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Integrating Remote Sensing and GIS-Based Map Analysis in Determining Spread of Built-Ups and Land-Use Dynamics of Terrain of Onitsha Metropolis, Anambra State, Nigeria

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Abstract: Land scarcity in most cases hampers development and encourages the misuse of land. The suitability of land must be considered before appropriating or allocating land for any use. Land supports the livelihood of every being on the Earth and therefore determines survival, success, and sustainability (sustainable living). This study aimed at integrating remote sensing and GIS-based analysis to determine the rate at which built-up areas have spread across the terrain of Onitsha Metropolis, Anambra State, Nigeria, and the dynamics of other land uses. This research involved both primary and secondary data. The primary data included measurements, direct field observations, and key informant interviews to understand people's perceptions of the land use in the area. The secondary data included satellite images of the area obtained from USGS and analyzed using ArcGIS 10.2 for variations in the terrain of the Onitsha Metropolis; to determine the land use and land cover change (LULCC) of the Onitsha Metropolis over 40 years, published and unpublished articles and books were also consulted. The geological analysis of the study showed that the area of the Ogwashi/Asaba formation is 318.57 km^2; the areas of the Nanka sands and Bende-Ameke are 423.07 km^2 and 259.42 km^2, respectively. The Nanka sands and Bende-Ameke formations are best suited for engineering construction purposes, while the Ogwashi/Asaba formation is suitable for agriculture and should be designated as a buffer zone or park. However, due to the unavailability of land as a result of the growing population and the proximity of the area to the city center, the area is being encroached upon, and a large area (about 30.40%) has been converted to built-up areas as of 2022. Forecast analysis showed that if the trend continues, 158.28 km^2 (49.68%) of the alluvium soils of the Ogwashi/Asaba formation will be covered with buildings by 2072. The geology and the terrain of the Onitsha Metropolis determine the soil characteristics and the land use suitability; mapping the geological formations and overlaying these with the land use and land cover change of the area revealed the extent of the encroachment on the Ogwashi/Asaba formation, which must be discouraged.

Keywords: map analysis; terrain; built-up; Onitsha Metropolis; Anambra State

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1. Introduction

Land is a resource that is very limited in supply. It is the foundation upon which other human activities are carried out [1–3]. Land is scarce in Anambra State. The influx of migrants into the state, which has occurred more in the Onitsha Metropolis axis, is consequently increasing the population of the state in general and the Onitsha Metropolis in particular, straining the existing infrastructure as well as the land itself. This tension is gradually being transferred to the land due to the activities of the owners and developers of land, who are driven by desires to make profits. It has been stated that the interaction between physical land variables such as slope and soil particles is determined through their control of ground loss processes and rates as well as the suitability of the landscape for all human activities, including urban development [4]. Depending on the geological history of a studied area, detailed observation and mapping may be needed because old fault lines can reopen by crustal movements and new fault lines may develop [5]. Consequently, by neglecting the above-mentioned possibilities, urban growth and development may result in a catastrophic disaster in the future; hence, there is a need for corrective measures and factors to be identified during the predevelopment, development, and post-development analysis stages of any urban area.

While global conferences have been calling for predevelopment sustainability verifications in all climes [6–11], compliance with the doctrine is not yet common. The spatial patterns of natural disasters suggest that cities may be situated in locations that were safe but later turned to be unsafe, or no surveys or incomplete surveys were carried out before the development of the cities in question. Whether a city is favorable and safe for lives and investment is beyond the realm of law-making; rigorous predevelopment evaluation is needed to allocate land uses only to suitable land parcels. The land allocation master plans need to be enforced, and continuous post-development monitoring is required for the early detection of impending hazards and disasters that may affect the cities and their populations. An assessment of the compliance of the city-controlling authorities concluded that, in Nigeria, the authorities are 'long on laws and short on compliance', and this shortcoming largely explains the current trend in the consequences that have resulted from climate-change-related floods in various parts of the country, gully erosion, landslides, and earth tremors in Abuja, and scattered building collapse cases in many states in Nigeria [12–14].

Many studies have been carried out in Onitsha Metropolis and its environs. Nkiruka et al. [15] looked at the land use–land cover change of the Metropolis with a focus on their effects on flooding; Ezeomedo and Igbokwe [16] studied the land use–land cover change of Onitsha Urban and environs to establish the pattern, extent, and magnitude of change from 1964 to 2008. Akinbobola [17] simulated the land use change from 1986 to 2016 with emphasis on land surface temperature (LST) and predicted the possible outcome of the land use change spread in 2030 and 2044. Ifeka and Akinbobola [18] in their study in some selected stations in Anambra State, of which Onitsha Metropolis was among, established that there are land use change variations in Onitsha Metropolis and other selected stations from 1986 to 2013. Onwuka et al. [19] modeled the land use cover change of Onitsha Metropolis from 1986 to 2016 and predicted the possible scenario of the land use–land cover change of Onitsha Metropolis in 2031 and the consequent negative effects of environmental problems associated with unplanned and congested built-ups.

The sole purpose that formed the idea and attracted attention to this study is to identify, on average, the match between the terrain of Onitsha Metropolis and the human habitations and activities that give grounds for the assumption of a high degree of safety for the people and sustainable development of the area with the report of the analysis of the terrain. In addition, the study intends to establish and quantify the extent of encroachment of built-up areas on the geologic formations that are not suitable for building construction.

2. Materials and Methods

2.1. The Study Location

The study location is in Anambra State—the Onitsha Metropolis comprises of Onitsha North and Onitsha South LGAs and the surrounding towns influenced by the socio-economic activities in the main city of Onitsha (Figure 1). Onitsha Metropolis is located between latitude 6°14′3.42″ N and 6°2′43.68″ N; longitude 6°44′56.05″ E and 6°55′28.27″ E, with a landmass area coverage of 1016.16 km^2 [3,20,21].

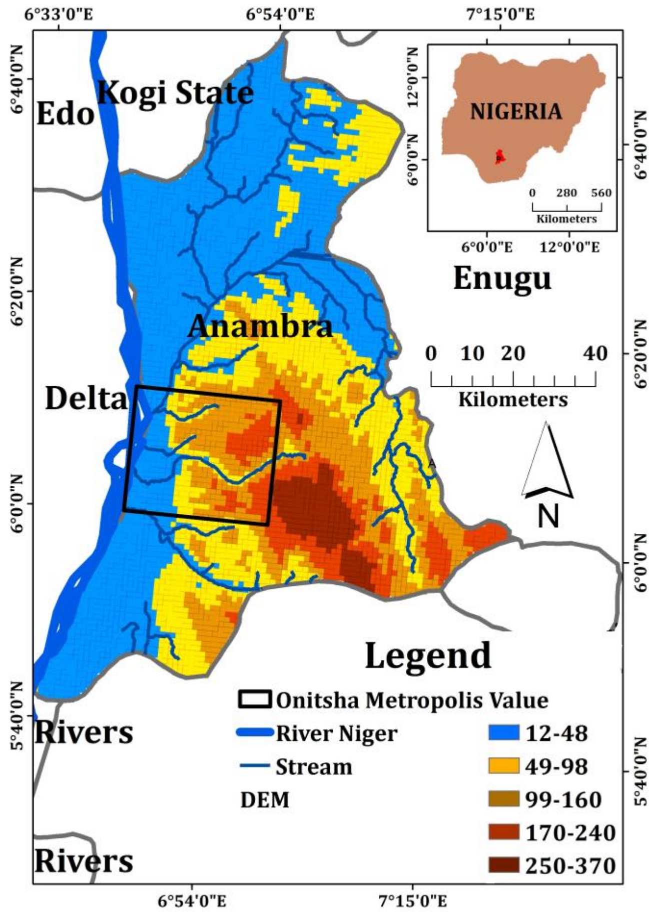

Figure 1. Anambra State with the Study Location. **Source:** USGS, processed by the author (2023).

Onitsha Metropolis has been described in detail by Ofomata [22,23], Nwajide [24], and Ndulue [3], among others. The geology of Onitsha Metropolis is formed by aggradation that rises gradually in some areas south of the Nkisi River and sharply in some areas north of the Nkisi River. The north of the Idemili and Nkisi basins' divide is underlain by the Bende-Ameke sandstone formation (Upper Eocene period). This formation contains undulated laterites, stone lines, and gravelly materials. The topography is heavily dissected by what Mbanugoh [25] called 'orthogonal faults' (Figure 2A). The dissection is owed to dry valleys once containing streams issuing from numerous contact springs in this part of the study area. Only a few of these springs survived to date following climate change and increased distraction of water from the ground reserves. The Bende-Ameke formation houses the Obele-Oyi and Nkisi-Nakweze streams, whose channels are incised into the face of the topography. Residuals consisting of stones, gravels, and coarse sandy soils of white to purple and brown colors dotted the topography and formed medium-sized scarps between 107 and 137 m high. South of the Nkisi-Idemili basin divide, the area is underlain by the Nanka sands (Miocene—Eocene period), which have been described by Egboka and Nwankwor [26]. Nanka sands extend south beyond the Idemili River basin and consist of fewer undulated indulations and summits with typical long slopes. The formation is cut into by the Idemili River, which is also incised into the land surface and flows in valleys with sides of about 180 m high, which today is still subject to failures due to the weakness of the soil materials (Figure 2B). The Ogwashi/Asaba formation (Holocene Quaternary period) is made up of low and flat topology lying generally below 60 m above mean sea level (AMSL). It consists of the deposits of the fine particles eroded from the older formations of Bende-Ameke and Nanka sands as well as the deep weathered shale of the Niger–Idemili flood plains, with the entire formation made up of riverine alluvium. The soil is made up of a large percentage of clay, silt and fine sands with an average weight-bearing capacity of

6.5% [3,27,28], 'greyish in colour with a slope angle of about 5º and below, requires high remedial modifications for engineering purposes due to the nature of the soils (Figure 2C) and is found in Ayamelum, Anambra West, Awka North, Onitsha North, Onitsha South, Idemili South, and Ogbaru Local Government Areas' of Anambra State [29,30].

