CHAPTER THREE

METHODOLOGY

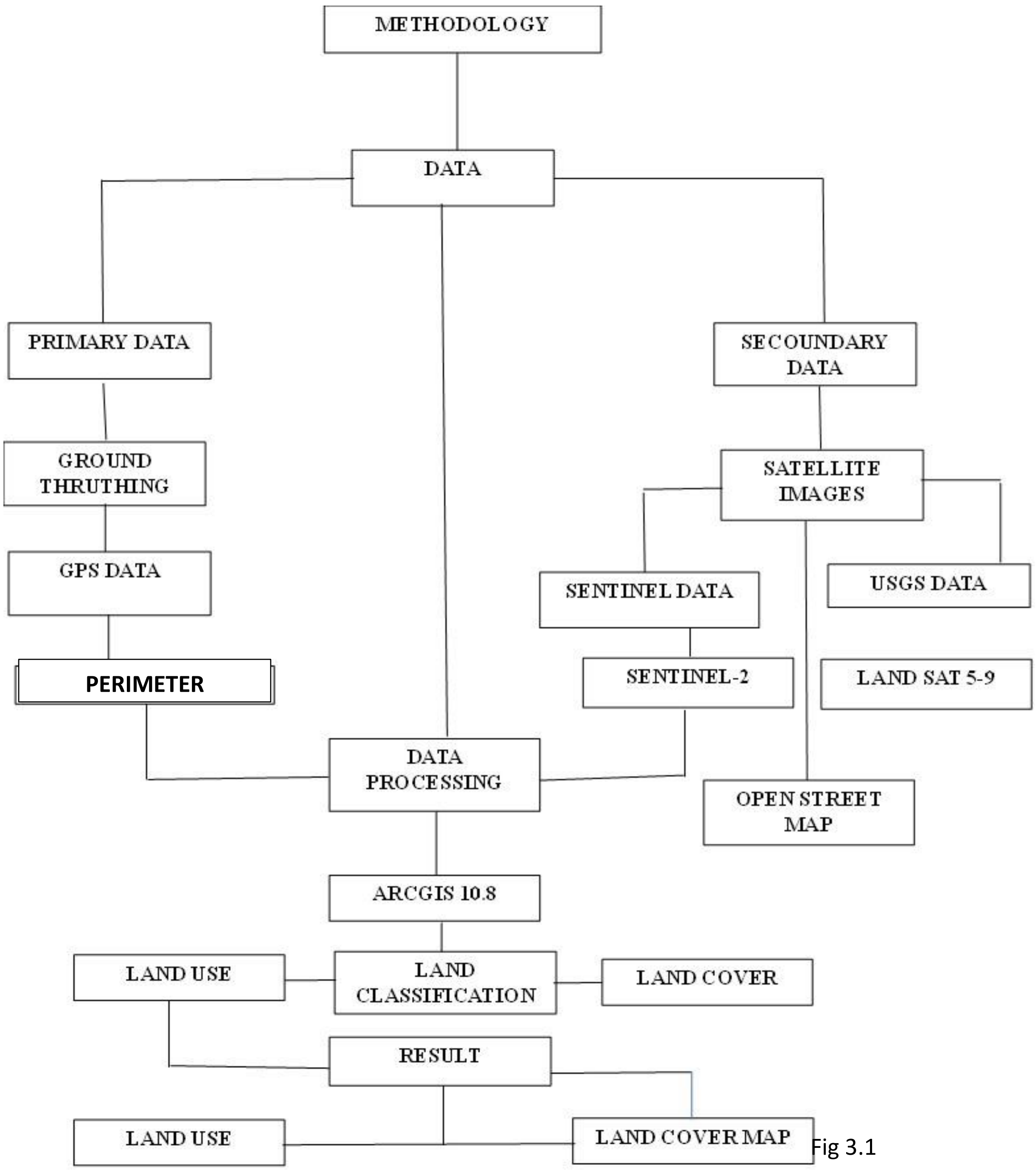


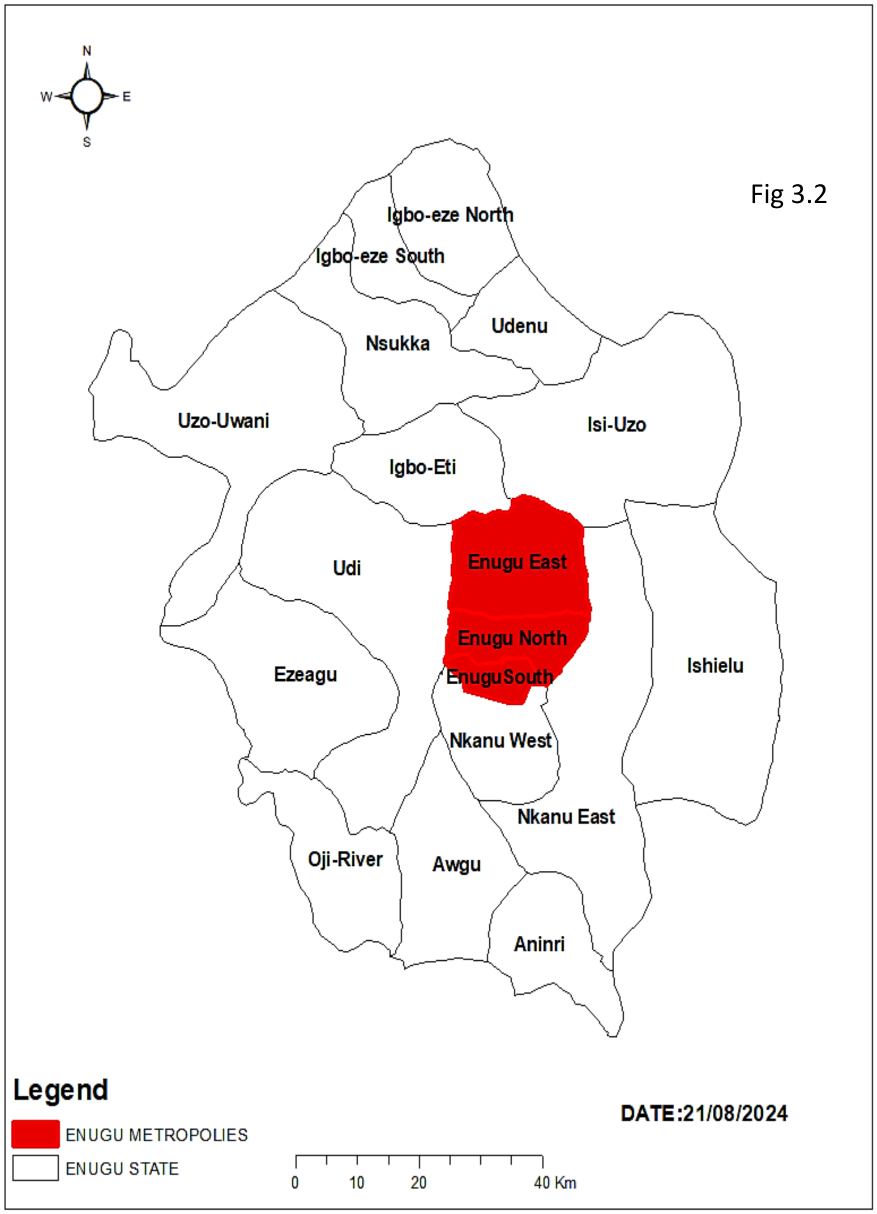
Fig 3.1

3.1 Study Area

The study area is Enugu Metropolis and its surrounding environs, located in southeastern Nigeria. This region has experienced significant urbanization, making it an ideal case study for analyzing land use and land cover changes over time. Enugu Metropolis is situated approximately between latitudes 6.300°N and 6.600°N and longitudes 7.300°E and 7.700°E. The geographical coordinates and specific boundaries of the study area will be delineated using Geographic Information System (GIS) tools to ensure precise spatial analysis. The study area includes both urban and peri-urban zones, allowing for a comprehensive analysis of various land use patterns and their implications.

