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Spatio-Temporal Dynamics and Human Drivers of Land Use/Land Cover Change and Erosion in the Onitsha Section of the Nkisi River Watershed

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Abstract: This study examines the spatio-temporal dynamics and drivers of land use and land cover change in the Onitsha section of the Nkisi River Watershed over a forty-year period using a quasi-experimental research design that integrates satellite imagery, GIS techniques, and statistical analysis. The findings reveal a clear transition from a predominantly vegetated landscape to a more urbanized environment, largely driven by human activities. Built-up areas expanded significantly, while vegetation declined, with urban growth concentrated along transport corridors and near the Nkisi River. Socio-economic factors such as trading, farming, poverty, and unemployment were identified as major drivers of land use change, alongside population growth, infrastructure development, and weak regulatory enforcement. Human activities, particularly construction, vegetation removal, bush burning, poor drainage, and sand mining, were also strongly linked to increased erosion. The interaction between land use change, soil characteristics, and topographic factors has intensified erosion across the watershed, resulting in uneven but severe soil loss, mostly human-induced land transformation shaping land use patterns and accelerating environmental degradation, with significant implications for ecosystem stability and local livelihoods.

Keywords: *Spatio-Temporal Dynamics, Drivers of Land Use/Land Cover Change, Nkisi River Watershed.*

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I. INTRODUCTION

➢ *Background to the Study*

Human activities have significantly driven land use and land cover (LULC) changes in recent years, with important implications for environmental sustainability. These changes, largely influenced by urbanization, agriculture, and deforestation, play a critical role in shaping soil erosion dynamics and ecosystem balance. Urbanization, particularly in rapidly expanding cities like Onitsha, replaces natural vegetation with impervious surfaces, thereby disrupting hydrological processes and increasing surface runoff (Xiao, Chen, Liu, Jin, and Gao, 2019). Understanding patterns of land use and land cover change and their underlying drivers is essential for effective land use planning and decision-making (Arowolo and Deng, 2017). Land use refers to the various human activities carried out on land and the purposes they serve, while land cover describes the physical materials present on the Earth's surface (Food and Agriculture Organization, 2020; Das, 2014; Cracknell, 2015; Erb, 2015). Changes in land use often result in alterations to natural land cover, thereby affecting ecological stability and resource availability (Taye, Diyessa, Mekuria and Haileslassie, 2024). Soil erosion, defined as the removal and transport of soil particles by agents such as water and wind, poses a serious environmental challenge (Alexander, 2018). It contributes to sedimentation in waterways, damages infrastructure, and threatens human health and livelihoods (Nwankwo, Nwankwo and Okolo, 2022). In Nigeria, erosion varies widely in severity and form due to differing climatic, geological, and soil conditions, often leading to hazardous consequences (Amangabara, Njoku and Iwuji, 2017).

The Onitsha section of the Nkisi River Watershed is particularly vulnerable, as soil erosion affects both environmental integrity and socio-economic well-being (Eze, Okoro and Okeke, 2022). This watershed, which supports many communities, is increasingly threatened by land use changes linked to urban growth and agricultural expansion (Jain, Singh, and Kumar, 2020; Adewole, Adeleke and Oyedele, 2022; Oke and Oke, 2020). Agricultural practices and deforestation expose soil to erosion and degrade water

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quality through sedimentation and agrochemical runoff (Montgomery and Schmidt, 2019; Wang, Xu, and Du, 2020). Effective land use planning and conservation strategies are therefore essential to mitigate these impacts and promote sustainable environmental management (Xiao, Chen, Liu, Jin and Gao, 2019). It as a result that this study focus on Spatio-Temporal Analysis and Drivers of Land Use/Land Cover Change in the Onitsha Section of the Nkisi River Watershed (1984–2024)

➢ *Statement of the Study*

The interaction between land use and land cover changes and soil erosion is a critical environmental issue driven by human activities such as urbanization, agriculture, and deforestation. These activities alter natural landscapes, disrupt hydrological processes, and increase soil vulnerability to erosion, particularly in areas with heavy rainfall and steep slopes. In the Onitsha section of the Nkisi River Watershed, rapid urban and agricultural expansion has intensified soil erosion, reduced water quality, and contributed to biodiversity loss. Despite these impacts, there is limited comprehensive research on erosion patterns, their link to land use changes, and their socio-economic effects on local communities. This study therefore aims to examine land use and land cover change dynamics and their influence on erosion in the study area.