A B C


Figure 2. Soil types of the different geologic formations in Onitsha Metropolis. (**A**) Bende-Ameke, (**B**) Nanka Sands, and (**C**) Ogwashi/Asaba formations.

Onitsha Metropolis is being drained by a network of streams that have the River Niger as their base river. Anambra State consists of five major sub-basins, out of which three form the study area. The five major sub-basins are Omambala, Mamu, Nkisi, Idemili, and Orashi basins, while Omambala joined with Mamu, Nkisi, and Idemili to form the three sub-basins of Onitsha Metropolis (Figures 1, 3 and 4).

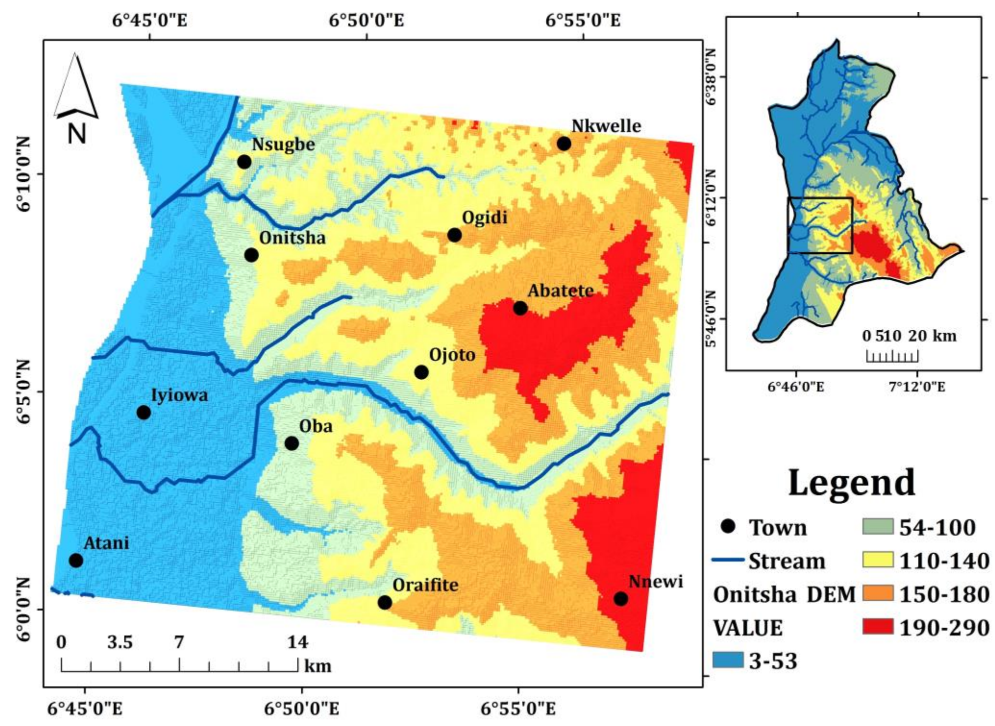

Figure 3. Elevation map of Onitsha Metropolis. **Source:** USGS, processed by the author (2023).

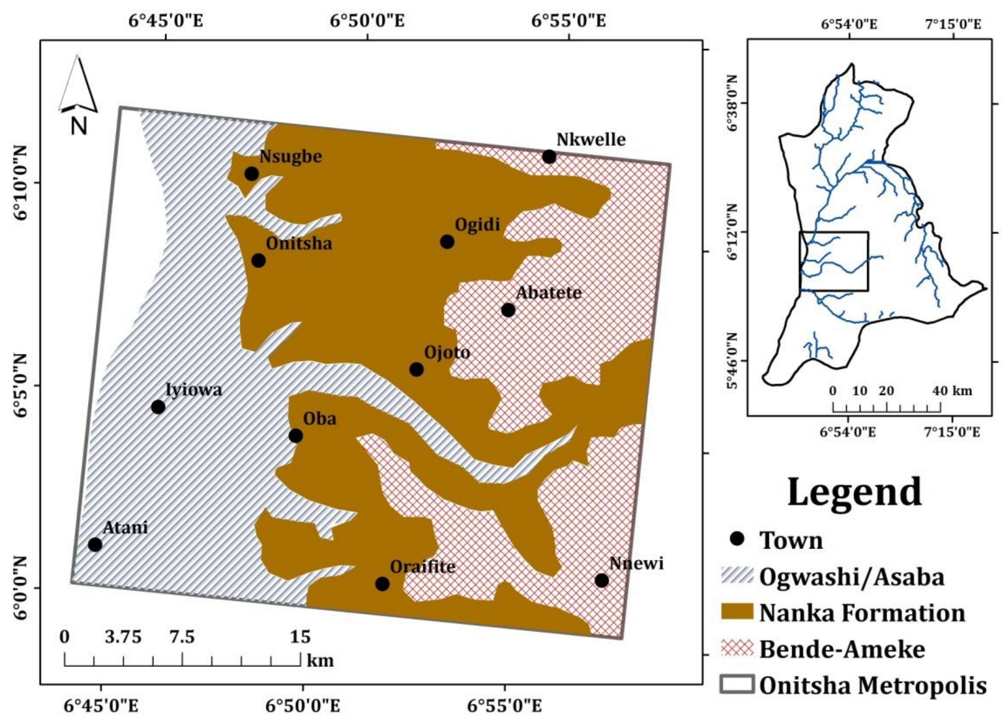

Figure 4. Geologic map formations of Onitsha Metropolis. **Source:** USGS, processed by the author (2023).

2.2. Research Design, Data Collection, and Method of Analysis

Research design is a description of the major steps taken by the researcher in order to achieve the aim and objectives of the research. In this study, reliance on empirical study to physically observe the topography, determine the elevation, slope angle, soil types, and soil particle distribution was adopted. A mixed method of data analysis was used in this research; in other words, data were analyzed using both quantitative and qualitative methods of analysis. The study applied primary and secondary data sources. The primary data are made up of field visits and physical observations, visual and physical measurements, and interviews. The study interviewed at random 25 elderly residents of the study area on their empirical knowledge of Onitsha Metropolis and the observed transformational drive of the area prior to 1982 and beyond. The secondary data are made up of satellite images, books, and published and unpublished research/journal articles, among others. The satellite images were sourced from the United States Geologic Survey (USGS) archive (Shuttle Radar Topographic Mission (SRTM) and Landsat 4–5 TM, 7 ETM, and 8 OLI-TIRS) (Table 1). The geology and geomorphological variables extracted from the satellite image data (Shuttle Radar Topographic Mission (SRTM)) were processed using ArcGIS 10.2. Land Use Land Cover Change (LULCC) of Onitsha Metropolis was analyzed with much emphasis on built-up areas (Appendix A). Landsat 4–5 TM, 7 ETM, and 8 OLI-TIRS satellite image data of the area sourced from USGS were processed using ArcGIS 10.2, for the period of forty (40) years from 1982 to 2022, with intervals of ten (10) years. For the purpose of this study, out of the nine (9) bands, bands 4, 3, and 2 were chosen for land use analysis. Some of the stages in data processing and analyses that were employed in the study include layer stacking of bands 4, 3, 2, and 5, 4, 3 of the TM, ETM, and OLI Landsat satellite images, respectively; radiometric and geometric correction using ERDAS Imagine 9.2 to correct the haze distortion where necessary; and image sharpening to enhance the appearance of the images. Image extraction of the shape file of the study area was performed by masking in ArcGIS 10.2, while the accuracy assessment and ground truth verifications were also carried out.

Table 1. Satellite image data used for the GIS analysis of the variables for the study.

Data	Download Date	Sources	Map
Satellite images (**SRTM and Landsat 4–5 TM, 7 ETM, and 8 OLI-TIRS**)	4 February 2022	USGS Earth Explorer	Elevation, land use–land cover change (LULCC), geology/geomorphology, and streams channel

Two different coordinate systems were used in the GIS analysis of this study. The World Geodetic System 1984 (WGS 1984) was used for the large map (Anambra State), while the Universal Transverse Mercator (NGN UTM Zone 39N) was used for the small map (Onitsha Metropolis). The geology and geomorphological variables of Onitsha Metropolis were presented in the form of maps on which the LULCC variables were overlain and intersected so that the areas that are most vulnerable to engineering construction can be determined. The resultant maps and other generated information from the attribute tables were used to compute percentage changes in the variables of interest.

