



Sustainable Environment and the built Space: Integrating Ecology, Planning and Human Well-being

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URBAN EXPANSION: A MAJOR CAUSE OF FOREST LOSS

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Abstract

Urban expansion is increasingly recognised as a primary driver of forest loss across sub-Saharan Africa, with far-reaching consequences for biodiversity, climate regulation, carbon sequestration, and human well-being. This paper examines urban expansion as a major cause of forest loss in Asaba metropolis, Delta State, Nigeria, drawing on geospatial analysis of four epochs of Landsat satellite imagery spanning 1991 to 2021. Supervised Maximum Likelihood Classification (MLC) was applied to extract land use and land cover (LULC) data across six categories, while Normalized Difference Vegetation Index (NDVI), Normalized Difference Building Index (NDBI), Land Surface Temperature (LST), and Urban Heat Island (UHI) indices were computed to assess the spatial dimensions of urban-induced environmental change. Overall classification accuracy exceeded 97% for all epochs, with Kappa coefficients ranging from 0.92 to 0.98. Findings reveal that built-up area expanded from 0.91% of the total metropolitan land mass in 1991 to 26.56% in 2021, while vegetation cover declined from 18.19% to 8.83% over the same period. Farm land also contracted from 68.34% to 53.17%, confirming the compound nature of green land loss. NDBI values rose progressively from -0.18 to 0.17 in 1991 to 4.7 to 9.4 in 2021, while NDVI values contracted sharply to a range of -0.09 to 0.39 by 2021, indicating widespread vegetation degradation. Land surface temperature and urban heat island intensity also increased across the study period, reflecting the thermal consequences of reduced green cover and expanding impervious surfaces. Projections indicate that built-up area could reach approximately 51% of the metropolitan land mass by 2051 under current growth trajectories. The study concludes that urban expansion is a primary and ongoing cause of forest loss in Asaba metropolis and calls for integrated land use planning, green infrastructure policies, and strict enforcement of forest conservation regulations as essential steps toward sustainable urban development in peri-urban areas.

Keywords: Urban expansion, deforestation, forest loss, LULC change, NDVI, NDBI, Land Surface Temperature, Urban Heat Island, Asaba metropolis, Nigeria

1. INTRODUCTION

Forest loss is widely acknowledged as one of the most pressing environmental crises of the twenty-first century. Despite sustained global conservation efforts, the world continues to lose approximately 15 million hectares of forest cover annually, a trend driven in large part by rapidly expanding urban settlements, particularly in developing regions of Africa and Asia (Contreras-Hermosilla, 2000). Urbanization, defined as the agglomeration of large numbers of people at specific points on the earth's surface (Onyemelukwe,

1977; Agbola, 2004), is recognised as a principal driver of environmental change at both local and global scales (Grimm et al., 2008). Urban areas directly alter forest ecosystems by removing vegetation cover, and indirectly by modifying hydrology, altering nutrient cycling, introducing non-native species, and changing atmospheric conditions.

In Nigeria, urbanization has proceeded at an alarming pace. The country stands among nations with the highest global deforestation rates, having lost more than half of its forestland within fifty years (FAO, 2010). The creation of Delta State and the subsequent designation of Asaba as state capital accelerated urban growth in the city and surrounding communities, converting farmland, wetlands, and forest resources to built-up uses. Between 1991 and 2021, Asaba metropolis experienced dramatic spatial transformation, yet the precise nature and magnitude of forest loss attributable to urban expansion remained inadequately documented in the scientific literature.

This paper addresses that gap by presenting a geospatial analysis of urban expansion and forest loss in Asaba metropolis across a 30-year period. The study employs Landsat satellite imagery and Remote Sensing-Geographic Information System (RS-GIS) methods to characterise LULC dynamics, quantify vegetation loss, analyse thermal consequences, and project future trends. Framed within the conference theme of Sustainable Environment and the Built Space: Integrating Ecology, Planning, and Human Well-being, the paper argues that urban expansion is a major and proximate cause of forest loss in Asaba, with significant implications for ecological integrity, urban heat regulation, and the well-being of the metropolis's growing population.

2. THEORETICAL AND CONCEPTUAL FRAMEWORK

The study is anchored in two complementary theoretical perspectives. The first is the Human-Environment (Socio-Ecological) Systems perspective (Miller, 2017), which conceptualises urban areas as coupled social and ecological systems wherein human actions such as land conversion and urban expansion alter ecosystem structure and function, and these environmental changes in turn affect human well-being and behaviour. This framing supports the combination of spatial data from remote sensing with community-level evidence on reported environmental impacts.

