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(Research Article)

NDVI-Based Assessment of Land Cover Change and Urban Expansion in Benin City, Nigeria (2014 – 2024)

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Abstract

This study applies the Normalized Difference Vegetation Index (NDVI), one of the most widely used indices for vegetation monitoring, to examine Land Use Land Cover (LULC) changes in Benin City, Edo State, Nigeria, focusing on Oredo, Egor, and Ikpoba-Okha Local Government Areas over a 10-year period (2014–2024). Using Landsat 8 Level-2 imagery, NDVI values were derived from the near-infrared and red bands and reclassified into LULC categories through color slicing. The study mapped and quantified transitions in three classes: built-up area/bare soil, sparse vegetation/exposed soil, and moderate vegetation. Results indicate a significant increase in built-up areas from 14.17% in 2014 to 45.03% in 2024, accompanied by a steep decline in moderate vegetation from 42.88% to 0.4%. Sparse vegetation showed a marginal increase, suggesting land degradation. Key drivers include urbanization, deforestation, and infrastructure development. The findings emphasize the need to urgently implement sustainable land management, including urban planning, reforestation, and environmental regulation, as NDVI-based statistics and projections reveal a marked shift in land cover over the decade.

Keywords: NDVI; Benin City; Land Use; Urbanization; Vegetation loss; Remote sensing

1. Introduction

Land use and land cover (LULC) represent distinct yet interrelated concepts that describe both the physical attributes of the Earth's surface and the ways humans utilize it [7–10]. Specifically, land use refers to human activities on land such as agriculture, housing, recreation, and resource management, while land cover represents the biophysical features observed on the Earth's surface, including vegetation, water, bare soil, and built-up structures [11–14]. Monitoring LULC changes has become increasingly critical because of their direct influence on ecosystem health, resource distribution, and human livelihoods [9]. Understanding these changes is essential for effective environmental management and sustainable urban planning [10].

Land cover mapping is one of the most important applications of remote sensing data because it provides accurate and timely information on the spatial configuration and dynamics of the Earth's surface [6]. Among the various indices used for vegetation and land cover monitoring, the Normalized Difference Vegetation Index (NDVI) is one of the most widely applied because it utilizes the red and near-infrared spectral bands to effectively distinguish vegetation from non-vegetated surfaces [5, 6]. NDVI values theoretically range between −1 and +1, with higher values corresponding to dense, healthy vegetation, while low or negative values indicate water, bare soil, or built-up areas.

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Benin City, the capital of Edo State, Nigeria, is undergoing rapid urbanization with associated socio-economic and environmental challenges. Historically characterized by dense tropical forests, the city has experienced significant land transformation due to population growth, rural–urban migration, and infrastructure expansion. Over the past decade, the conversion of vegetated land into built-up areas has intensified deforestation, biodiversity loss, flooding, and land degradation. Despite these pressures, there is limited spatial research quantifying recent LULC changes in Benin City.

Several studies in Nigeria have applied NDVI to monitor vegetation and land cover dynamics. Daramola and Eresanya [1] analyzed urban expansion in Akure and reported a strong negative correlation between NDVI and Land Surface Temperature (LST), indicating vegetation decline with rising surface temperatures. Similarly, Alademomi *et al.* [2] examined the interplay between NDVI, the Normalized Difference Built-up Index (NDBI), and LST in Lagos, showing that increasing built-up surfaces corresponded to reduced vegetation indices. In Ibadan, Fashae *et al.* [3] used NDVI threshold-based emissivity to derive LST and confirmed a strong inverse NDVI–temperature relationship. Collectively, these findings demonstrate NDVI's effectiveness for assessing vegetation loss and thermal impacts across Nigeria's rapidly urbanizing cities.

