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SPATIO TEMPORAL ASSESSMENT OF URBAN EXPANSION PATTERNS AND THEIR IMPACT ON FOREST FRAGMENTATION IN NIGER STATE, NIGERIA

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Abstract

This study analyzed the spatio-temporal dynamics of urban expansion and its impact on forest fragmentation in Kontagora Metropolis, Niger State, Nigeria, covering the period from 2015 to 2024, with predictive modeling extended to 2033. The study aim of to analyze spatio-temporal assessment of urban expansion patterns and their impact on forest fragmentation in Niger State, Nigeria. Utilizing an integrated methodological framework of Remote Sensing (RS), Geographic Information Systems (GIS), landscape metrics, and questionnaire surveys, the research mapped land use/land cover (LULC) changes using multi-temporal Landsat imagery and predicted future growth trajectories using Cellular Automata–Markov Chain analysis. LULC classification via a supervised maximum likelihood algorithm revealed significant spatial transformations: between 2015 and 2024, built-up areas expanded from 711.84 km^2 (32.66%) to 873.76 km^2 (40.09%), while forest cover declined from 781.35 km^2 (35.85%) to 653.11 km^2 (29.96%). Landscape metric calculations (via FRAGSTATS) demonstrated progressive structural forest degradation from 2015 to 2023, marked by an increase in Number of Patches (NP), Patch Density (PD: 0.1775 to 0.2691), Total Edge (TE: 1,059,360 to 1,709,040), and Edge Density (ED: 4.6426 to 7.4898), alongside reductions in the Largest Patch Index (LPI: 91.579 to 86.987) and Contiguity Index (CONTIG_AM). Predictive modeling for 2033 projects a continued surge in built-up land to 1,328.37 km^2 (60.95%) and a further reduction of forest cover to 300.31 km^2 (13.78%). Survey findings indicated that integrating green infrastructure (urban forests and parks) was

Keywords: Urban expansion, Forest fragmentation, Remote Sensing, GIS, CA–Markov modeling, Kontagora, Niger State.

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identified by 47.7% of respondents as the primary strategy for sustainable urban management. It is concluded that rapid, unguided horizontal urban sprawl is the primary driver of ecosystem fragmentation in the area. The study recommends enforcing strict urban green belts, implementing real-time satellite-based land monitoring, and adopting community-led participatory forest management strategies.

Introduction

Background to the Study

Urban areas are envisaged to triple by 2030 to accommodate the rising global population increase (Wennersten and Qie, 2017). The envisaged urban change in terms of the spatial change in built-up areas and the population growth is said to be responsible for the declining vegetation cover in urban areas of the world. It is believed that due to the increased population and demand for land for physical development, nearly 4 million hectares of vegetation cover are lost in Africa annually (Assede, 2023). The loss of vegetation covers due to urban change is often accompanied by increased land surface temperature, frequently leading to urban heat islands ((Grigoraș and Urițescu, 2019; Rahaman *et al.,* 2022).

Urbanization as a phenomenon can be considered to be a boon to the human society if it occurs in a well-planned, controlled and coordinated manner (Rahaman *et al.,* 2022). But, in case of the developing countries of the world the process of urbanization is rather considered a curse as it shoulders along with it problems of huge magnitude such as environmental deterioration, unplanned landscape development, increasing climatological and ecological disturbances, biodiversity loss, increasing pollution and many more (Rahaman *et al.,* 2022). Global urbanization reached a historic milestone when the proportion of the world's population living in urban regions crossed 50% for the first time, signaling a fundamental transformation in human settlement patterns (United Nations, 2025). Nigeria has closely mirrored this expansion, experiencing sustained urban growth driven by rapid population dynamics, rural-to-urban migration, and peri-urban land conversion (Bak, 2024). In the fast-developing countries like Nigeria, there is a mass migration of people from rural to urban and also from smaller to bigger urban areas and then to metropolises.

