# A Study of Urban Growth Model in Nigeria Using Geospatial Approaches: A GIS-Based Methodologies

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## ABSTRACT

The study examines the application of geospatial methodologies in urban growth modeling within Nigeria's cities. It underscores the vital role of Geographic Information Systems (GIS) techniques in understanding rapid urbanization for informed decision-making and sustainable development. The study analyzed various GIS-based modeling methods, comprising Cellular Automata (CA)-Markov models, Analytical Hierarchy Process (AHP), and Multi-Criteria Evaluation (MCE), demonstrating their utility in assessing urban growth patterns and facilitating urban planning. It further highlighted the importance of integrating GIS with remote sensing technologies to enhance the accuracy and applicability of urban growth models. However, despite the potential of these tools, several challenges, such as limited access to reliable data and technical expertise, hinder their widespread adoption. Therefore, the paper recommends enhanced collaboration among researchers, policymakers, and communities to overcome these barriers and leverage geospatial technologies for improved urban management and sustainable urban development.

**Keywords:** Urban Growth; Geospatial Techniques; Land Use/Land Cover; Urban Planning; Sustainable Development

## INTRODUCTION

Urban growth and expansion are a complex and dynamic process influenced by numerous socio-economic, environmental, and political considerations (Abdullahi et al., 2017; Auwalu et al., 2021; Mahtta et al., 2022). In recent years, cities have expanded globally at an unprecedented rate, with the challenges of 21st-century urbanization becoming a subject of great concern. The United Nations (2018) estimates that by 2050, two-thirds of the global populace will reside in urban centres. In many developing countries, such as Nigeria, the consequences of rapid urbanization will have profound implications for sustainable growth, infrastructure development, and environmental planning (Auwalu & Bello, 2023; Olubi & Fadamiro, 2022). Nigeria, which is Africa's most populous country, is experiencing one of the fastest urban expansion rates on the continent (Farrell, 2018). Its major cities, comprising Lagos, Abuja, and Kano, have witnessed exponential development driven by economic transformations, rural-urban migration, and population growth (Auwalu et al., 2023; Unah & Okopi, 2021). Lagos, for example, has grown from just over 1.4 million people in 1970 to over 22 million today, making it one of the largest megacities in the world. Similar trends can be observed in cities such as Abuja, Kano, Port Harcourt, etc. The rapid urban expansion of these cities has yielded economic opportunities with several challenges that include infrastructural pressure, housing deficit, environmental degradation, and unregulated alteration of urban land uses (Enoguanbhor, 2021; Essien, 2023). Therefore, to overcome these challenges, urban growth modelling has become a vital tool for urban planners and policymakers (Korah et al., 2024)It allows for monitoring, analyzing, and predicting future patterns of urban LULC scenarios. Therefore, a comparative evaluation of how different modeling approaches perform in diverse urban contexts is vital.

Geospatial approaches comprising Geographic Information Systems (GIS) and remote sensing techniques have revolutionized urban growth modelling (Chaminé et al., 2021; Elangovan & Krishnaraaju, 2023). It provides the spatial data needed for the mapping and analyses of the dynamics of urban growth. Over the years, GIS-based modelling methods that include Cellular Automata (CA), the Markov Chain (MC), and Multi-Criteria Evaluation (MCE) have been utilized in several studies globally for modelling future patterns of urban development (Azabdaftari & Sunar, 2024; Ghosh et al., 2017; Mithun et al., 2022). However, the utilization of these methods remains limited in Nigeria. A critical examination of why these methods are underutilized in Nigeria would enhance the depth of the study. Therefore, this paper examines the utilization of GIS-based urban growth models in Nigeria, reviewing the methodologies used and the insights they provide for understanding and managing urban LULC. The study also highlighted the potential of geospatial tools in addressing urbanization challenges in Nigeria's cities and provided recommendations for improving urban growth modelling and planning.