➢ *Aim/Objectives of the Study*

The aim of the study is to ascertain the Spatio-Temporal changes and Drivers of Land Use/Land Cover Change in the Onitsha Section of the Nkisi River Watershed (1984–2024). Specific objectives are to ascertain;

- Primary drivers of land use/land cover change.
- spatio-temporal changes in land use/land cover over a 40-year period (1984–2024).
- socio-economic and anthropogenic drivers contributing to land use changes.

II. LITERATURE REVIEW

➢ *Conceptual Framework*

Spatio-temporal changes refer to variations in a phenomenon across both space and time, capturing how patterns, distributions, or processes evolve geographically and temporally (Goodchild, 2013). While,Longley, Goodchild, Maguire, & Rhind, (2015) defined Spatio-temporal changes denote the combined spatial and temporal dimensions of change, emphasizing how events or conditions vary across geographic areas while also evolving over time.

Land cover change refers to the measurable alteration in the physical characteristics of the Earth’s surface such as vegetation, water bodies, and built-up areas over time, often driven by human activities and environmental processes (Acheampong, Agyemang, & Abdul-Fatawu, 2016). Singh *et al.*, (2016) described Land cover change as the transformation in the composition and spatial distribution of surface features, reflecting dynamic interactions between natural systems and anthropogenic influences across space and time. While in the view of Olotuah *et al.*, (2016), land cover change denotes the modification or replacement of natural land surfaces with alternative cover types, such as urban or agricultural land, as a result of processes like urban expansion and land use conversion.

➢ *Theoretical Studies*

- *Primary Drivers of Land Use/Land Cover Change*

The Concept of Land Use and Land Cover Changes refers to the alterations in the way land is used and covered by human activities, such as deforestation, urbanization, agriculture, and infrastructure development (Feng *et al.*, 2019). These changes can have significant impacts on the environment, including soil erosion, water pollution, and loss of biodiversity (Zhang *et al.,* 2020). In this concept, there are numerous drivers of change which include human activities, such as population growth, economic development, and technological advancements, drive land use/land cover changes (Liu *et al.,* 2020). These drivers will be effectively investigated in the study areas.These changes are categorized into different types such as deforestation and forest degradation, urbanization and infrastructure development, agricultural expansion and intensification and wetland conversion. Land use/land cover changes can lead to various environmental impacts such as soil erosion and sedimentation, water pollution and decreased water quality, loss of biodiversity and ecosystem degradation, increased greenhouse gas emissions and climate change. Land use/land cover changes can as well create feedback loops and interactions with other environmental and social systems, such as climate change and land use/land cover changes, water cycles and land use/land cover changes and social and economic systems and land use/land cover changes

In the context of the study of the Onitsha section of Nkisi River Watershed, Land Use/Land Cover Changes can help explain the impacts of human activities on erosion dynamics. The conceptual framework can be applied through analyzing the drivers of change, identification of the types of change, assessing the environmental impacts, examination of feedback loops and interactions.

- *Spatio-Temporal Changes in Land Use/Land Cover Over a 40-Year Period (1984–2024).*

Spatio-temporal Land use, and cover changes have a significant impact on erosion, as they alter the hydrological and geomorphological processes that govern soil erosion and sediment transport (Feng *et al.*, 2019). Understanding this relationship is crucial for assessing the impacts of land use, land cover changes on soil erosion and water quality (Zhang *et al.*, 2020).

The conceptual framework of the relationship between land use, land cover changes and erosion dynamics can be understood through changes in land use and land cover, such as deforestation, urbanization, and agricultural expansion which can alter the hydrological and geomorphological processes that govern soil erosion and sediment transport (Liu *et al.*, 2020), erosion which is influenced by land use and land cover changes, which can alter the rates and processes of soil erosion, sediment transport, and deposition (Feng *et al.*,

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2019), land use and land cover changes which alters hydrological processes, such as runoff and infiltration, which in turn affect erosion dynamics (Zhang *et al.,* 2020), and also alters geomorphological processes, such as soil erosion and sediment transport, which shape the landscape and affect erosion dynamics (Liu *et al.,* 2020). The relationship between land use, land cover changes and erosion dynamics can help explain the impacts of human activities on soil erosion in the Onitsha section of Nkisi River Watershed. The concept can be applied by analyzing land use and land cover changes via understanding the types and rates of land use/land cover changes occurring in the watershed, evaluating the impacts of land use and land cover changes on erosion dynamics, including soil erosion, sediment transport, and deposition. It can also examine the area's hydrological processes by understanding the impacts of land use/land cover changes on hydrological processes, such as runoff and infiltration, and evaluate geomorphological processes by assessing the impacts of land use/land cover changes on geomorphological processes, such as soil erosion and sediment transport.

