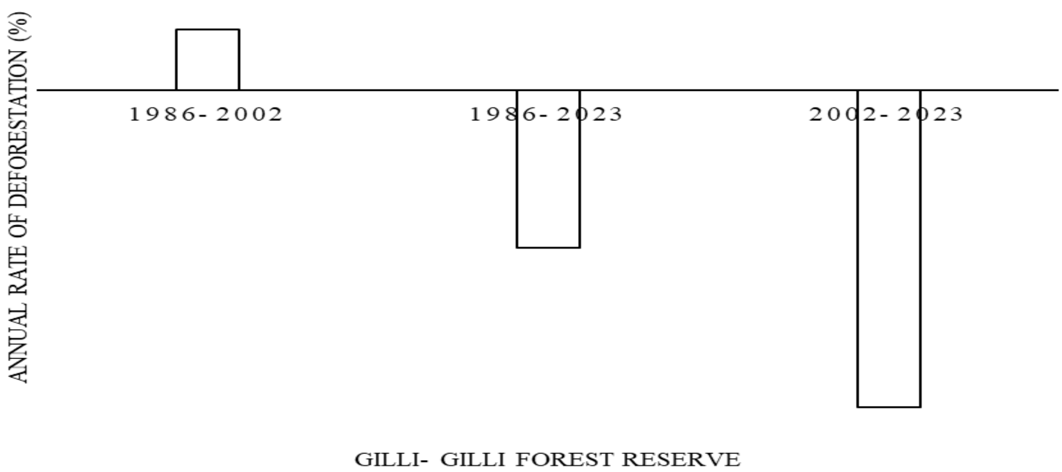

Figure 5: Annual rate of deforestation of dense forest in Gilli- Gilli forest reserve.

Normalized Difference Vegetation Index (NDVI): NDVI map for 1986: The NDVI map for 1986 showed high vegetation index values across most of the reserve, denoting a healthy, dense vegetation cover. Areas with high NDVI values corresponded to dense forest areas. High NDVI values are associated with green healthy plants. The overall NDVI pattern suggests that the reserve maintained a healthy vegetation structure during this period (Figure 6).

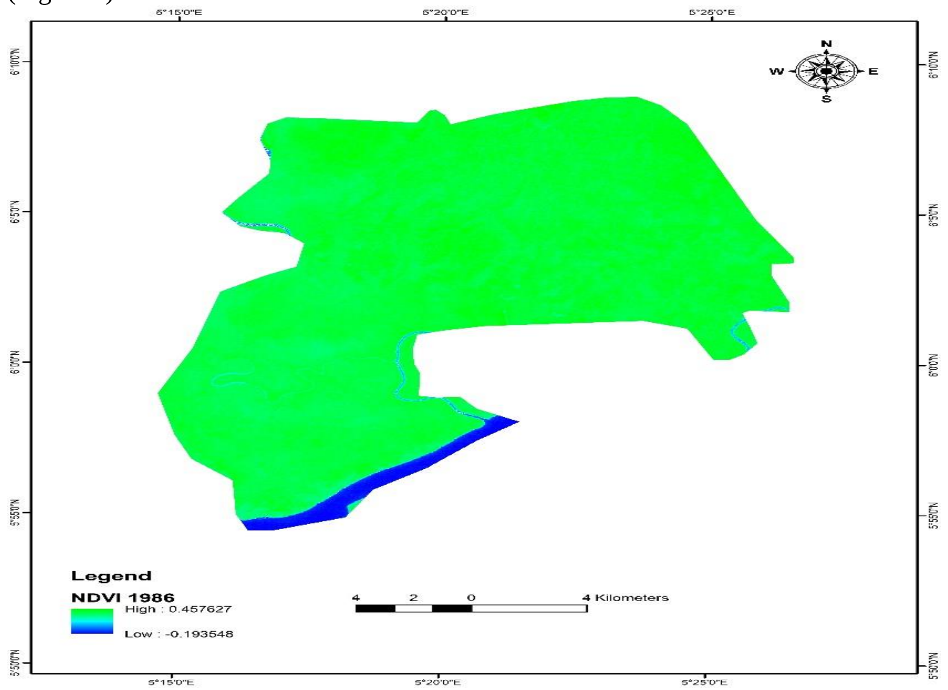

Figure 6: NDVI of dense forest and other land cover types for 1986 in Gilli- Gilli forest reserve

NDVI map for 2002: The NDVI map for 2002 indicates a reduction in vegetation density in some parts of the forest reserve. Although dense forest areas showed high NDVI values, fragmented regions and areas with sparse vegetation showed lower values. This reduction shows early signs of forest disturbance and gradual vegetation degradation (Figure 7).