As of the most recent census data, the population of Enugu is estimated to be over **820,000** within the city limits, with the larger metropolitan area housing over **1 million** residents. This growing population is a key driver of the rapid urbanization observed in the region, further underscoring the importance of this study in understanding the dynamics of land use and land cover changes.

MAP OF ENUGU STATE SHEWING STUDY AREA



3.2 Research Design

The research adopts a mixed-method approach, integrating both qualitative and quantitative methods to achieve the study's objectives. The study design is primarily exploratory and descriptive, aimed at understanding the patterns, drivers, and impacts of land use and land cover changes in the study area from 1990 to 2023. Remote sensing and GIS technologies will be central to the data collection, processing, and analysis phases of the study. Additionally, ground-truthing and field surveys will be conducted to validate and complement the satellite-based data.

3.3 Sources of Data

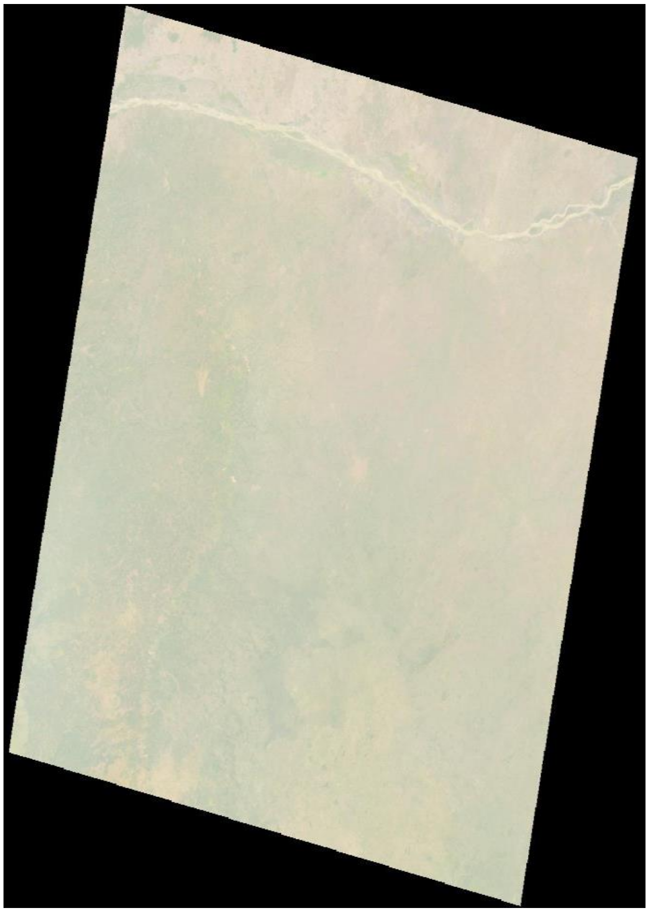
Data for this study will be collected from both primary and secondary sources, ensuring a comprehensive and reliable dataset for analysis.

3.3.1 Secondary Data Source

The secondary data includes satellite imagery and other geospatial datasets essential for land use and land cover analysis:

- **Satellite Images:** The study will utilize satellite imagery from various sources, including Sentinel-2 and Landsat 5-9. Due to challenges with Landsat 7's scan line corrector (SLC) failure, images from 1990-2010 may have gaps that will require correction or supplementary data sources. The study will also incorporate data from OpenStreetMap for additional spatial information.

FIG 3.3 SATELLITE IMAGE SAMPLE



LANDSAT 8 IMAGE

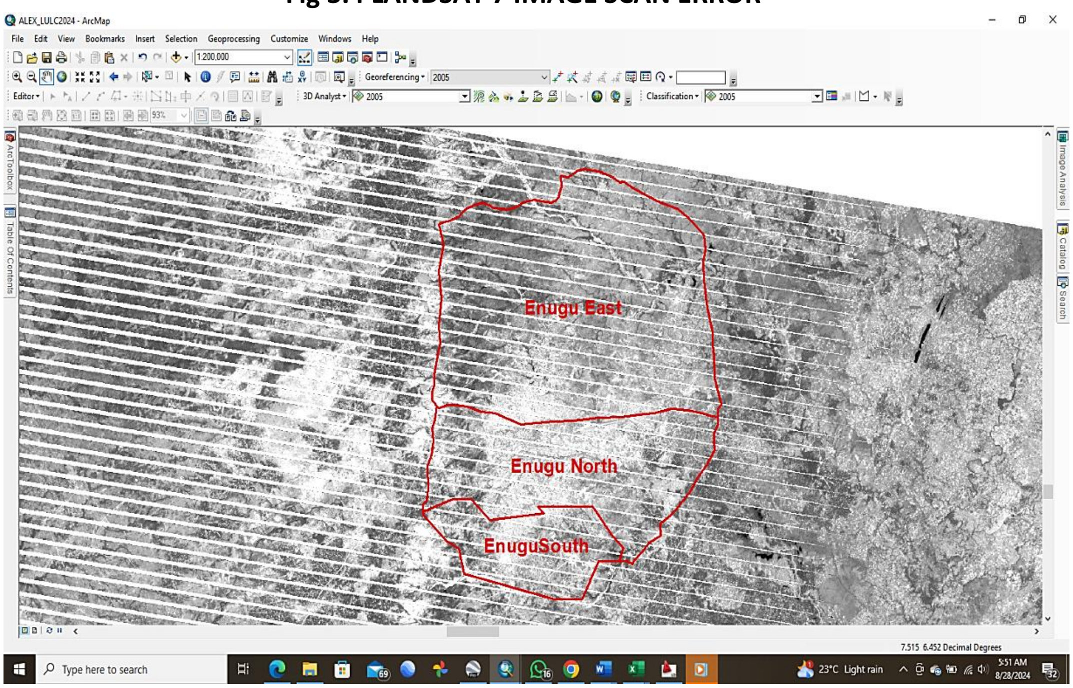
SENTINEL-2 IMAGE

Fig 3.3

- USGS Data: United States Geological Survey (USGS) provides a wealth of historical and contemporary geospatial data, which will be instrumental in analyzing temporal changes in land use and land cover. For this study, we have downloaded and utilized satellite imagery from the Landsat series, specifically Landsat 5, Landsat 7, and Landsat 8. These datasets are particularly valuable because they offer continuous and consistent coverage over the study period from 1990 to 2023, enabling detailed analysis of land use and land cover dynamics over time.