3. Results of the Data Analysis

3.1. Geologic Formations of Onitsha Metropolis

The analysis reveals that the sizes of the geologic formations in Onitsha Metropolis are 259.42 km^2, 423.07 km^2, and 318.57 km^2 for Bende-Ameke, Nanka sands, and Ogwashi/Asaba formations, respectively. Scholars like Ofomata [22,23] and Nwajide [24], among others, gave a qualitative description of the geology that comprises Onitsha Metropolis, but this research went further to determine the tentative boundaries and sizes of the geologic formations of Onitsha Metropolis (Figures 4 and 5).

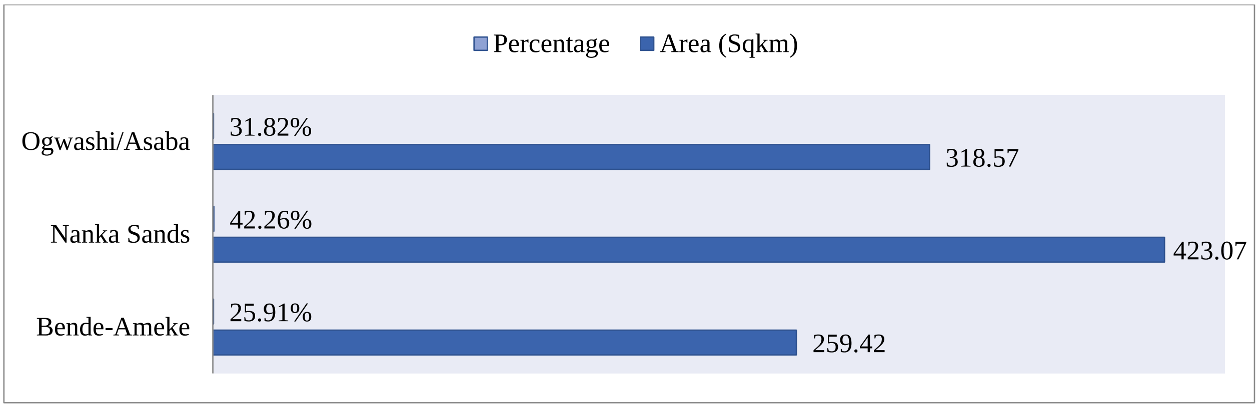

Figure 5. Chart representing the sizes of the geologic formations of Onitsha Metropolis.

3.2. Land Use Land Cover Change (LULCC) of Onitsha Metropolis from 1982 to 2022

Onitsha is located at the bank of the river, which made it accessible to people in Northern Nigeria as well as people in Southern Nigeria to the Atlantic Ocean. The position of Onitsha attracted the famous '*Ose-Okwodu*' that led to the establishment of Onitsha Main Market, which earned Onitsha the status of a market town, and subsequent development of other markets later within and around the Metropolis. The area has seen an unprecedented influx of people that has led to an informal expansion of the city, especially the built-up spaces, which have significantly affected other land uses in the area.

Land use land cover change analysis of Onitsha Metropolis shows the changes in various land use types and the direction of change, especially the built-up areas from 1982 to 2022. The land use–land cover change maps of Onitsha Metropolis are presented in Figures 6–10 below:

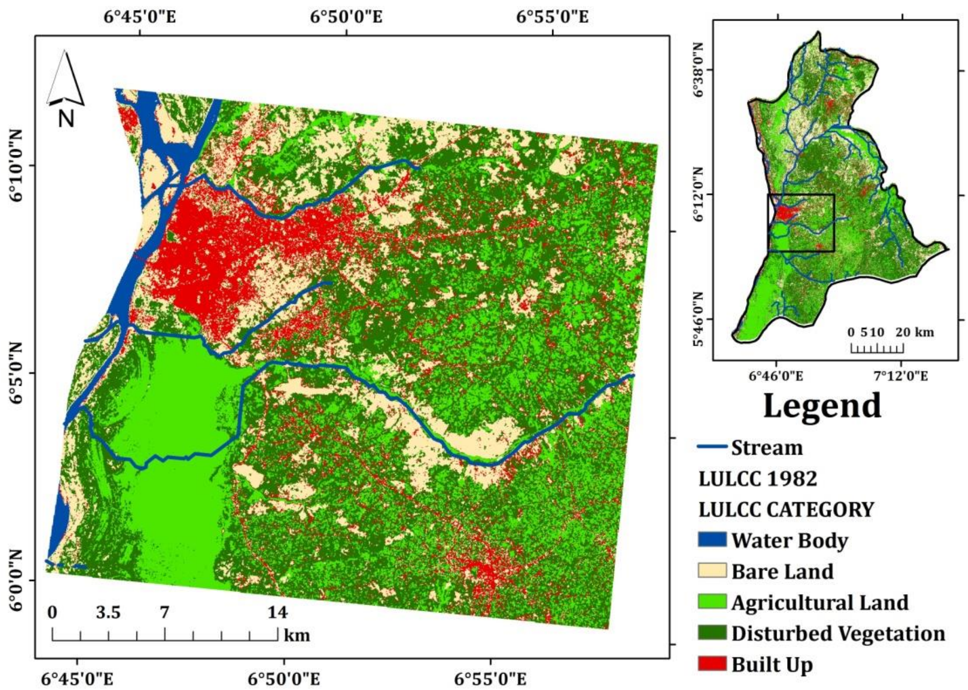

Figure 6. LULCC map of Onitsha Metropolis in 1982. **Source:** USGS, processed by the author (2023).

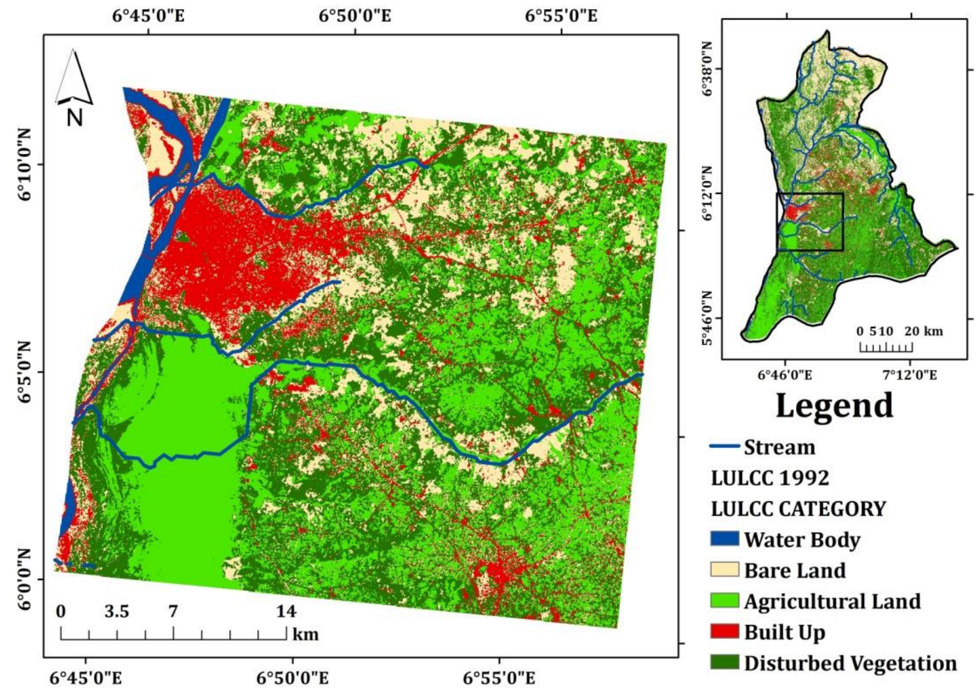

Figure 7. LULCC map of Onitsha Metropolis in 1992. **Source:** USGS, processed by the author (2023).