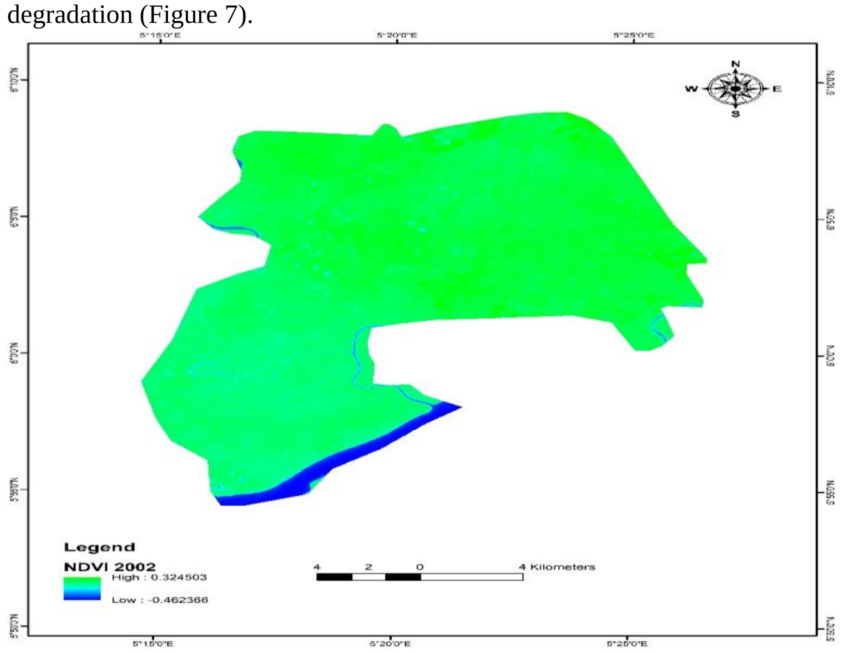

Figure 7: NDVI of dense forest and other land cover types for 2002 in Gilli- Gilli forest reserve

NDVI map for 2023: Analysis of the 2023 NDVI map shows a noticeable decline in vegetation density and canopy health relative to 1986 and 2002. Reduced NDVI values were observed in the reserve, particularly in areas affected by urban development, vegetation disturbance, and deforestation. These lower NDVI readings indicate vegetation degradation and a reduction in dense forest cover throughout the forest reserve (Figure 8).

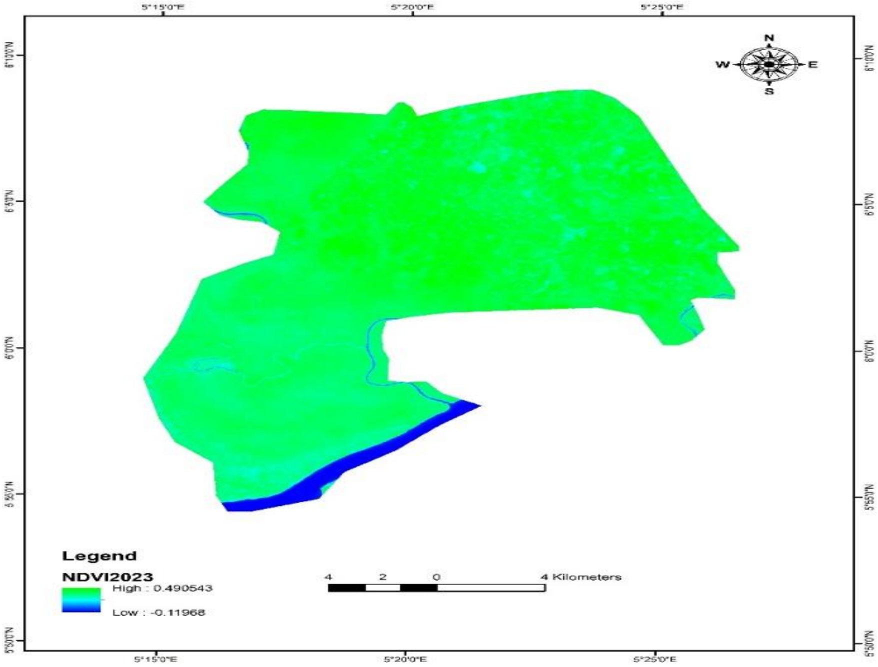

Figure 8: NDVI of dense forest and other land cover types for 2023 in Gilli- Gilli forest reserve

Minimum and maximum NDVI values: Normalized Difference Vegetation Index (NDVI) analysis was conducted to evaluate vegetation greenness and canopy density across the Gilli-Gilli Forest Reserve between 1986 and 2023. The results revealed temporal variations in vegetation condition within the reserve. The maximum NDVI values recorded were 0.4576 in 1986, 0.3245 in 2002, and 0.4905 in 2023, while the minimum NDVI values were -0.1935, -0.4623, and -0.1197, respectively. Higher NDVI values corresponded to dense vegetation cover, whereas lower and negative NDVI values represented water bodies, built-up areas, and non-vegetated surfaces (Table 2).

