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Analyzing Urban Sprawl in Okene using Remote Sensing Techniques.

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Abstract

Urbanization, a global phenomenon, profoundly impacts human habitation, leading to environmental and socioeconomic changes. In Okene, Nigeria, rapid urbanization has resulted in unchecked urban sprawl, driven by factors such as population growth, housing construction, and deforestation. This research aims to analyze urban sprawl in Okene using remote sensing techniques, focusing on its extent, drivers, and impacts, to inform sustainable urban planning strategies. Remote sensing data from Landsat satellites were utilized to analyze land cover changes between 1991 and 2021. Spatial analysis techniques, including supervised classification and change detection, were employed to determine the extent and rate of urban sprawl. The study revealed a significant increase in the built-up area, with urban land expanding from 1.86% to 4.57%. Urban sprawl occurred at an annual rate of 19.94% between 1991 and 2001, slowing to 0.6% between 2001 and 2021. However, the overall sprawl from 1991 to 2021 amounted to 145.70%. The findings underscore the urgency of implementing sustainable urban planning and management strategies to mitigate the negative impacts of urbanization and enhance the region's sustainability and livability.

Keywords: Urban sprawl, Remote Sensing, Geographic Information System (GIS), Landuse/Land cover, Okene.

Introduction

UN-DESA, (2018), stated that, 55% of the world's population resides in urban areas, a figure projected to rise to 68% by 2050. Projections indicate that urbanization—the gradual shift of human populations from rural to urban areas—along with overall population growth, could add another 2.5 billion people to urban areas by 2050. Nearly 90% of this increase is expected to occur in Asia and Africa, according to new data from the United Nations. The UN DESA, (2018) further noted that future growth in the global urban population is expected to be concentrated in a few key countries. India, China, and Nigeria are projected to contribute 35% of the world's urban population increase between 2018 and 2050. By 2050, India is expected to add 416 million urban residents, China 255 million, and Nigeria 189 million. According to Ritchie, Samborska, and Roser (2018), urbanization is projected to continue its upward trend as incomes rise and employment shifts from agriculture. Urban population growth leads to increased land consumption by urban settlements. This issue can be addressed through two primary approaches: urban densification and urban expansion. Urban densification involves raising the population density within existing urban areas, while urban expansion involves extending the boundaries of urban areas into surrounding lands (Shlomo, 2023). The patterns of urbanization and industrialization vary widely based on geographical location, environmental conditions, and each area's unique history, resulting in diverse spatial patterns and land zoning.

Consequently, the processes of urbanization and industrialization have become highly dynamic and complex, making it increasingly challenging to monitor all these changes effectively. Rapid urban growth has led to complex issues, including environmental pollution, depletion of natural resources, loss of open spaces, changes in thermal climates, inadequate infrastructure, and poorly planned or uncontrolled land development (Ishaya, 2020).

The growth of urban areas frequently results in inadequate infrastructure to support the increasing populations, leading to unprecedented environmental degradation. Urban expansion typically involves altering the environment or replacing natural or agricultural land with urban land uses, such as buildings, transportation networks, and parking lots (Johnson et al., 2021: Ejaro and Abubarkar 2013). As noted by Long et al. (2008), urban areas are characterized by high population densities, and the rapid growth in these areas is driven by such concentrations of people. This urbanization process results in changes to land use and cover patterns, which can have detrimental effects on local ecology, particularly affecting hydro-geomorphology and vegetation. Population growth drives the demand for new services and amenities, pushing for decentralization from urban centers and leaving valuable farmland vulnerable to commercial or residential development. These changes in land use and land cover (LULC) are significant drivers of global change (Long et al., 2008). At present, both rural development and urban development in Nigeria can be likened to other places in the world that are in a transitionary period—the transformation of a traditional agricultural society into a modern industrial and urban society (Long et al, 2008: Babamaaji et al, 2018). According to Brovkin et al. (2013), human activities have altered approximately one-third to one-half of the Earth's land surface, and this extent of land use modification is expected to increase in the future to meet the rising demand for land. Nigeria, has been experiencing an unprecedented and accelerated urban expansion since the 1980s. and according to Slemp et al., (2012) numerous LULC studies in Nigeria, utilizing maps, aerial photos, and satellite images, have documented these changes. The original land cover in Nigeria has reportedly been altered due to a variety of factors, including agricultural expansion, the growth of rural towns, the development of rural road networks, and government activities.