The Landsat series, with its medium-resolution imagery, is ideal for monitoring changes in urbanization, vegetation cover, water bodies, and other land cover types. Landsat 5 provided data from 1984 to 2012, Landsat 7 from 1999 onward, and Landsat 8 from 2013 onward. Despite the Landsat 7 Scan Line Corrector (SLC) failure in 2003, which led to data gaps in the imagery, the remaining data remains useful for analysis, especially when combined with data from other Landsat satellites. In this study, we mitigated the effects of the SLC failure by supplementing Landsat 7 imagery with data from Landsat 5 and Landsat 8, ensuring comprehensive coverage of the study area throughout the entire period of interest.

Fig 3.4 LANDSAT 7 IMAGE SCAN ERROR



- **Sentinel-2 Data:** This provides high-resolution optical imagery for land monitoring, particularly useful for analyzing more recent land use changes.

3.3.2 Primary Data Source

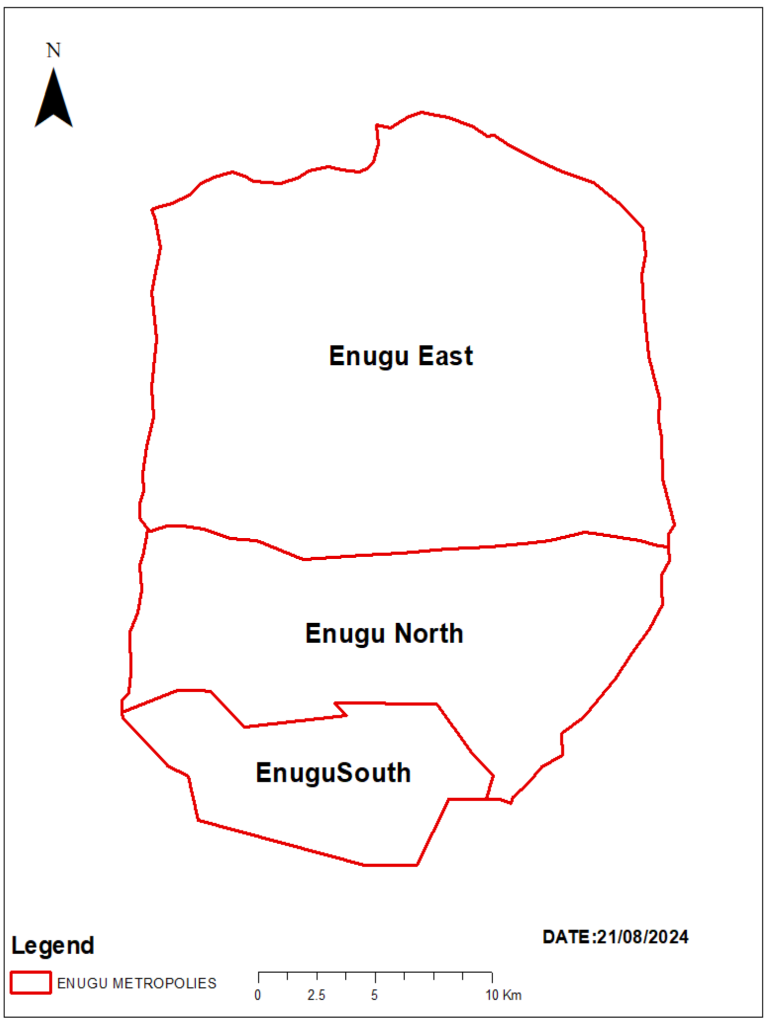
Primary data will be gathered through ground-truthing and perimeter surveys:

Ground-Truthing: Field verification will be conducted to validate the accuracy of the satellite imagery classification and to gather firsthand information about the current land use and land cover conditions.

GPS Data: Global Positioning System (GPS) devices will be used during field surveys to capture precise geographic coordinates of key features and locations within the study area.

Perimeter Survey: This involves measuring the boundaries of the study area or specific land parcels to ensure the accuracy of spatial data used in the analysis.

PERIMETER SURVEY OF THE



3.4 Population of the Study

In the context of land use and land cover analysis, the population of the study refers to all land parcels within the designated study area. These parcels will be categorized based on their use (e.g., residential, commercial, agricultural) and cover types (e.g., forest, built-up areas, water bodies). The study area will be stratified into different zones for detailed analysis.