- *Socio-Economic and Anthropogenic Drivers Contributing to Land Use Changes.*

Land use change (LUC) is a dynamic process influenced by a myriad of factors, prominently including socioeconomic drivers. Understanding these drivers is crucial for sustainable land management, especially in regions experiencing rapid urbanization and environmental degradation. Land use change is driven by both biophysical and socioeconomic factors. Socioeconomic drivers encompass population growth, economic development, policy decisions, and cultural practices. These factors often interact, leading to complex land use dynamics. For instance, urban expansion driven by population growth can lead to the conversion of agricultural lands into residential or industrial areas. Similarly, economic incentives may encourage deforestation for agricultural expansion.

- *Socioeconomic Dimensions of Land Use Change:*

Population growth is a significant driver of land use change. In Hawassa City, Ethiopia, Nigeria and other countries of the world with rapid urbanization which has led to the displacement of peri-urban farmers, altering traditional land use patterns (Tessema *et al*., 2024). Similarly, in Dar es Salaam, Tanzania, unregulated urban expansion has resulted in the conversion of bushland and forest areas into agricultural and urban lands (Simona et al., 2024). The Economic activities, particularly agriculture, play a pivotal role in land use dynamics. In the Migori River watershed in Kenya, agricultural expansion, driven by the need for food security and income, has led to significant deforestation and land degradation (Omondi *et al.,* 2022). In southern Mexico, the volatility of coffee prices and the incidence of pests have influenced land use decisions, leading to habitat loss and degradation (Ramos-Fernández *et al*., 2023).

Policy decisions and institutional frameworks significantly impact land use patterns. In the Teso farming system of eastern Uganda, political instability and lack of supportive institutions have contributed to unsustainable land use practices (Nkonya *et al.,* 2010). Conversely, in Wuhan, China, government policies have facilitated urban expansion at the expense of farmland, highlighting the role of governance in land use transitions (Li *et al.,* 2023).

Studies have employed various methodologies to analyze land use change and its drivers. Remote sensing and Geographic Information Systems (GIS) are commonly used for spatial analysis. For instance, in Dar es Salaam, Landsat images and Random Forest algorithms were utilized to detect land cover changes over time (Simona *et al.,* 2024). In the Migori River watershed, remote sensing data combined with household surveys provided insights into land use dynamics and community perceptions (Omondi et al., 2022). Statistical models, such as logistic regression and probit models, have also been applied to assess the influence of socioeconomic factors on land use decisions (Tessema *et al*., 2024). A recurring pattern in the literature is the conversion of natural and agricultural lands into urban and built-up areas, driven by population growth and economic development. However, contradictions arise regarding the role of population growth in environmental degradation. While some studies support the neo-Malthusian perspective that population growth leads to resource depletion (Cleaver & Schrieber, 1994), others align with Boserup's theory, suggesting that population pressure can lead to technological innovations and improved land management (Boserup, 1965). These differing viewpoints underscore the complexity of land use dynamics and the need for context-specific analyses.

The strengths of existing studies lie in their multidisciplinary approaches, combining spatial analysis with socioeconomic assessments. The integration of remote sensing, GIS, and statistical models has enhanced the understanding of land use dynamics. However, limitations include the scarcity of long-term data, challenges in model calibration, and the underrepresentation of socio-economic factors in land use planning. Moreover, the generalization of findings across diverse ecological zones without considering local specificities may lead to inaccurate conclusions.

The literature on drivers of land use change and their socioeconomic dimensions reveals significant transformations driven by urbanization, agricultural expansion, and policy decisions. These changes have profound implications for environmental sustainability and community livelihoods. While methodological advancements have enhanced the assessment of land use impacts, challenges persist in data availability, model integration, and policy implementation.

➢ *Theoretical Framework*

- *Human Environment System (HES) Theory*

Human environmental system Theory is propounded by Ian McHarg, a Scottish American landscape architect and environmentalist, in the year 1969. This theory provides a framework for understanding the dynamic interactions between human and environmental systems through ecological planning, system thinking, layer cake method for analysing environmental factors and carrying capacity of a particular area to reduce environmental degradation. This

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theory recognizes that human activities are embedded within environmental systems, and that understanding these relationships is crucial for achieving sustainability (Ostrom, 2009). In the context of the Onitsha section of Nkisi River Watershed, HES Theory can help explain how land use/land cover changes have impacted erosion. The theory suggests that human activities (Land use changes), such as deforestation and urbanization, can alter environmental processes and increase erosion risk (Feng et al., 2019), the erosion may also lead to sedimentation, water pollution, and loss of biodiversity, which can have cascading effects on human well-being (Zhang et al., 2020). System dynamics helps in understanding the complex interactions between human and environmental systems can inform strategies for sustainable land use management (Liu et al., 2020). Human Environment System Theory is relevant to this study because it explains the causes of erosion by examining human activities and environmental feedback (Feng et al., 2019), also it provides a framework for analysis in the impact of land use changes on erosion dynamics to be evaluated (Liu et al., 2020). It helps in guiding recommendations for sustainable land use practices.