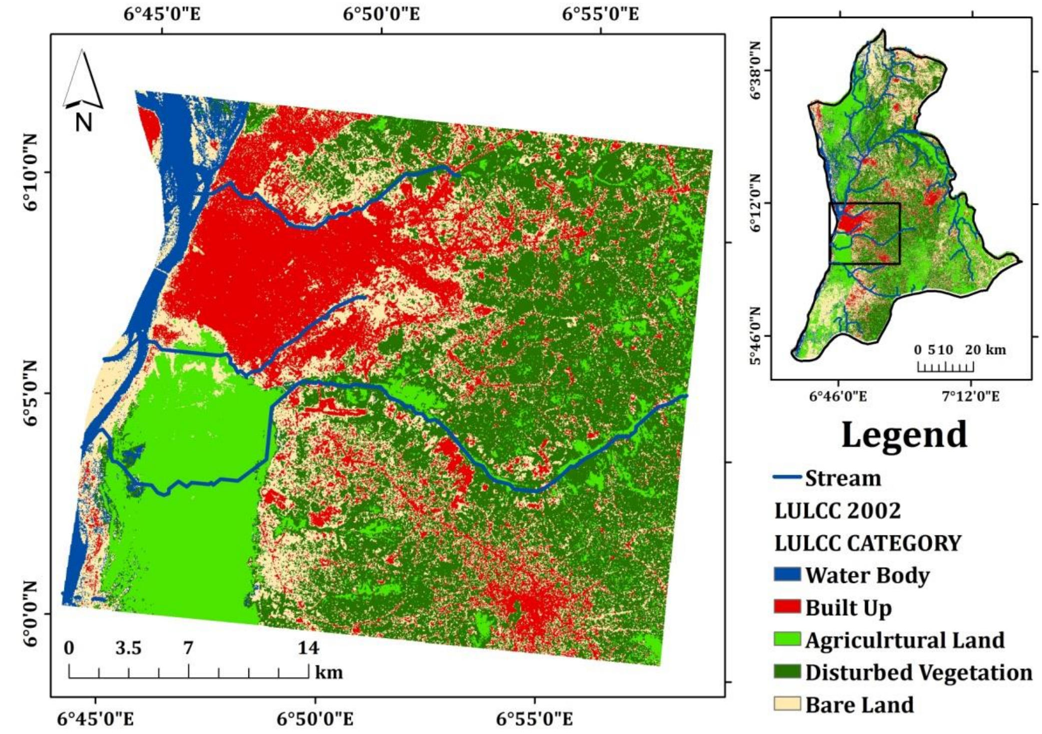

Figure 8. LULCC map of Onitsha Metropolis in 2002. **Source:** USGS, processed by the author (2023).

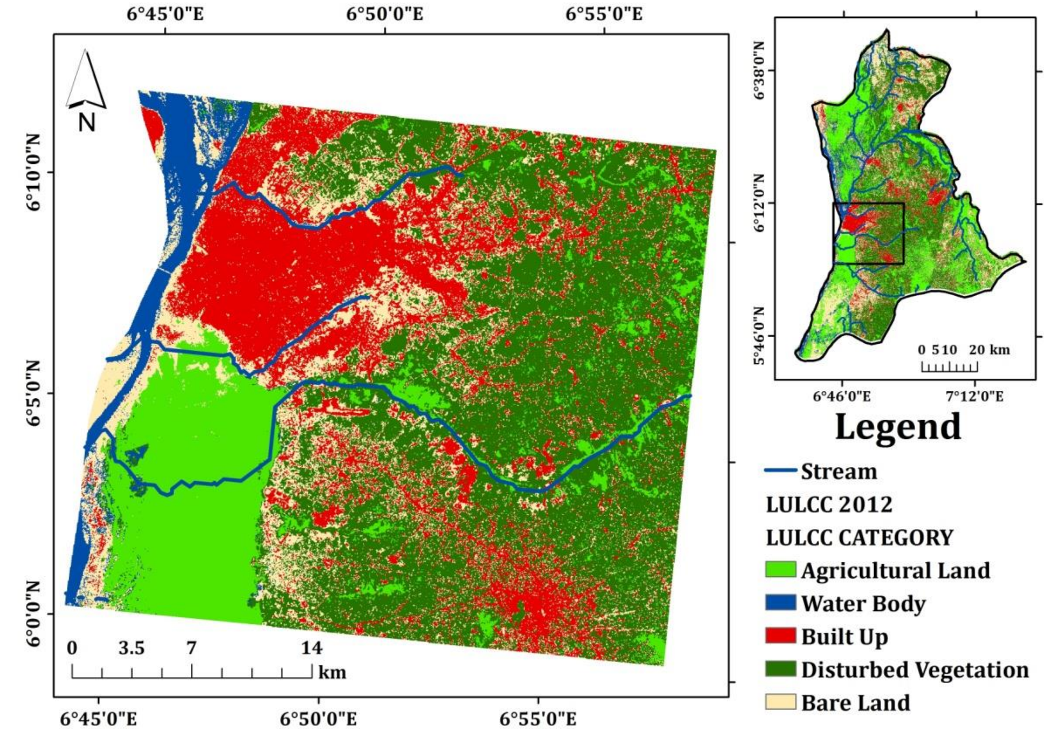

Figure 9. LULCC map of Onitsha Metropolis in 2012. **Source:** USGS, processed by the author (2023).

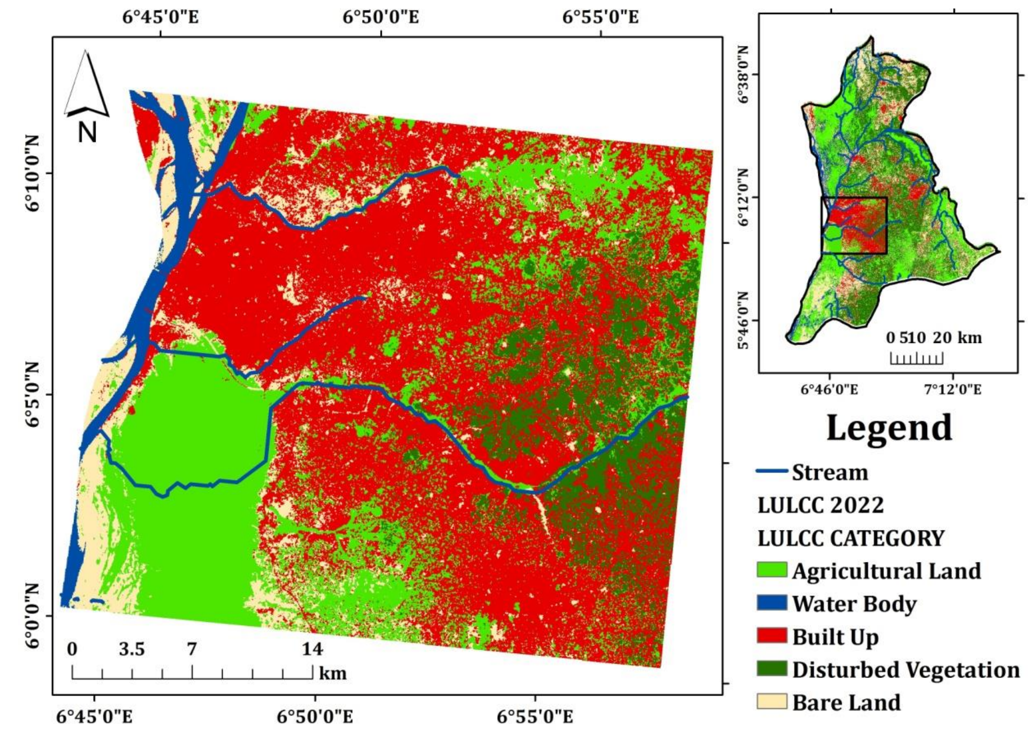

Figure 10. LULCC map of Onitsha Metropolis in 2022. **Source:** USGS, processed by the author (2023).

The LULCC analyses show variations in the values of all the categories of land uses sampled. The LULCC analysis result is presented in the chart below (Figure 11).

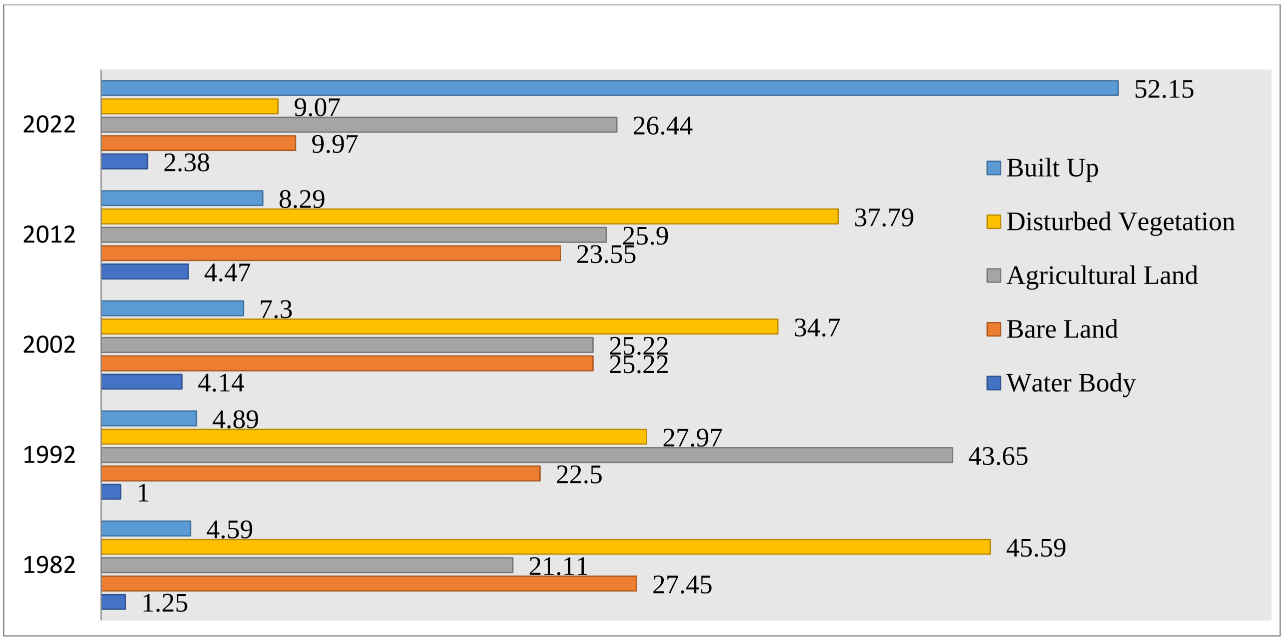

Figure 11. Land use percentage change in 1982, 1992, 2002, 2012, and 2022.