More recently, Fabolude and Aighewi [4] evaluated land use/land cover changes in Benin City from 1987 to 2019, but their analysis relied primarily on supervised classification without the explicit use of NDVI thresholds. These studies highlight the usefulness of NDVI for vegetation assessment but also reveal a gap in NDVI-based threshold analysis for Benin City. This study therefore addresses that gap by analyzing Landsat 8 satellite imagery for 2014, 2019, and 2024 using NDVI-based classification. The objectives are:

- To map and classify LULC types for 2014, 2019, and 2024
- To quantify changes in forest, agricultural, and urban areas
- To identify the drivers of LULC change
- To evaluate the implications of vegetation loss and urban sprawl
- To recommend strategies for sustainable land management.

2. Materials and Methods

2.1. Study Area

Benin City, the capital of Edo State, Nigeria, is located in the southern part of the country between latitudes 6°12′–6°27′ N and longitudes 5°29′–5°45′ E (Figure 1). The city comprises three main Local Government Areas (LGAs): Oredo, Egor, and Ikpoba-Okha, which form its metropolitan core. It is bordered by Delta State to the south, Ondo State to the west, and other LGAs within Edo State to the north and east. The topography is predominantly flat with gently undulating plains.

Historically, Benin City lies within the humid tropical rainforest zone, once characterized by dense and diverse forest species that have been exploited for centuries. However, extensive deforestation and urbanization have drastically reduced forest cover, accelerating land degradation. Rapid conversion of agricultural and forest lands into residential and commercial developments has led to several ecological challenges, including biodiversity loss, flooding, and soil erosion. The area experiences two distinct seasons: a rainy season (April–October) and a dry season (November–March). The soils are mostly acidic, deep, and highly leached, with reddish to brown coloration due to the predominance of iron and aluminum oxides [16].

Economically, Benin City is dominated by trade, services, and light industrial activities concentrated in Oredo LGA. Subsistence and small-scale commercial agriculture persist in the outskirts, particularly in Egor and Ikpoba-Okha. The city's distinctive radial road network enhances interconnectivity between its core and surrounding areas, a spatial feature that has supported its urban growth and regional importance [15].

