



SPATIO-TEMPORAL ANALYSIS OF URBAN EXPANSION IN BIU BORNO STATE USING REMOTE SENSING AND GIS TECHNIQUES

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Abstract

This study examined urban sprawl in Biu, Borno State, Nigeria, for the period of thirty years using Remote Sensing (RS) and GIS and analyzed spatio-temporal land use/land cover (LULC) dynamics. Ideally, Biu's urban growth would be systematically planned which would have balance socio-economic needs with ecological sustainability, fostering a livable urban environment. In reality, Biu experiences rapid, unplanned urban sprawl driven by population growth, rural-urban migration, and post-conflict resettlement following insurgencies in Borno State. The aim was achieved through four objectives of acquiring Landsat imagery, classifying LULC changes, assessing classification accuracy, and determining spatio-temporal transitions. Landsat imageries were sourced from USGS Earth Explorer, they were classified via supervised Maximum Likelihood method. Five LULC classes were defined: built-up, vegetation, agriculture, water bodies, and bare soil, accuracy was evaluated with 100 random points. Results showed built-up area increased 22.17% (73,604.4 ha), from 9.35% (31,042 ha) in 1995 to 31.52% (104,646.4 ha) in 2025, Vegetation declined 34.85%, agriculture 3.76%, water bodies 0.34%, while bare soil rose 16.76%. Vegetation (26.59%) and bare soil (6.76%) were primary sources of built-up expansion. The study concludes that GIS-based monitoring is vital for sustainability and recommends integrating socio-economic data for future urban planning.

Keywords Urban Sprawl, Land use, Land cover, Changes, Remote Sensing

1.0 INTRODUCTION

Urban sprawl is characterized as the uncontrolled expansion of urban areas into surrounding regions, which poses a significant challenge in developing countries like Nigeria, where urbanization often exceeds planning capacity (Akamatsu & Yamamoto, 2023; Behnisch, Krüger & Jaeger, 2022), it is a result of population growth, frequent human activity such as industrialization, migration from rural to urban areas, and resettlement, all of which alter local and regional Land Use Land Cover (LULC) patterns (Sani, *et al* 2023).



Urban sprawl is a global phenomenon, evident in regions such as the United States, where suburban expansion has led to environmental degradation (Ewing & Hamidi, 2015; El Garouani & Knight, 2021), and in Asia, where rapid urbanization in cities like Beijing has strained resources (Tian & Wang, 2013). In Africa, similar patterns are observed in Nairobi, Kenya, where informal settlements have proliferated due to inadequate planning (Mundia & Aniya, 2005). In Nigeria the story remains the same particularly in urban area such as Biu, a semi-urban town in Borno State, with population growth, economic activities, and rural-urban migration have driven extensive urban expansion, altering the spatial and environmental landscape (Al Jarah, et al., 2021; Grigorescu, et al., 2022).

Wakirwa (2015) opined that all cities in Nigeria are experiencing sprawl, and Biu is no exception, owing to the magnitude and patter of development on some of the city's most agriculturally productive land. The city's built-up area has increased dramatically in recent decades, absorbing previous agricultural land at an alarming rate (Mbaya, 2012). This is a result of unchecked population growth (Alabi, 2009). To plan land use effectively, one must have a thorough understanding of current LULC and the ability to track the dynamics of urban sprawl caused by changing popolation demands and natural forces that shape the landscape. For decades, data from RS and GIS has been used to detect and identify urban sprawl and other natural resource management issues (Wang & Maduako, 2018). RS data enables the detection of changes on the earth's surface more rapidly and economically than traditional ground survey methods (Karimi et al., 2018). The data serves as a scientific foundation for land use planning, management, and policy development. Numerous studies have successfully mapped and analyzed urban sprawl by utilizing various satellite data sets.

Biu's role as an economic and administrative hub in southern Borno has intensified urban sprawl, with residential and commercial developments encroaching on agricultural lands and natural ecosystems (Odiji, *et al.*, 2024). This expansion has transformed Biu's spatial structure, leading to informal settlements and landscape fragmentation. Ideally, Biu's urban growth would be systematically planned, with GIS and RS technologies regularly used to monitor spatio-temporal sprawl patterns, the urban planning would balance socio-economic needs with ecological sustainability, fostering a livable urban environment. In reality, Biu experiences rapid, unplanned urban sprawl driven by population growth, rural-urban migration, and post-conflict resettlement following insurgencies in Borno State (Okeleye, *et al.*, 2023). This uncontrolled expansion has led to significant LULC changes, with built-up areas replacing fertile agricultural lands and natural vegetation, disrupting ecosystems and livelihoods.