**Urban Growth in Nigeria**

Like many developing countries, Nigeria's urban growth is driven by demographic, economic, social, and political factors (Ojo & Ojewale, 2019). With an estimated population of over 220 million in 2024, Nigeria is Africa's most populous country, having one of the fastest urbanization rates globally (United Nations, 2018). The rapid urbanization and unplanned expansion of Nigeria's major cities are among the most pressing issues facing urban centres (Auwalu & Bello, 2023). This urbanization is often associated with the gradual movement of people from rural to urban areas due to industrialization and economic growth. Lagos city has been at the forefront of this rapid urbanization. With a population of over 20 million, Lagos City embodies the challenges and opportunities of urban growth in Nigeria. Other major cities such as Abuja, Kano, and Port Harcourt are also experiencing fast-paced growth due to various physical, environmental, and socio-economic factors. These cities have experienced population increases, better employment opportunities, education, and healthcare services (Morse & MacNamara, 2020; Mustapha et al., 2023). Despite the potential of urbanization to drive economic development and improve living standards, the rapid urban growth of Nigeria's cities has presented numerous challenges that could hinder the country's development trajectory (Olubi & Fadamiro, 2022). Such challenges relate to inadequate infrastructure, weak urban governance, environmental degradation, poverty, and city inequality (Abubakar & Aina, 2019; Ogunkan, 2021). A more thorough exploration of the socio-economic and financial constraints of implementing GIS-based solutions is necessary to contextualize these challenges. Therefore, this review offers valuable insights into how GIS modelling techniques can be utilized to manage Nigeria's rapidly urbanizing landscape while highlighting potential areas for future research.

## RESEARCH METHODOLOGY

The review adopted a systematic approach to gathering and analyzing literature, case studies, and relevant research papers on urban growth modelling. Secondary data were obtained from studies conducted in Nigeria using GIS-based modelling techniques. The research critically evaluated the different methodologies applied to the GIS-based urban growth modelling, drawing insights from prominent case studies conducted in Nigeria's cities such as Lagos, Abuja, and Kano to identify the best measures for achieving sustainable urban development. Only studies published within the last decade were analyzed to ensure relevance, specifically focusing on more recent work reflecting advancements in geospatial technologies. This paper further evaluated the case studies for their use of GIS in understanding urban sprawl, land-use change, and environmental impacts.

## RESULTS AND DISCUSSION

**Geographic Information System (GIS) For Urban Growth Modelling**

Geographical Information Systems (GIS) methodologies have become integral to urban growth modelling and management. It comprises computerized software, hardware, and data that manipulates, analyses, and presents information related to the earth's surface (Ershad & Ali, 2020). The complex GIS approaches help combine spatial data with analytical capabilities, enabling urban planners, researchers, and policymakers to visualize, analyze, and interpret sophisticated geographical patterns and relationships (Xhafa & Kosovrasti, 2015). It employs computer technology to process geographic data, producing digital information and maps. GIS techniques help develop spatio-temporal maps regarding changes in LULC (Mehra & Swain, 2024). Information on urban land use changes, as well as urban growth and expansion, is vital to urban planners,

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government authorities, and decision-makers in developing strategies for sustainable urban development (Iduseri et al., 2024). Therefore, GIS is useful for problem-solving, decision-making, and data visualization in a spatial context.

In the context of urban growth, GIS methods provide the vital tools needed to understand how cities expand and identify the trends and drivers of urban expansion. It provides visualization tools for creating maps and other visual representations of data that aid spatial querying, overlay analysis, and buffer analysis (Reddy, 2018; Rocha et al., 2023). Also, GIS helps assess the impact of 21st-century urbanization on the environment and supports decision-making processes through modelling future LULC (Murayama et al., 2021). Several spatial models have been utilized in Nigeria to model urban growth and predict spatial land-use changes. These models aided the simulation of different urban growth scenarios based on varying assumptions about population growth, land use policies, and various environmental factors. Such models include the CA-Markov Model, Analytical Hierarchy Process (AHP) Model, Multi-Criteria Evaluation (MCE) Model, and Integrated GIS-Remote Sensing Model.