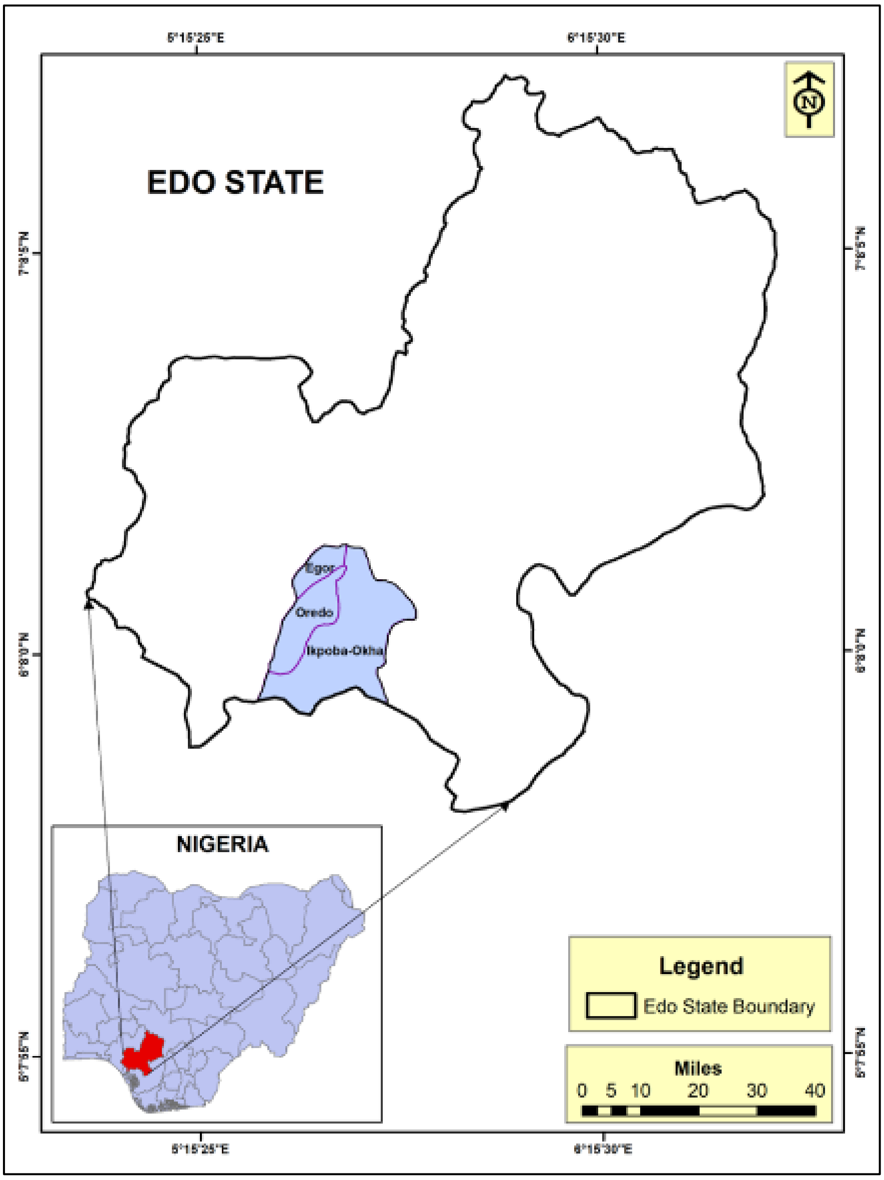

Figure 1 Map of Edo State showing study area (Benin City and Local Government Areas), created using ArcGIS 10.8 based on shapefiles of administrative boundary shapefiles from GADM [17]

2.2. Data Acquisition

Landsat 8 Collection 2 Level-2 surface reflectance imagery for the years 2014, 2019, and 2024 was obtained from the United States Geological Survey (USGS) Earth Explorer platform [18]. The datasets were selected based on minimal cloud cover and temporal proximity to the dry season to ensure consistent surface conditions. The imagery was used to derive NDVI and assess multi-temporal land cover changes across the study period.

2.3. Data Processing

Radiometric and atmospheric corrections were automatically applied to the Landsat 8 Collection 2 Level-2 data, which are provided as surface reflectance products by the United States Geological Survey (USGS) [18]. Each image was visually inspected to ensure minimal cloud contamination before analysis. The Area of Interest (AOI) was extracted in ENVI 5.6 using shapefiles of the study area, and the images were clipped to the AOI extent to generate subsets for NDVI computation. All datasets were resampled to a spatial resolution of 30 m and reprojected to the Universal Transverse Mercator (UTM) Zone 31 N, WGS-84 coordinate system to maintain spatial consistency across the three study years. All image processing and NDVI computation were performed using ENVI 5.6, while ArcGIS 10.8 was used for spatial analysis and map generation.

