

# Mapping Rapid Urban Expansion and Sprawl in Keffi, Nigeria: A 21-Year Study Using Geospatial Techniques

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## Abstract

This study analyzes the spatio-temporal dynamics of urban sprawl in Keffi, Nigeria, from 2002 to 2023 using geospatial technologies. Landsat imagery was classified to map land use/land cover (LULC), achieving good accuracy. The results show a dramatic expansion of the built-up area, which grew from 3.12% (495.00 ha) in 2002 to 11.45% (1,813.05 ha) in 2023. Analysis of landscape metrics (e.g., a rise in the Largest Patch Index from 1.1 to 6.3) and Shannon's Entropy confirmed trends of fragmentation, aggregation, and dispersed growth. A sharp increase in entropy in the outermost zones (0.007 to 0.356) signifies pronounced sprawl, particularly in the eastern and northwestern sectors. The study concludes that Keffi is experiencing rapid, sprawling growth, highlighting the urgent need for proactive urban planning and monitoring to guide sustainable development.

## 1. Introduction

The rapid pace of urbanization is a defining global phenomenon of the 21st century, with cities in countries like China, India and Nigeria projected to account for 37 per cent of the increase of nearly 2.5 billion people in the urban population by 2050 (United Nations, 2019). This growth often manifests as urban sprawl—an unplanned, low-density expansion of urban areas into surrounding rural lands, leading to inefficient land use, poor societal well-being, negative economic prosperity, and deteriorating environmental sustainability (Bhatta et al., 2010; Park, 2023; Shi et al., 2023). Effective urban planning and management require timely and accurate data on the rate, pattern, and extent of this expansion.

Keffi LGA, located in north-central Nigeria adjacent to the Federal Capital Territory, Abuja, is one such area experiencing rapid urbanization. Its proximity to Abuja has fueled significant population growth and haphazard physical development, creating a pressing need for empirical analysis of its urban dynamics. While several studies (Akintunde et al., 2016; Balogun & Onokerhoraye, 2017) have examined urban sprawl in other Nigerian cities, a comprehensive spatio-temporal analysis specific to Keffi LGA was identified as a critical gap.

Geospatial technologies, particularly Remote Sensing (RS) and Geographic Information Systems (GIS), provide powerful, cost-effective tools for mapping and monitoring urban sprawl over time (Shaw & Das, 2018). The integration of multi-temporal satellite imagery with spatial analysis techniques like landscape metrics and Shannon's Entropy allows for a quantitative assessment of urban growth patterns.

The aim of this study is to determine the spatio-temporal pattern of urban sprawl in Keffi LGA from 2002 to 2023 to provide a basis for sustainable urban land management. The

specific objectives are: to generate land use/land cover (LULC) maps for 2002, 2013, and 2023, b) to analyze urban sprawl using landscape metrics, c) to quantify the pattern of urban sprawl using Shannon's Entropy.

## 2. Methodology

### 2.1 Study area

Keffi LGA is situated in Nasarawa State, Nigeria, approximately 60 kilometers southeast of Abuja. It lies within latitudes 8°50'42.19"N to 8°51'57.16"N and longitudes 7°51'40.49"E to 7°54'52.16"E, covering an area of about 138 km<sup>2</sup> (Figure 1). The area experiences a tropical wet and dry climate and has witnessed rapid growth due to its strategic location, hosting institutions like Nasarawa State University and its proximity to the Federal capital territory Abuja Nigeria.

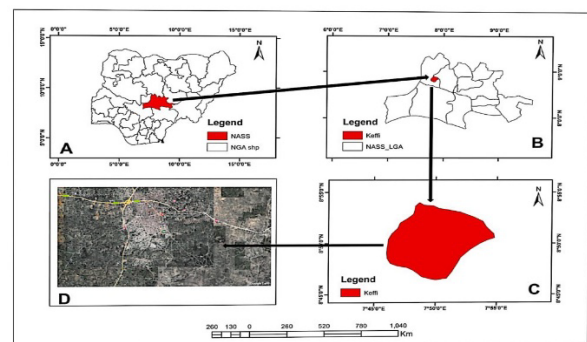


Figure 1. Locational Maps of the study area. (A) Top left, Map of Nigeria showing Nasarawa state. (B) Bottom left, Map of Nasarawa state showing Keffi local Government

Area. (C) Map of the study area showing Keffi Local Government Area. (D) Imagery of the study site

## 2.2 Data acquisition and pre-processing

Multi-temporal satellite images were acquired from the United States Geological Survey (USGS) portal. Landsat 7 ETM+ (2002) and Landsat 8 OLI (2013, 2023) images were selected for path/row 188/54 based on availability and minimal cloud cover.

