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Vegetation Cover Change and Land Use/Land Cover Dynamics in the Gombe Metropolitan Region, Nigeria: Implications for Rural Development and Population Distribution

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Abstract

Rapid urbanisation, agricultural expansion, and infrastructure development are increasingly transforming peri-urban landscapes in Nigeria, with major implications for vegetation stability, land-resource governance, and rural livelihood systems. In the Gombe Metropolitan Region, understanding long-term vegetation-cover change through geospatial evidence is critical for explaining land-use transitions and their possible effects on rural development and population redistribution. Thus, this current study examined vegetation cover change in the Gombe Metropolitan Region from 1990 to 2024, with emphasis on the relationship between land use/land cover (LULC) dynamics and vegetation decline. Multi-temporal Landsat satellite imagery (TM, ETM+, and OLI/TIRS) and geospatial analysis techniques were used to classify LULC and track vegetation-cover shifts for 1990, 2004, and 2024. Supervised maximum likelihood classification was performed in ERDAS Imagine, with overall classification accuracies of 85.6%, 87.2%, and 89.4%, and Kappa coefficients of 0.82, 0.84, and 0.87 for the respective years. Results showed a substantial decline in vegetation cover from 97.31 km² in 1990 to 66.21 km² in 2004 and 42.36 km² in 2024, representing a total loss of 54.95 km² (56.5%) over 34 years. This decline coincided with rapid urban expansion, agricultural conversion, and infrastructural development, while built-up areas increased from 10.36 km² in 1990 to 44.47 km² in 2024. Because the study did not directly measure demographic or livelihood indicators, implications for rural development and population dynamics are interpreted from LULC evidence and supported by secondary census and agricultural literature. Ongoing vegetation loss and land degradation may intensify biodiversity decline, soil erosion, and pressure on peri-urban livelihoods. The study recommends targeted reforestation in high-loss zones, stronger land-use regulation, sustainable urban planning, and climate-adaptation strategies.

Keywords: Vegetation Cover, Land Use/Land Cover (LULC), Urbanization, Deforestation, Geospatial Analysis, Gombe Metropolitan Region, Accuracy Assessment

INTRODUCTION

Vegetation cover is a crucial component of the Earth's ecosystem because it supports biodiversity, regulates climate, stabilizes soils, and sustains hydrological cycles (Chapin *et al.*, 2000). It also provides ecosystem services such as carbon sequestration, erosion control, water regulation, and wildlife habitat. Over the past few decades, urbanisation and industrialisation have significantly altered land use and land cover (LULC) patterns, resulting in substantial vegetation-cover change (Lambin *et al.*, 2003; Foley *et al.*, 2005). These changes are especially pronounced in rapidly growing sub-Saharan African cities, where infrastructure and demographic pressures continue to intensify (Seto *et al.*, 2012; Güneralp & Seto, 2013).

The Gombe Metropolitan Region, located in northeastern Nigeria, reflects these global trends. As Gombe's population has increased from an estimated 250,000 in 1991 to more than 450,000 by 2023 (NPC, 2006; NBS, 2023), the natural landscape has been progressively transformed. The region has experienced rapid urban growth and infrastructural development, leading to the conversion of natural landscapes into built-up areas, agricultural land, and bare land. These changes have important implications for ecological stability, biodiversity, and the livelihoods of rural communities that depend on natural resources.

Despite the importance of vegetation cover, there is limited comprehensive, spatially explicit data on how it has changed over time in Gombe. This lack of information hinders effective urban planning and sustainable management of natural resources (Musa *et al.*, 2013). A systematic, multi-temporal analysis using satellite imagery and GIS is therefore critical for informing planning decisions and environmental management strategies.

This study aimed to analyse vegetation-cover change in the Gombe Metropolitan Region from 1990 to 2024 and to examine the relationship between LULC change and vegetation dynamics. Specifically, the study sought to: (i) determine the LULC pattern of the study area in 1990, 2004, and 2024; (ii) quantify changes in vegetation cover across the three periods; and (iii) interpret the implications of vegetation change for LULC dynamics, rural development, and population distribution. The study was guided by the following research questions: What were the LULC patterns in the Gombe Metropolitan Region in 1990, 2004, and 2024? How did vegetation cover change across these years? What are the likely implications of vegetation loss for land-use dynamics, rural livelihoods, and population distribution in the region?