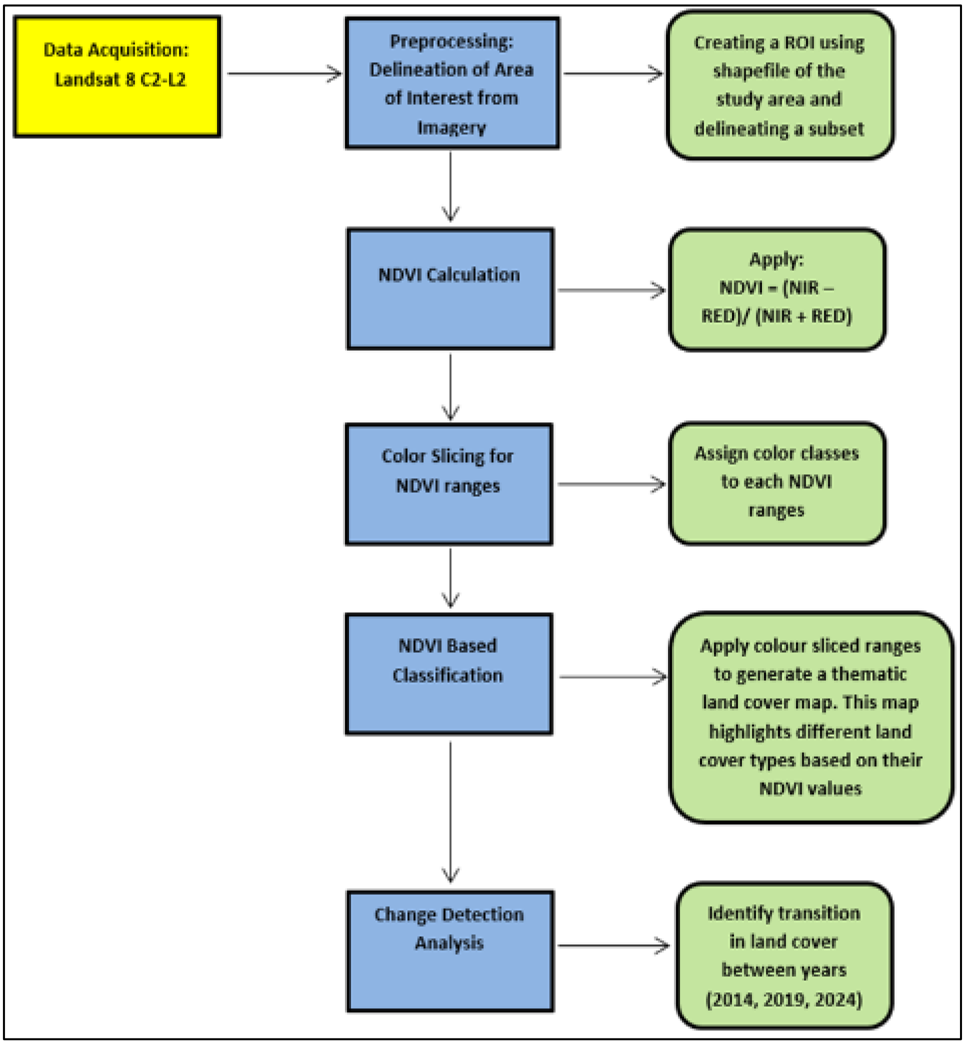

Figure 2 Workflow showing sequential steps of the methodology, from Landsat 8 data acquisition, preprocessing, NDVI calculation, color slicing, and NDVI classification to change detection analysis for 2014, 2019, and 2024

2.4. NDVI Calculation

NDVI was derived using the formula:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$$

With NIR = Band 5, RED = Band 4. The NDVI tool in ENVI automated the calculation for each year.

2.5. NDVI Thresholding and Classification

Color slicing assigned NDVI ranges to land cover categories for classification thresholds that were adapted from published studies. Taufik et al. [5] classified NDVI ≤ 0.1 as non-vegetation, 0.2–0.5 as moderate vegetation, and ≥ 0.6 as dense vegetation. Similarly, Jeevalakshmi et al. [6] reported vegetation NDVI values between 0.151 and 0.563, with dense vegetation >0.445. In this study, the vegetation range was subdivided, with 0.2–0.3 defined as sparse vegetation and 0.3–0.6 as moderate vegetation, to capture transitional and degraded vegetation zones observed in Benin City.

Table 1 NDVI thresholds and assigned LULC categories

NDVI	Category	Description
0.0 – 0.2	Built-up/Bare Soil	Urban areas, exposed
0.2 – 0.3	Sparse Vegetation	Grassland. Shrubs, degraded land
0.3 – 0.6	Moderate Vegetation	Farmlands, secondary forest

2.6. Change Detection

Classified NDVI maps for 2014, 2019, and 2024 were exported to ArcMap for spatial overlay and change detection analysis. Transition trends among the different land cover categories were derived using pixel-based statistics and percentage area calculations. Since this study employed NDVI-based threshold reclassification rather than supervised classification, formal accuracy assessment was not applicable. Classification reliability was verified visually using high-resolution Google Earth imagery and cross-checked across temporal datasets.