- *Watershed Management Theory*

Watershed Management Theory provides a framework for understanding the complex relationships between land use, water resources, and environmental impacts within a watershed context (Folke *et al.*, 2016). This theory emphasizes the importance of integrated management approaches that consider hydrological, ecological, and social factors (Newson, 2010). The Nkisi River Watershed Management Theory can help explain how land use/land cover changes have impacted erosion dynamics. The theory suggests that land use changes alterations in land cover can bring increase in soil erosion, sedimentation, and water pollution (Feng et al., 2019), Hydrological processes changes in land use can affect water flow, runoff, and erosion rates (Bulygina et al., 2018). The ecological impacts of erosion can lead to loss of biodiversity, habitat degradation, and decreased ecosystem services. Watershed Management Theory is relevant to this study because it explains the causes of erosion by examining land use changes and hydrological processes (Feng et al., 2019). It provides a framework for analysis in the impact of land use changes on erosion dynamics to be evaluated (Folke et al., 2016) and equally guides recommendations for sustainable land use practices.

III. EMPIRICAL REVIEW

➢ *Numerous Case Studies have Demonstrated the Efficacy of IWM in Watershed Restoration:*

- Ethiopian Highlands: A study by Alemu and Kidane (2014) highlighted the success of participatory watershed management in enhancing soil fertility, increasing crop yields, and providing additional resources such as fuelwood and construction materials. This approach also contributed to poverty reduction and improved food security.
- China, Europe, and Canada: Case studies reviewed by German *et al.* (2016) illustrated the application of IWM in diverse geographical contexts, showcasing its adaptability and effectiveness in addressing region-specific challenges.

➢ *Challenges and Limitations of IWM: Despite its Advantages, IWM Faces Several Challenges:*

- Institutional Constraints: Limited capacity at various administrative levels can hinder the implementation of IWM strategies (Wickrama, 2016).
- Financial and Technical Resources: Insufficient funding and technical expertise may impede the development and execution of comprehensive watershed management plans (Siraw *et al.*, 2018).
- Stakeholder Conflicts: Diverging interests among stakeholders can lead to conflicts that undermine collaborative efforts.
- Climate Change Impacts: Altered precipitation patterns and increased frequency of extreme events complicate the management of watershed resources.

➢ *Synthesis and Future Directions:*

The literature indicates a growing recognition of the importance of IWM in watershed restoration. However, to enhance its effectiveness, future research and practice should focus on:

- Capacity Building: Strengthening institutional frameworks and local capacities to support IWM initiatives.
- Innovative Financing: Exploring sustainable funding mechanisms to support long-term watershed management projects.
- Conflict Resolution Mechanisms: Developing strategies to address and mitigate stakeholder conflicts.
- Climate Resilience: Incorporating climate change projections into watershed management planning to ensure adaptability.

Integrated Watershed Management represents a comprehensive approach to watershed restoration, addressing ecological, social, and economic dimensions. While challenges persist, the integration of adaptive management practices, participatory planning, and technological tools offers promising avenues for enhancing the sustainability and effectiveness of watershed restoration efforts.

IV. MATERIALS AND METHODS

The study area is Onitsha Section of Nkisi River Watershed, Onitsha South-Eastern Nigeria with a geographical coordinate of approximately 6.14° N latitude and 6.80° E longitude. The river originates from the hilly areas of Awka and Nsugbe in Anambra State, Nigeria.