Ujoh, Ifatimehin, and Baba (2011) posits that urbanization stands as a key anthropogenic factor influencing changes in LULC. A multitude of scholars (Zubair et al., 2015; Eshleman and Townsend, 2011; Ujoh et al., 2011; Adelekan, 2010; Akinola and Adewale, 2012; Kabanda and Palamuleni, 2013; Maina, 2014), have linked urban growth, the concentration of populations in urban areas, and the expansion of built-up areas to urbanization, thereby contributing to a range of societal challenges. These days, scholars (Zubair et al, 2015: Owoeye and Akinluyi, 2018: Chukwubueze et al., 2022: Emetumah et al., 2023), to mention a few, are paying attention to various areas in the country facing urban sprawl. In Okene, urbanization, unregulated housing construction, agriculture, and deforestation are identified as the primary drivers of land cover change, consequently leading to urban sprawl. These alterations significantly impact the local climate, land consumption, and population expansion dynamics (Owoeye and Akinluyi, 2018: Ishaya, 2020). Balogun et al. (2009) emphasize that the land use and cover pattern of a region reflect the historical interaction between natural and socioeconomic elements across time and space. Unchecked urban growth in Okene has adversely impacted its ecology, potentially leading to indirect effects on weather variables and local climate change (Akinbode et al., 2007). If left uncontrolled, urban sprawl can result in unplanned and monotonous developments, hindering the functional mix of land uses. Glaeser and Kahn (2004) characterized urban sprawl as a pattern exhibiting various attributes such as proximity, centralization, concentration, and continuity. This type of development can appear as low-density ribbon or strip development, scattered and discontinuous growth, or inefficient land use practices. Zhang (2012) noted that urban sprawl has a substantial impact on environmental quality, mainly through the encroachment on cultivated land, destruction of wetlands, and pollution. It also exacerbates severe air pollution problems such as haze. Johnson et al. (2021) and

Alabi (2009) defined urban sprawl as the expansion of new developments on isolated parcels of land, often separated by vacant areas from other developed regions. They also referred to this phenomenon as leapfrog development, a term initially coined by Torrens and Albert (2000). According to Johnson et al. (2021), urban sprawl is characterized by unplanned and uneven growth, driven by various processes that result in inefficient resource utilization. Accurately detecting changes on the Earth's surface is crucial for comprehending the relationships and interactions between human activities and natural phenomena. Remote Sensing and Geographic Information Systems (GIS) offer the capability to deliver precise information about land use and land cover changes (Alqurashi and Kumar, 2013). Simelane, Hansen, and Munghemezulu, (2021) state that continuous monitoring of the Earth's surface using remote sensing technologies is an essential source of spatiotemporal data for acquiring valuable information on land use and land cover (LULC). Al-doski et al. (2020) also asserted that remote sensing technology significantly improves the assessment and management of urban areas. It offers reliable thematic maps, such as those depicting land cover, by consistently capturing spatial features of the Earth's surface across different spatial and temporal scales. Long et al. (2008) highlight that Remote Sensing (RS) and Geographic Information Systems (GIS) are recognized as powerful and effective instruments widely applied for detecting spatial and temporal variations in land use and land cover (LULC). By employing RS, researchers can collect valuable multi-temporal data critical for monitoring land use trends and processes, while GIS techniques enable the analysis and mapping of these patterns. Simelane, Hansen, and Munghemezulu, (2021) posited that urban planners often utilize remotely sensed imagery, overlaying it with other demographic or geographic information to gain a more comprehensive and insightful understanding of the human landscape.