The lower maximum NDVI value observed in 2002 suggests a temporary decline in vegetation greenness and canopy density during that period, while the increase in maximum NDVI value in 2023 indicates some level of vegetation recovery or regrowth within portions of the reserve.

Table 2: Minimum and maximum NDVI values for Gilli-Gilli forest reserve

NDVI Indicator	1986	2002	2023
Maximum NDVI	0.4576	0.3245	0.4905
Minimum NDVI	-0.1935	-0.4623	-0.1197

Land cover change matrix analysis: The change matrix analysis demonstrated substantial reductions in dense forest cover over the 37-year study period. Dense forest declined from 235.30 km² in 1986 to 156.12 km² in 2023, representing a net loss of approximately 79.18 km² (Table 3). Approximately 49.34 km² of dense forest was converted into sparse vegetation, indicating extensive forest degradation and agricultural encroachment. Additional forest losses occurred due to the expansion of built-up areas and water bodies. The persistence of only 135.50 km² of unchanged dense forest suggests increasing fragmentation and instability of the reserve ecosystem over time.

Table 3: Gilli- Gilli forest reserve cover change matrix (Km2) between 1986 and 2023

Land Cover type (km²)	Built-up area	Dense forest	Sparse vegetation	Water bodies	Total LC 2023
Built-up area	**5.80**	49.06	22.99	0.20	78.05
Dense forest	4.70	**135.50**	15.66	0.26	156.12
Sparse vegetation	1.21	49.34	**25.92**	0.01	76.48
Water bodies	0.52	1.40	0.30	**10.63**	12.85
Total LC (1986)	12.23	235.30	64.87	11.10	323.50

+The figures in bold indicate that there was no change in those time periods

Change matrix between 2002 and 2023: The greatest forest loss occurred between 2002 and 2023. Dense forest lost 56.72 km² to built-up areas, 63.90 km² to sparse vegetation, and 1.93 km² to water bodies (Table 4). The large transition from dense forest to sparse vegetation indicates progressive degradation rather than complete removal in some areas. However, the extensive increase in built-up areas demonstrates accelerated urbanization and settlement expansion within the reserve. Although some forest gain occurred from other land cover categories, these gains were insufficient to compensate for the large-scale forest losses recorded during this period.

Table 4: Gilli- Gilli forest reserve change matrix (km2) between 2002 and 2023

Land Cover (km²)	Built-up area	Dense forest	Sparse vegetation	Water bodies	Total LC 2023
Built-up area	**4.24**	56.72	16.94	0.16	78.06
Dense forest	23.13	**129.83**	3.09	0.07	156.12
Sparse vegetation	0.35	63.90	**12.24**	0.00	76.49
Water bodies	0.58	1.93	0.01	**10.33**	12.85
Total LC (2002)	28.30	252.38	32.28	10.56	323.52

+The figures in bold indicate that there was no change in those time periods

Change matrix between 1986 and 2002: Table 5 shows the forest reserve change matrix between 1986 and 2002; the area of dense forest increased from 235.30 km² to 252.38 km². The increase may reflect forest regeneration, reduced exploitation, or temporary conservation success during this period. Sparse vegetation declined substantially between 1986 and 2002, suggesting that some degraded areas may have regenerated into denser vegetation. However, this trend was later reversed after 2002 due to intensified anthropogenic activities.

Table 5: Gilli- Gilli forest reserve cover change matrix (Km²) between 1986 and 2002

Land Cover (km²)	Built-up area	Dense forest	Sparse vegetation	Water bodies	Total LC 2002
Built-up area	**2.47**	23.00	2.66	0.17	28.30
Dense forest	6.84	**199.14**	45.85	0.55	252.38
Sparse vegetation	2.79	13.09	**16.36**	0.04	32.28
Water bodies	0.13	0.07	0.01	**10.35**	10.56
Total LC (1986)	12.23	235.30	64.88	11.11	323.52

+The figures in bold indicate that there was no change in those time periods

Total land cover area and percentage change: Built-up areas increased from 12.24 km² (3.78%) in 1986 to 78.06 km² (24.13%) in 2023 (Table 6). This increase indicates urban expansion, infrastructural development, and increased human activities in the forest reserve. Dense forest increased between 1986 and 2002 but later declined to 156.12 km² (48.26%) by 2023. The decline indicates deforestation and forest fragmentation. Sparse vegetation declined between 1986 and 2002 but increased by 2023, signifying ongoing forest reserve degradation and expansion of farmland or degraded vegetation. Water bodies remained stable throughout the study period, indicating minor changes relative to other land cover types.