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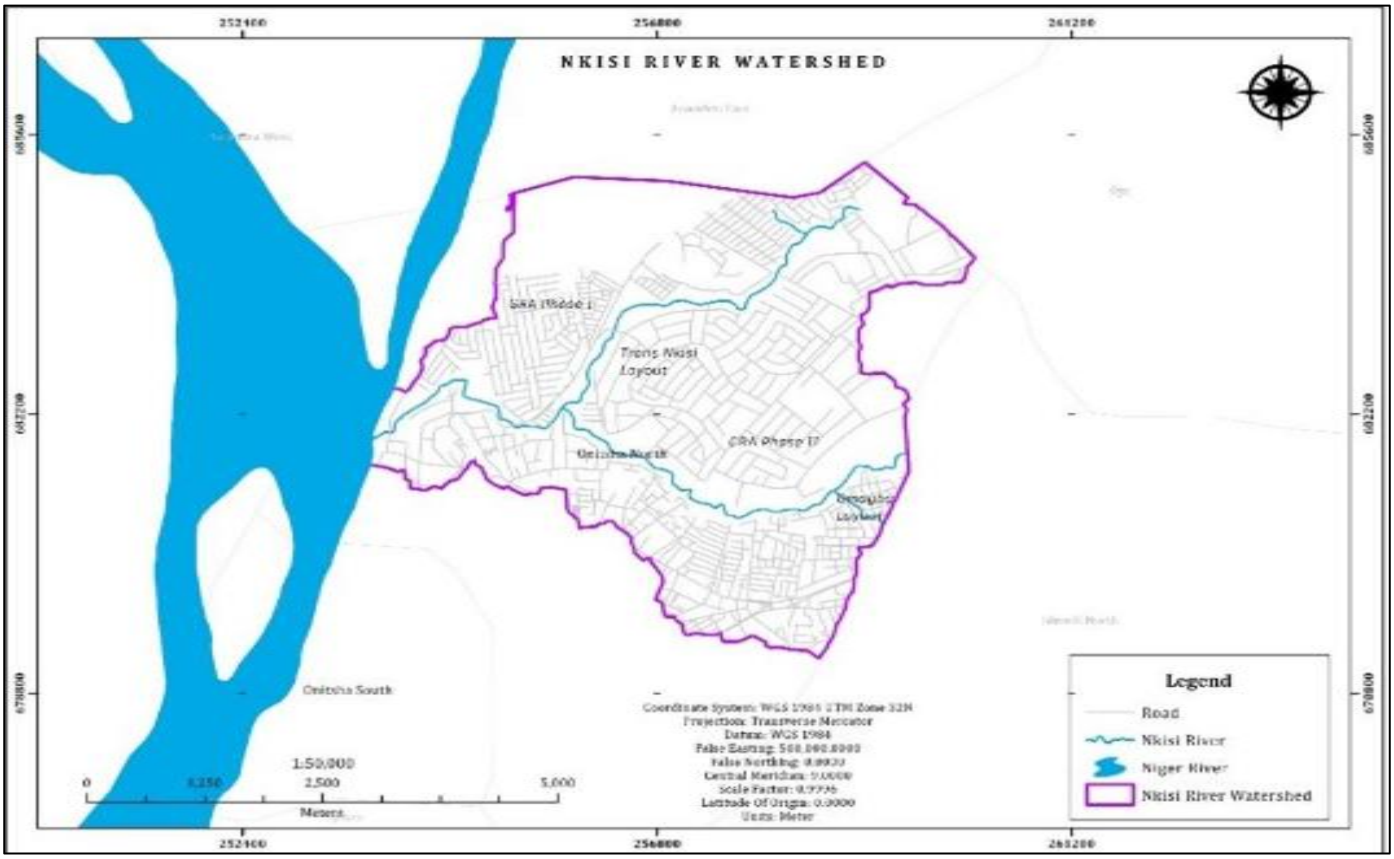

Fig 1 Map Showing the Study Area Nkisi River Watershed Onitsha
Source: Digitalized ArcGIS 10.8 (2024)

Fig 2 Showing Nigeria Map Indicating Anambra State, the Study Town
Source: Digitalized ArcGIS10.8 (2024)