The percentage of water bodies was 1.25 in 1982, 1.00 in 1992, 4.14 in 2002, 4.47 in 2012, and 2.38 in 2022, respectively. Water bodies in Onitsha Metropolis decreased in 1992, increased in 2002 and 2012, and drastically decreased again in 2022. Water bodies can increase as a result of inflow during the rainy seasons; however, this assumption is ruled out because the images used for the analysis were captured in December. The variations were attributed to human factors as a result of the clearing of the vegetation over the years that exposed the water bodies covered by the vegetation from the view of the satellite. Also by 2022, the effects of reclamation have become visible, hence the reduction in water bodies as captured by the satellite images. The percentage of bare land was 27.45in 1982, 22.50 in 1992, 25.22 in 2002, 23.55 in 2012, and 9.97 in 2022, respectively. The high percentages of bare land recorded in 1982, 1992, 2002, and 2012 are as a result of the bush clearing activities; most of the areas seen as bare land are predominantly used for farming, and the area is the Idemili–Niger flood plain (Ogwashi/Asaba formation) consisting of the alluvium type of the soil (Figures 2C and 4). The farming (bush clearing) period in these areas starts in December, the same period the images for this work were captured. The cleared areas would have been captured and processed as bare lands in 1982, 1992, 2002, and 2012. However, in 2022, the majority of these areas have been converted to built-ups, hence the low percentage value. The percentage of agricultural land was 21.11 in 1982, 43.65 in 1992, 25.22 in 2002, 25.90 in 2012, and 26.44, respectively. The agricultural land increased in 1992, not because the people engaged more in agriculture that period, but because a high percentage of the natural forest was reduced to shrubs, which the software recognized to be the same with farmlands. In 2000, most of the areas recognized as farmlands by the software were gradually taken up for plantations and later for building up. The percentage of disturbed vegetation cover was 45.59 in 1982, 27.97 in 1992, 34.70 in 2002, 37.79 in 2012, and 9.07 in 2022, respectively. In 1982, there was more natural but disturbed vegetation, which was reduced in 1992 as a result of firewood and timber harvesting. In 2000, the people of the area went into massive palm plantations, which replaced the natural vegetation and the remnant of what was being seen in 2022 as disturbed vegetation. The percentage of built-up area was 4.59 in 1982, 4.89 in 1992, 7.30 in 2002, 8.29 in 2012, and 52.12 in 2022, respectively. The surge in the unprecedented growth of buildings and other constructions became noticed in 2000 and since then has grown to cover more than half (52.12%) of the area under study. This surge has led to acquiring lands and building houses in areas that ordinarily are not suitable for housing and/or other constructions; such areas are the flood plains, steep slopes, and stream channels, among others.

3.3. Overlay Analysis of the Geologic Formations and LULCC of Onitsha Metropolis

An overlay analysis of the geology and land use–land cover change of Onitsha Metropolis revealed the rate of encroachment to the weakest part of the area (Ogwashi/Asaba formation), which ordinarily would have been designated for agriculture and other agro-related businesses for which it is best suited [3,24]. Due to shortage and pressure on available lands as a result of population increase, attention has now shifted to areas, especially in Okpoko, Odekpe, Iyiowa, Obosi, and Oba, among others, with alluvium soils (Figure 2C)—areas not suitable for housing and/or other constructions because of the sensitive nature of the soils. The resultant maps of the analyses are presented in Figures 12–16 below:

The overlay method applied determines the extent to which built-up categories of land use had encroached on the Ogwashi/Asaba formation. The extent of the encroachment is presented below (Figure 17). It shows that out of the 318.57 km^2 of the Ogwashi/Asaba formation, 30.44 km^2 (9.56%) was encroached on in 1982; 33.31 km^2 (10.46%) in 1992; 45.71 km^2 (14.35%) in 2002; 52.64 km^2 (16.52%) in 2012; and 96.84 km^2 (30.40%) in 2022, respectively.

Allowing this trend to continue, the entire alluvium soils of the Ogwashi/Asaba formation will be covered with buildings in no distant time. This claim was supported by a forecast analysis presented below (Figure 18). It shows that out of the 318.57 km^2 of the Ogwashi/Asaba formation, 97.43 km^2 (30.58%) will be encroached on in 2032; 112.64 km^2 (35.36%) in 2042; 127.85 km^2 (40.13%) in 2052; 143.07 km^2 (44.91%) in 2062; and 158.28 km^2 (49.68%) in 2072, respectively.

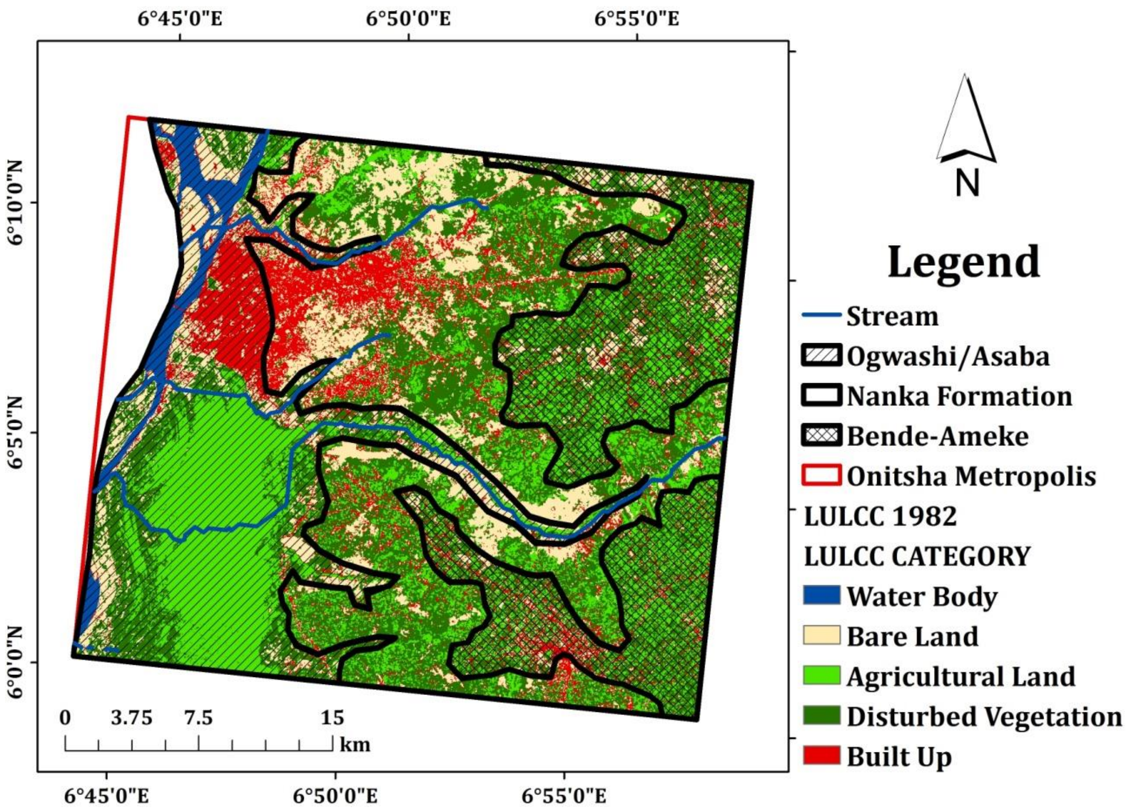

Figure 12. Map overlay of the geology and LULCC of Onitsha Metropolis (1982). **Source:** USGS, processed by the author (2023).