Over the past three decades, spatial growth has fragmented Biu's landscape, reducing ecological connectivity and straining resources like water and soil. These problems are exacerbated by limited funding for urban planning, weak institutional frameworks, and the diversion of resources to conflict recovery efforts in Borno State (Abubakar, et al, 2024). This study proposes a spatio-temporal analysis of urban sprawl in Biu from 1995 to 2025 using RS and GIS to address these challenges (Akamatsu, et al, 2023; Kumar, *et al.*, 2022)

The study is justified by the urgent need to address Biu's unplanned urban sprawl, which threatens sustainable land use, agricultural productivity, and environmental integrity. Rapid urban expansion has converted arable lands into built-up areas, increasing ecological stress and requiring spatial data to guide planning efforts. By employing GIS and Landsat satellite imagery to analyze sprawl from 1995 to 2025, this research will provide detailed insights into urban growth patterns, enabling evidence-based urban management. The focus on a semi-urban, conflict-affected region like Biu addresses a gap in Nigerian urban research, where studies often prioritize megacities (Alsharif, *et al*, 2024; Mithun, *et al*, 2021).

The findings will benefit the Biu Local Government Authority, urban planners, and policymakers by providing spatial data to inform land use policies and zoning regulations. Academically, the study contributes to the limited literature on semi-urban sprawl in Nigeria, offering a spatio-temporal model for similar contexts, by advancing knowledge on urban dynamics, the research supports Nigeria's sustainable development goals.

2. Study Area

Biu is a Local Government Area in southern Borno State, Nigeria, spanning latitude 10° 30' N to 11° 00' N and longitude 11° 45' E to 12° 30' E, Biu had a population of 175,760 in 2006, with growth driven by rural-urban migration and post-conflict resettlement. Agriculture, including maize, millet, and groundnut farming, and trade are the dominant economic activities, supporting livelihoods in the region. Biu's topography, with elevations of 600-700 meters, facilitates urban expansion but pressures arable lands. The semi-arid climate features an average annual temperature of 32.16°C (ranging from 13°C to 41°C) and approximately 1000 mm of rainfall, concentrated in July and August, shaping land use patterns. Recovery from conflict has accelerated urban sprawl, making Biu a critical case for spatio-temporal analysis using GIS and RS. Agriculture is dominant, with crops like sorghum, millet, maize, cotton, and cowpea cultivated under traditional farming methods, livestock rearing is common, and informal trade proliferates through local markets.

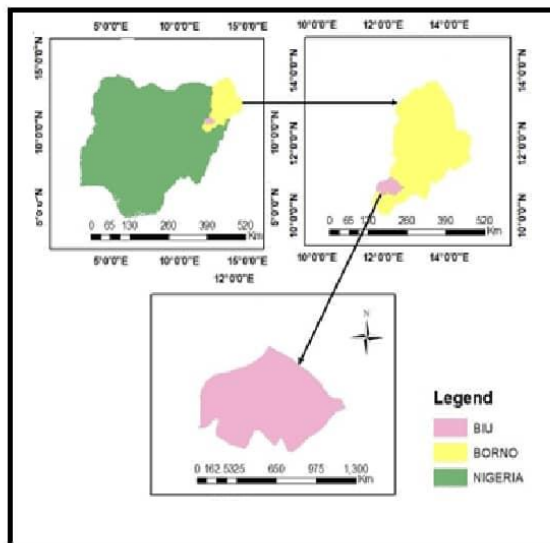


Figure 1: Map of the Study Area.

3.1 Material and Methods

The methodological framework that was used in analyzing the spatio-temporal pattern of urban sprawl in Biu, Borno State, over a 30-year period using GIS and RS data with focused on collecting Landsat satellite imagery and supplementary datasets to support the spatio-temporal analysis of urban sprawl in Biu, the detail description of the dataset used as shown in table 1.

3.2 Land Use/Land Cover Classification

Supervised classification in ArcGIS using Maximum Likelihood Classifier which categorizes superimposed Landsat imagery into five LULC classes: built-up areas, vegetation, agricultural land, water bodies, and bare land (Ogunleye et al., 2024; Roy, et al., 2021). Training samples (20–30 per class) were collected for each year (1995, 2005, 2015, and 2025) using Google Earth Pro imagery, Table 2 shows sample LULC Classification scheme used as suggested (Chetry, V., 2022).