This study is significant because it provides spatially explicit, multi-temporal evidence of vegetation loss to inform environmental management strategies (Chapin *et al.*, 2000). It also provides evidence for urban planners and policymakers to design sustainable urban-expansion strategies that minimize environmental degradation (Angel *et al.*, 2011), contributes to scholarship on LULC and vegetation dynamics in northeastern Nigeria, and raises awareness about the environmental implications of urbanization for peri-urban and rural communities (Musa *et al.*, 2013). However, the discussion of rural development and population dynamics is inferential and is based on LULC evidence supported by secondary census and livelihood literature, rather than direct household surveys or original population-displacement data.

LITERATURE REVIEW

Vegetation Cover Change and Urbanization

Rapid urban expansion is one of the leading drivers of vegetation loss globally. Seto *et al.* (2012) projected that urban land cover globally would increase by 1.2 million km² by 2030, with disproportionate impacts on biodiversity hotspots in developing regions. Güneralp and Seto (2013) further demonstrated that future urban expansion could threaten 139 endemic bird, mammal, and amphibian species by encroaching on critical habitats. In the West African context, urban growth in cities like Lagos, Kano, and Abuja has been accompanied by dramatic losses of forest and savannah cover, driven by population pressure, economic activities, and weak land governance (Lambin *et al.*, 2003; Foley *et al.*, 2005; Hansen *et al.*, 2013).

The relationship between urbanization and vegetation loss in Nigeria is well- documented. Studies in Kano, Ibadan, and Abuja all report accelerating conversion of natural land covers to built-up areas, particularly since the 1990s (Ogunwale *et al.*, 2014; Musa *et al.*, 2013). In northeastern Nigeria, the pace of urban growth in cities such as Gombe has been shaped by a combination of natural population increase, rural-urban migration, and the concentration of administrative services (Adebayo & Zemba, 2012).

Remote Sensing and LULC Change Detection

Multi-temporal Landsat imagery has become a standard tool for monitoring LULC change over decadal time scales. Rwanga and Ndambuki (2017) provide a useful framework for accuracy assessment, emphasizing confusion matrices, overall accuracy, producer's accuracy, user's accuracy, and Kappa coefficients as indicators of classification reliability. Post-classification comparison remains widely used in tropical LULC studies because it enables direct comparison of independently classified maps and supports the generation of transition matrices (Jensen, 2007). However, because classification errors can compound between dates, rigorous accuracy assessment is essential in any multi-temporal change- detection study.

The Normalized Difference Vegetation Index (NDVI), derived from near-infrared and red spectral bands, is widely used to assess vegetation density and health. NDVI values theoretically range from −1 to +1., with higher positive values, typically above 0.30, indicating denser and healthier vegetation cover. Multi-temporal NDVI analysis complements LULC classification by providing a continuous quantitative measure of vegetation change beyond discrete land-cover class boundaries (Jensen, 2007, Song *et al.*, 2018).

Vegetation Loss and Rural Livelihoods

The loss of vegetation cover has well-documented consequences for rural communities. Haddad *et al.* (2015) demonstrated that habitat fragmentation resulting from land conversion reduces biodiversity and ecosystem service provision, with cascading effects on agriculture, water supply, and local climate. In semi-arid African contexts, vegetation cover loss accelerates soil erosion and reduces soil organic matter, diminishing agricultural productivity (Foley *et al.*, 2005). FAO (2010) estimates that deforestation in West Africa contributes to declining fuelwood availability and increased energy poverty in rural households. These dynamics frequently drive rural-to-urban migration, further intensifying pressure on urban infrastructure (Seto *et al.*, 2012).