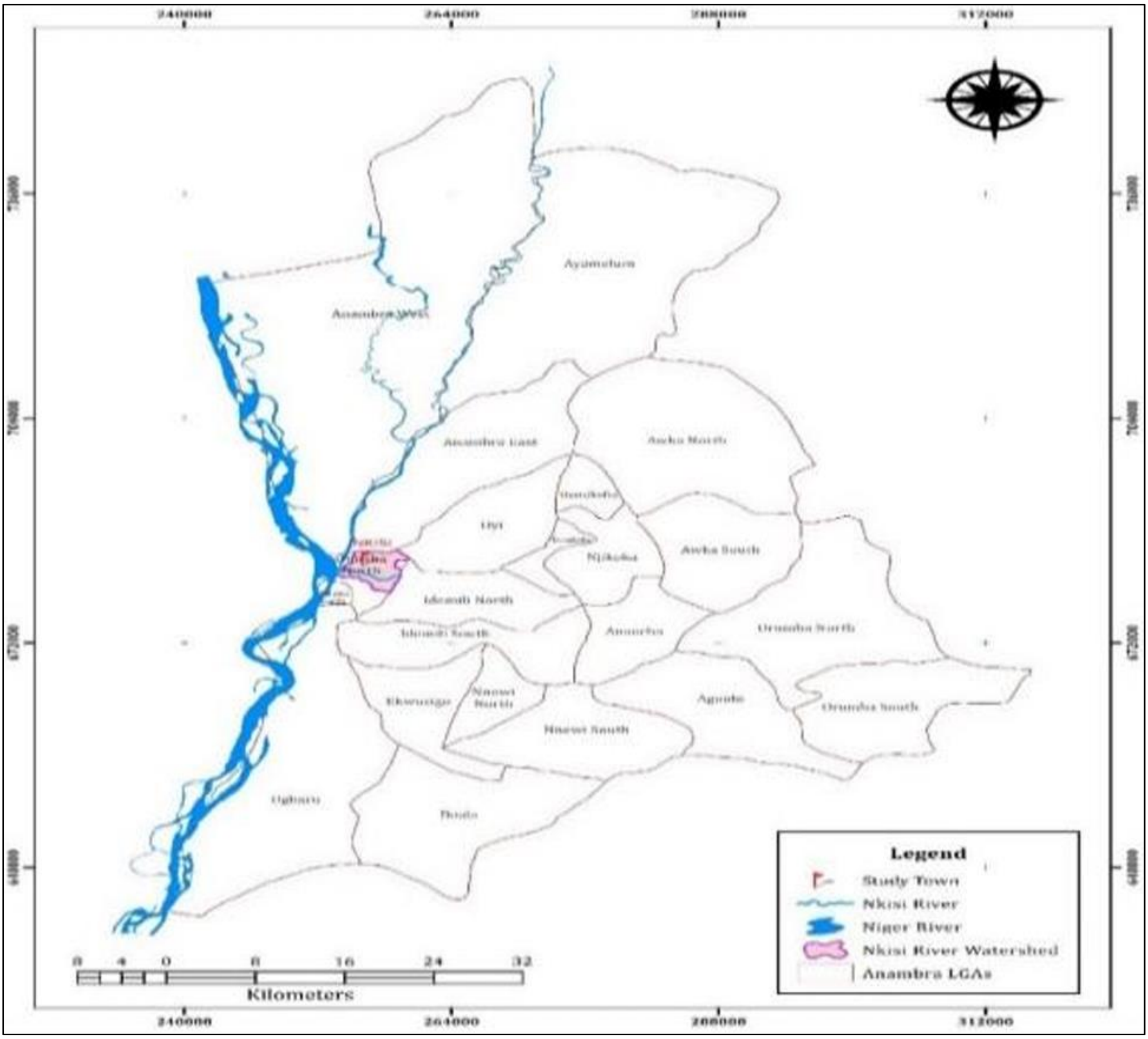

Fig 3 Map of Anambra State Indicating the Study Town Onitsha
Source: Digitalized ArcGIS 10.8 (2024)

➢ *Research Design*

This study employs a survey design and quasi-experimental research design, combining satellite imagery, GIS, and statistical analysis to investigate land use/land cover changes and their impacts in the Onitsha section of Nkisi River Watershed. A retrospective analysis (1984-2024) using Landsat imagery to examine historical land use/land cover changes.

Based on the research objectives, quasi -experimental design was used where remote sensing and GIS analysis were be done. This employed image classification of Landsat imagery, with intervals set at 10 years. This is to discern the evolving landscape patterns and transformations that have unfolded over the specified time frame.

➢ *Data Processing Techniques*

The processing techniques involve the integration of Geographic Information System (GIS) and Remote Sensing approaches to derive land use/land cover (LULC) change, soil texture characteristics, and soil erosion susceptibility within the Onitsha section of the Nkisi River watershed. Each step from data preprocessing to model computation was designed to ensure precision, replicability, and scientific robustness of the results.

➢ *Satellite Image Preprocessing*

The multitemporal Landsat imagery used for this study (1984, 1994, 2004, 2014, and 2024) was subjected to a sequence of preprocessing operations to correct geometric, radiometric, and atmospheric distortions. The purpose of these corrections was to ensure spectral comparability and

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geometric alignment between image epochs before classification.