Pre-processing steps in ERDAS Imagine 2015 included: Layer Stacking - combining individual spectral bands into a single composite image, Radiometric Correction - calibrating digital numbers to reflectance values to correct for sensor and atmospheric effects and finally Subsetting - clipping the images to the boundary of Keffi LGA using an administrative shapefile.

## 2.3 Image classification and accuracy assessment

A supervised classification was performed using the Maximum Likelihood Classification (MLC) algorithm. Training samples were collected for four LULC classes: Built-up, Vegetation, Bare Land, and Rock. Post-classification smoothing using a majority filter was applied to reduce salt-and-pepper noise. The accuracy of the classified maps was assessed using randomly generated reference points, calculating overall accuracy and Kappa coefficient.

## 2.4 Urban sprawl analysis

- **Change Detection:** A post-classification comparison technique was used to quantify the aerial extent and rate of change between the three epochs.
- **Landscape Metrics:** The classified rasters were analyzed using FRAGSTATS (McGarigal and Marks 1995) software to compute key class-level metrics, Patch density (PD), Number of patches (NP), Percentage of land (PLAND), Largest patch

index (LPI), Landscape shape index (LSI), Mean patch size (MPS) and Aggregation index (AI).

- **Shannon's Entropy:** To measure the dispersion or concentration of urban growth, the study area was divided into five concentric buffer zones (0-2km, 2-4km, 4-6km, 6-8km, 8-10km) from the urban core. Shannon's Entropy (both absolute and relative) was calculated for the built-up class within each zone for each time period. The formula of Shannon's entropy (AE) mostly termed absolute is:

$$AE = - \sum_{i=1}^n P_i \ln(P_i) \quad \text{Equ (1)}$$

Where  $p_i$  is the proportion of built-up land in an  $i$ th zone

$$P_i = \frac{x_i}{\sum_{i=1}^n x_i}$$

$x_i$  is the observed value of the variable in the  $i$ th

zone and  $n$  is the aggregated number of zones. The values of Entropy ranges between 0 and  $\log(n)$ , for this study  $n = 5$ . The value closer to zero indicates the compact distribution and the value of near  $\log(n)$  indicates very high dispersed distribution and therefore indicate sprawl. The relative entropy (RE) which gives a better perception of the urban sprawl is calculated by dividing absolute entropy by  $\log(n)$  and values between 0 and 1.

## 3. Results and discussion

### 3.1 Land use/land cover change

Cohen's Kappa (Cohen, n.d.) statistics which is mostly used for the measure of reliability was used to assess the accuracy of the classified images, due to its superiority in a much better interclass discrimination than the producer's accuracy (PA), user's accuracy (UA) and the overall accuracy (Landis & Koch, 1977; Das et al., 2021). The classified LULC maps for 2002, 2013, and 2023 are shown in Figure 2. The accuracy assessment yielded Kappa coefficients of 0.81 (2002), 0.78 (2013), and 0.76 (2023) (see Table 1). Based on Landis & Koch, (1977) suggestions, the Kappa coefficient of the study indicates very good agreement between the classified images and actual land use patterns.

Table 1. Summary of the error matrices for 2002, 2013 and 2023

	Producer Accuracy			User's Accuracy			Overall Accuracy			Kappa Coefficient		
	2002	2013	2023	2002	2013	2023	2002	2013	2023	2002	2013	2023
Built-up	91.67	90.91	76.47	78.57	76.92	81.25						
Vegetation	80.95	85.71	80.00	85.00	80.00	80.00	88.00	88.00	84.0	0.81	0.78	0.76
Bare land	89.47	87.69	86.79	92.73	93.44	92.00						
Rock	90.00	90.00	90.00	81.82	81.82	64.29						