Table 1: Dataset used

S/N	SATELLITE	PATH/ROW	RESOLUTION	SOURCE
1.	Landsat 5 TM	186/052 & 053	30 m	USGS Earth Explorer
2.	Landsat 7 ETM+	186/052 & 053	30 m	USGS Earth Explorer
3.	Landsat 8 OLI/TIRS	186/052 & 053	30 m	USGS Earth Explorer
4.	Landsat 9 OLI2/TIRS2	186/052 & 053	30 m	USGS Earth Explorer

Preprocessing includes radiometric calibration, atmospheric correction, and geometric alignment in ArcGIS (Alzahrani et al., 2024). Composite images (Landsat 5/7: Bands 3, 2, 1; Landsat 8: Bands 4, 3, 2) and NDVI enhance classification accuracy (Miller et al., 2024). Accuracy assessment uses a confusion matrix with 100 random points per year, targeting $\geq 85\%$ overall accuracy and a Kappa coefficient of ≥ 0.80 (Adeola et al., 2020).

Table 2: Sample LULC Classification scheme

CLASS NAME	DESCRIPTION	REPRESENTATION
Built-up	Residential and commercial	High reflectance in SWIR, low in NIR
Vegetation	Forests, grassland and plantations	High reflectance in NIR
Bare Land	Exposed soil, sand and rock	High reflectance in Red, low in NIR
Water Bodies	River and pond	High absorption in NIR
Agriculture	Cropland and irrigated fields	Seasonal variation in NIR

3.3 Assessing the extent of urban sprawl between the period of 2000-2020

The attribute and statistics from the classification result was generated and used for post-classification comparison among the years. The extent of the urban sprawl from 1995 to 2025 was analyzed by subtracting LULC area of the reference year of 1995 from the base year 2025. In order to obtained expansion rate, the result was then divided by area of the base year and multiplied by hundred and to get annual rate the result was divided by number of years within the period as thus:



$$E_T = T_2 - T_1$$

Where: T_1 = the base year (1995); T_2 = the reference year (2025) and; E_T = the total extent of urban sprawl between 1995 and 2025.

And Rate of expansion (R_E) was calculated as:

$$R_E = (E_T / T_1) * 100$$

And yearly urban expansion rate (R_Y) as:

$$R_Y = R_E / n \text{ Where 'n' is number of years.}$$

3.4 Accuracy Assessment

To ensure the reliability of the LULC classifications for 1995, 2005, 2015, and 2025, an accuracy assessment was conducted to evaluate the correspondence between classified maps and reference data. The method involved generating random points, validating them with high-resolution imagery, and computing accuracy metrics, including overall accuracy, user's accuracy, producer's accuracy, and Kappa coefficient, to quantify classification performance table 3.

The Sample tool (Spatial Analyst > Extraction) was used to extract classified values from the LULC maps at the 100 random points, producing output tables that paired true and classified classes, these tables were exported to Excel to construct a confusion matrix for each year, comparing true versus classified classes. Overall Accuracy, User's Accuracy, Producer's Accuracy and Kappa Coefficient were computed table 3. The accuracy results were compiled into tables for each year, summarizing overall accuracy, Kappa coefficient, and class-specific user's and producer's accuracies. The target was an overall accuracy of $\geq 85\%$ and a Kappa coefficient of ≥ 0.80 , aligning with RS standards for reliable classification, Accuracy assessments, based on 100 random points validated with Google Earth Pro imagery, are detailed also in Table 3 shows a sample of accuracy assessment of 1995, including overall accuracy, Kappa coefficients, and class-specific metrics from the confusion matrix.

Tables 3 Accuracy Assessment for 1995

S/No	LULC Class	Built-Up	Vegetation	Agriculture	Water	Bare So	Total	U_Accuracy	Kappa
1	Built-Up	6	0	0	0	1	7	0.857	0
2	Vegetation	2	59	4	1	0	66	0.894	0
3	Agriculture	0	1	14	0	0	15	0.933	0
4	Water	0	1	0	1	1	3	0.333	0
5	Bare Soil	0	0	0	0	9	9	1.000	0
	Total	8	61	18	2	11	100	0.000	0
	P_Accuracy	0.750	0.967	0.778	0.500	0.818	0.00	0.890	0
	Kappa	0	0	0	0	0	0	0	0.80