The first stage involved radiometric calibration, where the raw Digital Number (DN) values were converted into Top-of-Atmosphere (TOA) reflectance using the standard equation:

$$\rho_\lambda = M_\rho Q_{cal} + A_\rho$$

Where:

$\rho\lambda$ = TOA reflectance,

$M\rho$ = band-specific multiplicative rescaling factor,

$A\rho$ = band-specific additive rescaling factor, and

$Qcal$ = quantized calibrated pixel value (DN).

Subsequently, atmospheric correction was performed using the Dark Object Subtraction (DOS) method to minimize haze and scattering effects. The corrected imagery was then orthorectified and reprojected to the WGS 1984 UTM Zone 32N coordinate system to maintain consistent spatial referencing across all datasets.

A cloud masking procedure was applied to eliminate obscured pixels, and each image was spatially clipped to the Nkisi River watershed boundary derived from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM). These preprocessing steps ensured the spatial, spectral, and radiometric integrity of all satellite datasets prior to classification.

- *Land Use/Land Cover (LULC) Classification*

The preprocessed Landsat images were classified into four thematic categories Bare ground, Built-Up Area, Vegetation, and Waterbody representing the major land-cover types in the watershed. The Maximum Likelihood Supervised Classification (MLC) algorithm, which assumes a normal distribution of class spectral signatures, was adopted due to its high accuracy in heterogeneous urban–rural landscapes.

Training samples were delineated using signature samples of each class picked from the images. The spectral separability of classes was assessed using the Transformed Divergence (TD) index, ensuring values exceeded 1.9, which indicated strong class distinction.

After classification, post-classification filtering was applied using a 3×3 majority kernel to remove isolated misclassified pixels. Each classified raster was then converted into polygon features, and the areal extent of each class was calculated in hectares using the Calculate Geometry tool in ArcGIS Pro.

- *Change Detection and Transition Analysis*

Land use/land cover change detection was conducted using the post-classification comparison technique, which provides a pixel-by-pixel evaluation of land-cover transitions across time. Classified maps from 1984, 1994, 2004, 2014, and 2024 were overlaid, and the resulting changes were tabulated using the Cross Tabulation tool in ArcGIS to generate a Transition Matrix.

The Transition Matrix quantified the direction and magnitude of change among the four classes (Bare ground, Built-Up Area, Vegetation, and Waterbody) between 1984 and 2024, expressed in hectares. The Annual Rate of Change (ARC) was computed using the equation:

$$ARC = \frac{A_2 - A_1}{T}$$

Where:

A_1 = area of the class at the initial date,

A_2 = area of the class at the later date, and

T = time interval in years.

This method provided both the spatial and temporal trends of LULC transformation, which were used to construct graphs and interpret urban growth dynamics within the watershed.

V. RESULT

Land use and land cover (LULC) changes in the Onitsha section of the Nkisi River watershed over the past four decades have been driven mainly by human activities, with some influence from natural factors. Rapid urbanization and population growth have expanded built-up areas significantly, converting vegetation and bare land into residential, commercial, and infrastructural developments. Deforestation, sand mining, and land reclamation have further reduced vegetation cover and altered the natural landscape. Natural factors such as topography, slope, and climatic variability, including flooding and rainfall, also shape land use patterns and contribute to environmental changes. Overall, the watershed has transitioned from a largely vegetated environment to an increasingly urbanized landscape, raising concerns about ecological balance and long-term sustainability.