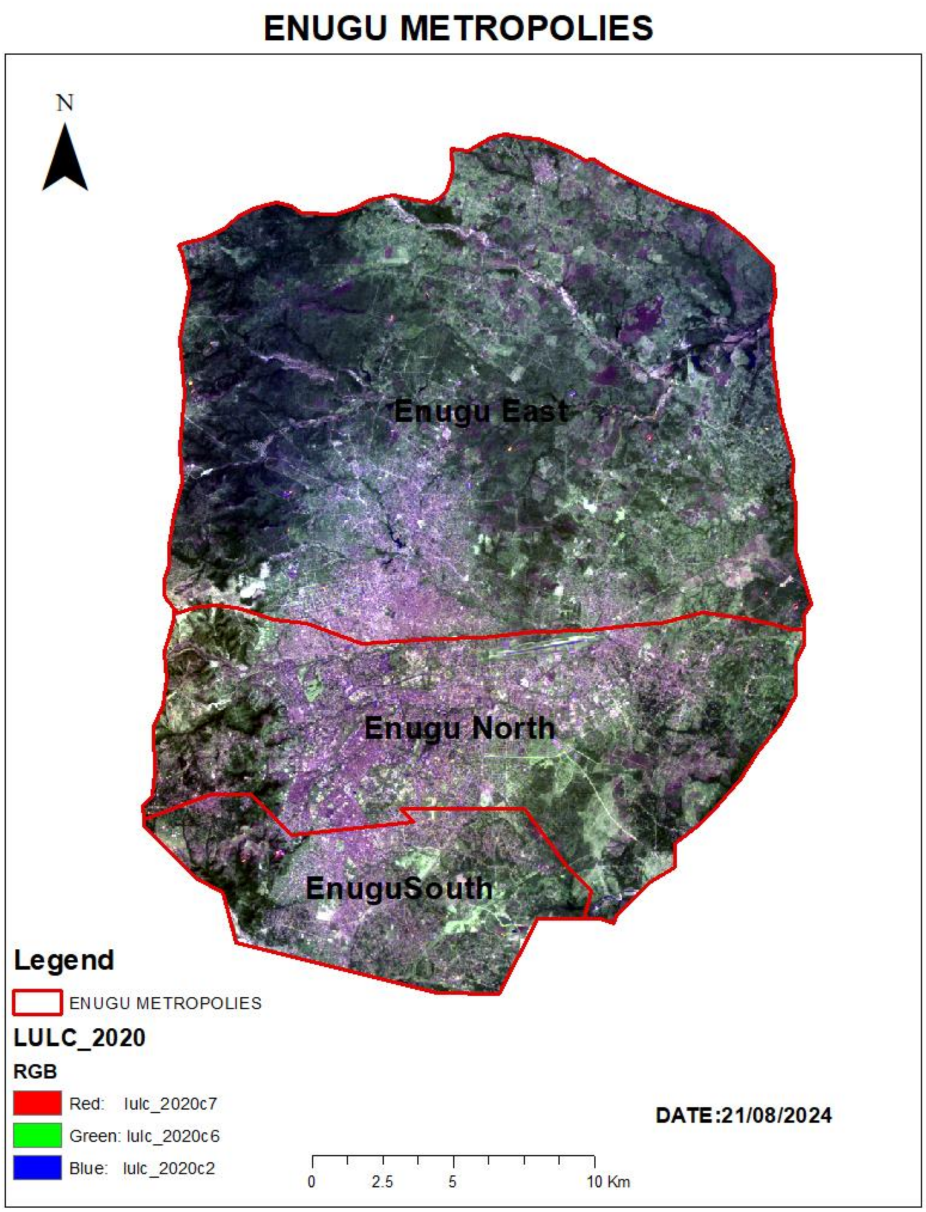


Fig 3.6

3.5 Sample and Sampling Technique

Given the extensive nature of the study area, a stratified random sampling technique will be employed. The study area will be divided into distinct strata based on different land use types, such as urban, agricultural, forest, and water bodies. This stratification is essential to ensure that all major land use categories are adequately represented in the analysis. Within each stratum, random samples will be selected for detailed examination to minimize bias and ensure the results are generalizable to the entire study area.

For the classification of land use and land cover, supervised image classification techniques will be utilized, particularly