METHODOLOGY

Study Area

The Gombe Metropolitan Area is situated in northeastern Nigeria and covers 265.85 km² as delimited for this study (Figure 1). It lies between latitudes 10°14′N and 10°20′N and longitudes 11°07′E and 11°13′E. The metropolitan boundary adopted in this study extends beyond the formally gazetted urban core of approximately 175.94 km² to include peri-urban and transitional zones that are important for vegetation-dynamics analysis. Consequently, all area-based calculations and analyses were conducted consistently within this broader boundary. The study area has a tropical humid climate with distinct dry (November–March) and rainy (April–October) seasons, mean annual rainfall of approximately 850 mm, and temperatures ranging from 21°C to 38°C.

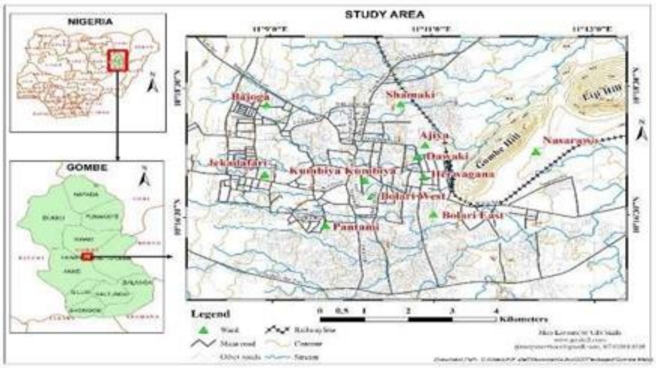

Figure 1: Gombe Metropolitan Area
Source: GIS Unit, Department of Geography, Gombe State University (2024)

Data Sources

This study used both primary and secondary data. Remote-sensing data comprised three Landsat scenes acquired from the United States Geological Survey (USGS) Earth Explorer portal, as detailed in Table 1. Images were selected from the dry season (November–January) to minimize seasonal vegetation variability and improve comparability across dates. All selected scenes had cloud cover below 10%.

Secondary data included Digital Elevation Models (DEMs) from the Shuttle Radar Topography Mission (SRTM),

Table 1: Satellite Imagery Details

Year	Sensor	Path/Row	Acquisition Date	Resolution (m)	Cloud Cover (%)
1990	Landsat 5 TM	185/052	December 1990	30	<5
2004	Landsat 7 ETM+	185/052	November 2004	30	<8
2024	Landsat 9 OLI/TIRS	185/052	December 2024	30	<3

Source: USGS Earth Explorer, 2024

administrative boundary shapefiles from the Nigeria Geospatial Data Infrastructure (NGDI), population census data from the National Population Commission (NPC, 2006) and the National Bureau of Statistics (NBS, 2023), and published agricultural and livelihood reports from FAO and relevant academic literature.

Ground-truth data were collected during field surveys conducted in October–November 2024 using GPS-enabled devices. A total of 120 ground control points (GCPs) were recorded, with 30 points assigned to each land-cover class to validate the 2024 classification. Historical reference points for 1990 and 2004 were supplemented using high-resolution Google Earth Pro imagery and published land-use maps from the Gombe State Ministry of Lands and Survey. Google Earth Pro historical imagery available nearest to the Landsat acquisition dates was used.

Historical validation samples for 1990 and 2004 were generated through a combination of temporally appropriate ancillary datasets, including archived Google Earth Pro imagery, historical land-use maps obtained from the Gombe State Ministry of Lands and Survey, topographic maps, and stable land-cover features identifiable across time periods. Validation points were selected only in locations exhibiting long-term land-cover persistence and where supporting evidence from multiple sources confirmed class identity. Because high-resolution imagery corresponding exactly to 1990 and 2004 was not available for all locations, the historical accuracy assessment should be interpreted as an approximate but accepted validation approach consistent with similar retrospective LULC studies.

Image pre-processing

All satellite images were pre-processed in ERDAS Imagine 2020. The pre-processing steps included: (i) radiometric calibration to convert digital numbers (DN) to top-of- atmosphere (TOA) reflectance; (ii) atmospheric correction using the FLAASH module to derive surface reflectance; (iii) geometric correction and co-registration of all images to a common UTM Zone 33N projection (WGS84 datum), with a root mean square error (RMSE) of less than 0.5 pixels; and (iv) layer stacking and subsetting to the study-area boundary.