The second perspective draws on Ernest Burgess's Concentric Zone Theory (1925) and Homer Hoyt's Sector Theory (1939), which describe how urban land use expands outward from the central business district and restructures peripheral land. In the Asaba context, these models are instructive: as the city grew following state creation, development spread from the urban core toward peri-urban communities, converting farmland and forest reserves along radial corridors and progressively eroding the green areas that provide carbon sequestration and ecosystem services to urban populations.

The concept of sustainable development, as articulated by the 1987 Brundtland Commission and operationalised through the United Nations Framework Convention on Climate Change (UNFCCC), also underpins the analysis. Sustainable urban growth requires that present developmental activities do not compromise the ecological resource base for future generations (UNESCO, 2021). The progressive conversion of forested and vegetated land to impervious surfaces in Asaba represents precisely the kind of trajectory that sustainable development frameworks seek to reverse.

3. STUDY AREA

Asaba metropolis is located in the northwestern part of Delta State within the Niger Delta region of Nigeria. The study area spans parts of Oshimili North and Oshimili South Local Government Areas and encompasses five major communities: Asaba, Ibusa, Okpanam, Okwe, and Anwai. Geographically, the area lies between latitudes 6 degrees 15 minutes N and 6 degrees 40 minutes N, and longitudes 6 degrees 40 minutes E and 6 degrees 45 minutes E, with an aerial extent of approximately 773 km².

The metropolis experiences a tropical monsoon climate, with a mean annual temperature of approximately 26.8 degrees Celsius and annual precipitation of around 1,331 millimetres. Vegetation is classified as tropical evergreen rainforest, though secondary growth now dominates across most of the study area owing to intensive anthropogenic disturbance including farming, bush burning, grazing, and rapid urban expansion (Okhakhu, 2016). The creation of Delta State in 1991 and the siting of its capital in Asaba catalysed urbanisation that has since transformed the spatial character of the metropolis and its surrounding communities. The total projected population as of 2021 was approximately 1.3 million persons spread across the five study communities.

4. METHODOLOGY

The study employed a mixed-methods design combining quantitative geospatial analysis with structured survey data. Four epochs of Landsat satellite imagery were acquired from the United States Geological Survey (USGS) for the years 1991, 2002, 2015, and 2021. All images were cloud-free and geo-referenced to the UTM WGS84 Zone 32 projection at a spatial resolution of 30 metres (Table 1).

Table 1: Characteristics of Satellite Imagery Used

S/N	Year	Image Type	Sensor	Pixel Size	Projection
1	1991	Landsat TM	TM	30 m	UTM WGS84, Zone 32
2	2002	Landsat ETM+	7ETM	30 m	UTM WGS84, Zone 32
3	2015	Landsat OLI	OLI_TIRS	30 m	UTM WGS84, Zone 32
4	2021	Landsat OLI	Landsat 8	30 m	UTM WGS84, Zone 32

Digital image processing was performed using ESRI ArcGIS 10.5 and ENVI 5.1. The workflow involved image enhancement, layer stacking, mosaicking, and spatial subsetting. Supervised Maximum Likelihood Classification (MLC) was applied to classify six LULC categories: built-up area, vegetation, farm land, water bodies, open/bare surface, and marshy area. Accuracy assessment was conducted using error matrices and Kappa coefficient calculations, achieving overall classification accuracy exceeding 97% for all four epochs with Kappa coefficients ranging from 0.92 to 0.98.

NDVI was computed as $(\text{Band } 5 - \text{Band } 4) / (\text{Band } 5 + \text{Band } 4)$. NDBI was derived as $(\text{Band } 6 - \text{Band } 5) / (\text{Band } 6 + \text{Band } 5)$, where positive values indicate built-up surfaces and negative values denote vegetation or water. Land Surface Temperature (LST) was extracted from thermal infrared bands following Top of Atmosphere radiance conversion, brightness temperature derivation, proportional vegetation index computation, emissivity estimation, and final LST calculation. Urban Heat Island (UHI) intensity was computed as $(\text{LST} - \text{LST}_{\text{mean}}) / \text{Standard Deviation}$. Change detection involved calculating differences in LULC areal extents across consecutive epochs, with average rates of change computed over the 30-year study period and projections extended to 2051.

Survey data from 2,000 structured questionnaires administered across the five communities validated the geospatial findings and captured residents' perceptions of urban growth, forest change, and environmental impact. Sample sizes were computed using the Taro Yamane (1967) formula, yielding approximately 400 respondents per community. Descriptive statistics, Principal Component Analysis (PCA), and multivariate correlation analysis were applied using IBM SPSS version 22.2 and R Console 4.43.