## Cellular Automata (CA)-Markov Model

Cellular Automata (CA) models have been utilized over the years for local and regional studies in environmental modelling for urban land use/land cover (LULC) planning and management (Gaur & Singh, 2023; Xu et al., 2023; Yeh et al., 2021). According to Cosentino et al. (2013), Cellular Automata is a mathematical model developed in the 1940s by John von Neumann and Stanislaw Ulam, which simulates urban growth based on the local interactions between the cells representing different LULC classes (Yang et al., 2023; Zeng et al., 2024). Despite the CA models considering spatial factors such as population density, land suitability, and transportation networks, they cannot depict cities' micro-scale economic, social, and cultural drivers. The integration of CA models with GIS techniques enhances the model's descriptive ability (Musikhin & Karpik, 2023). The CA models are developed using geospatial approaches, which help store spatial information in GIS databases during the modelling process. Therefore, such a model is vital for monitoring the future change dynamics of urban land uses.

CA-Markov has been utilized in Nigeria to predict LULC change in rapidly growing cities such as Lagos and Abuja (Ibrahim et al., 2016; Koko et al., 2021). The model was employed to identify spatial interactions and simulate the different urban land cover classes. CA-Markov plays a vital role in modelling and assessing LULC change dynamics across specified time nodes, providing the scientific basis for predicting future LULC patterns (Azabdaftari & Sunar, 2024). In a study conducted by Aburas et al. (2021), the accuracy of the CA-Markov model was validated by comparing actual and simulated maps using the Kappa statistical index. The kappa index assesses the consistency between a graded image or map and reference data using the Kappa coefficient presented in Table 1, which defines the different values of Kappa statistics (Viera & Garrett, 2005).

Table 1: Description of Kappa Statistical Values

| S/No | Kappa Co-efficient | Description |
|---|---|---|
| 1 | < 0.00 | Less than chance Agreement |
| 2 | 0.00 – 0.20 | Slight Agreement |
| 3 | 0.21 – 0.40 | Fair Agreement |
| 4 | 0.41 – 0.60 | Moderate Agreement |
| 5 | 0.61 – 0.80 | Substantial Agreement |
| 6 | 0.81 – 1.00 | Almost perfect Agreement |

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In a study conducted in Lagos City, Nigeria, Amaechi et al. (2024) employed the CA-Markov model to simulate the study area's land cover using ENVI 5.3 and IDRISI 17.0 software. The result demonstrated the strong ability of the CA-Markov to model future LULC, having a Kappa value between 0.86 and 0.83 and an overall accuracy between 89.87% and 87.50%. Six LULC classes were mapped and analyzed between 2002 and 2022 and further simulated from 2022 to 2050, as shown in Figure 1.

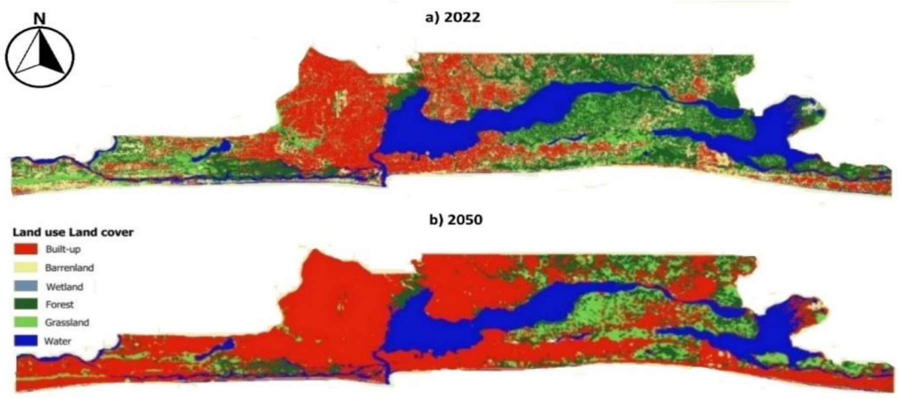


Figure 1: (a) Actual Land Use Land Cover (LULC) Mapping for Lagos, Nigeria, in 2022 and (b) Simulated LULC Mapping for Lagos, Nigeria, in 2050. Amaechi et al (2024)