Statement of the Problem

Urban sprawl, characterized by uncontrolled and unplanned expansion of urban areas into rural land, is a significant issue impacting cities worldwide (Owoeye, 2020: Owoeye and Akinluyi 2018: Ukoje, 2016: Rahman et al., 2007). In Okene, this phenomenon has become increasingly prominent due to rapid population growth, unregulated housing construction, agricultural expansion, and deforestation. The town's unchecked urbanization is resulting in substantial land cover changes, leading to a myriad of ecological, social, and economic problems that threaten the sustainability and quality of life in the region (Akinbode et al., 2007). Akinbode et al. (2007) highlighted that one of the primary concerns related to unregulated housing construction and urbanization is its adverse impact on the local environment. These changes disrupt local biodiversity and contribute to environmental issues such as soil erosion, deterioration of water quality, and increased greenhouse gas emissions. Moreover, according to Glaeser and Kahn (2004), the alteration of natural landscapes due to urbanization exacerbates local climate conditions, leading to urban heat islands and changes in precipitation patterns. These factors can significantly affect the region's climate resilience. Ahmadi et al. (2023) highlighted the critical role of effective governance and strategic planning in urban development. They underscored the necessity for urban planners and policymakers to manage the growth and expansion of metropolitan areas carefully. This approach aims to prevent the inefficient use of nonrenewable resources, preserve environmental equilibrium, address social disparities, and foster comprehensive and sustainable development initiatives. The social fabric of Okene is being strained by the pressures of urban sprawl. The influx of people into urban areas often leads to overcrowded living conditions, lack of affordable housing, and increased social disparities. These social issues are compounded by the insufficient provision of public amenities, such as schools, healthcare facilities, and recreational spaces, further impacting the well-being and social cohesion of the community. Despite the pressing nature of these issues, there is a lack of comprehensive studies and reliable data on the extent and effects of urban sprawl in Okene. Traditional methods of land cover analysis, such as ground surveys and historical records, are often time-consuming, costly, and may not provide the spatial and temporal resolution needed to understand and manage urban expansion effectively. The use of RS and GIS enable the continuous monitoring and analysis of land use changes over large areas with high accuracy and at various temporal scales. By leveraging satellite imagery and advanced spatial analysis tools, it is possible to obtain detailed and up-to-date information on the patterns and drivers of urban sprawl in Okene. Therefore, this study aims to analyze urban sprawl in Okene using remote sensing techniques to provide a comprehensive understanding of its extent, drivers, and impacts. By doing so, the research seeks to inform sustainable urban planning and management strategies that can mitigate the negative effects of urban sprawl, promote efficient land use, and enhance the overall sustainability and livability of Okene.

The Study Area

Okene town is situated in the Okene Local Government Area (LGA) of Kogi State, Nigeria. Covering an area of 328 km², it had a population of 325,623 according to the 2006 census. Geographically, Okene is positioned between latitude 7°32'18.2" N to 7°35'29.5" N and longitude 6°14'19.8" E to 6°16'19.8" E. The LGA shares boundaries with Adavi, Ajaokuta, and Ogori-Magongo LGAs within Kogi State, as well as with Okpella in Edo State. It is located in Nigeria's North Central Geopolitical Zone, also known as the Middle Belt region (Yaro et al., 2019). According to a World Bank Study (2018), the study area experiences two distinct seasons annually: the wet and dry seasons. The wet season extends from mid-March to October, while the dry season occurs from October to March. During the dry season, the air is arid, and temperatures fluctuate significantly throughout the day. The region has an average maximum temperature of 34.5°C and an average minimum temperature of 22.8°C, with annual rainfall ranging between 1016 mm and 1524 mm. Relative humidity is higher between April and November, coinciding with peak rainfall values (World Bank, 2018). The study area features seasonal streams and springs with a complex dendritic drainage network. Many rivulets act as tributaries to major rivers such as Osse, Osara, and Omyi (Adabanija et al., 2020). Most rivers are perennial, flowing in different directions due to varied topography and geological structures. Okene's relief, akin to other parts of the Middle Belt, includes stable land surfaces and erosional features. The stable surfaces are level or undulating plateaus over 1,200 feet, with smooth, rounded inselbergs around Okene and Upogoro. Flat-topped hills and bold ridges, including notable hills like Oborenyi, Okunchi, Anyioke, Atami, and Odunmi, dominate other areas, trending predominantly in the NW-SE direction (Gideon, 2019; Igbah et al., 2022).