Land is an indispensable natural resource that contributes to local, regional, and global economic development. The continuous alteration of land use/land cover (LULC) patterns due to socio-economic development has recently been at the forefront o f global land use research (Mir *et al.,* 2025). Land use/land cover (LULC) changes play a major role in the study of global change. Land use/land cover and human/natural modifications have largely resulted in deforestation, biodiversity loss, global warming and increase of natural disaster-flooding. These environmental problems are often related to LULC changes. Therefore, available data on LULC changes can provide critical input to decision-making of environmental management and planning the future (Mir *et al.,* 2025). The advancement of remotely sensed technology has introduced vital ways for effectively tracking and assessing LULC changes. The broad availability of spatial and temporal remotely sensed images has expanded the ability to see and interpret the pattern. As a result, the

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difficulties associated with land management can now be approached in middle- and lower-income nations. The identification of the spatiotemporal variation of LULC within the urban context is crucial owing to sustainable land management, assessment of urban climatic variation and the evaluation of urban growth trajectories(Mir *et al.*, 2025).

A lack of robust land use management plans that are implemented effectively is allowing this negative trend to continue unchecked. There is a need for a data-driven, spatio-temporal analysis using remote sensing and GIS techniques to accurately quantify the rate and pattern of both urban expansion and forest loss. This information is crucial for developing evidence-based policies and management strategies.

Materials and Methods

The area of study is located in the North Central region of Nigeria. It will focus on Kontagora LGA, in Niger State, Nigeria. Kontagora LGA is located between Longitude 5° 28' 22.80"E to 5° 28' 46.70"E and Latitude 10° 24' 10.80"N to 10° 40' 30.00"N (Figure 1.1).