Land Use/Land Cover Classification

Supervised maximum likelihood classification (MLC) was used to classify each image into four LULC categories: built-up area, cultivated land, open space/bare land, and vegetation/forest. Training samples were collected for each class by digitizing representative areas from the satellite imagery, guided by ground-truth data, aerial photographs, and ancillary maps. A minimum of 50 training samples per class was used for each image date. Post- classification smoothing using a 3 × 3 majority filter was applied to remove isolated pixels and reduce salt-and-pepper noise. The three dates were selected because 1990 represents the pre-rapid-urbanisation baseline; 2004corresponds to a period of significant agricultural and infrastructure expansion following Gombe's elevation to state capital status in 1996; and 2024 represents the most recent, temporally consistent dry-season image available, allowing assessment of contemporary LULC conditions.

Accuracy Assessment

Classification accuracy was assessed independently for each year using error matrices (confusion matrices) generated from validation sample points withheld from the training dataset. For the 2024 map, 120 field-validated GCPs were used; for 1990 and 2004, accuracy was assessed using 100 points each, derived from temporally consistent high-resolution reference imagery. Overall accuracy, producer's accuracy, user's accuracy, and the Kappa coefficient were computed. Results are summarized in Table 2.

Table 2: Classification Accuracy Summary

Year	Overall Accuracy (%)	Kappa Coefficient	No. Validation Points	Classification Method
1990	85.6	0.82	100	MLC
2004	87.2	0.84	100	MLC
2024	89.4	0.87	120	MLC

MLC = Maximum Likelihood Classification.
Source: GIS Analysis, 2024

Overall accuracy values exceeded the commonly accepted threshold of 85% (Rwanga & Ndambuki, 2017), and Kappa coefficients above 0.80 indicate strong agreement between classified maps and reference data, supporting the reliability of the change detection results.

Change Detection and NDVI Analysis

Post-classification comparison (PCC) was used for change detection because it supports the generation of land-cover transition matrices that identify specific conversions between classes across periods. Net change, gain, loss, and persistence were calculated for each class and period. NDVI was computed for each image date using the formula NDVI = (NIR - Red)/ (NIR + Red), where NIR represents the near-infrared band and Red represents the red band. Mean NDVI values were extracted by LULC class and year to provide a continuous quantitative complement to the discrete classification results. ArcGIS 10.8 was used for spatial analysis and cartographic output.

RESULTS AND DISCUSSION

Land Use/Land Cover of the Gombe Metropolitan Region

The LULC analysis of the Gombe Metropolitan Region for 1990, 2004, and 2024 reveals substantial changes across all four categories (Table 3 and Figure 2). Built-up area increased from 10.36 km² (3.90%) in 1990 to 18.61 km² (7.00%) in 2004 and 44.47 km² (16.73%) in 2024, representing a net gain of 34.11 km² over 34 years. This 329% increase reflects urbanisation associated with population growth, economic activity, and residential and commercial infrastructure expansion (Seto *et al.*, 2012). Cultivated land initially increased from 107.14 km² (40.30%) in 1990 to 126.74 km² (47.67%) in 2004, indicating intensified agricultural expansion during that period.

By 2024, however, cultivated land declined to 102.07 km² (38.40%), suggesting displacement by urban development, a pattern consistent with the urban-agricultural land competition described by Foley *et al.* (2005). Open space/bare land increased steadily from 51.04 km² (19.20%) in 1990 to 76.96 km² (28.95%) in 2024, indicating ongoing land degradation, deforestation, and possible abandonment of marginal agricultural land. Vegetation/forest cover declined sharply, as discussed in Section 4.2.

Vegetation Cover Changes: 1990–2024

The analysis of vegetation cover reveals a consistent and substantial decline over the 34-year period (Table 4 and Figure 3). In 1990, vegetation/forest covered 97.31 km², representing 36.60% of the study area. By 2004, this declined to 66.21 km² (24.91%), a loss of 31.10 km² in 14 years. The decline continued, with only 42.36 km² (15.93%) of vegetation remaining by 2024.