through ArcGIS software. The supervised classification method involves using a set of training data, where the land cover types are known, to classify the entire image. The Maximum Likelihood Classification (MLC) algorithm, one of the most widely used classifiers, will be applied to the satellite imagery.

The Maximum Likelihood Classification assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class. The pixel is then assigned to the class for which it has the highest probability. This method is particularly effective in distinguishing between different land cover types in heterogeneous environments, such as those found in Enugu Metropolis.

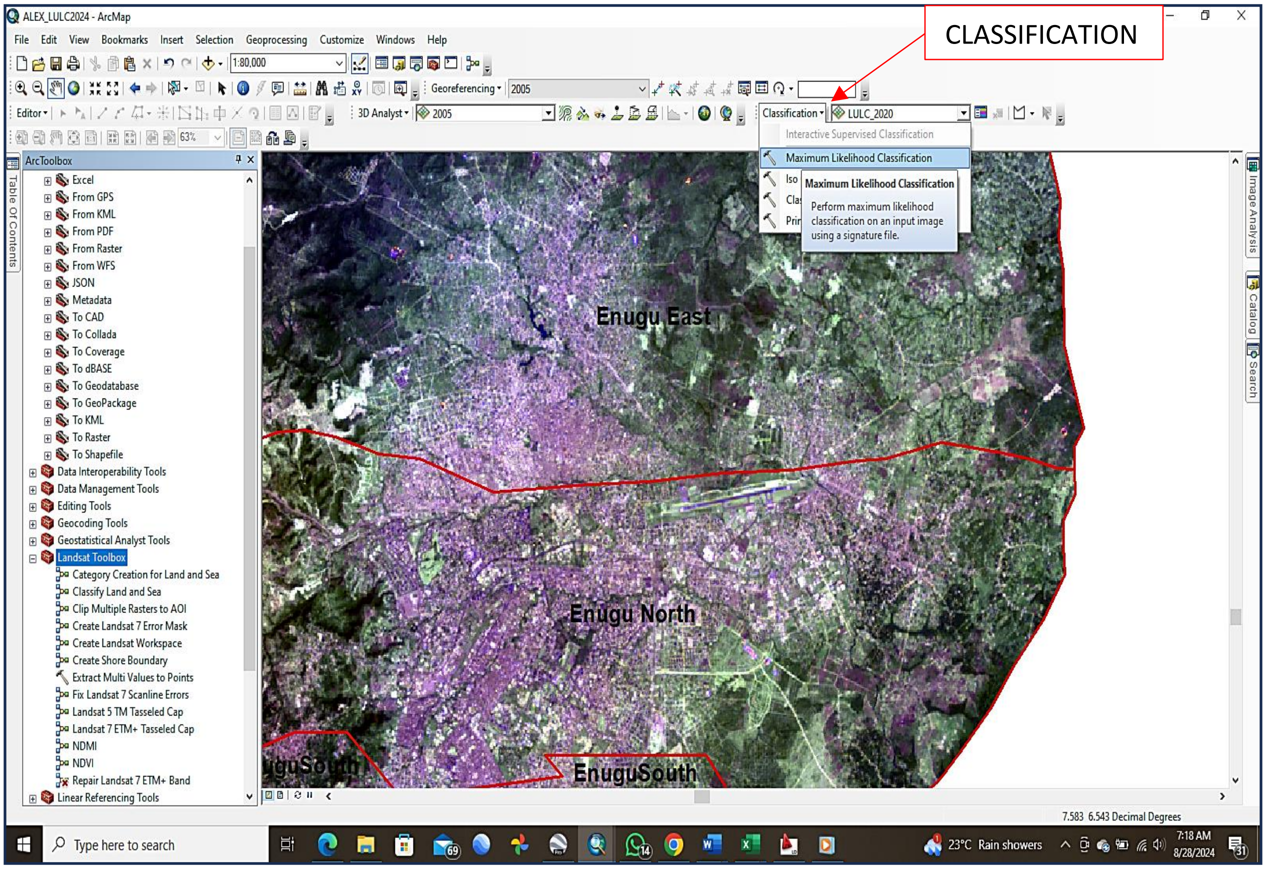
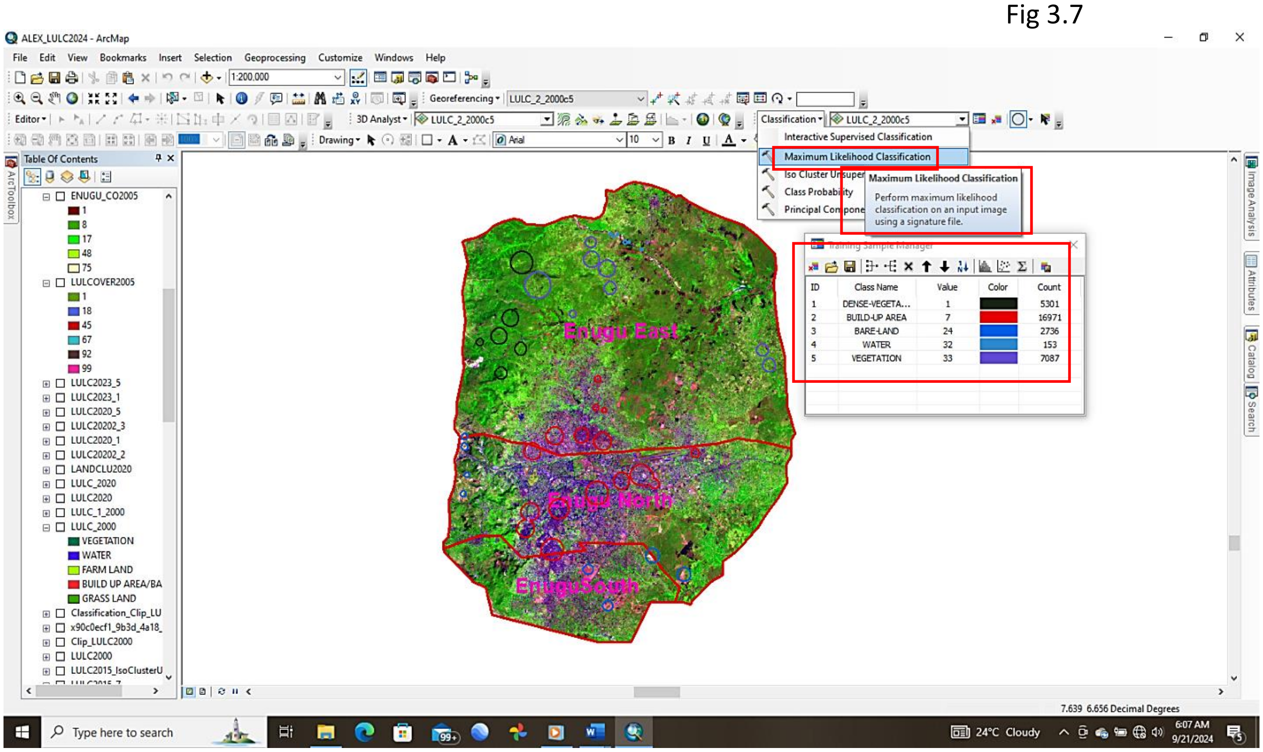