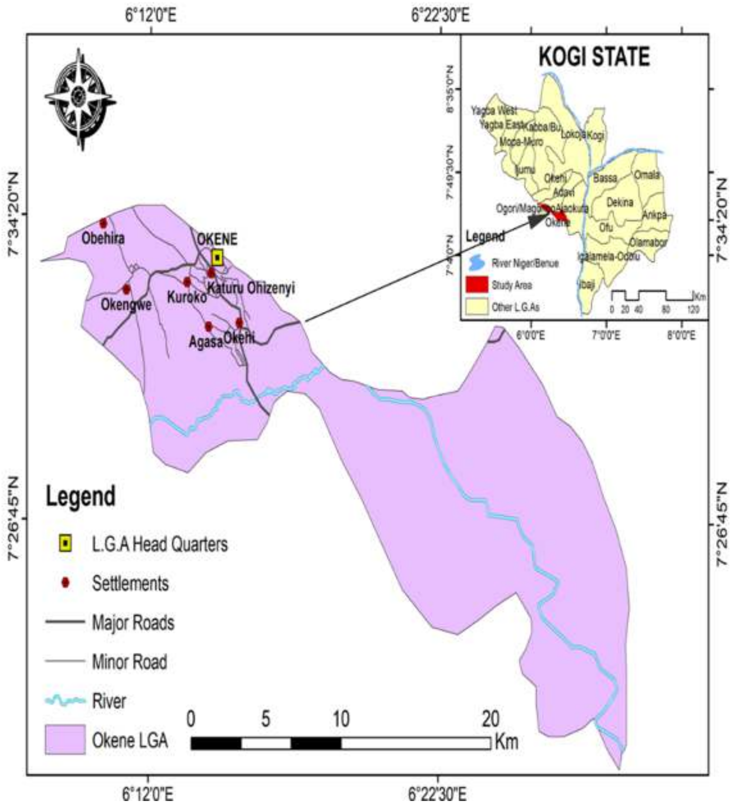


Figure 1: THE STUDY AREA
Source: Authors, 2023

Geologically, Okene lies within the Precambrian basement rocks, characterized by a migmatite-gneiss complex associated with a series of meta-sedimentary rocks and older granites. The dominant lithological units in the study area include gneisses (which are regionally emplaced), ferruginous quartzite, granites, pegmatite, and charnockite. The streams and springs in the area are seasonal and feature a complex dendritic drainage network. Numerous rivulets act as tributaries to the major rivers: Osse, Osara, and Omyi (Adabanija et al., 2020). The vegetation in Okene consists of Tropical Guinea savannah, characterized by tall grasses and scattered trees. During the rainy season, the landscape is lush with green leaves and tall grasses, while in the dry season, it becomes open, revealing charred trees and the remains of burnt grasses. The vegetation predominantly includes sparsely distributed trees, herbs, shrubs, and tall grasses (Igbah et al., 2022).

Table 1: Source and Types of Data

Methods

Data Types and Sources

As part of the methodology for analyzing urban sprawl in Okene using remote sensing techniques, the following types of data were utilized as shown in Table 1. These satellite imageries were sourced from the United States Geological Survey (USGS). The obtained images were then processed and analyzed to extract relevant information and insights into the patterns and trends of urban sprawl in Okene. Table 1 provides a summary of the sources and types of data used to achieve the study's objectives. These datasets offer comprehensive temporal coverage and high-resolution imagery, enabling detailed analysis of land cover changes over the specified periods. The integration of these data types is crucial for understanding the extent and impact of urban sprawl in Okene.

Data Type	Date	Spatial Resolution	Source
Landsat ETM	December 1991	30 meters	USGS
Landsat ETM	December 2001	30 meters	USGS
Landsat OLI/TIRS	December 2021	30 meters	USGS

Data Processing

Image Pre-Processing

All images were clipped to the study area using the 'subset' function in ArcGIS 10.5. Since the images were orthorectified, radiometric and geometric corrections were not necessary. However, the images were geometrically adjusted to the Universal Transverse Mercator (UTM) coordinate system using ArcGIS 10.5 (Strimbu, (n.d.). This description indicates the process of preparing and aligning the images for analysis within the specified coordinate system, following necessary adjustments based on their orthorectification status. Ground Control Points (GCPs) were collected through an extensive field survey using a Global Positioning System (GPS) to obtain accurate locational point data for each land use and land cover class included in the classification scheme. These datasets are utilized for accuracy verification, georeferencing, and ensuring consistency in classification. Collecting ground control points (GCPs) through field surveys with GPS significantly enhances the overall accuracy and reliability of spatial information derived from remotely sensed images, even after undergoing prior correction processes such as orthorectification.

Image Classification

To detect changes in land use and land cover across different years, a post-classification comparison change detection technique was employed. Yuan et al. (2005) argued that change detection is the most common approach for comparing data from different sources and dates. The advantage of post-classification techniques is that they bypass the difficulties associated with analyzing images acquired at different times. ERDAS Imagine software was used for pixel-based classification, employing a supervised classification method using the maximum likelihood classifier. The three images were classified into different land cover types. Supervised classification allows for distinct natural spectral clusters with a high degree of objectivity (Hudak & Brockett, 2004). This classification method involves identifying pixels with the same spectral features. ERDAS Imagine software was used to digitally process and identify the spectral clusters on the Landsat images. The signature editor in the classifier icon of ERDAS Imagine was used to identify the spectral signatures of different features. The maximum likelihood algorithm classified the images, grouping the digital numbers of the pixels into organized land cover classes such as built-up areas, bare surfaces, vegetation, water bodies, and scattered cultivation.

Classification System: Based on Anderson et al.'s (1976) land use/land cover classification scheme, the various land use/land cover types were modified into five classes within the study areas, as presented in Table 2.