Overall, the study area lost 54.95 km² of vegetation, representing a 56.5% reduction from the 1990 baseline.

Table 3: Land Use/Land Cover of the Gombe Metropolitan Area (Total Area:65.85 km²)

LULC Class	1990 Area (km²)	1990 (%)	2004 Area (km²)	2004 (%)	2024 Area (km²)	2024 (%)	Net Change (km²)
Built-up Area	10.36	3.90	18.61	7.00	44.47	16.73	+34.11
Cultivated Land	107.14	40.30	126.74	47.67	102.07	38.40	-5.07
Open Space/Bare Land	51.04	19.20	54.29	20.42	76.96	28.95	+25.92
Vegetation/Forest	97.31	36.60	66.21	24.91	42.36	15.93	-54.95
Total	265.85	100.00	265.85	100.00	265.85	100.00	—

Source: GIS Analysis, 2024.
Note: Percentages corrected to sum to 100% per year

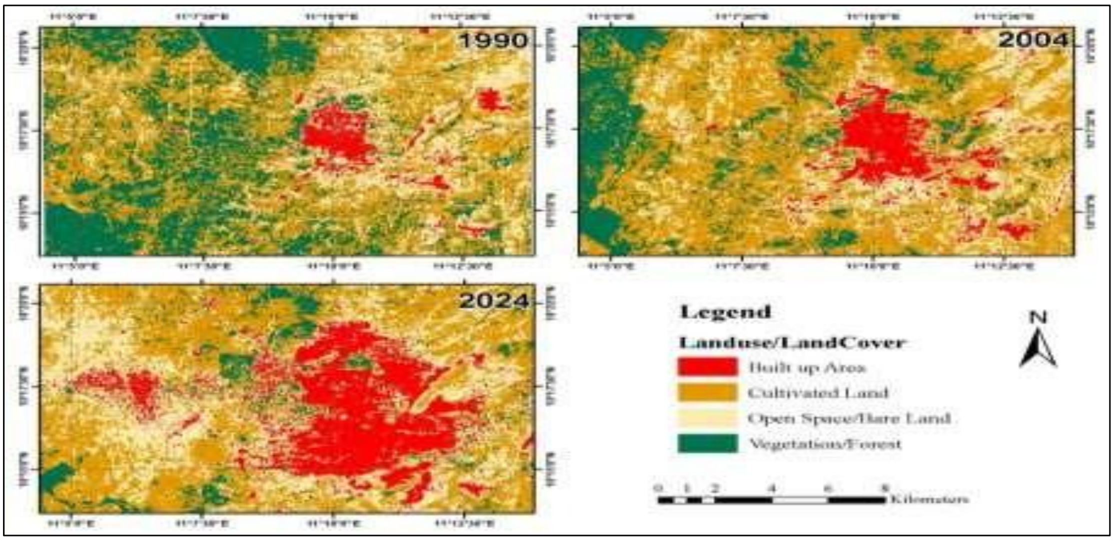

Figure 2: LULC of the Study Area
Source: GIS Analysis, 2024

Table 4: Summary of Vegetation Cover Change

Year	Area (km²)	% of Total Area	Change from Previous Period (km²)	Rate of Loss (km²/yr)	Mean NDVI
1990	97.31	36.60	—	—	0.42
2004	66.21	24.91	-31.10	-2.22	0.34
2024	42.36	15.93	-23.85	-1.19	0.26
Net change 1990–2024	-54.95	-20.67 pp	—	-1.62 avg	-0.16