Table 6: Gilli- Gilli forest reserve cover area, percentage change, and magnitude of change for 1986, 2002 and 2023

Land use	1986		2002		2023		Magnitude of change (Km²)		
	1986 Area (Km²)	% change	2002 Area (Km²)	% change	2023 Area (Km²)	% change	2002-2023	1986-2002	1986-2023
Built-up area	12.24	3.78	28.30	8.75	78.06	24.13	49.76	16.02	65.82
Dense forest	235.30	72.73	252.37	78.00	156.12	48.26	-96.25	17.07	-79.18
Sparse vegetation	64.87	20.05	32.29	9.98	76.48	23.64	44.19	-32.58	11.61
Water bodies	11.10	3.43	10.56	3.26	12.85	3.97	2.29	-0.54	1.75
Total	***323.5**	100	***323.51**	100	***323.5**	100	-0.01	-0.03	0

Discussion

The findings of this study demonstrate significant land-use and land-cover changes in the Gilli- Gilli Forest Reserve over the past 37 years. The most noticeable pattern was a steady decline in dense forest areas, accompanied by growth in both built-up zones and regions of sparse vegetation. The increase in built-up areas may result from rapid urban population growth and the allocation of land for settlement within the forest reserve. Previous studies have reported (Osehobo, 2013; Abiodun, 2015; Dami *et al*., 2014; Frank and Ureigho, 2021), that increasing populations and expanding infrastructure have been significant contributors to forest decline. Such urban growth typically results in habitat fragmentation, biodiversity loss, and changes to natural ecosystem functions. The expansion of sparse vegetation by 2023 indicates widespread forest degradation, largely driven by agricultural activities, timber harvesting, and the clearing of forested land. Agricultural encroachment ranks among the main factors responsible for tropical forest loss in Sub-Saharan Africa (Kpienbaareh *et al*., 2022; Okoduwa *et al*., 2026). Changing dense forests into non-vegetated areas has dire consequences for ecosystem stability, biodiversity, and carbon storage.

The short-term rise in dense forest cover observed between 1986 and 2002 could be attributed to reduced forest use or to natural regrowth. Nevertheless, this positive trend was offset by increased human activity after 2002.

NDVI results further confirmed the decrease in vegetation health and canopy density across the reserve. The reduction in NDVI values observed between 1986 and 2002 reflected increasing forest disturbance, plant stress, and degradation. The lower NDVI trend noted in this investigation aligns with the land cover analysis, reinforcing evidence of escalating environmental disruption in the reserve. Although NDVI values improved in 2023, the substantial decline in dense forest cover indicates that much of the vegetation recovery may consist of secondary vegetation rather than intact mature forest. Similar findings have been reported in other studies in Edo State, where decreases in NDVI have been linked to urban growth and environmental pressures (Aiguobarueghian *et al*., 2025; Amaechi and Ajokpauwu, 2022).

Ongoing deforestation in the reserve has led to several ecological issues, such as loss of species diversity, habitat fragmentation, altered water cycles, soil erosion, and reduced carbon sequestration. Since tropical forests are crucial for climate regulation and environmental stability, their continued decline poses significant risks to ecosystem health and human livelihoods.

This study underscores the importance of using remote sensing and GIS tools for effective forest monitoring and informed conservation planning. Ongoing satellite-based surveillance offers timely data to support policy-making and promote sustainable management of forest resources.

Conclusion

Between 1986 and 2023, Gilli-Gilli Forest Reserve underwent marked changes in land use and land cover. There was a pronounced reduction in dense forest cover, accompanied by notable expansion of built-up areas and areas with sparse vegetation—trends largely attributed to human activities such as urban growth, agriculture, and logging. Findings reveal a steady rise in deforestation and ecological decline within the reserve, especially following 2002. The use of GIS and remote sensing was instrumental in identifying and monitoring these environmental changes. To help curb further forest degradation, it is essential to reinforce conservation policies, ensure stricter compliance with forestry regulations, adopt sustainable land management strategies, encourage active involvement of local communities in forest stewardship, and maintain regular GIS and remote sensing assessments of forest resources. Integrating remote sensing and GIS tools into Nigeria's environmental management systems will enhance the long-term monitoring and protection of forested areas.

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