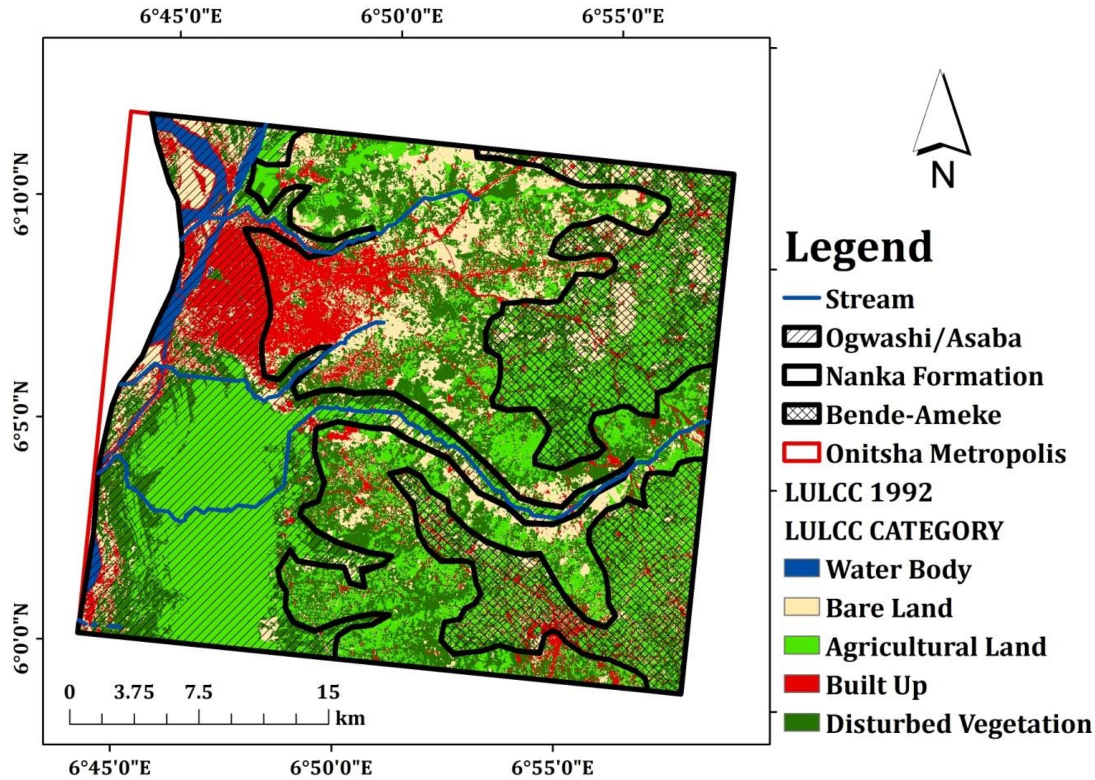

Figure 13. Map overlay of the geology and LULCC of Onitsha Metropolis (1992). **Source:** USGS, processed by the author (2023).

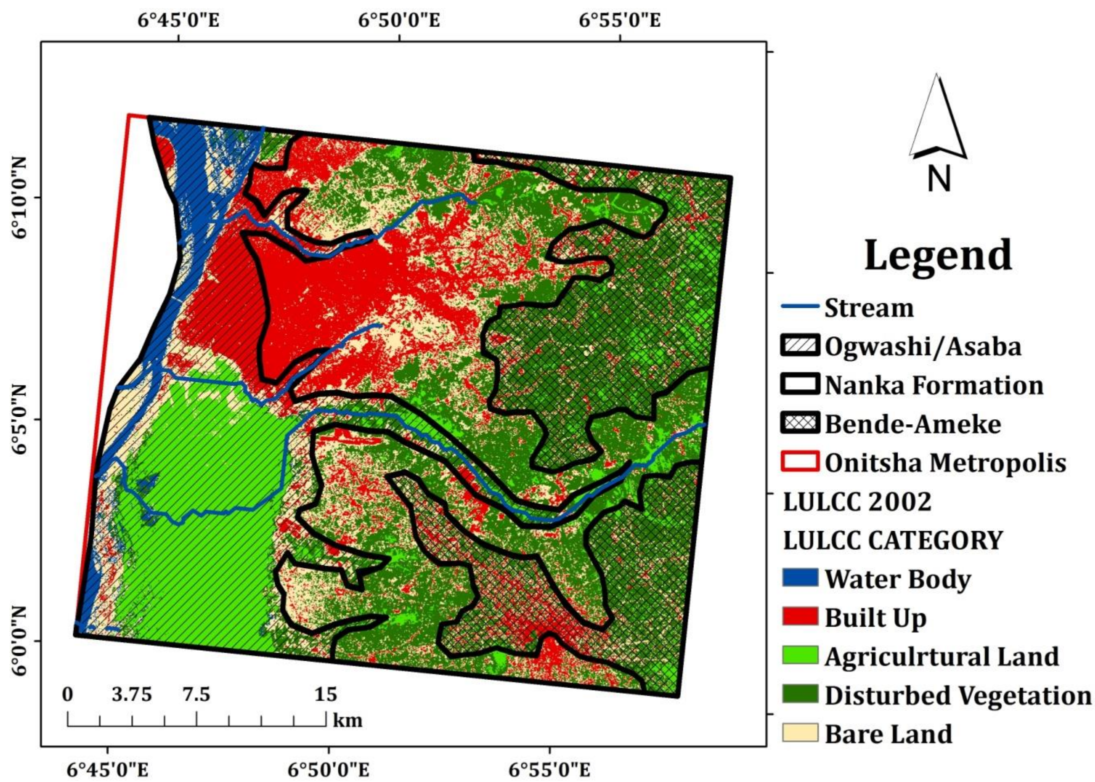

Figure 14. Map overlay of the geology and LULCC of Onitsha Metropolis (2002). **Source:** USGS, processed by the author (2023).

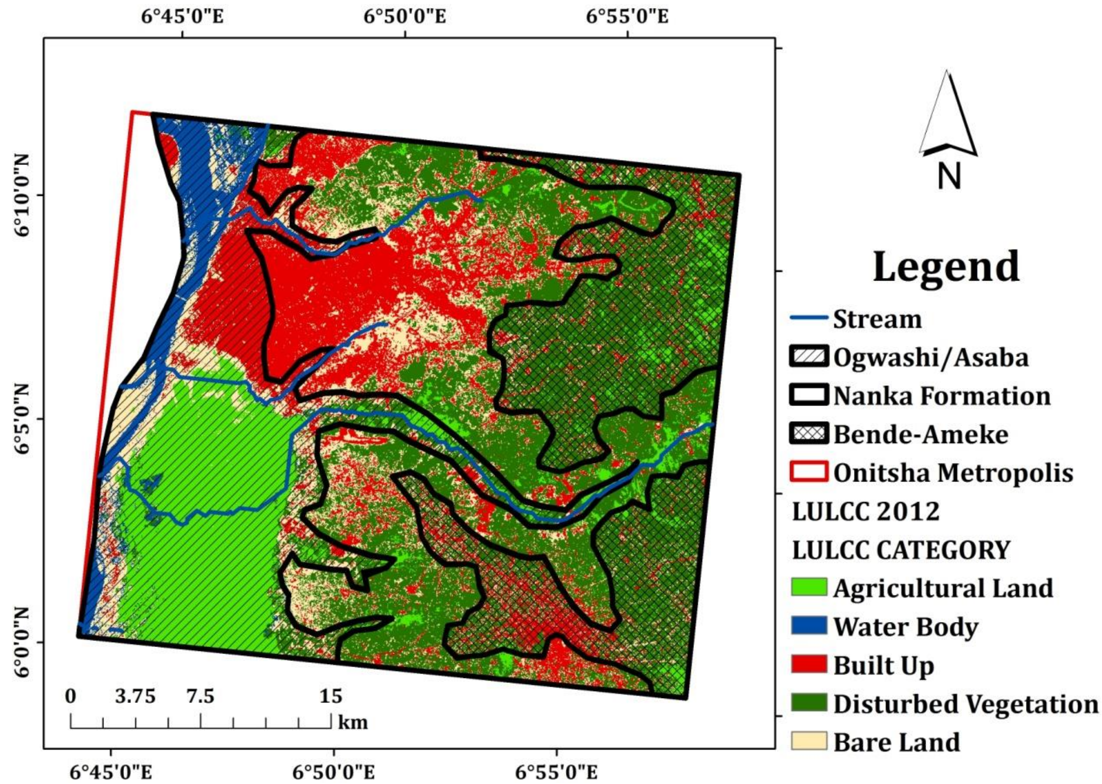

Figure 15. Map overlay of the geology and LULCC of Onitsha Metropolis (2012). **Source:** USGS, processed by the author (2023).