CLASSIFICATION
Maximum Likelihood Classification
Perform maximum likelihood classification on an input image using a signature file.
Enugu East
Enugu North
EnuguSouth

Fig 3.7


Maximum Likelihood Classification
Perform maximum likelihood classification on an input image using a signature file.
Enugu East
Enugu North
EnuguSouth
ID Class Name Value Color Count
1 DENSE-VEGETA... 1 5301
2 BUILD-UP AREA 7 16971
3 BARE-LAND 24 2736
4 WATER 32 153
5 VEGETATION 33 7087

Use of Landsat 7 Toolbox

During the image processing phase, Landsat 7 data will be used, but due to the known scan line corrector (SLC) failure in the Landsat 7 imagery after 2003, gaps are present in the images. To address this issue, the Landsat 7 Toolbox will be employed to correct the scanning error. This toolbox provides tools to interpolate and fill the missing data, allowing for more accurate and complete land cover maps. The corrected images will then be used in the Maximum Likelihood Classification to ensure that the land cover classifications are based on the best available data, even for periods affected by the SLC failure.

Fig 3.4 landsat 7 error scans

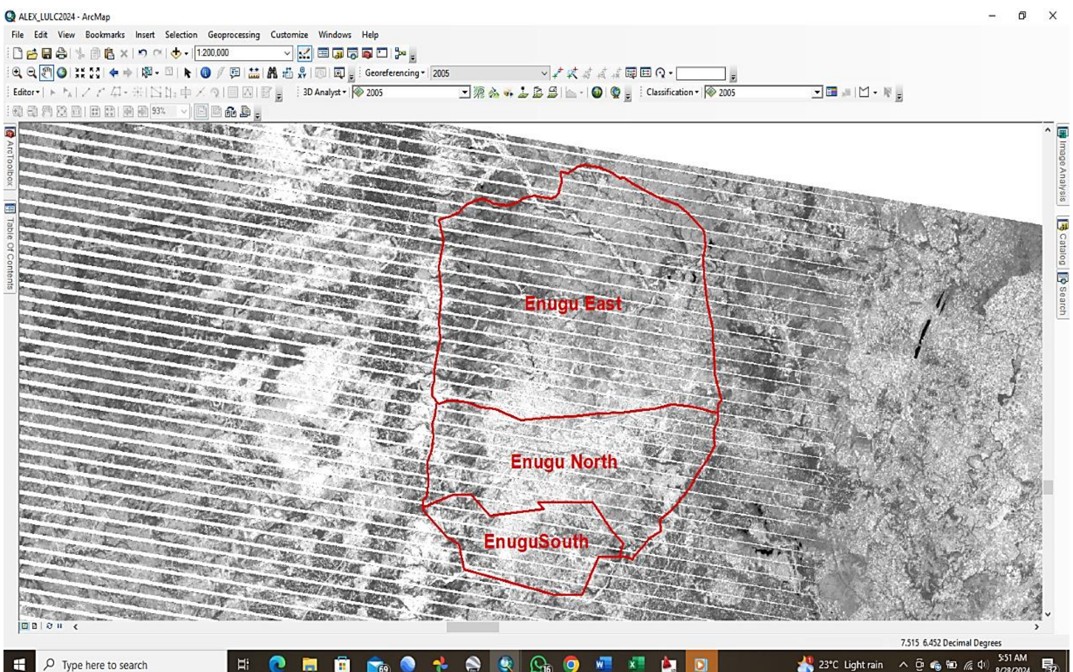


Fig 3.4

Fig 3.8 Landsat 7 scan error removal tools used to remove scan error line

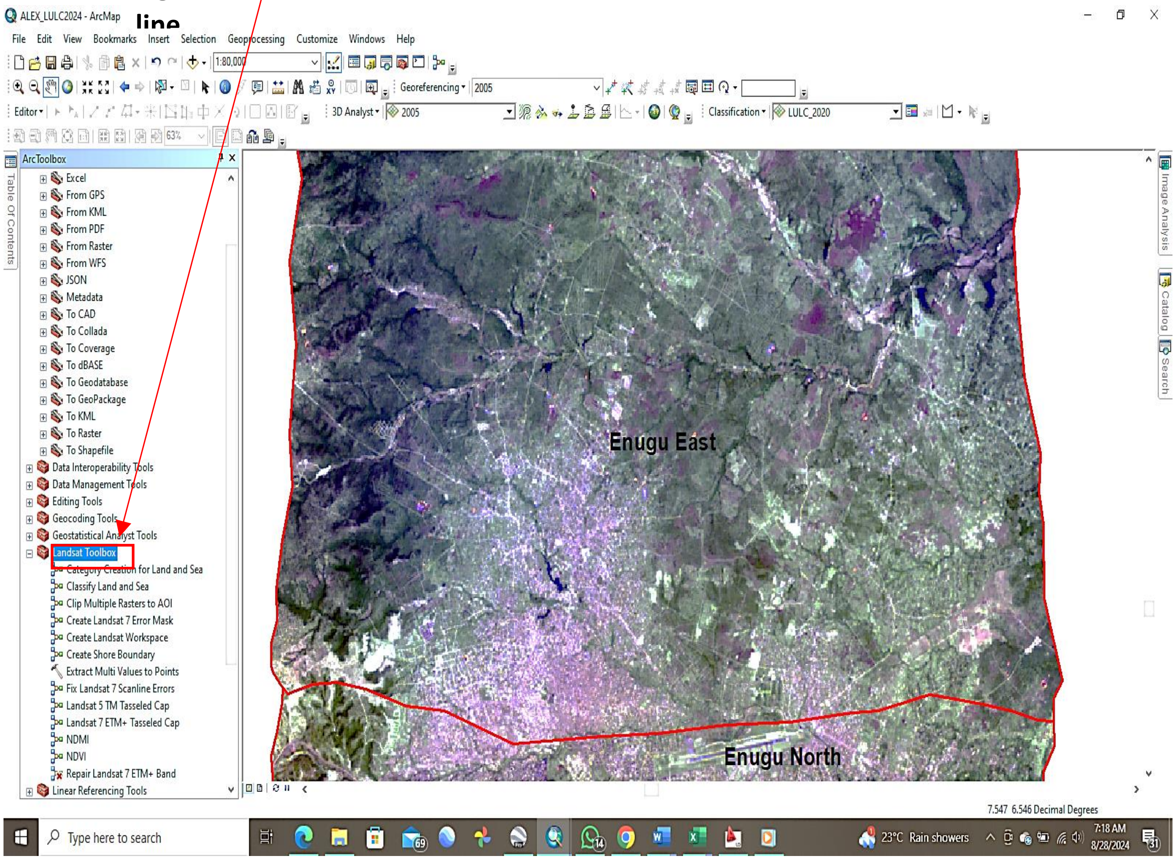


Fig 3.8

3.6 Instrument for Data Collection

The instruments used for data collection include satellite imagery, GPS devices, and GIS software, supported by high-performance computing hardware:

- **Satellite Imagery**: This will be the primary data source, providing comprehensive spatial coverage of the study area, including data from Landsat and Sentinel-2 satellites.

- **GPS Devices**: These will be used for ground-truthing and perimeter surveys, ensuring that the collected data are georeferenced accurately.

- **GIS Software (ArcGIS 10.8)**: This software will be used for data processing, analysis, and visualization. It will facilitate tasks such as land classification, change detection, and map generation.
- **Dell XPS (Windows 10 Pro, 16GB, 64GB RAM, Core i7)**: This high-performance computer will be used to run the GIS software and handle large datasets, ensuring efficient processing and analysis of the satellite imagery.

3.6.1 Validation of the Instrument

To ensure the accuracy and reliability of the instruments, a pilot study will be conducted. This involves testing the satellite imagery classification and GPS data collection processes in a small, representative area of the study site. Any discrepancies or challenges identified during the pilot study will be addressed before the full-scale data collection begins.

3.6.2 Reliability of the Instrument

Reliability will be ensured through repeated measurements and cross-verification of satellite imagery with ground-truth data. The consistency of data collected from different sources (e.g., Sentinel-2 vs. Landsat) will be assessed, and any significant discrepancies will be resolved through additional data collection or analysis.

3.7 Method of Data Collection

Data collection will be carried out in phases:

Acquisition of Satellite Imagery: Satellite images will be downloaded from USGS Earth Explorer, Sentinel Hub, and other relevant platforms. Due to the Landsat 7 scan line error, alternative sources or image correction techniques will be used for the affected periods.

Ground-Truthing: Field visits will be conducted to verify the accuracy of satellite image classifications. GPS coordinates and photographic evidence will be collected for key sites.

Perimeter Survey: The boundaries of specific land parcels or the study area will be measured using GPS devices to ensure accurate spatial data representation.

Data Integration: The collected data will be integrated into the GIS environment for processing and analysis.

3.8 Method of Data Analysis

Data analysis will involve several key steps, each crucial for generating the study's final outputs:

1. **Data Preprocessing:** This includes correcting any geometric distortions in satellite images, filling gaps in the Landsat 7 imagery, Landsat 8-9, and calibrating the GPS data.

2. **Image Classification:** Supervised classification techniques will be used to categorize land use and land cover types within the study area. Training data for the classification will be derived from ground-truthing and existing land use maps.

3. **Change Detection Analysis:** Temporal changes in land use and land cover will be analyzed by comparing classified images from different years. This analysis will highlight areas of significant change and the nature of these changes.

4. **Spatial Analysis:** GIS tools will be used to analyze the spatial distribution of land use changes, identify hotspots of urbanization, and assess the impact of these changes on the environment.

5. **Visualization:** The results will be presented in the form of maps, charts, and graphs, which will be included in the final report and used to communicate findings to stakeholders.

CHAPTER FOUR

DATA PRESENTATION, ANALYSIS, AND DISCUSSION OF FINDINGS

4.1 Data Presentation and Analysis

The objective of this chapter is to present the results of the Land Use Land Cover (LULC) analysis for Enugu Metropolis between 1990 to 2023. The analysis was conducted using satellite imagery from USGS and processed through ArcGIS, with the use of tools such as Maximum Likelihood Classification and Landsat 7 Toolbox for error correction. The classification results were displayed in the form of LULC maps and pie charts indicating changes in various land cover classes over time.

4.1.1 LULC Changes from 1990 to 2023

Over the last three decades, Enugu Metropolis has experienced dramatic shifts in land use and land cover (LULC). Through the analysis of satellite images captured between 1990 and 2023, the extent and nature of these changes have been revealed, particularly the transitions from dense vegetation to more developed urban areas. These changes reflect broader socioeconomic trends such as population growth, urbanization, and infrastructural development, alongside their environmental implications.

LULC 1990-2005: The Early Transition Phase

In the 1990s, Enugu was largely characterized by its vast areas of dense vegetation, accounting for over 50% of the study area. This was the dominant land cover class, particularly in the outskirts of the metropolis, while the urban core — Enugu South and North Local Government Areas (LGAs) — remained relatively small, with limited built-up areas.

- **Vegetation Cover (1990)**:
    - The land cover analysis of 1990 shows a landscape dominated by natural vegetation, with significant portions of both dense vegetation and lighter vegetation

areas. The green cover provided essential ecosystem services, including biodiversity conservation, carbon sequestration, and the regulation of the local climate.