5. RESULTS AND DISCUSSION

Land Use and Land Cover Change: Tracing Forest Loss (1991-2021)

Supervised classification of the four Landsat epochs reveals a clear and progressive pattern of urban expansion at the direct expense of vegetation and farm land. Table 2 presents the LULC distribution across all study years.

Table 2: Land Use and Land Cover Change in Asaba Metropolis, 1991-2021 (% of Total Area)

LULC Class	1991 (%)	2002 (%)	2015 (%)	2021 (%)
Built-up Area	0.91	4.95	11.31	26.56
Vegetation	18.19	44.47	11.95	8.83
Farm Land	68.34	36.72	66.81	53.17
Water Bodies	5.59	6.02	4.67	4.96
Open/Bare Surface	1.09	1.37	0.45	0.53
Marshy Area	5.89	6.47	4.81	5.96

The data confirm that built-up area expanded consistently from 0.91% in 1991 to 4.95% in 2002, 11.31% in 2015, and 26.56% in 2021, representing a net increase of 25.65 percentage points at an average annual rate of 0.855%. Vegetation cover declined from 18.19% in 1991 to 8.83% in 2021, a net loss of 9.36 percentage points over the study period. Farm land also underwent significant reduction, declining from 68.34% to 53.17%, reflecting the conversion of agricultural hinterland to urban use. Projections indicate that built-up area could reach approximately 51.3% of total metropolitan land by 2051 if current trends continue unchecked, while vegetation cover is projected to decline to approximately 18.72% below its 1991 baseline.

The trajectory confirms that urban expansion is the dominant and proximate driver of land cover transformation in the study area. These findings align with Musa et al. (2017), who documented rapid built-up area expansion and forest decline in Bauchi metropolis, and with Ancha et al. (2021), who found that expansion of built-up areas in Otukpo Local Government Area, Benue State, greatly reduced forest resources. The fluctuating relationship between forest and farm land across epochs reflects a compound dynamic: in years of heightened agricultural activity, forest cedes to farming before subsequent urban expansion consumes both. This layered process underscores the cumulative and irreversible nature of forest loss in peri-urban settings.

NDVI and NDBI Analysis: The Urban-Vegetation Inverse Relationship

The NDVI and NDBI analyses provide complementary spatial evidence of the inverse relationship between urban expansion and vegetation cover. NDVI values ranged from 0.50 to 0.71 in 1991, indicating moderately healthy vegetation across the metropolitan area. By 2002, values rose to 0.7 to 0.9, reflecting a period of agricultural intensification and secondary vegetation recovery. However, by 2015, the range contracted to 0.6 to 0.7, and by 2021 values had fallen sharply to -0.09 to 0.39, indicating widespread vegetation degradation in formerly productive zones.

NDBI values present a mirror trajectory. In 1991, NDBI ranged from -0.18 to 0.17, consistent with a predominantly agricultural and forested landscape with minimal impervious cover. By 2002, the range had risen to 1.7 to 9.6, then to 2.2 to 4.9 in 2015, and 4.7 to 9.4 in 2021. Positive NDBI values confirm the progressive expansion of impervious cover at the expense of green land. These findings are consistent with Sejati et al. (2018), who demonstrated a strong negative correlation ($r = -0.99$) between NDBI and NDVI in Metropolitan Semarang, and with Maskooni et al. (2021), who found that vegetation cover in Shiraz city declined by 69.3% as built-up areas expanded by 25.8% over 25 years.

Thermal Consequences: LST and UHI Analysis

The loss of vegetated land and the expansion of impervious surfaces carry measurable thermal consequences. Land Surface Temperature in Asaba metropolis ranged from -44.38 to -29.0 degrees Celsius in 1991, rising to 58.5 to 69.3 degrees Celsius in 2015, and 68.9 to 77.5 degrees Celsius in 2021. A notable anomaly in 2002, where values reached 71.1 to 115.73 degrees Celsius, was attributed to spectral interference from water bodies during classification. The general upward trend nonetheless confirms progressive surface warming associated with urban expansion and vegetation reduction.