3. Results and Discussion

3.1. Change Detection Analysis

The spatial pattern of land-use and land-cover (LULC) change in Benin City between 2014 and 2024 was derived from NDVI-based reclassification of Landsat imagery (Figure 3). Three main classes were identified: built-up area/bare soil, sparse vegetation/exposed soil, and moderate vegetation. The LULC maps reveal a progressive transformation of the landscape during the decade, characterized by declining vegetation cover and the corresponding expansion of built-up surfaces.

In 2014, the southern and central portions of Benin City were predominantly vegetated, with extensive patches of moderate vegetation (NDVI > 0.3) interspersed with sparse vegetation. The northern and northeastern districts primarily contained built-up and bare-soil areas. By 2019, vegetation cover had become increasingly fragmented, particularly in Oredo and Egor Local Government Areas, where expanding residential and infrastructural development replaced much of the sparse vegetation.

By 2024, built-up and bare-soil areas had expanded markedly, occupying a substantial portion of the mapped region, while vegetation persisted only as isolated patches in the southern and southwestern regions. This pattern of change reflects rapid urban expansion, surface sealing, and vegetation degradation, consistent with NDVI-decline trends documented in other rapidly growing Nigerian cities such as Akure, Lagos, and Ibadan [1–3].

Overall, the NDVI-based LULC change-detection analysis demonstrates a clear spatio-temporal shift from vegetated to impervious surfaces within the decade, underscoring the environmental implications of unchecked urbanization, namely increased surface runoff, reduced evapotranspiration, and local microclimatic warming. The continuous increase in built-up and sparsely vegetated surfaces corresponds to the conversion of forested and agricultural lands into residential and commercial developments, reflecting the influence of population growth, migration, and infrastructure development on land demand. Similar NDVI-decline patterns associated with urban expansion have been documented in other Nigerian cities such as Akure, Lagos, and Ibadan [1–3]. These findings call attention to the urgent need for effective land-use planning, enforcement of environmental regulations, and promotion of urban greening to mitigate further vegetation loss and maintain ecosystem stability in Benin City.