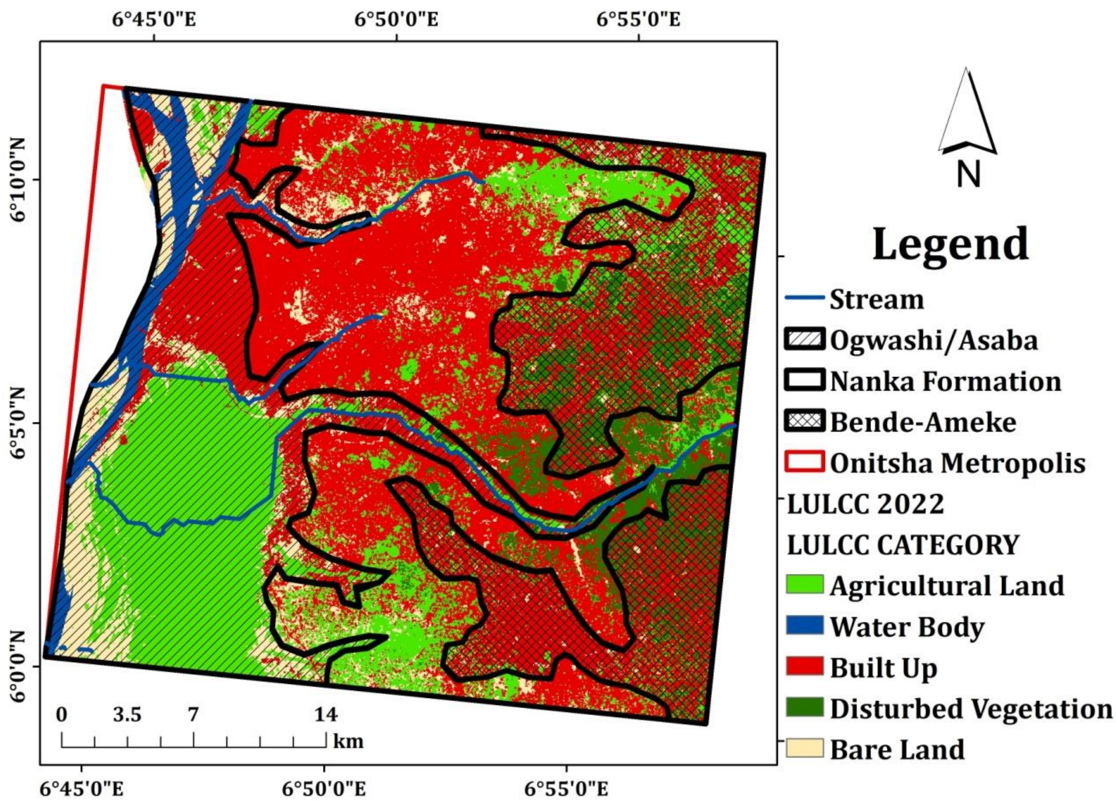

Figure 16. Map overlay of the geology and LULCC of Onitsha Metropolis (2022). **Source:** USGS, processed by the author (2023).

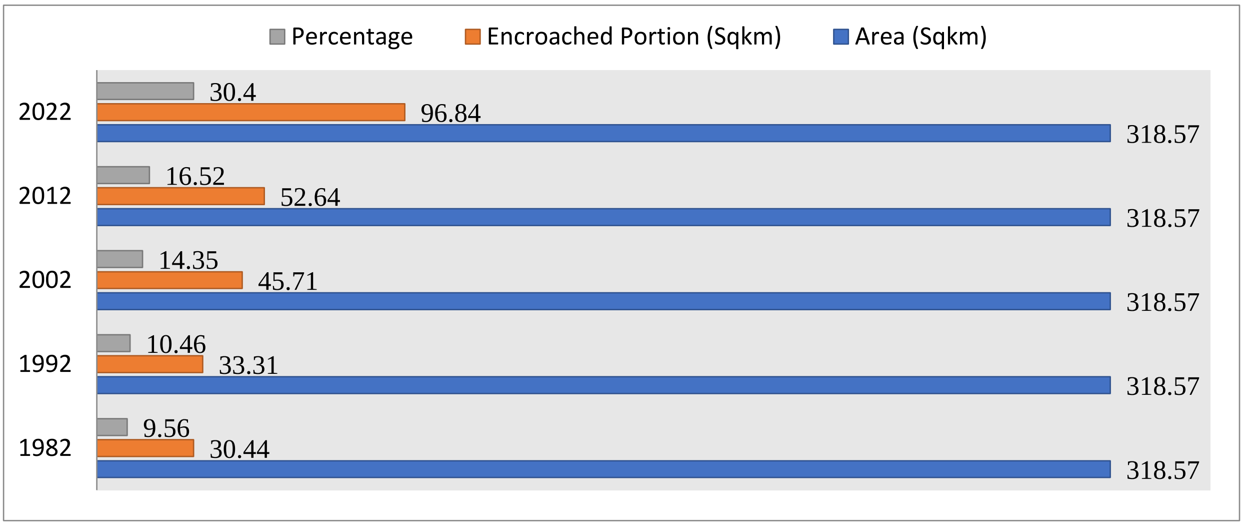

Figure 17. Chart representing the encroached size of the Ogwashi/Asaba formation by built-ups.

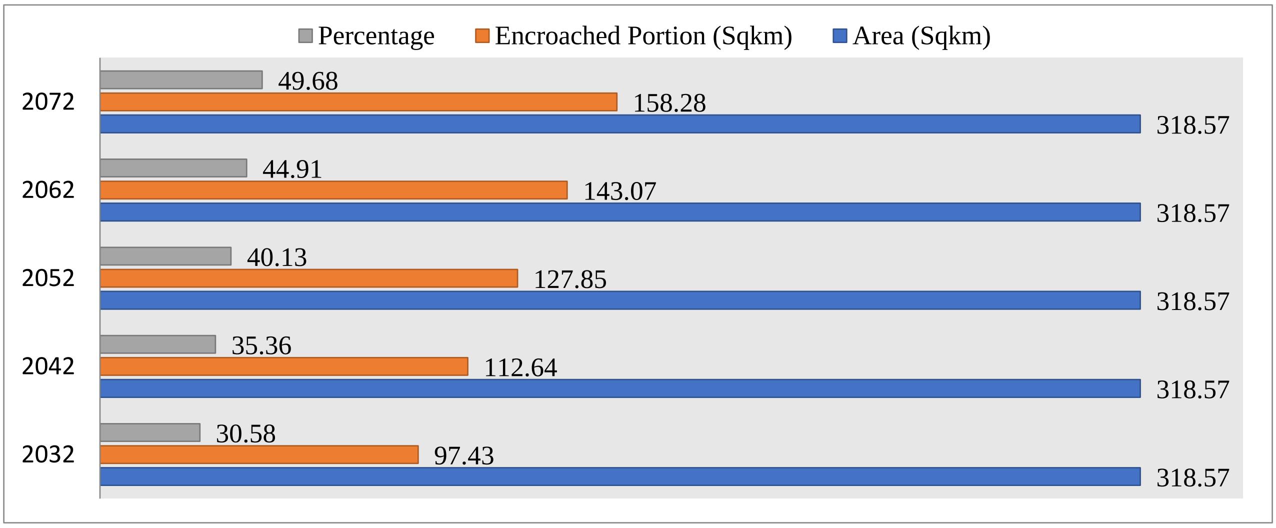

Figure 18. The forecast of built-up encroachment on the Ogwashi/Asaba formation in 40 years.

Note: The forecast function in Microsoft Excel may have limitations in accuracy, but it shows a direction of the possible outcome. That is, in the next forty (40) years, the built-up category of land use would have covered about fifty (50) percent of the entire Ogwashi/Asaba formation.

4. Discussion

The analyses of the geologic formations show that the Ogwashi/Asaba formation has an area of 318.57 km^2, the Nanka Sands formation has an area of 423.07 km^2, and Bende-Ameke has an area of 259.42 km^2. The Nanka sands and Bende-Ameke formations are best suited for engineering constructions and other structural engineering-related land uses; and since according to Klingebiel and Montgomery [31], no land is useless, but its uses depend on suitability, lands in the Ogwashi/Asaba formation can be put into uses suitable for it, i.e., agriculture and agro-based related businesses. The analyses further ascertain the transition zones of one geologic formation to another, which serves as a guide in determining 'what,' 'where,' 'when,' and 'how' to build or use the land resources, which are the most pertinent questions in geography whose right answers ensure the sustainability use of land resources [24,32,33], and the attainment of the SDGs [34]. *'Goal 11—Sustainable*