pp = percentage points. Source: GIS Analysis and NDVI computation, 2024

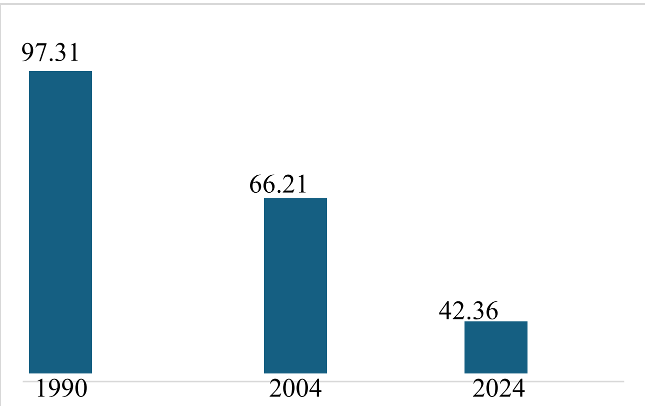

Figure 3: Vegetation Cover Change in the Gombe Metropolitan Region, 1990–2024

Spatial analysis revealed that vegetation loss was concentrated primarily within the peri-urban fringe of the metropolitan area, particularly along major transportation corridors and rapidly expanding residential zones. Significant vegetation-to-cultivated-land transitions occurred in the northern and southwestern sectors of the study area, while vegetation-to-built-up conversions were concentrated around expanding urban settlements. These hotspot areas represent priority locations for vegetation restoration and land-use management interventions**.**

The mean NDVI for the vegetation class declined from 0.42 in 1990 to 0.26 in 2024, corroborating the classified area statistics and indicating a reduction not only in vegetation extent but also in vegetation density and health. NDVI values for built-up and bare-land classes remained consistently below 0.10 across all dates, while cultivated land showed moderate values of 0.20–0.30, reflecting seasonal cropping. The rate of vegetation loss was higher in the first period (2.22 km²/year, 1990–2004) than in the second (1.19 km²/year, 2004–2024), likely reflecting the particularly intensive agricultural expansion following Gombe's elevation to state capital status in 1996 (Adebayo & Zemba, 2012).
However, absolute built-up expansion was greatest in the second period (2004–2024), when 25.86 km²

of new urban area was added, driven by residential and commercial development accompanying continued population growth. NDVI analysis provides independent confirmation of the vegetation-cover trends identified through supervised classification. The decline in mean vegetation NDVI from 0.42 in 1990 to 0.26 in 2024 indicates not only a reduction in vegetation extent but also deterioration in vegetation condition and biomass density. Areas exhibiting low NDVI values correspond spatially with zones of expanding bare land and urban development, suggesting progressive ecological degradation. The convergence of classified LULC results and NDVI trends enhances confidence in the observed vegetation-loss patterns.

Land Cover Transition Analysis

The land-cover transition matrices (Tables 5 and 6) provide a detailed account of the spatial pathways of LULC change between periods, going beyond net area statistics to reveal the gains, losses, and persistence of each class.

Table 5: Land Cover Transition Matrix, 1990–2004 (km²)

1990 \ 2004 →	**Built-up**	**Cultivated**	**Bare Land**	**Vegetation**	**Total 1990**
Built-up Area	8.43	0.45	1.45	0.03	10.36
Cultivated Land	1.56	63.51	26.11	15.96	107.14
Bare Land	8.36	18.76	21.04	2.89	51.05
Vegetation/Forest	0.27	44.01	5.69	47.33	97.30
Total 2004	**18.62**	**126.73**	**54.29**	**66.21**	**265.85**

Diagonal cells (bold) = persistence (unchanged areas). Off-diagonal = transitions. **Note:** Kappa = 0.84, Overall Accuracy = 87.2% for 2004 classification

Source: GIS Analysis, 2024

Table 6: Land Cover Transition Matrix, 2004–2024 (km²)

2004 \ 2024 →	**Built-up**	**Cultivated**	**Bare Land**	**Vegetation**	**Total 2004**
Built-up Area	14.23	0.88	3.29	0.21	18.61
Cultivated Land	14.29	61.80	39.56	11.08	126.73
Bare Land	13.22	18.43	21.02	1.63	54.30
Vegetation/Forest	2.72	20.96	13.08	29.45	66.21
Total 2024	**44.46**	**102.07**	**76.95**	**42.37**	**265.85**

