

Analysis of Urban Growth and Population Density: A Case Study of Abuja Municipal Area Council (AMAC)

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Abstract: This study explores urban growth and population density dynamics in the Abuja Municipal Area Council (AMAC), Nigeria, using Geographic Information Systems (GIS), Remote Sensing, and data science techniques. Satellite imagery from NigeriaSat-X and Gaofen-1 for the years 2013 and 2021 was classified using a Support Vector Machine (SVM) algorithm to produce land use/land cover (LULC) maps, achieving overall accuracies of 87% and 89% respectively. Post-classification change detection revealed a decrease in barren land from 72% to 55% and an increase in developed land from 22% to 28%, indicating significant urban expansion. Population density was estimated using a geometric growth model, rising from 983.05 persons/km² in 2013 to 2169.80 persons/km² in 2021, a 121% increase. Ordinary Least Squares (OLS) regression analysis was employed to examine the relationship between population density and the working-age population (15–65 years), yielding R² values of 0.90 and 0.91 for 2013 and 2021 respectively, indicating strong positive correlations. The annual population growth rate was estimated at 10.40% for the general population and 10.34% for the working-age group.

Keywords: Abuja; AMAC; GIS; OLS regression; population density; remote sensing; urban growth; working-age population.

I. INTRODUCTION

A. BACKGROUND OF THE STUDY

Urbanization, the process by which cities expand and populations increasingly migrate from rural to urban areas [1], has become a global phenomenon driven by industrialization and economic opportunities. Urbanization in Nigeria reflects global trends, especially in Abuja, where economic opportunities attract an influx of people from rural areas. Rapid urban expansion and increased population density present challenges for sustainable development. Urban sprawl often leads to unplanned settlement patterns [2], causing an expansion of the urbanized land cover known as urban growth, which affects infrastructure, environmental sustainability, and social services. Abuja's development trajectory necessitates understanding urbanization patterns and population dynamics to inform effective urban policies.

B. AIM AND OBJECTIVES

The study aims to analyze the relationship between population density and urban growth in AMAC, with an emphasis on the influence of the working-age population on urban expansion. Key objectives include:

- Mapping built-up areas and urban growth from 2013 to 2021 using GIS and Remote Sensing data.
- Analyzing population density trends and estimating annual growth rates.
- Examining the correlation between population density and the working-age population through OLS regression analysis.

C. JUSTIFICATION OF THE STUDY

This research contributes to the fields of urban studies, population density analysis, and sustainable development. By integrating GIS and Remote Sensing with data science, this study provides insights into the drivers of urban growth, informing policymakers and urban planners about effective strategies to manage rapid urbanization.

II. LITERATURE REVIEW

The literature reviewed for this study discusses urbanization patterns in developing nations, the use of GIS and Remote Sensing for urban monitoring, and population density trends in fast-growing urban centres. The study builds on previous research by employing modern data science techniques, including OLS regression, to analyze the spatial and demographic interactions in AMAC. Studies show that high population densities, especially in economically active populations, correlate with rapid urban expansion, emphasizing the need for sustainable urban planning to balance growth with environmental preservation [3]–[6].

III. METHODOLOGY

A. STUDY AREA

AMAC, within the Federal Capital Territory (FCT) of Nigeria, located at an elevation of 840 meters (2,760 feet) above sea level and at latitude 9.07°N and longitude 7.48°E, serves as the study area. It has a moderate climate due to its elevation and tropical location. With its rapid urban growth and expanding population, it serves as an ideal location to examine urbanization dynamics and the influence of population density on land use. AMAC has experienced significant shifts in its built environment due to the migration of people from surrounding rural areas.