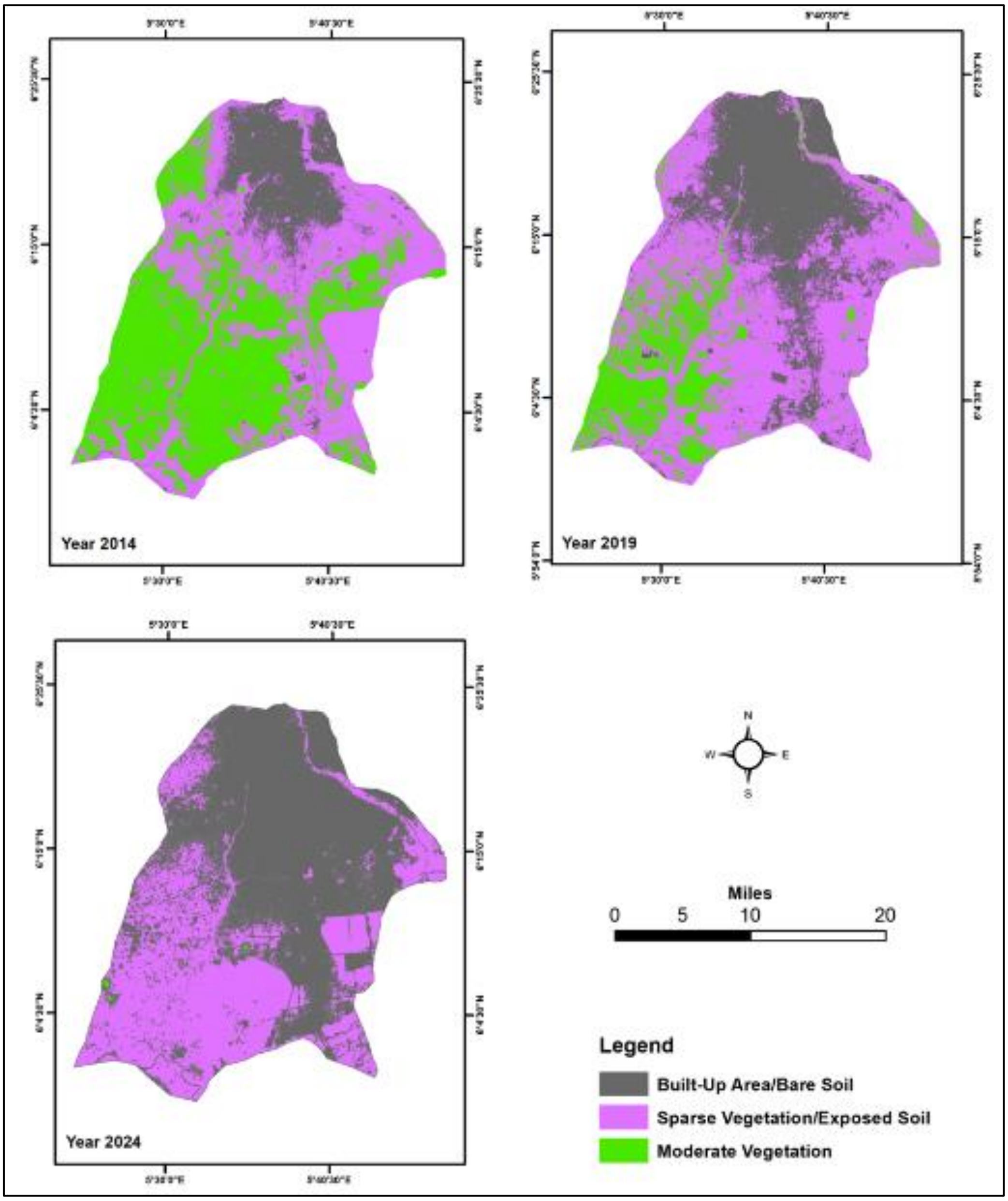

Figure 3 NDVI-based land cover maps of Oredo, Egor, and Ikpoba-Okha Local Government Areas, Benin City, Edo State, Nigeria, for 2014, 2019, and 2024. The maps were produced using ArcGIS 10.8, based on NDVI threshold reclassification of Landsat 8 Collection 2 Level-2 surface reflectance data, showing progressive urban expansion and a corresponding decline in vegetation cover over the ten-year period

3.2. Quantitative Analysis

Table 2 2014 NDVI-Based Classification Statistics

2014 NDVI-Based Classification Statistics (When Total Pixel = 1345910)				
S/N	**NDVI Values**	**Category**	**Pixel Count**	**Percentage (%)**
1	0 - 0.2	Built-Up Area/Bare Soil	190671	14.17
2	0.2 - 0.3	Sparse Vegetation/Exposed Soil	578129	42.95
3	0.3 - 0.6	Moderate Vegetation	577110	42.88
Total				100

Table 3 2019 NDVI-Based Classification Statistics

2019 NDVI-Based Classification Statistics (When Total Pixel = 1345883)				
S/N	NDVI Values	Category	Pixel Count	Percentage (%)
1	0 - 0.2	Built-Up Area/Bare Soil	417182	30.99
2	0.2 - 0.3	Sparse Vegetation/Exposed Soil	708606	52.65
3	0.3 - 0.6	Moderate Vegetation	220095	16.35
Total				99.99