The findings suggest an increase of 18.4% in urban areas over the next two to three decades, while forest areas are projected to decrease by 7.6%. Grassland is also expected to decrease by 7%, and wetland will slightly decline by 1.5%, with waterbodies decreasing by 3%. The Cellular Automata (CA) and Markov have also been utilized to analyze urban growth and land use change while simulating the likely land-use patterns expected to emerge in cities such as Abuja and Kano (Enoguanbhor, 2021; Koko et al., 2022). Amaechi et al. (2024) also utilized the integrated cellular automata (CA)-Markov module from IDRISI-TerrSet to forecast the land use and land cover changes of Nigeria's Federal Capital Territory, i.e., Abuja. The results estimate that the city will experience an urban growth of 182.93 sq. km over 28 years, i.e., in 2050. Between 2022 and 2050, as demonstrated in Figure 2, the study projected an increase in grassland, barren land, and waterbodies by 237.91 sq. km, 119.20 sq. km, and 1.75 sq. km, respectively. Meanwhile, Shrubland, wetland, and forest areas will decline by approximately -499.51 sq. km, -99.94 sq. km, and -39.78 sq. km, respectively. These findings necessitate controlling urban growth to achieve Goal 11 of the United Nations Sustainable Development Goal (SDG), which seeks to make cities inclusive, safe, and resilient.

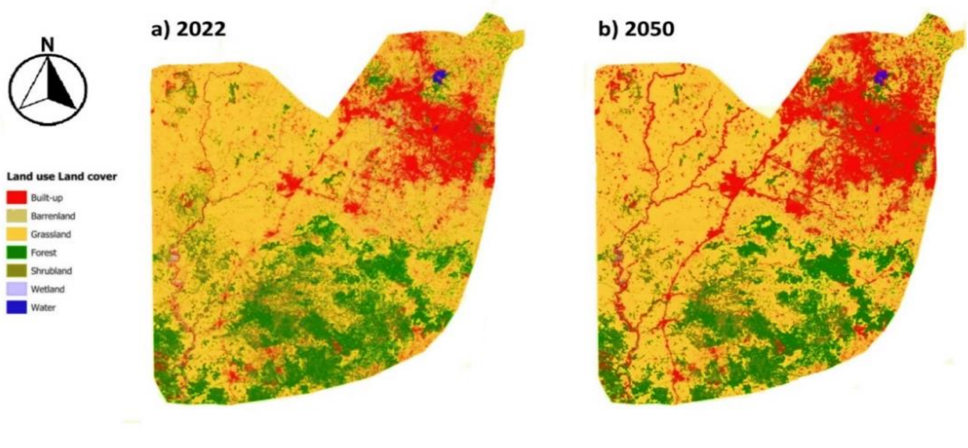


Figure 2: (a) Actual Land Use Land Cover (LULC) Mapping for Lagos, Nigeria, in 2022 and (b) Simulated LULC Mapping for Lagos, Nigeria, in 2050. (Amaechi, Ugwu, et al., 2024)

**Analytical Hierarchy Process (AHP)**

Initially developed by Saaty in 1991, the Analytical Hierarchy Process (AHP) method is recognized as a well-established approach for determining land suitability using GIS-based techniques (Makkulawu et al., 2023).

The AHP employs the analytical capabilities of GIS in assessing the various weight factors that influence urban growth. The weight factors are often derived using a preference matrix known as a pairwise comparison matrix that compares all specified criteria against each other. In a recent study conducted by Odiji et al. (2024), a pairwise comparison matrix was utilized to derive the weights of the competitors of the land resources in Benue, Nigeria, based on their suitability for future changes. The consistency ratio (CR) was determined based on land use competitors on the comparison matrices. The AHP was then employed to rank and weight the three major land-use competitors of the study area comprising settlement, agriculture, and conservation, as presented in Table 2. A consistency ratio of less than 0.10 indicates a reasonable consistency in pairwise comparisons, which in this case was 0.056.