3.5 Determination of Spatiotemporal Changes of LULC in the Study Area

Post-classification change detection in ArcGIS compares LULC maps (1995, 2005, 2015, 2025) to quantify urban sprawl in Biu, the raster calculator identifies transitions to built-up areas (e.g., agriculture to urban) across periods (1995-2005, 2005-2015, 2015-2025 and 1995-2025), as suggested by (Aslam et al., 2023; Thakkar, et al., 2020) on the other hand zonal statistics calculates the area (km²) and percentage change of built-up areas, with annual growth rates computed as percentage change/years (Boori *et al.*, 2021), for post-classification comparison it overlaid classified maps of different years to detect changes in LULC classes and for the change detection analysis it calculate change statistics (gain, loss, persistence) for each LULC class using raster calculator, in addition for the urban sprawl metrics which compute built-up area expansion rate and finally mapping and visualization which create change maps, graphs, and charts showing temporal trends

4.0 Results and Discussions

This section presents the results of the spatio-temporal analysis of urban sprawl in Biu, Borno State, conducted using GIS and RS techniques. According to the LULC classification (Figure 2), the four major classifications that encompass the Biu metropolis and environs are built-up areas, farmland, vegetation, and bare surface table 4. Throughout the study period, visual

interpretation of the classified images revealed an increase in the built-up class (urban area). Additionally, it depicted farmland as the dominant land use, which is primarily found outside of the built environment and throughout the research area. Additionally, it demonstrates that vegetation cover exists in the study area's southern and eastern regions.

Four LULC maps were generated for 1995, 2005, 2015, and 2025 in ArcGIS 10.7, additionally, 4 class change maps were created to analyze detailed transitions for 1995, 2005, 2015 and 2025. Figure 2 displays the LULC changes maps, showing overall built-up expansion from 9.35% in 1995 to 31.52% in 2025, notably along Biu-Gombe road. This is consistent with previous studies like (Ibrahim, M., *et al.*, 2021; Sani, A., *et al.*, 2023; Ahmed, A., *et al.*, 2024).

Table 4: Land Use Land cover classes

S/No	LULC Class	1995		2005		2015		2025	
		Area (Ha)	(%)	Area (Ha)	(%)	Area (Ha)	(%)	Area (Ha)	(%)
1.	Built-Up	3106.29	9.35	52628.67	15.85	85938.66	25.87	104707.53	31.53
2.	Vegetation	193143.15	58.11	14107.81	42.47	75881.34	22.84	77269.95	23.27
3.	Agriculture	60072.39	18.07	77409.00	23.31	4560489	13.73	47570.04	14.32
4.	Water	11073.42	3.33	13884.93	4.18	16615.53	5.00	9950.13	2.99
5.	Bare Soil	37003.41	11.13	47141.37	14.19	108178.83	32.56	92630.52	27.90

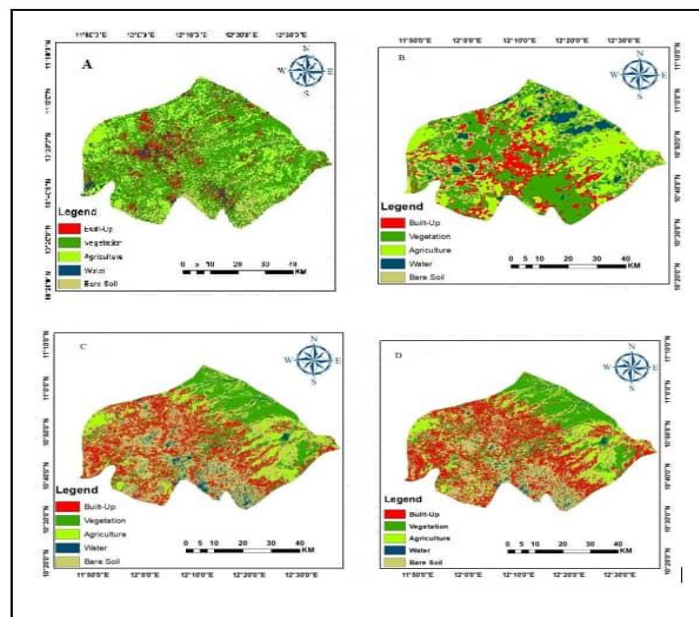


Figure 2: Land Use Land Cover Classes of (A) 1995, (B) 2005, (C) 2015 and (D) 2025

Built-up change maps for 1995–2005, 2005–2015, 2015–2025, and 1995-2025 Figure 3, a total increase of 73,604.4 hectares (22.17%), The increase in built-up area, can be attributed to rapid rural-urban migration driven by insecurity from Boko Haram insurgency, economic opportunities in urban centers, and post-conflict resettlement following displacements, which have accelerated population growth from 175,760 in 2006 to 257,500 in 2022. This expansion is further exacerbated by inadequate urban planning, environmental degradation from soil erosion and climate change, and the transformation of agricultural lands into informal settlements due to limited resources and governance challenges.