Table 4 2024 NDVI-Based Classification Statistics

2024 NDVI-Based Classification Statistics (When Total Pixel = 1345909)				
S/N	NDVI Values	Category	Pixel Count	Percentage (%)
1	0 - 0.2	Built-Up Area/Bare Soil	606015	45.03
2	0.2 - 0.3	Sparse Vegetation/Exposed Soil	734447	54.57
3	0.3 - 0.6	Moderate Vegetation	5447	0.4
Total				100

Tables 2 - 4 present NDVI-based classification statistics for 2014, 2019, and 2024, respectively. The results reveal a consistent decline in moderate vegetation and a corresponding expansion of built-up and sparsely vegetated areas over the ten-year period. In 2014, built-up/bare soil accounted for only 14.17% of the total area, while moderate vegetation and sparse vegetation each covered roughly 43%. By 2019, built-up/bare soil nearly doubled to 30.99%, and moderate vegetation dropped to 16.35%. By 2024, built-up/bare soil reached 45.03%, and moderate vegetation nearly disappeared (0.4%), indicating near-total vegetation depletion. Sparse vegetation remained dominant (approximately 54%), suggesting large-scale conversion of moderate vegetation into degraded or exposed land surfaces.

Table 5 Summary of LULC changes across 2014, 2019 and 2024

2014, 2019 & 2024 NDVI-Based Classification Statistics				
S/N	Category	Percentage (%)		
		2014	2019	2024
1	Built-Up Area/Bare Soil	14.17	30.99	45.03
2	Sparse Vegetation/Exposed Soil	42.95	52.65	54.57
3	Moderate Vegetation	42.88	16.35	0.4

Table 5 summarizes the percentage distribution of NDVI-based land-cover classes for 2014, 2019, and 2024. The results reveal a continuous decline in moderate vegetation and a sharp increase in built-up/bare soil areas, while sparse vegetation remains the dominant class throughout the study period. The temporal pattern of these changes is further illustrated in Figure 3, which visually depicts the progressive urban expansion and corresponding vegetation loss across Benin City.

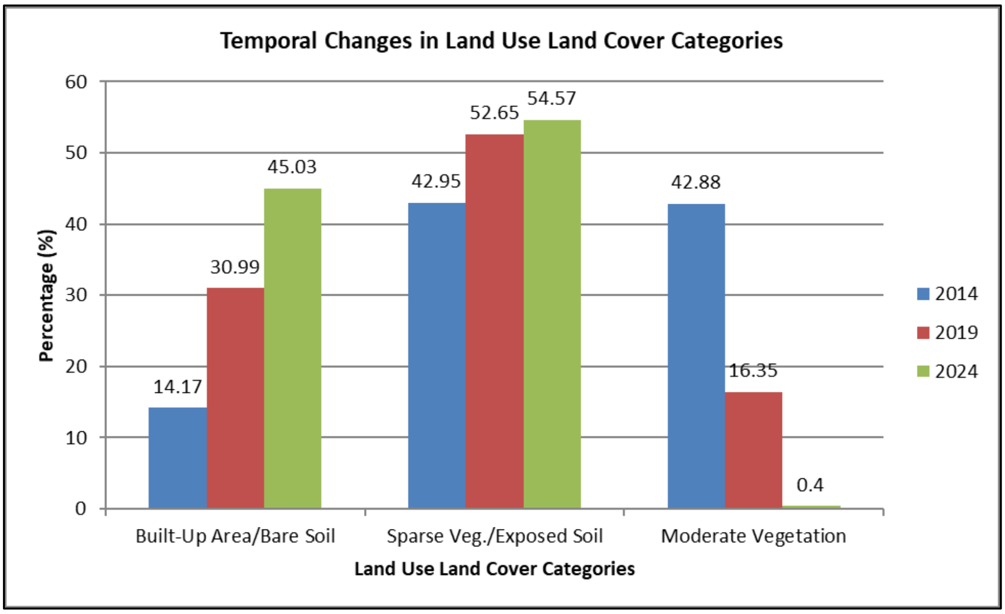

Figure 4 Temporal changes in land use and land cover (LULC) categories for 2014, 2019, and 2024. The chart illustrates a progressive increase in built-up/bare soil areas and a steady decline in moderate vegetation across the study period, with sparse vegetation remaining dominant. These results confirm the NDVI-based trend of urban expansion and vegetation degradation observed in Benin City, Nigeria