Note: Kappa = 0.87, Overall Accuracy = 89.4% for 2024 classification

Source: GIS Analysis, 2024

Between 1990 and 2004, the most significant transition was the conversion of 44.01 km² of vegetation/forest to cultivated land, which was the dominant conversion pathway of this period and reflects agricultural expansion driven by population growth and food demand. A further 5.69 km² of vegetation converted to bare land, while 0.27 km² converted to built-up area. Only 47.33 km² (48.6% of 1990 vegetation) persisted unchanged. Notably, 8.36 km² of former bare land converted to built-up area, indicating that early urban expansion also targeted previously degraded land

The 2004–2024 period was characterized by intensified urbanisation. The most significant vegetation losses occurred through conversion to cultivated land (20.96 km²) and bare land (13.08 km²), while 2.72 km² converted directly to built-up area. Only 29.45 km² (44.5% of 2004 vegetation) persisted to 2024. The large conversion of cultivated land to bare land (39.56 km²) suggests active land degradation and soil exhaustion in formerly cultivated areas. Built-up expansion during this period was driven mainly by the conversion of cultivated land (14.29 km²) and bare/degraded land (13.22 km²), suggesting that urban growth often occurred on previously used or degraded areas, although substantial indirect vegetation loss occurred through the forest-to-agriculture-to-urban pathway.

The transition matrices reveal that vegetation loss occurred through two dominant pathways. The first pathway involved direct conversion of vegetation to cultivated land, accounting for 44.01 km² between 1990 and 2004 and 20.96 km² between 2004 and 2024. This pattern reflects agricultural frontier expansion and increasing pressure on natural vegetation arising from population growth and food demand. The second pathway involved conversion of cultivated land to bare land, particularly evident between 2004 and 2024, when 39.56 km² transitioned to bare or degraded surfaces. This transition suggests possible soil exhaustion, land abandonment, erosion processes, or unsustainable cultivation practices. These pathways demonstrate that vegetation decline is not solely driven by urban expansion but also by agricultural intensification and land degradation processes operating simultaneously within the metropolitan fringe.

Implications for Rural Development

The decline in vegetation cover and the expansion of bare land have likely contributed to soil degradation and reduced agricultural productivity in rural communities surrounding the metropolitan region. Rural farmers in sub-Saharan Africa commonly depend on woody vegetation for soil fertility maintenance through fallowing; therefore, the loss of 54.95 km² of vegetation reduces the land available for fallow rotation and may accelerate soil-nutrient depletion (Foley *et al.*, 2005). The conversion of 44.01 km² of vegetation to cultivated land between 1990 and 2004 may have temporarily expanded agricultural area, but it likely brought marginal soils into cultivation and increased pressure on remaining vegetated land.

Fuelwood and timber scarcity is another likely consequence. FAO (2010) estimates that more than 75% of households in northeastern Nigeria rely on fuelwood for cooking. A reduction of more than 54 km² of forested land over 34 years directly reduces this resource base and may increase collection distances, time burdens, and household energy costs, especially for women and children. The increase in bare land from 51.04 km² to 76.96 km² also suggests active land degradation, with implications for soil erosion and water retention (Haddad *et al.*, 2015).

Regarding population dynamics, this study does not present original migration or census data. However, available NPC (2006) and NBS (2023) data indicate that Gombe's urban population increased from approximately 250,000 in 1991 to more than 450,000 by 2023, a trajectory consistent with regional patterns of rural-urban migration associated with declining agricultural viability and the pull of urban economic opportunities (Seto *et al.*, 2012). The rapid expansion of built-up area from 10.36 km² to 44.47 km² supports this interpretation. These inferences align with broader literature on urbanisation-driven rural livelihood stress in West Africa (Lambin *et al.*, 2003; Adebayo & Zemba, 2012), but dedicated household surveys and longitudinal agricultural productivity studies are needed to establish these relationships directly in the Gombe context.

To address these challenges, targeted interventions are recommended. Reforestation and afforestation programmes should prioritize zones identified in the transition matrices as having shifted from vegetation to bare land, particularly the 5.69 km² and 13.08 km² converted during the 1990–2004 and 2004–2024 periods, respectively. These areas are most vulnerable to soil erosion and least likely to recover naturally. Agroforestry should also be promoted where cultivated land borders remaining vegetation patches, in order to reduce boundary deforestation pressure while maintaining agricultural productivity (FAO, 2010).