Cities and Communities' seeks to address the effects of *'rapid growth of cities which has resulted in rising populations occasioned by increasing migration that has led to a boom in mega-cities, especially in the developing world, leading to slums becoming a more significant feature of urban life,'* according to the United Nations Development Programme [8]. The LULCC analysis shows that the percentage of water bodies was 1.25 in 1982; decreased to 1.00 in 1992; increased to 4.14 in 2002 and 4.47 in 2012; and again drastically decreased to 2.38 in 2022. It is observed that the variations were as a result of human factors—clearing of the vegetation cover over the years that led to more exposure of the water bodies to the view of the satellites, and the reduction in 2022 was as a result of reclamation activities. The percentage of bare land was 27.45 in 1982; 22.50 in 1992; 25.22 in 2002; 23.55 in 2012; and 9.97 in 2022, respectively. The high percentage of bare land was because the areas predominantly used for farming in the area are the Idemili–Niger flood plain (Ogwashi/Asaba formation), made up of alluvium soils. The percentage of agricultural land was 21.11 in 1982; increased to 43.65 in 1992; decreased to 25.22 in 2002; increased slightly to 25.90 in 2012; and 26.44, respectively. The variation was as a result of harvesting forest wood, which reduced the vegetation to cropland/shrub type vegetation. The percentage of disturbed vegetation cover was 45.59 in 1982; decreased to 27.97 in 1992; increased to 34.70 in 2002 when the people engaged in plantation farming; increased further to 37.79 in 2012; and drastically reduced to 9.07 in 2022 as a result of massive development in building construction. The percentage of built-up area was 4.59 in 1982; increased to 4.89 in 1992; and increased further to 7.30, 8.29, and 52.12 in 2002, 2012, and 2022, respectively. These findings agree with those of some researchers. The analysis result of the study conducted by Nkiruka et al. [15] revealed that built-ups increased by 9.4% from 2008 to 2013 and another 5.5% increase from 2013 to 2018, while there was a drastic reduction in the percentage of vegetation cover under the same period in Onitsha North and South Local Government Areas. Akinbobola [17] recorded 74.25% for vegetation, 22.31% for built-ups, and 2.45% for the water bodies in 1986. In 2002, vegetation was 69.80%, built-ups was 27.56%, and water body was 2.65%, while in 2016, the vegetation was 64.39%, built-ups was 33.26%, and water body was 2.35%. Ifeka and Akinbobola [18] recorded vegetation to be 26%, built-ups to be 45%, and water bodies to be 5% in 1986. In 2000, vegetation was 28%, built-ups was 57%, and water body was 7%, while in 2013, vegetation was 32%, built-ups was 61%, and water body remained 7%. Onwuka et al. [19] land use cover classification analyses showed that vegetation in 1986 was 79.43%, 65.64% in 2001, and 62.61% in 2016, respectively. Ezeomedo and Igbokwe [16] calculated the LULCC of Onitsha Metropololis to be 51.78% for vegetation, 41.64% for built-ups, and 5.84% for water bodies in 2005. In 2008, vegetation was 18.74%, built-up was 59.50%, and water body was 2.88%. There is a general concurrence in the sense that built-up area has been increasing and spreading into other land uses, thereby shrinking the space for them. It is very clear from other study findings that vegetation was decreasing rapidly and built-ups increasing in its place, even though the rate varies. This surge in buildings and other constructions became noticed in 2000 and has grown to cover more than half (52.12%) of the area under study.

However, due to the nearness of the Ogwashi/Asaba formation to Onitsha city center and the pressure on land in and around the city, the lands in the Ogwashi/Asaba formation have been encroached and built on, forming part of the slums in Onitsha Metropolis presently. The formation has an area of 318.57 km^2, and as of 1982, land use activities, especially built-up categories of land use, had encroached up to about 30.44 km^2. In 1992, 2002, 2012, and 2022, the trend continued and covered up to 33.31 km^2, 45.71 km^2, 52.64 km^2, and 96.84 km^2, respectively.

5. Conclusions

This study has looked at the geology and the terrain of Onitsha Metropolis and determined the soil characteristics vis-à-vis the land use suitability and identified and mapped the three (3) geologic formations, which are the Ogwashi/Asaba, Nanka sands, and Bende-Ameke. The soil analyses show that Nanka sands and Bende-Ameke formations have high carrying capacity and are suitable for any commercial land use activities. The Ogwashi/Asaba formation, on the other hand, is a very fragile and sensitive zone, made up of alluvium soils suitable for agriculture and other agro-based activities, and should have been designated as such and protected. Currently, however, due to the unavailability of land as a result of the growing population and the proximity of the area to the city center, the area is being encroached upon, and a large chunk of it (about 30.40%) has been converted to built-up areas as of 2022, and if the trend is not checked, 30.58% of the area would have been taken over by built-ups by 2032, two years after the United Nations Sustainable Development Goals (UNSDGs) deadline [9], and 49.68% by 2072, forty-two (42) years after. The implication is that the economic activities that are supposed to be intertwined with the environment and the social needs, such as food, to provide sustainability and sustainable livelihood in the cities are conspicuously absorbing the environment and, by extension, the social needs (food) in Onitsha Metropolis, and the consequences are high cost of food, food insecurity, and increased poverty. Also, construction of houses in the fragile zone of the Ogwashi/Asaba formation, though houses are a social need, having them in areas not suitable for such may pose a big challenge and threat to human habitation, such as possible building collapse, soil subsidence, and flooding for which the area is known.

Recommendations

The study made the following recommendations:

a. Creation of a committee of geospatial experts for post-developmental planning and re-evaluation of Onitsha Metropolis. These experts should consist of geographers, land surveyors, quantity surveyors, architects, urban and regional planners, civil engineers, and GIS experts, among others, who understand the environment and environmental management for the sustainable use of the limited land resources in Onitsha Metropolis for optimum satisfaction and achieving the SDGs' Goal 11—*'efforts must focus on implementing inclusive, resilient and sustainable urban development policies and practices that prioritize access to basic services, affordable housing, efficient transportation and green spaces for all'* [34].
b. Sand filling and reclamation attempts by developers occasioned by the encroachment of the Ogwashi/Asaba formation should be discouraged because of the potential dangers these actions portend to the flood plains and water bodies in Onitsha Metropolis. Sand filling and reclamation of valleys naturally endowed to trap floods during the rainy seasons displaces and diverts the floods to other places not susceptible to flooding, while the same actions on streams reduce streams' channel and increase flow velocity, thereby increasing erodibility capacity of the stream to the streambed and bank, and at the same time reducing the capacity of the streams to accommodate much runoff during heavy rainfall that may lead to runoff overflow of the streams' bank and causing flooding.
c. Increasing accessibility and ease of moving in and out of Onitsha Metropolis will lead to decongesting the city; hence, opening up and linking other nearby settlements in Anambra State through massive and expansive road network construction will ease mobility and encourage residents of Onitsha Metropolis to move and spread out, thereby decongesting the already choked-up city.

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Appendix A

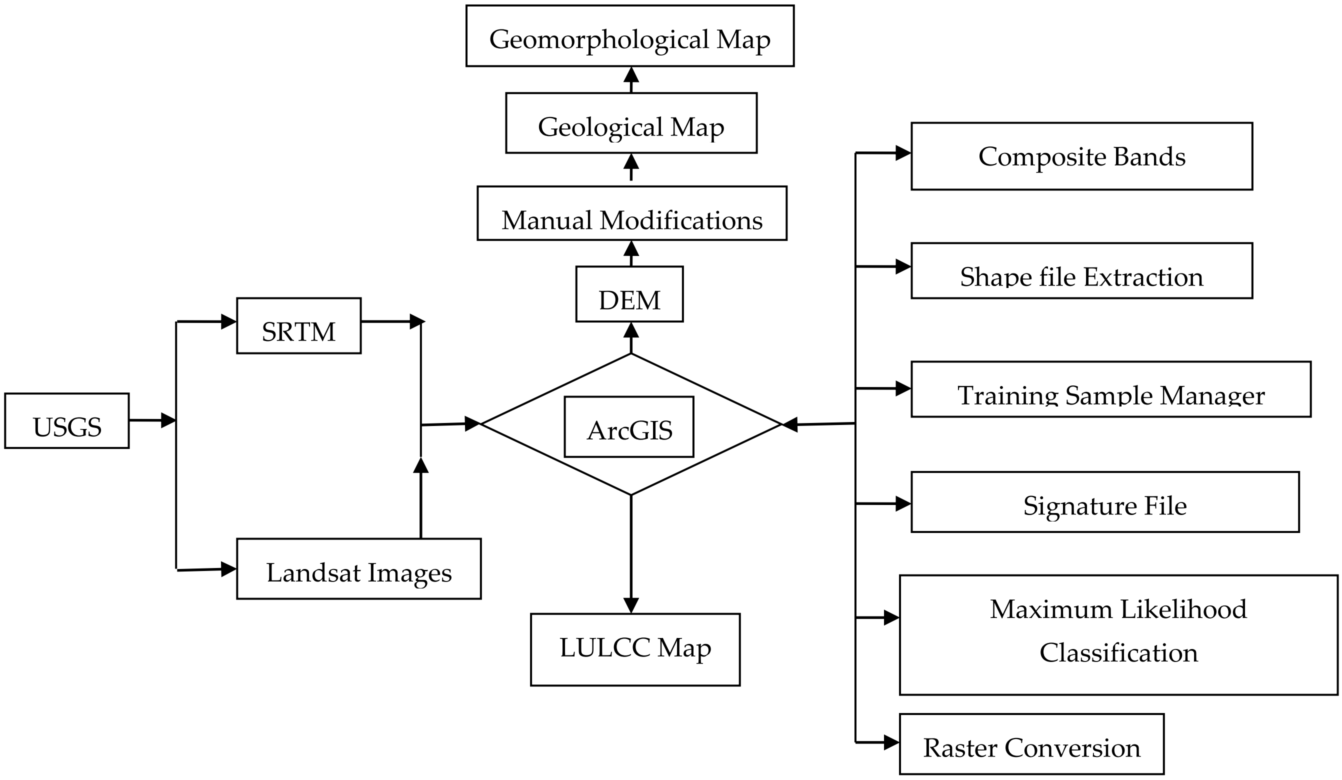

Figure A1. Diagrammatical Flowchart Representing the GIS Analysis Methods for the Geomorphological and LULCC Maps.

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