Table 2: Classification Scheme

CODE	LAND USE CATEGORIES	DESCRIPTION
1	BUILT-UP	Land used for residential and transportation/communication purposes (i.e. settlements and roads, high residential area, industry and administrative blocks)
2	Bare surface	Exposed soils, land devoid of vegetal cover
3	Vegetation	Land covered with natural vegetation that is predominantly grasses, shrubs and grass like plants
4	Water body	Areas covered by body of water e.g. dams, river, and lakes
5	Scattered cultivation	Areas that are spatially cultivated e.g. farmland, irrigation areas etc.

Data Analysis

Determining the Extent of Urban Land Use in 1991, 2001, and 2021

The attribute data and statistics from the classification results will be generated and used for post-classification comparison across the years. The built-up areas for each of the periods were extracted, and the extent of these built-up areas will be calculated in hectares.

Analyzing the Extent of Urban Sprawl Between 1991 and 2021

The extent of urban sprawl will be analyzed by subtracting the land cover of the base year (1991) from the reference year (2021). This can be represented mathematically as:

$$ET = B - A$$

where:

- A = the base year (1991)
- B = the reference year (2021)
- ET = the total extent of urban sprawl between 1991 and 2021

The formula ET = B - A, where A is the base year (1991), B is the reference year (2021), and ET represents the total extent of urban sprawl is a common approach used in urban studies and geographic analysis to quantify the increase in urban area over a specified period. While this specific formula does not have a single source citation as it represents a general arithmetic calculation widely used in urban planning and geographical research, it reflects a basic method for measuring urban sprawl by comparing urban area extents between two points in time.

Determining the Rate and Pattern of Urban Sprawl in the Study Area

To determine the rate and pattern of urban sprawl, statistical analysis was employed. The rate of urban sprawl was calculated using the total extent of urban sprawl (ET) derived from the previous analysis. The total extent of the sprawl in hectares will be divided by the number of years within the period from 1991 to 2021:

$$R = \frac{ET}{\text{number of years}}$$

where:

- R = Rate of urban sprawl
- ET = Total extent of urban sprawl

To express this as a percentage:

$$R = \frac{ET}{\text{number of years} \times 100}$$

Pattern indicators, including the shape change of the built-up area, fragmentation, and open space efficiency, as adopted from Siedentop and Fina (2008), was used to determine the pattern of urban sprawl.

Results and Discussion

Spatial Extent of Land Use/Land Cover Classes

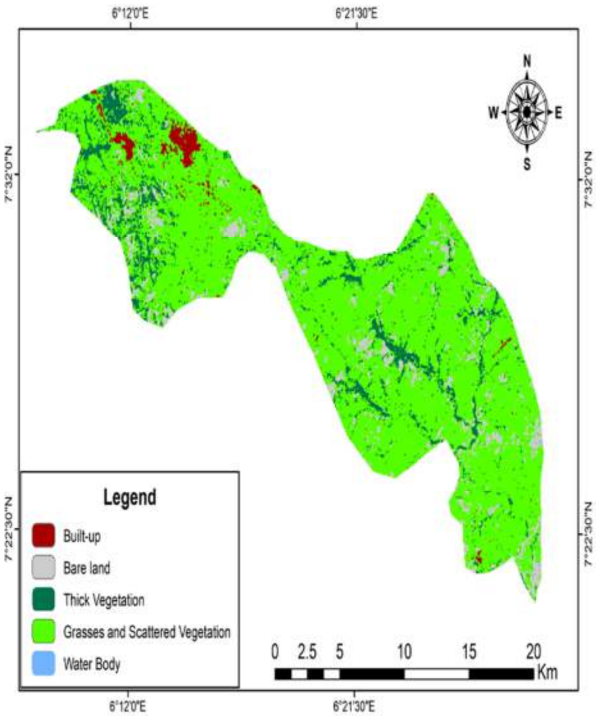
Table 3: Result of Classification of 1991, 2001, and 2021 Images

S/N	LAND USE	AREA_1991 (Km2)	Percent (%)	AREA_2001 (Km2)	Percent (%)	AREA_2021 (Km2)	Percent (%)
1	Built-up	6.1	1.86	13.39	4.08	15.01	4.57
2	Bare land	25.47	7.76	18.87	5.75	48.65	14.82
3	Thick Vegetation	30.50	9.29	34.22	10.42	10.42	3.17
4	Grasses and scattered vegetation	266.21	81.08	261.81	79.74	254.15	77.41
5	Water body	0.053	0.02	0.041	0.01	0.038	0.01
	Total	**328.33**	**100**	**328.33**	**100**	**328.33**	**100**