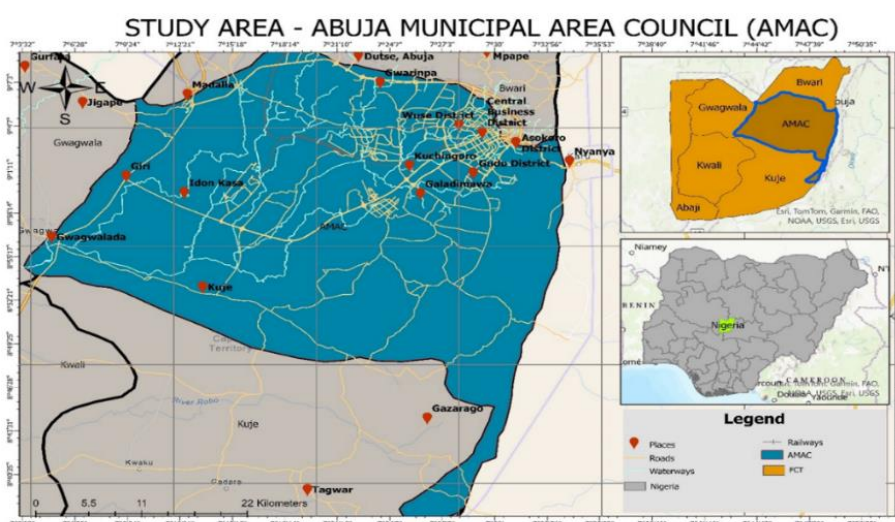


Fig. 1. Abuja Municipal Area Council

B. DATA ACQUISITION

Data for this study include satellite imagery and demographic information. Satellite images from NigeriaSat-X and Gaofen-1 (part of the Chinese Land Satellite Remote Sensing Application Centre – LASAC) for the years 2013 and 2021 were sourced from NASRDA, with boundary and population data obtained from the National Population Commission (NPC) and the U.S. Census Bureau.

C. IMAGE PROCESSING

Digital image processing was applied to classify land use and land cover (LULC) within the study area. Using ArcGIS Pro, a supervised classification algorithm (Support Vector Machine) distinguished urban, barren, water, and shrubland areas. Support Vector Machine can achieve strong classification accuracy with high-dimensional data even with a small training dataset [7, p. 1010]. The classification accuracy was assessed through a confusion matrix, yielding overall accuracies of 87% and 89% for 2013 and 2021, respectively, since generally, accuracy ratings over 80% are considered good, particularly in challenging classification problems [8].

D. CHANGE DETECTION ANALYSIS

Post-classification change detection techniques were used to compare land use patterns between 2013 and 2021. This approach identifies transitions in land cover and quantifies urban expansion, particularly changes in developed and barren land areas.

E. POPULATION DENSITY AND GROWTH ESTIMATION

Population density was calculated using the formula:

$$D_j = P/A_j \quad (1)$$

where D_j is the density of people, P is the total population, and A_j is the total area of land populated by people. This was derived from statistical modelling techniques used in land use correlation, which aim to increase accuracy by correlating population figures with different land use classifications [9]. Growth rates were derived using the geometric growth model:

$$P_t = P_0 \times (1 + r)^t \quad (2)$$

to project populations for 2013 and 2021 based on census data from 2006 and estimates from 2020.

F. ORDINARY LEAST SQUARES REGRESSION ANALYSIS

OLS regression was employed to analyze the relationship between population density and the working-age population (15–65 years). High R^2 values of 0.90 and 0.91 for 2013 and 2021, respectively, indicate strong correlations, emphasizing the influence of the economically active population on urban growth.

IV. RESULTS AND DISCUSSION

A. URBAN GROWTH AND LAND USE CHANGES

The analysis revealed significant changes in LULC within AMAC, particularly an increase in developed land from 22% to 28% and a decrease in barren land from 72% to 55%. This expansion reflects the region's rapid urbanization, fueled by economic opportunities that attract residents to AMAC. Fig. 2(c) illustrates an overlay of both the 2013 and 2021 vectorization, revealing the extent of urban growth between both years.