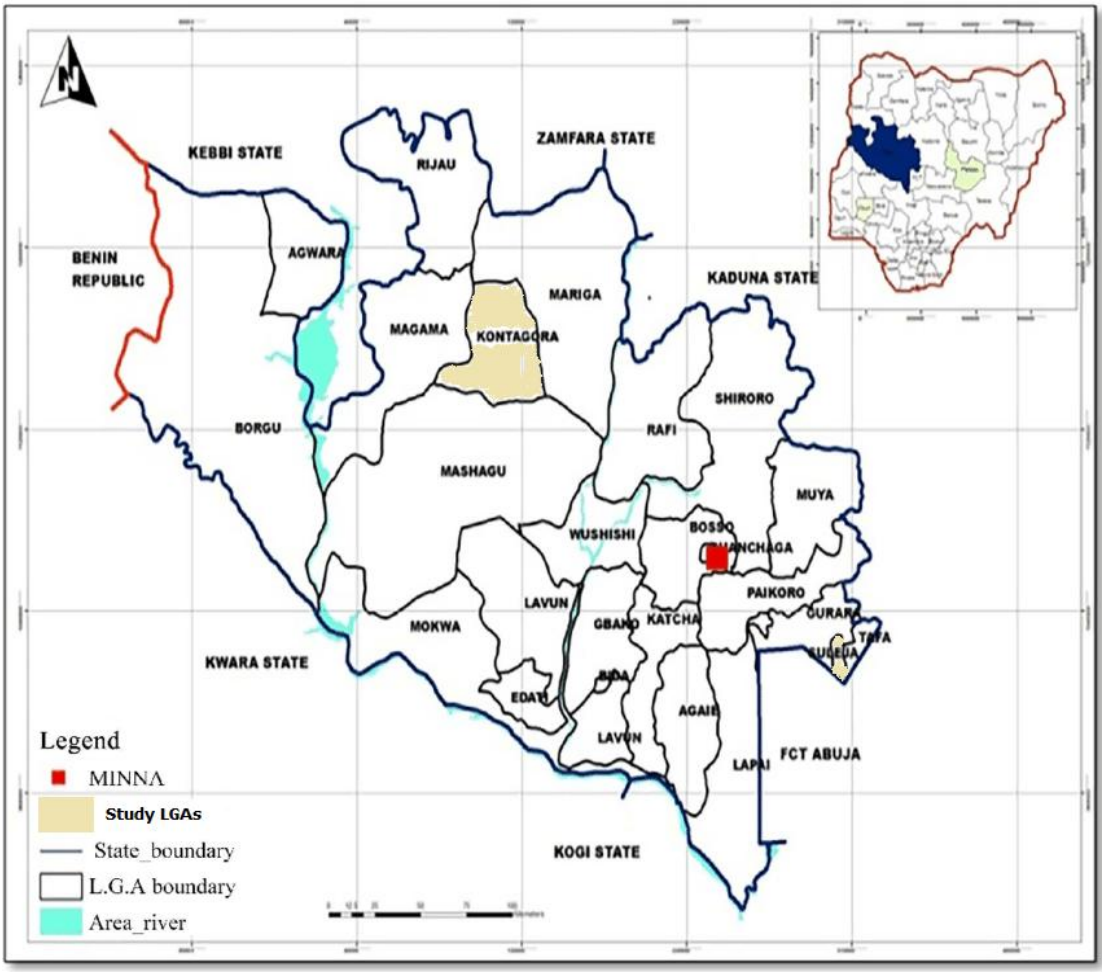


Figure 1.1: The Study Area (Nigeria Showing the Study Areas)
Source: Niger State Geographic Information System (2025)

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Research Design

A mixed-methods design incorporating remote sensing, Geographic Information System (GIS) techniques, and field survey approaches was adopted to analyze spatio-temporal patterns of urban expansion and forest fragmentation in Niger State, Nigeria, and to project future growth up to 2045. The workflow integrated both spatial analysis (laboratory work) and social survey methods (fieldwork).

Data Sources and Sampling

Data comprised both primary and secondary sources. Primary data were gathered using structured questionnaires, semi-structured oral interviews, and reconnaissance surveys to capture local socio-environmental dynamics. Secondary data included Landsat imagery ($30\ \text{m} \times 30\ \text{m}$ spatial resolution, $< 10\%$ cloud cover) for Path 194/Row 055 acquired from the United States Geological Survey (USGS) Earth Explorer for 2015 (Landsat 8 OLI) and 2024 (Landsat 8 OLI/TIRS).

The survey target population consisted of household heads, key policy stakeholders, and local residents within Kontagora town ($N = 629{,}600$). Sample size was calculated using Yamane's (1967) formula with a 95% confidence level and a 5% margin of error:

$$n = \frac{N}{1 + N(e)^2}$$

Where n is the sample size, N is the population, and e is the margin of error (0.05). This yielded a target sample size of $n = 400$. Questionnaires were distributed using simple random sampling, resulting in 371 completed and usable responses for statistical analysis.

Data Collection Instruments

1. Structured Questionnaire: Administered in three main sections: Section A captured demographic characteristics; Section B addressed perceived drivers of forest cover change and fragmentation; Section C gathered stakeholder perspectives on sustainable urban planning strategies.
2. Oral Interviews: Conducted with designated forestry officials and local stakeholders involved in afforestation programs to capture institutional context.
3. Reconnaissance Survey: Field visits were conducted to map existing urban forest sites, record spatial constraints, and obtain geo-tagged photographic evidence to complement survey findings.

Remote Sensing and Spatial Analysis

Satellite image processing was conducted using ArcGIS 10.1, QGIS, and Google Earth Engine. Images were geo-referenced, subset to the study boundary, and preprocessed. Land use/land cover (LULC) classification followed the Anderson et al. (1976) scheme across five categories: built-up area, water body, bare land, vegetation cover, and rock outcrop.

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A supervised maximum likelihood classification algorithm was implemented using ground-truth training samples. Accuracy assessment was evaluated using a confusion matrix of 600 random stratified points to derive overall accuracy (OA), producer's accuracy (PA), and user's accuracy (UA). Normalized Difference Vegetation Index (NDVI) mapping was used to highlight spatial variations in vegetation cover density over time.

Urban expansion extent (E_T) and rate (R) were calculated using:

$$E_T = B - A$$

$$R = \frac{E_T}{Y}$$

Where A is the base year area (2015), B is the reference year area (2024), and Y is the elapsed time in years.

Fragmentation and Predictive Modeling

Forest fragmentation metrics and landscape trajectories were computed using post-classification cross-tabulation matrices and landscape metrics software (e.g., LFTv2.0 / FRAGSTATS).

To project future urban growth and fragmentation patterns through 2045, an integrated Cellular Automata–Markov Chain (CA-Markov) model was deployed using IDRISI Kilimanjaro software. The Markov Chain derived transition probability matrices between baseline time steps, while the Cellular Automata component simulated spatial neighborhood interaction dynamics to predict spatial patterns.