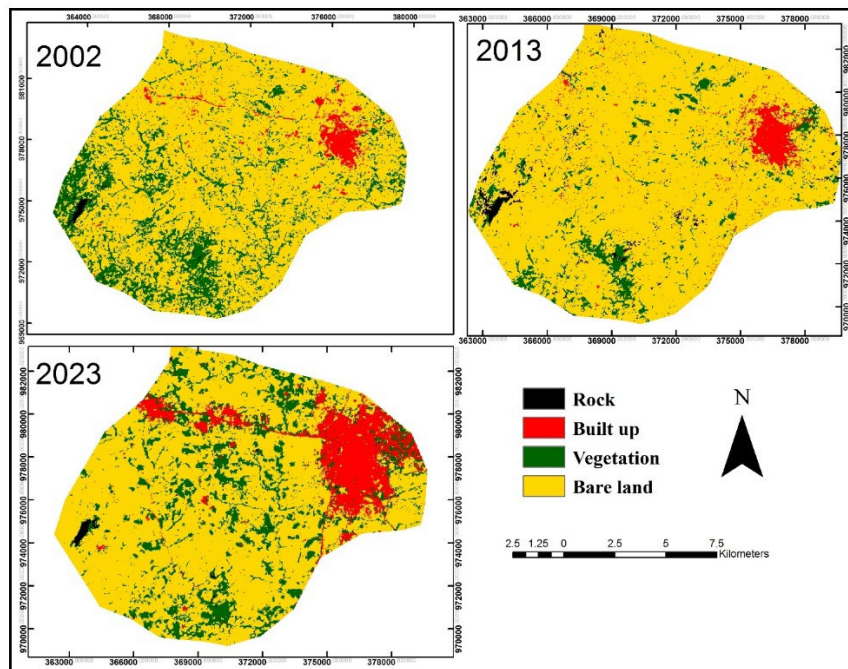


Figure 2: Classified image of the study area for the year 2002, 2013 and 2023

From the Table 2, the result shows that the trend of built-up increased could be due to natural and anthropogenic factors. Built-up land use increased from 495.00ha (3.12%) in 2002 to 588.60ha (3.72%) in 2013 and to 1813.05ha (11.45%) in 2023 respectively. Within the same period (2002, 2013 and 2023), vegetation land use decreased from 3065.29ha (19.35%) to 1173ha (7.41%) and later increased to 2748.24ha (17.35%) respectively. This could also have

occurred due to changes in the occupation of the work force in the area or anthropogenic factors such as deforestation, afforestation, overgrazing and improper land use. Bare land increased from 12229.37ha (77.20%) in 2002 to 13840.25ha (87.37%) in 2013 and in 2023, Bare land decreased to 11216.84ha (17.35%) while, Rocky area increased from 51.21ha (0.32%) to 238.95ha (1.51%) and then decreased to 63.18ha (0.40%).

Table 2. LULC Change Detection Statistics (2002-2023)

Class	2002 (Ha / %)	2013 (Ha/%)	2023 (Ha / %)
Built-up	495.00 / 3.12	588.60 / 3.72	1,813.05 / 11.45
Vegetation	3,065.29 / 19.35	1,173.51 / 7.41	2,748.24 / 17.35
Bare Land	12,229.39 / 77.20	13,840.25 / 87.37	11,216.84 / 70.80
Rock	51.21 / 0.32	238.95 / 1.51	63.18 / 0.40
Total	15,841.31 / 100	15,841.31 / 100	15,841.31 / 100

### 3.2 Landscape metrics analysis

The analysis of landscape metrics (see Table 3) from 2002 to 2023 reveals a clear trajectory of urban expansion and consolidation in Keffi.

**Urban expansion:** The built-up area showed substantial growth, increasing by 93.6 hectares between 2002 and 2013, and a more dramatic rise of 1224.50 hectares from 2013 to 2023. This expansion is further evidenced by the consistent increase in the Largest Patch Index (LPI) and the core area metrics (TCA and CPLAND), indicating a significant spread and consolidation of urban land.

**Patterns of fragmentation and cohesion:** The initial period (2002-2013) was characterized by increased fragmentation, marked by a rise in the Number of Patches (NP) and Patch

Density (PD). However, by 2023, this trend reversed, with a decrease in NP and PD suggesting the merging of patches into more compact forms. This consolidation is supported by a decreasing Landscape Shape Index (LSI) and an increasing CLUMPY index, which point towards a more aggregated and less fragmented urban landscape over time.

**Spatial configuration:** The high values of the Interspersion and Juxtaposition Index (IJI) for built-up and vegetation classes indicate that these patch types became highly interspersed with one another. Furthermore, the growth of built-up patches was consistent across the entire study period, confirming a pervasive urban expansion throughout the landscape.