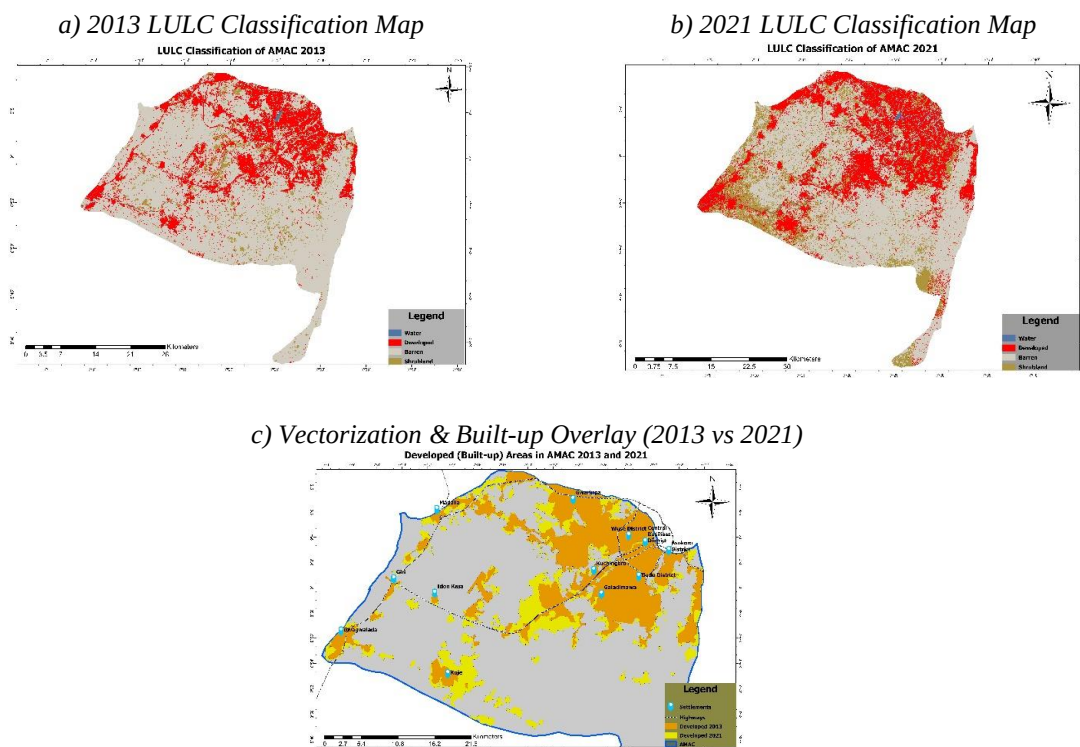


Fig. 2. LULC Classification and Vectorization of Built-up for 2013 & 2021.

B. POPULATION DENSITY ANALYSIS

Population density increased from 983.05 people/km² in 2013 to 2169.80 people/km² in 2021, indicating a 121% growth. This surge is largely attributed to the working-age population, which rose significantly during the study period. Fig. 3(a) and (b) illustrate this density increase in key urban areas within AMAC.

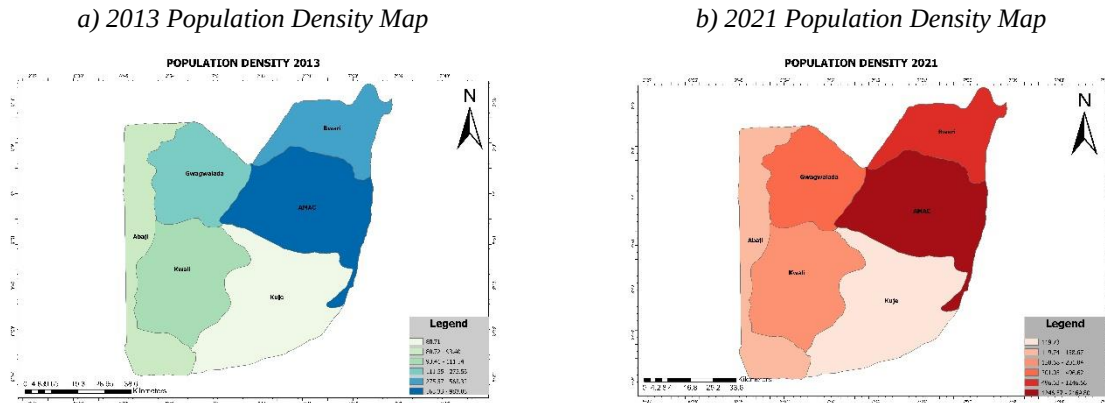


Fig. 3. Population Density Map of AMAC a) 2013 b) 2021

TABLE: I SUMMARY OF LAND USE/COVER CHANGE AND DEMOGRAPHIC METRICS (2013–2021)

Metric / Parameter	2013	2021	Observed Change
Barren Land Cover	72%	55%	-17% (Decline)
Developed Land Cover	22%	28%	+6% (Urban Expansion)
Classification Accuracy (SVM)	87%	89%	Reliable (>80%)
Population Density	983.05 persons/km ²	2169.80 persons/km ²	+121% Surge
Annual Growth Rate (General)	—	—	10.40% per annum
OLS Correlation (R ² vs. Working-Age)	0.90	0.91	Strong Correlation

C. REGRESSION ANALYSIS AND IMPLICATIONS

OLS regression analysis confirms a strong relationship between population density and the working-age population, with high explanatory power (R² values). This correlation suggests that economic activity among the working-age population significantly contributes to urban density and expansion. These findings align with other studies indicating that the working-age demographic is often the primary driver of urban growth in developing regions [3]–[6].