Quantitative and Qualitative Survey Analysis

Survey data were processed using IBM SPSS Statistics. Quantitative survey responses were analyzed using descriptive statistics to evaluate public perception and socio-economic drivers. Qualitative data from key stakeholder interviews were evaluated using thematic analysis and integrated with spatial Multi-Criteria Decision Analysis (MCDA) outputs to construct sustainable land management recommendations.

Spatio-Temporal Patterns of Urban Expansion (2015–2024)

Between 2015 and 2024, Kontagora metropolis experienced rapid urban growth, marked by a substantial transition from natural land covers to built-up environments. As summarized in Table 1, forest cover was the primary land cover category in 2015, spanning 781.35 km^2 (35.85%), followed closely by built-up areas covering 711.84 km^2 (32.66%).

By 2024, built-up area expanded to become the dominant land cover class, occupying 873.76 km^2 (40.09%). Conversely, forest cover declined to 653.11 km^2 (29.96%), reflecting an overall net loss of 128.24 km^2 (Table 2). Bare land, rocks, and water bodies also demonstrated net contractions, decreasing to 523.79 km^2 (24.03%), 116.87 km^2 (5.36%), and 11.80 km^2 (0.56%), respectively. The observed annual growth rate of 5.73% in built-up land directly mirrors regional population pressure, urban migration, and infrastructure expansion across Niger State.

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Expansion were observed as indicated in Figure 1 and Table 1 respectively.

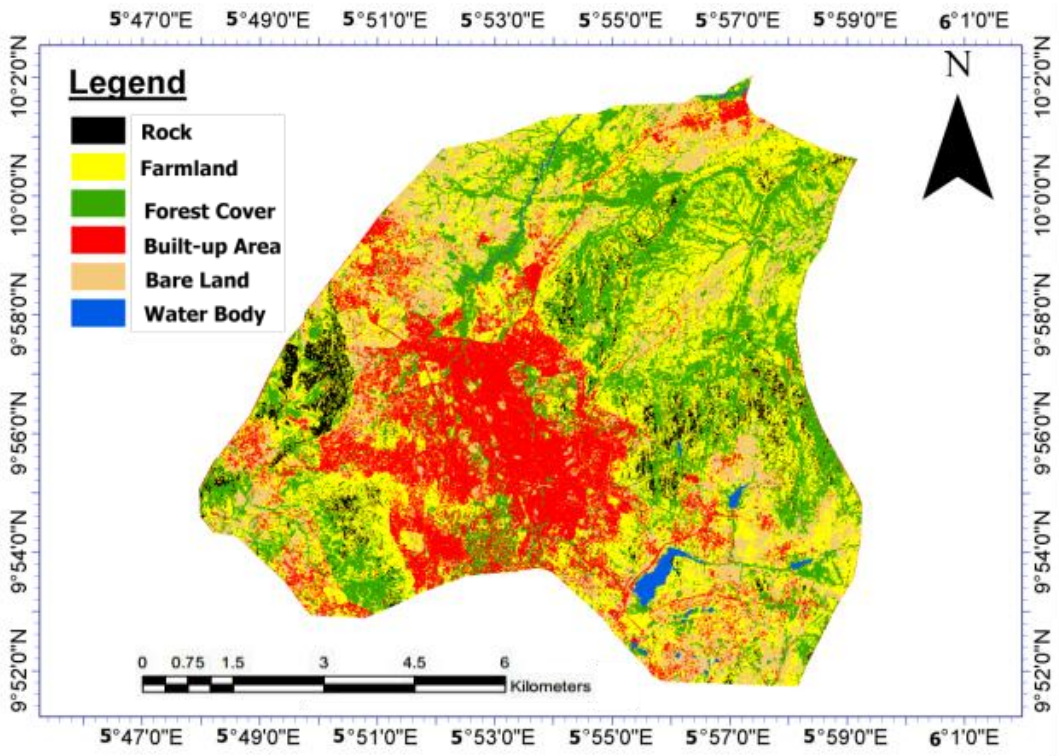


Figure 1: Spatio-temporal Patterns of Urban Expansion of Kontagora Metropolis (2015)