Table 2: Pairwise comparison of three land use competitors in Benue, Nigeria

| **LULC Competitors** | **Settlement** | **Agriculture** | **Conservation** | **Weight** |
|---|---|---|---|---|
| Settlement | 1 | 4 | 5 | 0.665 |
| Agriculture | 0.25 | 1 | 3 | 0.231 |
| Conservation | 0.2 | 0.33 | 1 | 0.103 |
| **CR = 0.056** | | | | |

Source: Odiji et al. (2024)

The results further revealed forest areas and grassland as the most degraded classes of land use. Cropland had a coverage of 33.2% in 1980, which increased to 69.79% in 2020 and is expected to rise to 83.45% in 2040. These findings suggest a high potential for land use conflict in 29% of the land area in Benue, while 16% of the land is at a very high risk of conflict. Moreover, agricultural areas and conservation land are anticipated to have the most significant areas of possible conflict in Benue, accounting for 5.38% of the study area. Therefore, urban planners, policymakers, and other stakeholders can significantly benefit from using the analytical hierarchy process modelling in mitigating potential land conflicts by ensuring sustainable urban development, as demonstrated in previous studies.

**Multi-Criteria Evaluation (MCE)**

MCE is a decision-making framework that evaluates multiple criteria to determine land suitability for various purposes (Zhao et al., 2024). By incorporating factors such as social, economic, and environmental variables, the multi-criteria evaluation can aid in sustainable planning and urban development (Singh et al., 2022). It is often integrated with GIS techniques to evaluate and prioritize LULC categories based on different land use criteria. The GIS-based MSE combines spatial mapping and decision-making preferences to assess likely outcomes (Gelan, 2021; Masoudi et al., 2021). The MCE prioritized land in Nigerian cities for development, conservation, and infrastructural growth. In a study by Ajala et al. (2023), the GIS-MCE techniques were used to identify potential areas for arable cropping in Kwara State, Nigeria. This analysis employed five factors based on weights determined by pairwise comparison comprising the soil depth (0.50), rainfall (0.30), temperature (0.10), slope (0.10), and elevation (0.02). All criteria or factors were combined using a weighted linear combination (WLC) approach to produce a land suitable for agricultural purposes, as presented in Table 3.

Table 3: Land Areas Suitable for Agricultural Purposes in Kwara.

| **S/No** | **Category of Land Suitability** | **Areas (hectares)** | **Coverage (%)** |
|---|---|---|---|
| 1. | Highly Suitable | 450,432 | 11.40 |

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| | | | |
|---|---|---|---|
| 2. | Moderately Suitable | 592,302 | 19.3 |
| 3. | Marginally Suitable | 1,136,354 | 30.40 |
| 4. | Presently not Suitable | 945,237 | 23.12 |
| 5. | Permanently not Suitable | 476,345 | 15.78 |
| | **Total** | 3,600,670 | 100.00 |

Source: Ajala et al. (2023)

Therefore, using GIS and MCE is a valuable method that helps urban planners and decision-makers implement sustainable urban land use (Rahman & Szabó, 2022). Studies that employed the GIS-based MCE in identifying suitable residential development help urban planners, and policymakers manage competing demands for land in rapidly urbanizing areas by controlling urban expansion using a strategic and sustainable approach.

**Integration of GIS and Remote Sensing**

The utilization of remote sensing techniques extends beyond satellite-based sensors. It encompasses digital and traditional photogrammetric methods that employ aerial photographs to acquire spatial data (Chaminé et al., 2021; Yin et al., 2021). Over the years, remote sensing has provided high-resolution spatial and temporal datasets for analyzing urban land use and land cover (LULC). The availability of these high-resolution datasets for Earth observation has established remote sensing as an essential tool in urban planning and environmental monitoring. Satellite platforms, such as MODIS, WorldView, RapidEye, Sentinel, and the Landsat series, have offered extensive spatial data that support urban planning initiatives (Hoffman & Lemper, 2018). In addition, integrating remote sensing with Geographic Information Systems (GIS) has significantly enhanced the monitoring and detection of LULC change dynamics across various local and regional scales, providing valuable resources for balancing developmental interests and conservation measures (Mehra & Swain, 2024). This integration has been instrumental in studies that map urban areas, analyze and model urban growth, and assess land use and cover changes. For example, in a study by Gilbert and Shi (2024), satellite images and other indices such as NDBI, NDVI, and BUI were used to track the dynamics of urban expansion in Lagos City, Nigeria, using various remote sensing and GIS methods. The study employed three images of the area for 2000, 2010, and 2020, acquired using different satellite sensors. The results produced the LULC maps illustrating different land use classes for the study period. Also, the study area's urban expansion was examined using the built-up area maps of Lagos presented in Figure 3.