### 3.3 Shannon's entropy analysis

The zone-wise computation of Shannon's entropy (Table 4) for Keffi from 2002 to 2023 reveals a clear trend of urban sprawl, with development radiating withing the northwestern sectors of the study region. A look at the overall trend, both absolute and relative entropy values increased over time, indicating a progression towards more dispersed, sprawl-like development. Spatially (see Figure 3),

the most significant sprawl occurred in the outer zones: zone 3 (4-6 km) which showed a substantial rise in entropy, indicating rapid sprawl in the eastern area and zone 5 (8-10 km) exhibited a drastic entropy increase, signifying major expansion and land-use fragmentation on the urban periphery. The entropy results confirm that urban growth has been strongest in the eastern and northwestern directions, transforming previously undeveloped areas.

Table 3. Different landscape metrics of the area

Year	CLASS AREA			PLAND			NP			PD			LPI		
	2002	2013	2023	2002	2013	2023	2002	2013	2023	2002	2013	2023	2002	2013	2023
Built up	495	588.6	1813.1	3.12	3.72	11.5	412	1022	550	1.7	4.2	2.2	1.1	1.5	6.3
Vegetation	3065.5	1173.5	2748.2	12.5	4.8	11.2	2297	1181	1660	9.3	4.8	6.7	2.2	0.9	1.1

Year	TCA			CPLAND			IJI			LSI			CLUMPY		
	2002	2013	2023	2002	2013	2023	2002	2013	2023	2002	2013	2023	2002	2013	2023
Built up	300	398.4	1228	1.22	1.6	4.9907	2.74	11.93	57.4	19.5	25.6	22.6	0.74	0.68	0.83
Vegetation	1304	557.9	1351	5.30	2.3	5.4938	9.72	19.70	40.8	61.4	39.6	50.2	0.62	0.64	0.68

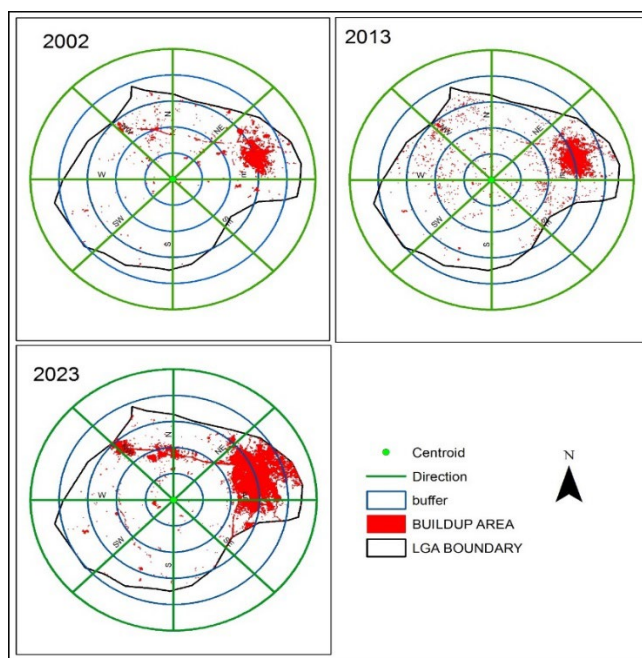


Figure 3. Urban sprawl map of the area

Table 4. Shannon's Entropy Results for Buffer Zones

Buffer(km)	2002	2013	2023	2002	2013	2023
	AE	AE	AE	RE	RE	RE
0-2	0.017	0.021	0.069	0.024	0.030	0.100
2-4	0.031	0.019	0.027	0.045	0.027	0.038
4-6	0.078	0.062	0.180	0.111	0.088	0.258
6-8	0.051	0.054	0.109	0.073	0.077	0.155
8-10	0.005	0.012	0.249	0.007	0.017	0.356

#### 4. Conclusion

This study successfully quantified the spatio-temporal patterns of urban sprawl in Keffi LGA between 2002 and 2023 using an integrated geospatial approach. The key findings are:

- i. **Significant Urban Expansion:** The built-up area more than tripled in size, increasing from 3.12 to 11.45 of the total land area.
- ii. **Spatially Dispersed Growth:** Landscape metrics revealed an evolution from fragmented to more aggregated but sprawling urban forms. Shannon's Entropy confirmed a strong trend towards dispersed growth, particularly in the outermost zones.
- iii. **Directional Pattern:** The sprawl occurred mainly in the eastern to northwestern directions, driven by Keffi's proximity to Abuja.

The uncontrolled sprawl has implications for infrastructure, environmental sustainability, and quality of life.

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