Table 1: *Land Use/Land Cover Distribution for Kontagora Metropolis (2015 and 2024)*

Land Cover Class	2015 Area (km2)	2015 Share (%)	2024 Area (km2)	2024 Share (%)
Built-Up Area	711.84	32.66	873.76	40.09
Forest Cover	781.35	35.85	653.11	29.96
Bare Land	545.01	25.01	523.79	24.03
Rocks	128.41	5.89	116.87	5.36
Water Body	12.69	0.59	11.8	0.56
Total	2,179.30	100	2,179.30	100

Forest Fragmentation Metrics and Landscape Dynamics

Landscape pattern metrics computed using FRAGSTATS demonstrated continuous ecological structural degradation between 2015 and 2023 (Table 3). The Number of Patches (NP) rose from 466 to 614, while Patch Density (PD) increased from 0.1775 to 0.2691 patches/km^2. Concurrently, the Largest Patch Index (LPI) fell from 91.58% to 86.99%, confirming that contiguous core forests are increasingly fragmented into smaller, physically isolated forest remnants.

Significant edge expansion accompanied this fragmentation. Total Edge (TE) rose from 1,059,360 m to 1,709,040 m, while Edge Density (ED) increased from 4.64 m/ha to 7.49 m/ha. The

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Area-Weighted Mean Shape Index (SHAPE_AM) increased from 7.06 to 10.04, and the Fractal Dimension Index (FRAC_AM) rose from 1.18 to 1.21, showing that urban patch geometries became progressively irregular and complex. This trend aligns with findings by Magidi and Ahmed (2019), who noted that uncoordinated urban sprawl induces structural complexity in land boundaries.

In addition, the Contiguity Index (CONTIG_AM) dropped from 0.93 to 0.90, illustrating reduced spatial connectivity across the forest canopy. These dynamics are primarily driven by agricultural encroachment, urban renewal schemes, and local fuelwood extraction (Saleh et al., 2023).

Table 2: *Landscape Fragmentation Metrics for Kontagora Metropolis (2015–2023)*

Metric	Full Metric Name	2015	2023	Trajectory
NP	Number of Patches	466.0000	614.0000	Substantial increase
PD	Patch Density (patches/km^2)	0.1775	0.2691	Fragmented landscape
LPI	Largest Patch Index (%)	91.5790	86.9870	Loss of contiguous forest
TE	Total Edge (m)	1,059,360	1,709,040	Expanded perimeters
ED	Edge Density (m/ha)	4.6426	7.4898	Increased edge exposure
SHAPE_AM	Area-Weighted Shape Index	7.0637	10.0394	Irregular spatial forms
FRAC_AM	Area-Weighted Fractal Dimension	1.1826	1.2146	Increased patch complexity
CONTIG_AM	Area-Weighted Contiguity Index	0.9311	0.8961	Decreased connectivity

Predictive Modeling of Future Trends (2033–2045)

Cellular Automata–Markov Chain (CA-Markov) projections reveal that urban conversion will continue to accelerate without targeted planning interventions. By 2033, built-up areas are modeled to encompass 1,328.37 km^2 (60.95%) of the metropolis. Forest cover is projected to shrink to 300.31 km^2 (13.78%), representing more than a 50% loss relative to 2024 levels. Bare land is predicted to decline to 321.87 km^2 (14.76%), while water bodies drop slightly to 9.53 km^2 (0.43%). High population expansion and unconstrained residential developments remain the main drivers behind these simulated land cover conversions.