Source: Author's analysis 2023

As depicted in Table 3, the built-up (urban) area has consistently expanded from 1.86% in 1991 to 4.57% in 2021. This trend aligns with findings from previous studies (Ade and Afolabi, 2013; Zubair et al., 2015; Owoeye and Akinluyi, 2018). Conversely, agricultural land, including grasslands and scattered vegetation, decreased from 81.08% in 1991 to 77.41% in 2021, indicating a conversion of agricultural land for other uses, consistent with observations by Nwafor (2006). Furthermore, dense vegetation and bare land exhibited fluctuations over the study period, likely influenced by urban expansion, development, and shifts in land use. This is evident in the fluctuating percentages of bare land, which decreased from 7.76% to 5.75% before rising to 14.82%.

Spatial Extent Visualizations



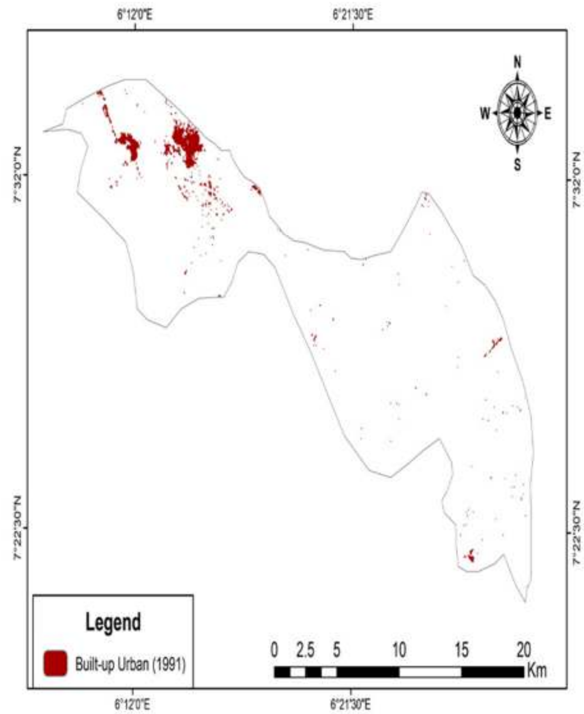
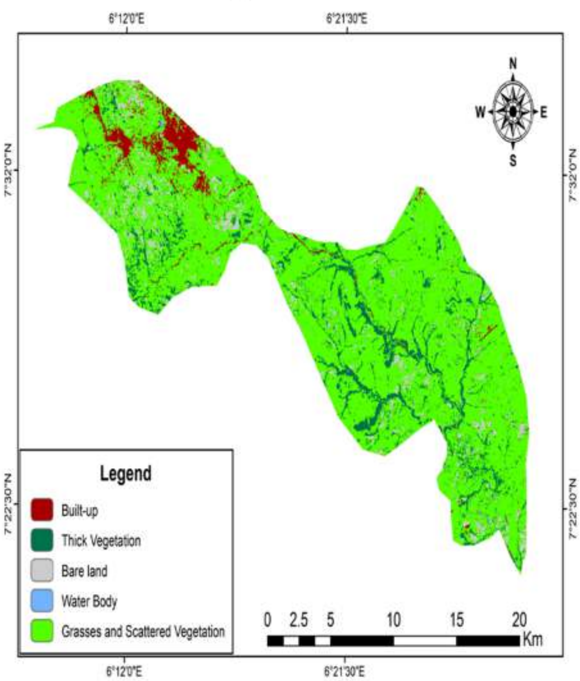


Figure 2: Spatial Extent of Land use/Land cover Figure 3: The Spatial Extent of Built-up/Urban Land in Okene 1991
Source: Authors Analysis, 2023