Urban Heat Island intensity also increased progressively. UHI ranged between 19.0 and 20.0 degrees Celsius in 1991, compared to 24.2 to 33.9 degrees Celsius in 2021, representing a significant rise in the heat gradient between urbanised and non-urbanised surfaces. While the intensity remained within broadly tolerable bounds during the study period, owing largely to the moderating influence of proximate water bodies and residual farmland vegetation, the trend is concerning. Achmad et al. (2019) and Ahmad et al. (2022) have consistently shown that continued built-up expansion intensifies UHI effects, elevates heat-related health risks, increases energy consumption, and degrades air and water quality. The moderating role of the River Niger and its tributary systems is at growing risk as peri-urban forest and wetland conversion accelerates.

Community Perceptions of Forest Loss and Urban Growth

Survey data from 2,000 residents across the five communities confirm that geospatial findings resonate strongly with lived experience. Net-agreement analysis of urban growth and LULC indicators showed that respondents overwhelmingly endorsed statements relating to the increase of built-up areas over forest and farm land (V22), the intensification of Urban Heat Island effects with climate change (V29, V30), and the decline of urban vegetation (V31), with each indicator recording net positive agreement levels approaching 70 to 100%. The majority of respondents identified decreasing forest availability as a negative environmental change, attributing it to increasing population and development activities.

Principal Component Analysis of the environmental indicator data revealed a structure dominated by two factors accounting for 81.7% of total variance. The first component, explaining 60.6% of variance, is dominated by indicators of high-impact environmental change associated with built-up expansion and vegetation loss. The strong correlation structure among built-up expansion, infrastructure growth, population density, and land-use change ($r = 0.85$ to 0.97) confirms that urban growth and environmental degradation are deeply integrated processes, reinforcing the theoretical proposition that physical expansion is a direct driver of forest loss in the metropolis.

Implications for Planning and Human Well-Being

The progressive loss of vegetation cover documented between 1991 and 2021 undermines the ecological services that forests and green spaces provide to urban populations, including carbon sequestration, microclimate regulation, flood attenuation, biodiversity support, and recreational amenity. As Calfapietra et al. (2015) observe, the difficult growing conditions facing urban forests parallel the pressures experienced by urban dwellers themselves in the context of global climate change.

Urban planners and municipal authorities in Asaba must prioritise green infrastructure integration into spatial planning frameworks. This includes the designation and enforcement of urban green belts and protected forest zones in peri-urban areas, mandatory tree planting requirements for new developments, and the incorporation of NDVI and LST monitoring into routine urban environmental assessments. The data presented here provide a spatial evidence base for identifying where vegetation losses are most severe and where reforestation and ecological restoration investments should be concentrated.

The findings also underscore the urgency of addressing infrastructure deficits in peripheral communities such as Ibusa Urban Fringe and Oduke, where development pressure is rising but service delivery remains inadequate. Providing infrastructure and livelihood support in these areas reduces the pressure on residents to convert adjacent forest land for subsistence farming and fuelwood extraction. Evidence from the study shows that infrastructure concentration near the CBD and Okpanam Road Axis, combined with underserved fringes, reproduces the spatial inequality that drives unplanned deforestation in the peri-urban zone.

The projected expansion of built-up area to approximately 51% of total metropolitan land by 2051 under current trends represents an existential threat to the ecological integrity of the Asaba environment. Accelerating post-2021 in-migration driven by perceived insecurity in southeastern Nigeria makes the need for proactive planning intervention more urgent than the 30-year data alone suggest. Achieving sustainable urban development requires coordinated intervention by planners, environmental regulators, state government, and local communities to protect, manage, and restore the remaining forest and vegetated land in and around the metropolis.

5. CONCLUSION

This paper has demonstrated through geospatial analysis of Asaba metropolis spanning 1991 to 2021 that urban expansion is a major and quantifiable cause of forest loss in the Nigerian urban context. Built-up area increased from 0.91% to 26.56% of the metropolitan land mass over the study period, while vegetation cover declined from 18.19% to 8.83%. NDVI contraction and NDBI growth confirm the progressive displacement of green land cover by impervious urban surfaces. Rising land surface temperatures and urban heat island intensity reflect the thermal consequences of this transformation, and community survey data confirm that residents perceive and experience the environmental deterioration associated with forest loss.

The study contributes a replicable RS-GIS framework for documenting urban-induced forest loss and its environmental indicators in peri-urban African cities. Its findings affirm that urban expansion, if unmanaged, constitutes a direct threat to the ecological, climatic, and well-being foundations of sustainable urban development. The paper calls for evidence-based land use planning, green infrastructure policy, and proactive forest conservation regulation as essential responses to the urbanisation pressures reshaping Asaba and comparable cities across Nigeria and sub-Saharan Africa. These responses are not optional additions to urban governance; they are preconditions for realising the vision of a sustainable built space that integrates ecology, planning, and human well-being.

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