Table 3: Magnitude and Percentage of Change in Land Use/Landcover between 2015 and 2023 for Kontagora Metropolis

LULC Class	2023 Extent km²	Magnitude of change km²	Percentage of Change	Annual Rate of Change percent
Built up Areas	873.76	161.92	57.26	5.73
Forest Cover	653.11	-128.24	-60.76	-6.08
Rocks	116.87	11.54	5.60	0.56

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Bare land	523.79	-21.22	36.36	3.64
Water Bodies	11.80	-0.89	-5.98	-0.60

Source: Field work 2025

Model future urban expansion and forest fragmentation trends in the study area

Simulations of urban expansion and forest fragmentation trends show a direct correlation between increased built-up area and forest fragmentation, characterized by reduced forest cover, loss of biodiversity, and soil degradation, which are often monitored using satellite imagery with tools like NDVI. Models has projected future deforestation trends by analyzing historical data, tree cover changes, and factors like kiln volume, landscape suitability, and infrastructure, often employing methods like Cellular Automata Markov (CA_Markov) or land change models (LCM) to understand these dynamics and inform sustainable forest management. Figure 4.3 indicates the urban expansion and forest fragmentation trends for the year 2033. It shows a drastic change among the various land use and land cover categories.

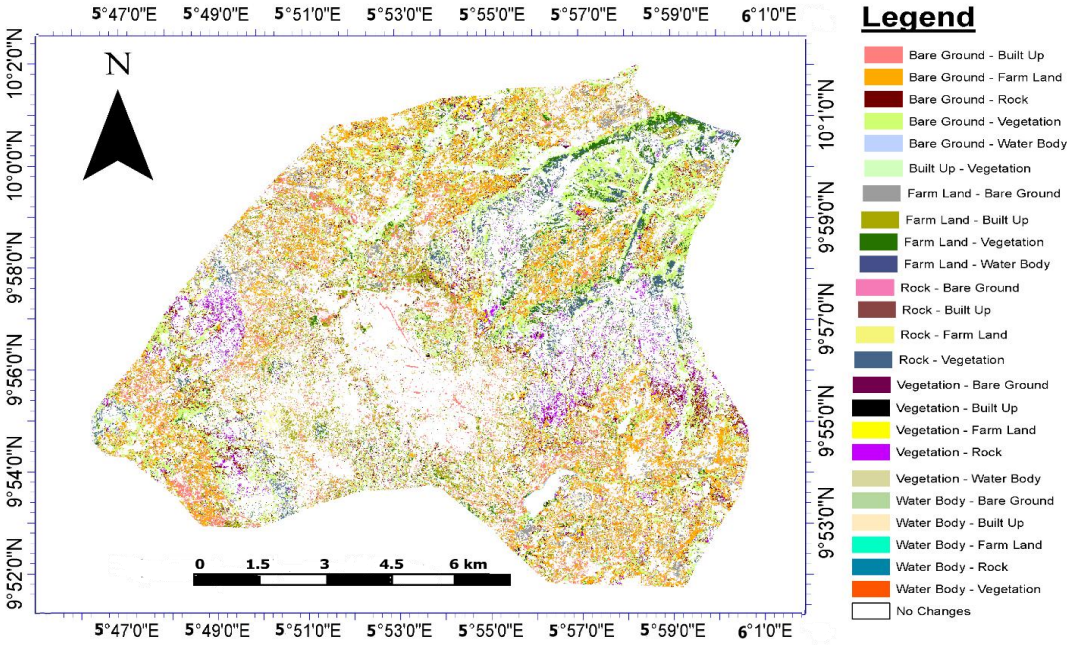


Figure 2: Model Urban Expansion and Forest Fragmentation Trends for Year 2033

As indicated in Figure 4.3 of the study, the dominant land cover in the study area is built-up area which will cover a significant area of 1328.37 km² (60.95 percent) in 2033 from 873.76 km², constituting (40.09 percent) in 2023. This followed by bare land with an area coverage amounting to 523.79 km² (24.03 percent) in 2023 but decreased significantly to 321.87 km² (14.76 percent) in 2033. Additionally, forest cover represent an area of 653.11 km² (29.96 percent) in 2023 and will decrease further to 300.31 km² (13.78 percent) in 2033, while water bodies occupy an area of 11.80 km² (0.56 percent) and will decreased to 9.53 km² (0.43 percent) in 2033 respectively. This decrease

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in forest cover is attributed to high level of forest fragmentation and increased built-up area across the study area due to increased in human population.