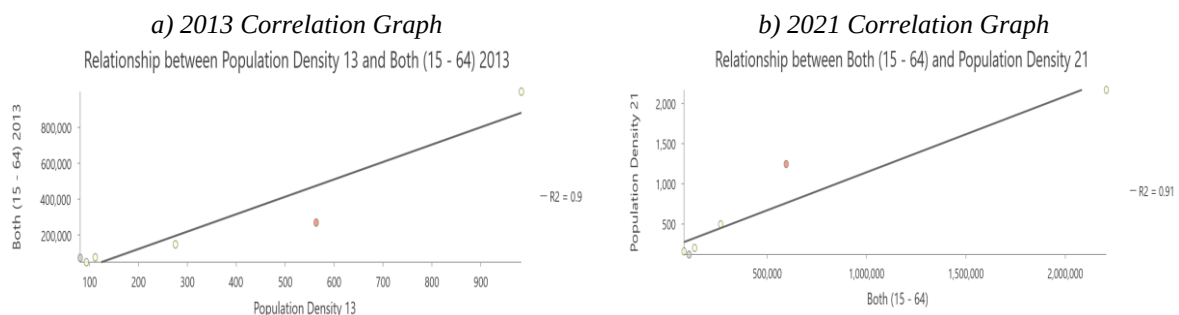


Fig. 4. Graphical representation of the correlations

D. IMPACT ON URBAN PLANNING

The implications of this study suggest that AMAC requires careful planning to manage urban growth sustainably. The significant land use change and high population density call for robust urban planning policies to address housing needs, infrastructure expansion, and environmental conservation. Sustainable practices, such as green building standards, efficient land use, and renewable energy adoption, are recommended to mitigate the environmental impact of urban expansion [10]–[12].

V. CONCLUSION

This study highlights the significant influence of the working-age population on population density and urban growth in the Abuja Municipal Area Council (AMAC), demonstrating that this demographic group is a primary driver of the observed urbanization trends. Through the integration of Geographic Information Systems (GIS), Remote Sensing, and data science techniques, the research has shown that population density in AMAC increased by 121% between 2013 and 2021, rising from 983.05 persons/km² to 2169.80 persons/km². The Ordinary Least Squares (OLS) regression analysis confirmed strong positive correlations between population density and the working-age population (15–65 years), with R² values of 0.90 and 0.91 for 2013 and 2021 respectively, indicating that this demographic is a statistically significant predictor of urban density.

The change detection analysis further revealed substantial land-use transformations, with barren land decreasing from 72% to 55% while developed land increased from 22% to 28% over the study period. These findings reflect the rapid pace of urbanization in AMAC, driven largely by economic opportunities that attract working-age individuals from surrounding rural areas. The annual population growth rate of 10.40% for the general population and 10.34% for the working-age group further underscores the urgency of addressing the challenges posed by this rapid expansion.

The implications of these findings are far-reaching. Rapid population growth and urban expansion necessitate sustainable urban planning strategies that balance development with resource optimization. Without proactive planning, the continued influx of residents into AMAC will place increasing strain on housing, infrastructure, transportation, and public services such as healthcare and education. Environmental sustainability is also at risk, as the conversion of barren land into developed areas reduces green spaces and alters local ecosystems.

These findings contribute to the broader understanding of urban dynamics in developing countries and underscore the importance of data-driven planning for managing population influx and resource demands. By demonstrating the effectiveness of integrating GIS, Remote Sensing, and regression analysis, this study provides a methodological framework that can be replicated in other rapidly urbanizing regions. Ultimately, the research highlights the need for policymakers to adopt evidence-based strategies that promote inclusive, resilient, and sustainable urban development in AMAC and similar contexts across Nigeria and the developing world.

VI. RECOMMENDATIONS

i. Strengthen Urban Planning and Land Use Management

Implementing comprehensive land-use policies is essential to manage rapid urban expansion effectively [13], [14]. These policies should prioritize balanced development, infrastructure improvements, and environmental preservation to support sustainable urban growth.

ii. Promote Sustainable Development Practices

Adopting green infrastructure and promoting environmentally friendly building materials are critical to reducing the ecological impact of urbanization [15]. These practices will help manage AMAC's growth while conserving natural resources.

iii. Establish Continuous Monitoring Systems

With rapid urbanization and increasing population densities, continuous monitoring of population and land use is necessary [16]–[18]. Regular updates to demographic data and LULC classifications will enable timely adjustments to urban policies.

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