CONCLUSION

This study provides a 34-year, multi-temporal analysis of vegetation-cover change in the Gombe Metropolitan Region, supported by classified Landsat imagery with verified accuracy (overall accuracy = 85.6–89.4%; Kappa = 0.82–0.87). The findings document a consistent decline in vegetation cover from 97.31 km² (36.60%) in 1990 to 42.36 km² (15.93%) in 2024, representing a total loss of 54.95 km² (56.5%). This decline occurred alongside a more than threefold increase in built-up area (10.36 to 44.47 km²) and a substantial expansion of bare/degraded land (51.04 to 76.96 km²). NDVI analysis corroborated the classified statistics, showing a decline in mean vegetation NDVI from 0.42 in 1990 to 0.26 in 2024. The transition matrices show that the dominant conversion pathway in the first period (1990–2004) was vegetation to cultivated land (44.01 km²), driven largely by agricultural expansion following Gombe's elevation to state capital status. In the second period (2004– 2024), urbanisation intensified, with cultivated land increasingly converted to built-up areas and vegetation continuing to decline through both direct conversion and the sequential forest- to-agriculture-to-urban pathway.

The study draws inferences, clearly distinguished from directly measured outcomes, for rural development and population dynamics. The spatial evidence, interpreted alongside published census and agricultural data, suggests that vegetation loss may be contributing to reduced fuelwood availability, soil degradation, and declining agricultural productivity in peri- urban rural communities, which may in turn reinforce rural-urban migration trends. Future studies should directly measure these relationships through household surveys and longitudinal agricultural productivity data. It concludes that urgent, spatially targeted interventions are required. Reforestation programmes should prioritize zones identified by the transition analysis as having converted from vegetation to bare land; urban planning frameworks should integrate green-space requirements in line with sustainable land-management principles; and regular monitoring using satellite imagery and GIS should be institutionalized to track progress toward sustainable land management goals.

RECOMMENDATIONS

Based on the spatial evidence from this study, the following recommendations are proposed:

1. Targeted Reforestation and Afforestation: Implement reforestation programmes that prioritize the 18.77 km² of vegetation converted to bare/degraded land between 1990 and 2024 (5.69 km² in 1990–2004 and 13.08 km² in 2004–2024), as these areas face the highest erosion risk and lowest probability of natural recovery (FAO, 2010).
2. Spatially Explicit Land-Use Regulations: Enforce a vegetation-buffer policy around remaining forested patches, focusing particularly on the southwestern and northern quadrants of the study area identified through GIS analysis as high-loss zones.
3. Sustainable Urban Planning: Incorporate mandatory green-space requirements into Gombe State's urban development plans to limit further conversion of the remaining 42.36 km² of vegetation and maintain ecosystem-service provision (Angel *et al.*, 2011).
4. Support for Sustainable Agricultural Practices: Promote agroforestry and conservation tillage in peri-urban agricultural zones to reduce deforestation pressure at the forest- agriculture boundary and address the 39.56 km² of cultivated land identified as transitioning to bare land between 2004 and 2024 (Foley *et al.*, 2005).
5. Regular Monitoring Using Geospatial Technologies: Institutionalize biennial LULC monitoring using Landsat or Sentinel-2 imagery and GIS analysis to support timely detection of vegetation loss and evaluation of intervention effectiveness (Jensen, 2007; Rwanga & Ndambuki, 2017).
6. Future Research: Commission dedicated household surveys, agricultural productivity assessments, and population-mobility studies to directly quantify the relationships between vegetation loss and rural livelihood outcomes inferred in this study.
7. Establish an Urban Green Infrastructure Framework for Gombe Metropolis that integrates green belts, urban parks, riparian buffers, and peri-urban forest reserves into future development plans.
8. Introduce geospatially informed development-control mechanisms requiring environmental impact assessments before conversion of remaining vegetation patches exceeding specified thresholds.

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