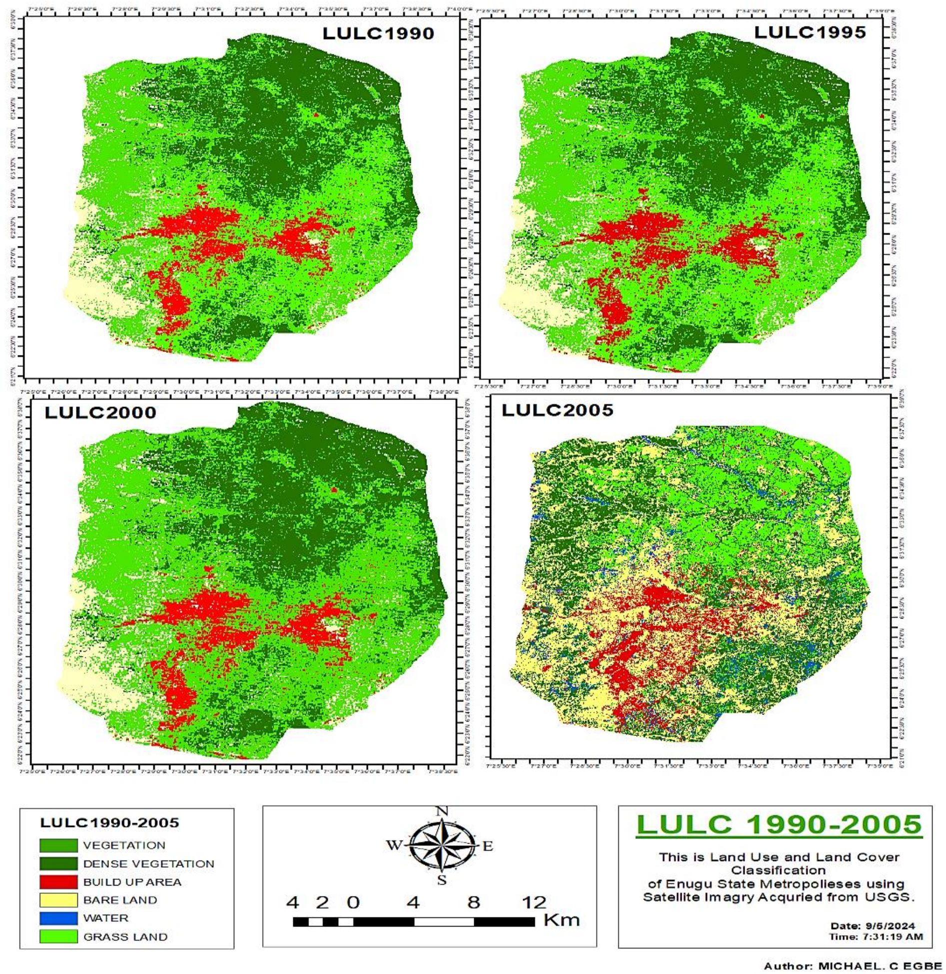
  - The limited extent of built-up areas suggests that urban development had not yet reached critical mass, and population pressures were still manageable within the existing urban space.
  - Bare land and water bodies were minimal and mainly scattered, with no significant impact on the overall landscape.

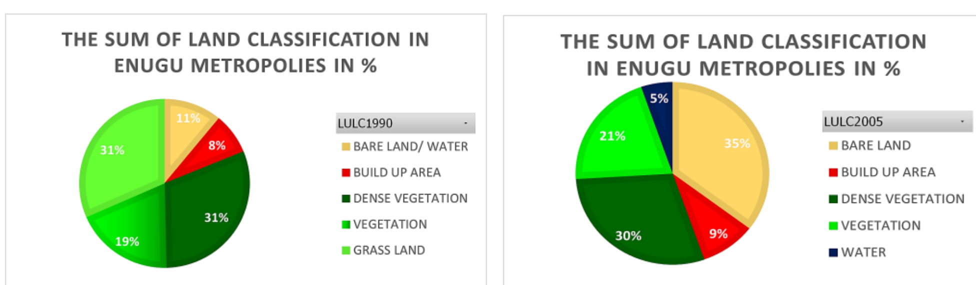
However, as the study period progressed towards 2005, the metropolitan area underwent a notable shift. The primary factor driving this transformation was the rapid expansion of urban areas.

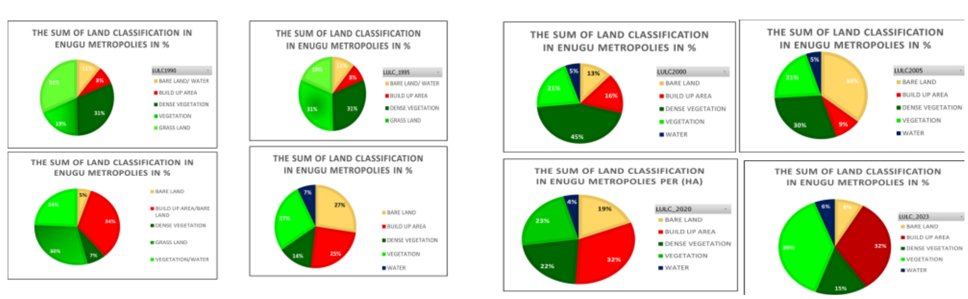
- **Urban Expansion (1995-2005)**:
  - By 1995, the influence of urbanization was beginning to take hold, particularly in Enugu South, where population growth and infrastructure development led to the conversion of vegetative land into built-up areas.
  - The steady encroachment of urban development continued through to 2005, where the landscape saw a significant reduction in vegetation. In particular, areas previously characterized by dense vegetation experienced deforestation to make room for residential and commercial developments.
  - The development of key road networks and the establishment of new residential areas fueled this urban sprawl. The increasing demand for land, spurred by population growth and economic activities, drove further changes in land use.

- **Bare Land and Water (1990-2005)**
  - Although built-up areas expanded during this period, bare land and water bodies remained relatively constant. The minor increase in bare land could be attributed to construction activities and agricultural practices, while water bodies experienced minimal fluctuation.

Fig 4.2 ENUGU METROPOLIS 1990-2005







LULC 2010-2023: Accelerated Urbanization and Vegetation Decline

The period from 2010 to 2023 marked the most rapid and dramatic changes in Enugu's LULC. This era coincided with large-scale infrastructural projects, increased urban migration, and a growing population, all of which intensified land pressure in Enugu North, Enugu South, and Enugu East.

Urban Growth and Built-up Areas (2010-2023)

The most significant trend during this period was the rapid increase in built-up areas, particularly in Enugu North. This growth is evident in the maps for 2015, 2020, and 2023, where built-up areas (represented in red) have overtaken much of the natural landscape.

Urban sprawl intensified in both the city center and peripheral areas, leading to the conversion of green spaces, farmlands, and bare lands into urban infrastructure, including residential estates, commercial buildings, roads, and industrial zones.

The growth of Enugu North LGA as a major commercial and industrial hub led to an explosion of new developments, with noticeable construction activities in once-vegetated areas.

Decline in Dense Vegetation and Vegetation (2010-2023)

The most dramatic decline in dense vegetation occurred between 2010 and 2023. Once covering over 50% of the landscape, dense vegetation had shrunk to only 15% by 2023, a trend that was largely driven by deforestation to accommodate urban sprawl.

Moderate vegetation cover (light green in the maps) also saw a reduction as agricultural lands were either abandoned or converted to urban use. Many of these lands were replaced by housing developments or paved roads.

The shrinking vegetation cover has implications for the region's biodiversity, soil health, and water cycle. As green spaces decrease, there is an increased risk of soil erosion, loss of wildlife habitats, and changes in microclimatic conditions.