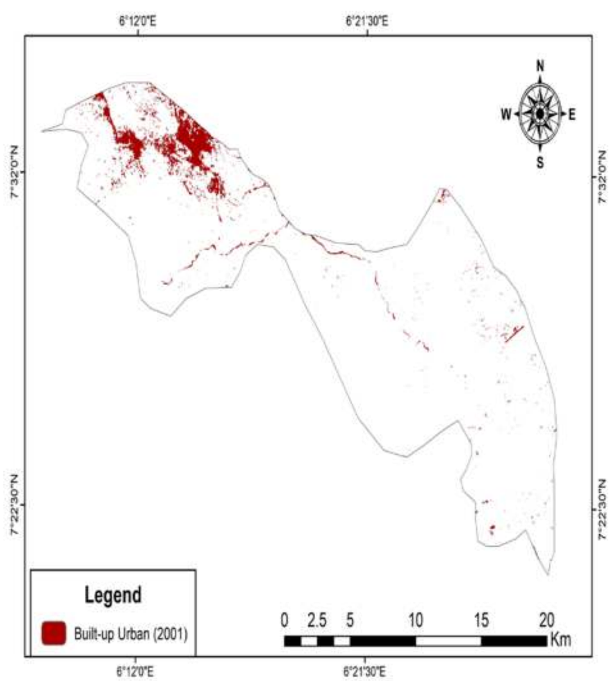
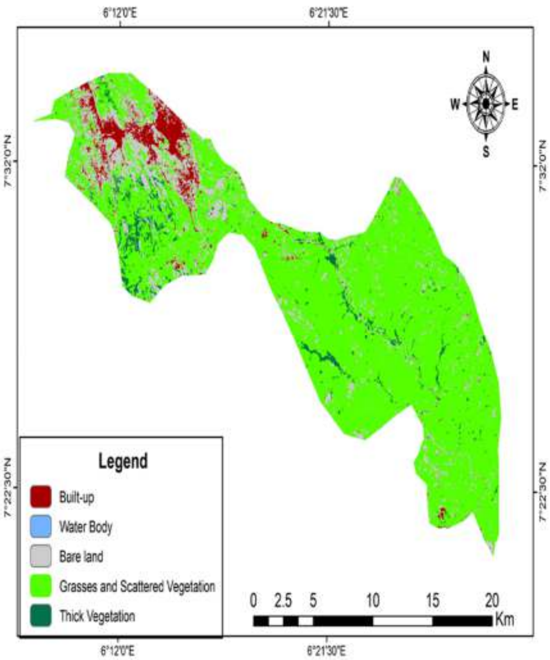


Figure 3: Spatial Extent of Land use/Land cover Figure 4: The Spatial Extent of Built-up/Urban in Okene 2001.

Source: Authors Analysis, 2023



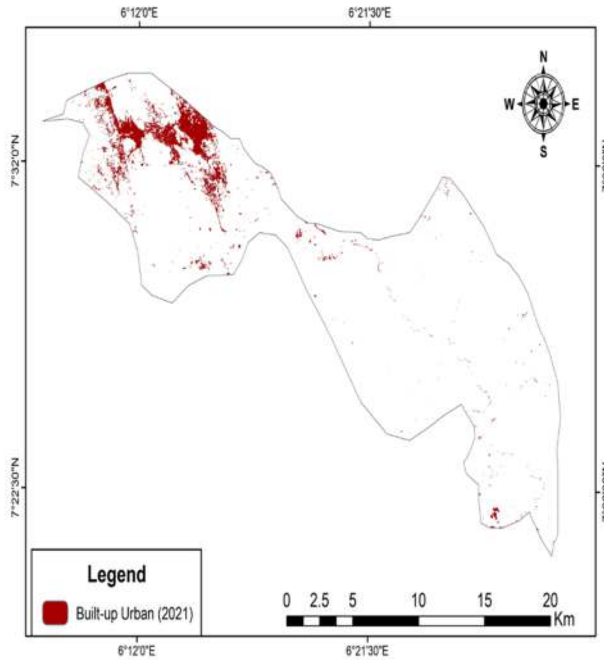


Figure 5: Spatial Extent of Land use/Land cover. Figure 6: The Spatial Extent of Built-up/Urban in Okene 2021.

Source: Authors Analysis, 2023

The analysis indicates a significant increase in the extent and rate of urban sprawl in the study area. As illustrated from 1991 to 2001, the area experienced a sprawl of 2.22 km² (119.35%) at an annual rate of 19.94%, representing the highest sprawl within the study period. Between 2001 and 2021, the sprawl slowed to 0.49 km² (12%) at an annual rate of 0.6%. Overall, from 1991 to 2021, urban land sprawled by 145.70% at an annual rate of 4.86%. Figure 7 illustrates the extent of urban sprawl in the study area. Similarly, in their 2008 study analyzing urban-rural land-use changes from 1995 to 2006 and the policy-driven forces behind these changes in Chongqing, China, Long et al. observed a reversal in the trend of forested land, with an increase of 0.11% during the study period. Although urban and rural settlements and construction land also showed an upward trend, their rates of change were relatively slow.

Extent and Rate of Urban Sprawl in Okene

The extent of urban sprawl is described in terms of changes (increase) in the built-up area over the years. Table 3 shows the extent and rate of urban sprawl in Okene.