Stakeholder Strategies for Sustainable Urban Planning

Stakeholder surveys ($n = 371$) revealed strong public consensus toward adopting proactive green management strategies (Table 3). The majority of respondents (47.7%, $n = 177$) identified the integration of green infrastructure such as urban forests and parks as the most critical strategy. Urban expansion management and smart growth policies were prioritized by 19.4% ($n = 72$) of respondents, followed by policy enforcement and updated forest legislation (17.3%, $n = 64$) and community-led conservation (15.6%, $n = 58$). These findings accord with Musa et al. (2025), who emphasized that incorporating urban green spaces into municipal plans is key to maintaining urban ecosystem services in rapidly expanding Nigerian cities.

Table 3: *Stakeholder Recommendations for Sustainable Planning and Conservation ($N = 371$)*

Strategy Category	Frequency (n)	Percentage (%)
Green infrastructure integration (urban forests & parks)	177	47.70
Urban expansion management (smart growth forms)	72	19.40
Policy strengthening & enforcement (updated forest laws)	64	17.30
Community-led conservation (community forest management)	58	15.60
Total	371	100.00

Source: Field work 2025

Summary of findings

- **Shift in Dominant Land Cover (2015–2024):** Kontagora metropolis underwent a rapid land transition, shifting from a forest-dominated landscape in 2015 (781.35 km^2, 35.85%) to a predominantly built-up environment by 2024 (873.76 km^2, 40.09%). During this period, forest cover contracted to 653.11 km^2 (29.96%), while bare land (24.03%), rock outcrops (5.36%), and water bodies (0.56%) all recorded minor net decreases.
- **Severe Forest Fragmentation:** Driven by rapid urbanization, agricultural expansion, and fuelwood harvesting, continuous core forests fragmented significantly into smaller, physically isolated patches between 2015 and 2023.
- **Future Urban and Landscape Trajectory (2023–2033 Projections):** Spatial modeling predicts that built-up areas will expand to cover $1{,}328.37$ km^2 (60.95%) of the metropolis by 2033. Consequently, forest cover is projected to fall below half its 2023 extent to 300.31 km^2 (13.78%), alongside declines in bare land (14.76%) and water bodies (0.43%).
- **Stakeholder Preferences for Conservation Strategies:** Local survey findings indicate that integrating green infrastructure (such as urban forests and parks) is the most preferred solution for sustainable planning (47.7%), followed by smart urban expansion management (19.4%), policy enforcement and updated forest laws (17.3%), and community-led forest conservation (15.6%).

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Conclusion

Unplanned low-density urban sprawl along transport corridors in Kontagora Metropolis, Niger State, acts as the primary catalyst for forest fragmentation. The outward expansion of concrete and asphalt has progressively split contiguous Guinea savanna woodlands into isolated patches, diminishing core forest areas while increasing edge habitats. This landscape transition has intensified urban heat island effects and heightened flood risks during rainy seasons.

Recommendations

- **Enforce Statutory Green Belts:** Establish clear ecological buffer zones around peri-urban fringes to limit horizontal expansion and curb encroaching sprawl.
- **Implement Geospatial Monitoring:** Integrate continuous remote sensing workflows within the Niger State Ministry of Lands and Housing to detect and halt illegal land conversion early.
- **Initiate Focused Reforestation:** Launch targeted agro-forestry and native tree planting schemes to reconnect fragmented forest corridors and restore ecological integrity.
- **Adopt Community-Led Forestry:** Engage local, traditional, and religious leaders in participatory forest governance to ensure decentralized conservation and protection of surrounding woodland areas.

Contributions to Knowledge

- **Empirical LULC Baseline (2015–2024):** Documented a major land cover shift where forest cover dropped from 781.35 km^2 (35.85%) in 2015 to 653.11 km^2 (29.96%) in 2024, while built-up land expanded from 711.84 km^2 (32.66%) to 873.76 km^2 (40.09%).
- **Quantification of Landscape Degradation:** Demonstrated through spatial metrics (FRAGSTATS) that agricultural encroachment, urban expansion, and fuelwood extraction systematically converted continuous core forests into smaller, fragmented patches between 2015 and 2023.
- **Predictive Growth Trajectory (2023–2033):** Modeled future land transformations, forecasting built-up areas to reach 1,328.37 km^2 (60.95%) by 2033, while forest cover is projected to shrink to 300.31 km^2 (13.78%).

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