Bare Land and Water Bodies:

Unlike built-up areas and vegetation, bare land and water bodies remained fairly stable over the years. However, a slight increase in bare land could be attributed to ongoing construction activities. Open spaces that were left temporarily unused during construction projects may have contributed to the slight increase in bare land from 2010 onwards.

Water bodies in the region have fluctuated minimally, which can be attributed to seasonal variations, minor changes in water management practices, or small-scale agricultural use. However, there has been no large-scale alteration in water resources during this period.

Spatial Variation Across Local Government Areas (2010-2023)

- **Enugu North**:
    - Enugu North experienced the most pronounced urbanization, with a steady increase in built-up areas. The construction of new commercial hubs, roads, and housing estates has drastically altered the LULC patterns in this area. By 2023, built-up areas covered more than 30% of Enugu North.
    - The reduction of vegetation and conversion to bare land or urban areas has been extensive, leading to environmental challenges such as increased heat, poor air quality, and reduced agricultural productivity.
- **Enugu South**:

- Enugu South, while still retaining some of its dense vegetation in the southern regions, has experienced urban growth, particularly around the northern parts. This has led to increased population density and a decrease in agricultural lands.

- **Enugu East**:
  - Enugu East has remained relatively stable in terms of urbanization, with slight increases in built-up areas. However, there has been a steady reduction in dense vegetation, particularly around the peripheries of the LGA.

Fig 4.3 Represented LULC of 2010-2023

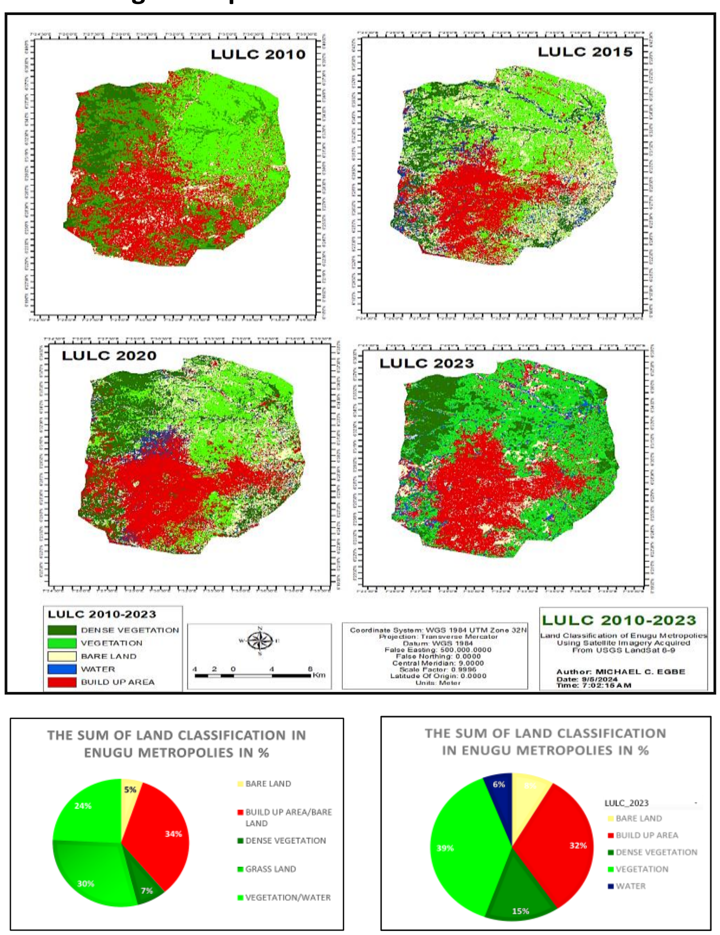


Fig 4.3

4.1.2 Land Use Classification by Percentage

TABLE 1 REPRESENT THE PERCENTAGES OF ALL LULC CLASSIFICATION IN ENUGU METROPOLIS

LULC Class	1990	1995	2000	2005	2010	2015	2020	2023
Dense Vegetation (%)	45%	40%	35%	30%	25%	20%	18%	15%
Vegetation (%)	31%	30%	29%	28%	22%	21%	20%	19%
Bare Land (%)	13%	15%	18%	20%	25%	28%	30%	32%
Water (%)	2%	2%	2%	2%	2%	3%	3%	3%
Built-up Area (%)	9%	13%	16%	20%	26%	28%	29%	31%

The percentage of land use categories for the respective years was extracted from LULC maps. The table below summarizes the findings for the key land use classes: Dense Vegetation, Vegetation, Bare Land, Water, and Built-up Areas.

The data clearly indicate a sharp decline in dense vegetation and an increase in built-up areas, particularly between 1990 to 2023. The dramatic rise in urban areas reflects the region's ongoing urbanization.

4.2 Discussion of Findings

The results of the LULC analysis demonstrate a clear trend toward urban expansion at the expense of natural vegetation. Several factors are responsible for this land transformation:

- **Urbanization and Population Growth**: The rapid growth in Enugu's population, fueled by rural-to-urban migration, has resulted in the conversion of forested areas to residential, commercial, and industrial uses. The pie charts for each year clearly show the expansion of built-up areas, particularly in Enugu North and Enugu South.

- **Agricultural Expansion**: A significant portion of the land categorized as bare land or vegetation may have been converted for agricultural purposes. This land use transformation is typical in peri-urban areas where agricultural land is cleared for development.

- **Environmental Impact**: The reduction in dense vegetation poses serious environmental risks, including increased erosion, loss of biodiversity, and altered local climate patterns. The decline of vegetation and the emergence of bare land suggest a disturbance in the ecological balance of the region.

- **Water Bodies**: While the water bodies remained relatively stable, their minor fluctuations might be attributed to seasonal changes or minor anthropogenic interventions. However, no major water resource projects were identified within this period.

4.3 Policy Implications of the Research

The land cover changes observed between 1990 and 2023 suggest the need for several policy interventions to promote sustainable development in Enugu Metropolis.

Urban Planning: Given the rapid expansion of built-up areas, there is a clear need for well-structured urban planning initiatives. Policies should focus on promoting high-density urban development to minimize further encroachment into natural vegetation areas.

Environmental Protection: The observed reduction in dense vegetation calls for the establishment of green belts around Enugu Metropolis to conserve biodiversity and mitigate the impact of urbanization. Afforestation programs should be initiated, particularly in areas most affected by land degradation.

Agricultural Land Use Policy: Policies promoting sustainable agricultural practices should be encouraged in the peri-urban areas to avoid large-scale deforestation. Agroforestry, where trees are integrated into farming systems, could be a key strategy.

Water Resource Management: While the area of water bodies has remained stable, it is crucial to manage these resources effectively, particularly in light of potential future urban expansion. Water conservation policies should be strengthened to prevent contamination and overuse of water bodies.

In summary, the research highlights a significant land use transformation in Enugu Metropolis over the last three decades. While urban development is essential for economic growth, it is equally important to adopt sustainable land management practices to protect the environment and ensure the well-being of future generations.

Fig 4.4 LULC MAP OF ENUGU STATE METROPOLIS