Table 3: The Extent Rate of Urban Sprawl in Okene LGA.

Period	**Urban**		**Extent of Urban Sprawl**		**Rate of Urban Sprawl**	
	Year	**(Km^2)**	**(Km^2)**	**%**	**Km/Year**	**%/Year**
1991-2001	1991	1.86	2.22	119.35	0.22	19.94
(10 Years)	2001	4.08				
	2001	4.08	0.49	12	0.025	0.6
2001-2021	2021	4.57				
(20 Years)	1991	1.86	2.71	145.70	0.090	4.86
	2021	4.57				
1991-2021						
(30 Years)						

Source: Author's Analysis, 2023

This research revealed significant growth in urban land use over the study period. From 1991 to 2001, the urban land area expanded significantly in the study area. Initially covering 6.1 km², which accounted for 1.86% of the total area, it grew to 13.39 km² by 2001, representing 4.08%. This marked a notable increase over this decade. In 2021, urban land use continued to expand, reaching 15.01 km², or 4.57% of the area. Between 1991 and 2001, the urban area expanded by 2.22 km², a significant 119.35% increase. The pace of expansion slowed from 2001 to 2021, adding 0.49 km², which reflects a 12% increase over two decades. Overall, from 1991 to 2021, the urban area grew by 2.71 km², amounting to a 145.70% increase. Analyzing the annual rate of urban sprawl reveals further insights. From 1991 to 2001, the annual rate averaged 0.22 km², corresponding to a 19.94% increase each year. The rate slowed considerably from 2001 to 2021, averaging 0.025 km² annually, or 0.6%. Across the entire 30-year period, the annual rate of urban sprawl was 0.090 km², translating to a 4.86% increase per year on average.

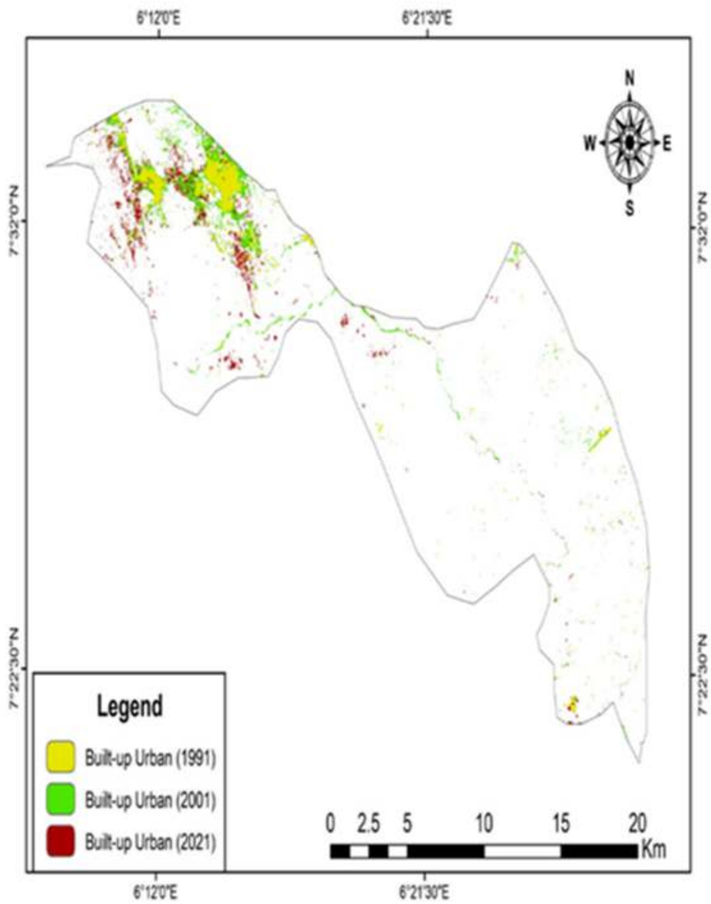


Figure 7: Spatial Extent of Urban Sprawl.

Conclusion

The results indicate a considerable increase in urban land use in Okene LGA over the past three decades, driven by population growth and increased developmental activities. The expansion has led to a substantial loss of vegetation and agricultural lands. These findings underscore the need for sustainable urban planning and land management strategies to balance development with environmental conservation. The application of GIS and Remote Sensing techniques proved effective in monitoring urban sprawl and provides valuable insights for policymakers and urban planners. By highlighting the extent of urban sprawl and its impact on land use, this study contributes to the broader understanding of urbanization patterns in developing regions and emphasizes the critical need for strategic planning in managing urban growth.

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