Urban sprawl metrics, derived from built-up percentages, include an annual growth rate of 0.74% and a total relative increase of 22.17% over 30 years. Period-specific rates are 0.65% (1995–2005), 1.00% (2005-2015), and 0.565% (2015-2025), with transition-based growth rates calculated. These urban sprawl growth rate from 2015-2025 in Biu, Borno State, can be attributed to several factors. Post-2015, improved security through military interventions against Boko Haram reduced forced migration and displacement, stabilizing urban influx. Economic challenges, including global oil price declines affecting Nigeria's revenue and Borno's reconstruction efforts, limited development funding.

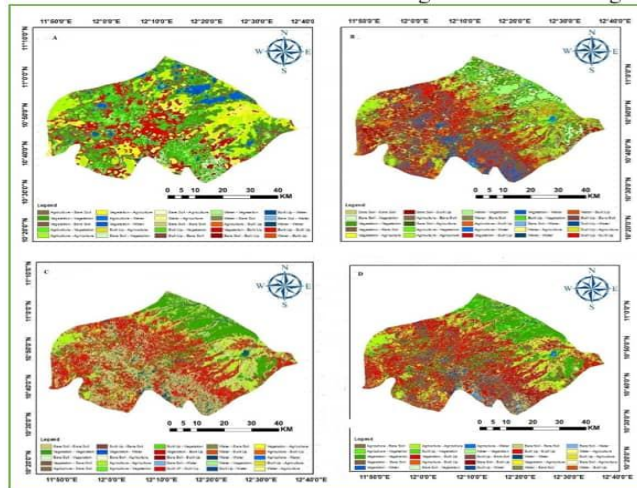


Figure 3: LULC Changes of (A) 1995-2005, (B) 2005-2015, (C) 2015-2025 and 1995-2025

Government policies, such as Borno State's 10-Year Transformation Plan (2022), emphasized controlled reconstruction and rural development, curbing unplanned urban expansion. Additionally, environmental factors like desertification and variable rainfall may have constrained habitable land, slowing sprawl. These trends align with national urbanization



patterns, where northeast Nigeria experienced moderated growth due to conflict recovery and economic slowdown.

Changes were observed across all the LULC classes of Biu town, the class with the most prominent changes is the built-up area which was increasing from 9.35% in 1995, 15.85% in 2005, 25.87% in 2015 and 31.53% in 2025 which signifies an exponential increase in human habitation and infrastructural development. Different types of changes were observed in the remaining classes. These distributions were validated using accuracy assessment which shows a consistent value in overall of over 90% all through the images, and a kappa index of over 80%, these figures showed that the land use land cover assessment is valid.

Conclusion

The analysis confirms a marked urban sprawl in Biu, with built-up areas growing by 73,604.4 hectares (22.17%) from 1995 to 2025, driven by an annual growth rate of 0.74%. The most rapid expansion occurred between 2005 and 2015 (10.02%, 33,277.36 ha), likely due to post-conflict resettlement following Borno State's insurgencies. Vegetation declined sharply by 34.85% (115,696.48 ha), reflecting land conversion, while agriculture decreased by 3.76% (12,486.36 ha), and water bodies showed a net reduction of 0.34% (1,115.52 ha), influenced by seasonal variability and classification challenges. Bare soil increased by 16.76% (55,640.82 ha), indicating degradation or abandonment.

Accuracy assessments validated the classifications, with 2005 achieving the highest reliability (92%, Kappa 0.887), though water and bare soil classifications exhibited spectral overlap, particularly in 1995 (user's accuracy 0.33 for water) and 2015 (86% overall accuracy). The 4-class change maps revealed that vegetation (26.59%) and bare soil (6.76%) were primary sources of built-up growth, underscoring the environmental impact of sprawl. Compared to regional semi-arid urban growth rates (0.5%), Biu's 0.74% annual rate highlights conflict-driven dynamics, though the slowing trend post-2015 (0.565%) suggests potential stabilization.



Recommendations

Based on the findings, the following recommendations are proposed to manage urban sprawl and promote sustainability in Biu:

1. **Urban Planning and Zoning:** Implement zoning regulations to protect agricultural land and vegetation, particularly along Biu-Gombi Road, where sprawl is concentrated.
2. **Ground Truthing:** Conduct field surveys to validate 2025 data, overcoming limitations of Google Earth Pro's historical gaps which will raise Kappa coefficients above 0.887.
3. **Future Research:** Expand the study to include socio-economic data like population growth providing a holistic view of sprawl drivers.



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