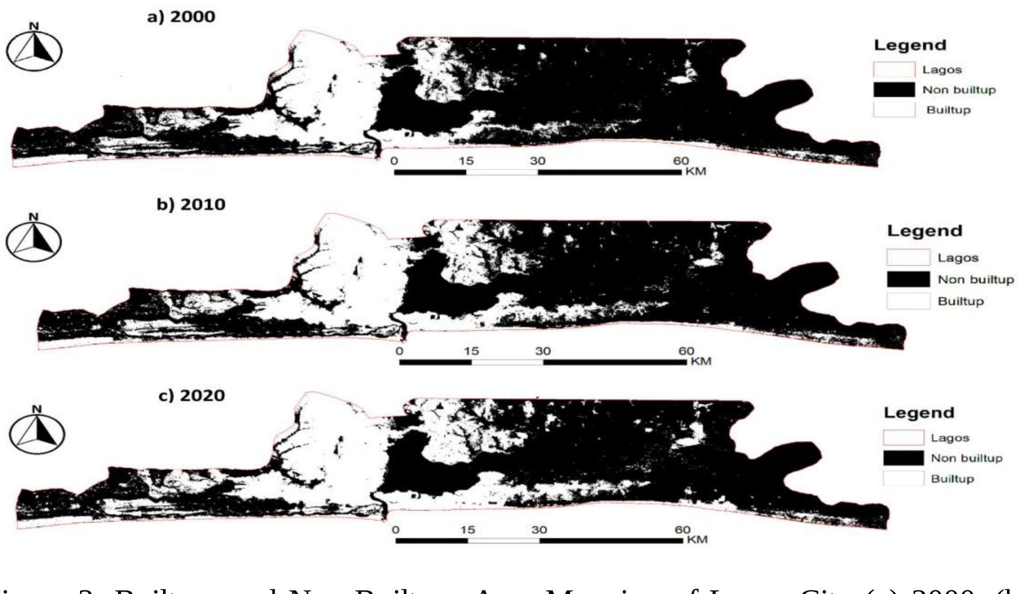


Figure 3: Built-up and Non-Built-up Area Mapping of Lagos City (a) 2000, (b) 2010, and (c) 2020. Source: Gilbert and Shi (2024)

The results indicated an increase in artificial terrain from 17.02% in 2000 to 25.21% in 2020. Hence, these findings suggest significant growth and development in the built-up areas of Lagos between 2000 and 2020. Also, the study analyzed other classes of land use, and the area of cultivation land increased from 1.24% in 2000 to 2.00% in 2020. Grasslands declined significantly from 7.839% to 1.875%, while forest areas increased from 39.319% to 43.081%. Marshes areas and shrublands decreased from 9.79% to 5.65% and 4.42% to 2.64% respectively. Based on these outcomes, geospatial methodologies provide a new perspective to monitoring LULC changes in the face of rising urbanization, helping urban planners and policymakers with the scientific basis for informed decision-making tools.

## CONCLUSIONS

The findings of this study demonstrate the ability to utilize various GIS-based urban growth models as an effective approach to remedying the environmental impact of rapid urbanization in urban centres and cities by providing a simulation tool for the mapping and prediction of future land use/land cover (LULC) patterns and its changes. The integration of GIS-based models, such as the CA-Markov models, Analytical Hierarchy Process (AHP), and Multi-Criteria Evaluation (MCE), with remote sensing techniques validate the accuracy and reliability of these predictive models. Such methodologies have provided urban planners and policymakers with vital tools for making informed decisions and offering more effective strategies to promote sustainable urban development. However, Despite the efficiency of GIS-based prediction models, the present study underscores the importance of continued research into the application of GIS and urban growth models. By expanding this body of knowledge, researchers can enhance the understanding of how GIS can be leveraged to systematically address specific challenges posed by changes in LULC. This will help recommend different strategies for the various stakeholders in urban centres and cities while raising awareness of the potential of GIS to support long-term, sustainable urban planning efforts.

**Conflicts of Interest:** The authors declare that there is no conflict of interest

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