3.3. Drivers of Changes

Urbanization, deforestation, and infrastructure development primarily drive the observed land cover transformations in Benin City. Rapid population growth and rural–urban migration has intensified the demand for housing, transportation networks, and social amenities, leading to extensive land conversion. Deforestation associated with agricultural expansion and settlement clearing has contributed significantly to the reduction of moderate vegetation, while infrastructure development, including new roads, residential estates, and industrial facilities, has further replaced natural landscapes with impervious surfaces. These combined pressures have accelerated vegetation loss and promoted the expansion of built-up and sparsely vegetated areas identified in the NDVI analysis.

3.4. Implications

The NDVI-based analysis of land cover change in Benin City has several important environmental and urban implications. Environmentally, the progressive decline in vegetation cover suggests biodiversity loss, soil erosion, and ecosystem disruption, as natural habitats give way to built-up and exposed surfaces. Hydrologically, the expansion of impervious areas is likely to increase surface runoff and the frequency of urban flooding, particularly during the rainy season. The reduction in vegetative cover also contributes to urban heat-island effects, as the loss of evapotranspiration capacity and increased surface albedo elevates local temperatures. Furthermore, rapid urbanization without adequate planning creates growing challenges for urban management, including inefficient waste disposal, uncontrolled sprawl, and inadequate infrastructure and green spaces. Together, these implications demonstrate the importance of sustainable urban development and vegetation restoration initiatives to mitigate the environmental consequences of land cover change in Benin City.

4. Conclusion

This study assessed land cover changes and urban expansion in Benin City, Nigeria, between 2014 and 2024 using the NDVI-based classification of Landsat-8 satellite imagery. The results revealed a marked transformation of the landscape, characterized by a significant increase in built-up and sparsely vegetated areas and a sharp decline in moderate vegetation. Built-up/bare soil areas increased from 14.17% in 2014 to 45.03% in 2024, while moderate vegetation nearly disappeared, dropping from 42.88% to 0.4%. These changes reflect the combined impacts of rapid urbanization, deforestation, and infrastructure development within the study area.

The findings demonstrate the usefulness of NDVI as a simple yet effective indicator for quantifying vegetation loss and land cover transition in fast-growing urban environments. The observed trends have critical implications for environmental sustainability, hydrological stability, and urban heat regulation. To mitigate the continuing degradation of vegetation cover, sustainable land use policies, urban greenbelt development, and regular remote sensing–based monitoring are recommended. Future research should integrate NDVI analysis with supervised classification and higher-resolution datasets to improve accuracy and to better understand the spatial patterns and drivers of land cover change across the region.

Recommendations

To address the rapid land cover transformation and vegetation decline observed in Benin City, several strategic actions are recommended. Urban planning should prioritize effective zoning regulations and the integration of green infrastructure, such as urban parks, vegetative buffers, and sustainable drainage systems, to balance development with environmental protection. Large-scale reforestation and afforestation programs, including community-based tree planting initiatives, are essential to restore vegetation cover and enhance ecological resilience. Continuous monitoring of land use and land cover (LULC) through geospatial technologies such as NDVI, remote sensing, and GIS should be institutionalized to enable evidence-based decision-making. Strengthened environmental policies and enforcement mechanisms are needed to curb deforestation and uncontrolled land conversion. Finally, sustained public awareness and education campaigns on sustainable land use practices will foster community participation and long-term environmental stewardship in Benin City.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The author declares no conflict of interest.

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