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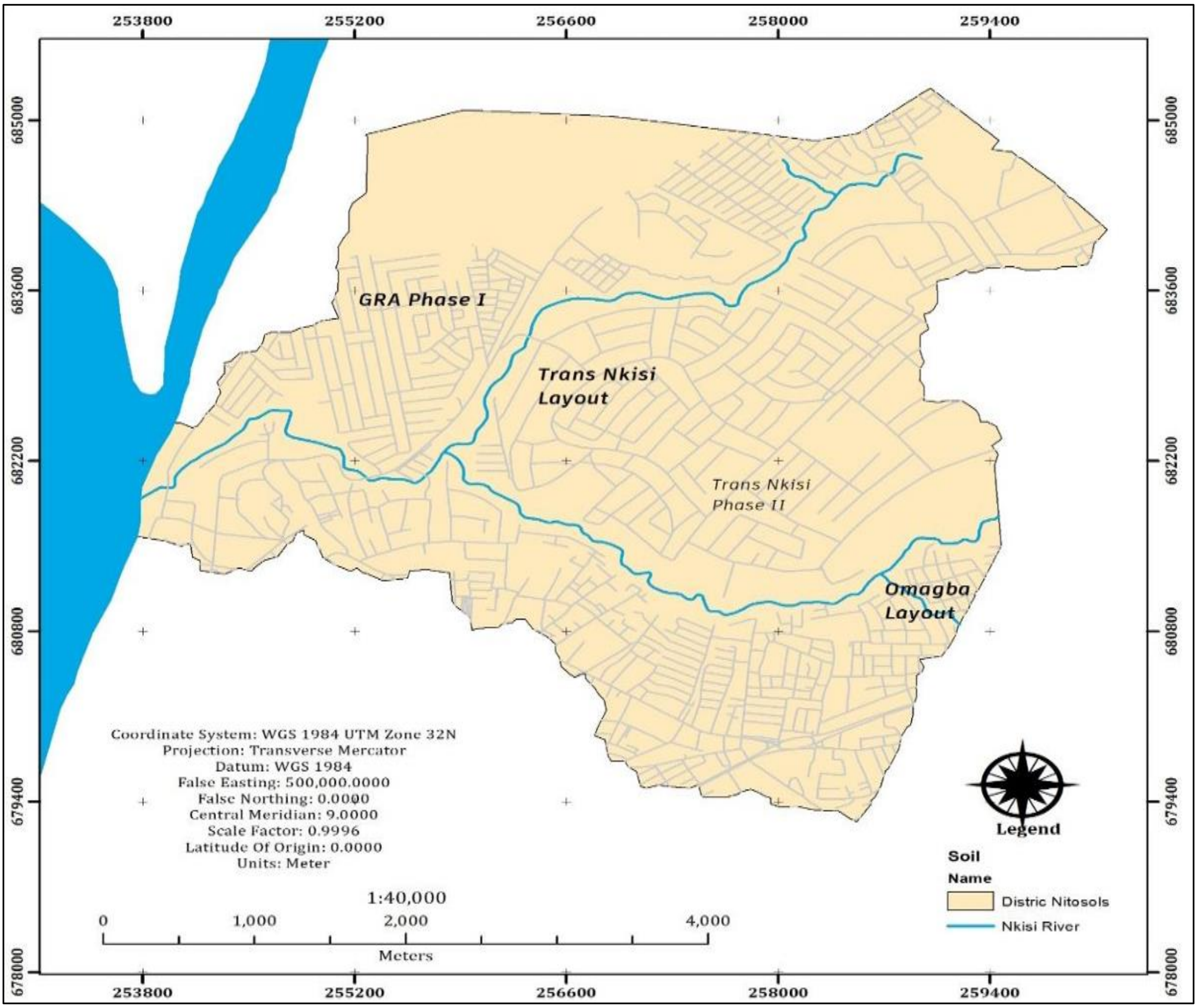

Fig 4 Soil Map of Onitsha Section of the Nkisi River

From Figure 1, the Distric Nitosols in the watershed are characterized by sandy loam to loamy textures with moderate permeability, which supports infiltration but also makes them vulnerable to erosion under intense rainfall. Sandy loam soils dominate the area, with smaller clayey loam pockets near the Nkisi River floodplain, and their high sand content increases susceptibility to sheet and rill erosion when vegetation is removed. Erosion processes are strongly influenced by rainfall intensity, slope gradient, and land use, with the mean LS-factor of 3.76 indicating that slope significantly accelerates runoff and soil loss. Although Nitosols remain stable under natural vegetation, urbanization and bare surfaces—evidenced by built-up expansion from 807.12 ha in 1984 to 1211.76 ha in 2024—have reduced infiltration and increased runoff-driven erosion. Laboratory results across Locations 1–6 confirm sandy loam textures, moderate porosity (40–55%), bulk density (1.2–1.5 g/cm³), permeability (1.0×10^{-5} to 1.3×10^{-5} m/s), organic matter (2.0–5.9%), pH (5.8–6.8), and CEC (12.0–15.1 cmol(+)/kg), collectively showing that while these soils are naturally well-drained, they become highly erosion-prone under human disturbance.

➢ *Land Use/Land Cover (LULC) Change Analysis (1984–2024)*

The temporal land use and land cover (LULC) dynamics of the study area between 1984 and 2024 were analyzed to understand the spatial and areal transformations in the landscape. The classification scheme consisted of four classes: Bare ground, Built-Up Area, Vegetation, and Waterbody. The area statistics and corresponding percentages for each epoch were derived from classified Landsat images for 1984, 1994, 2004, 2014, and 2024, as presented in Figure 2. The results are illustrated in Figures 2 to 7, showing the spatiotemporal variation in land cover patterns.

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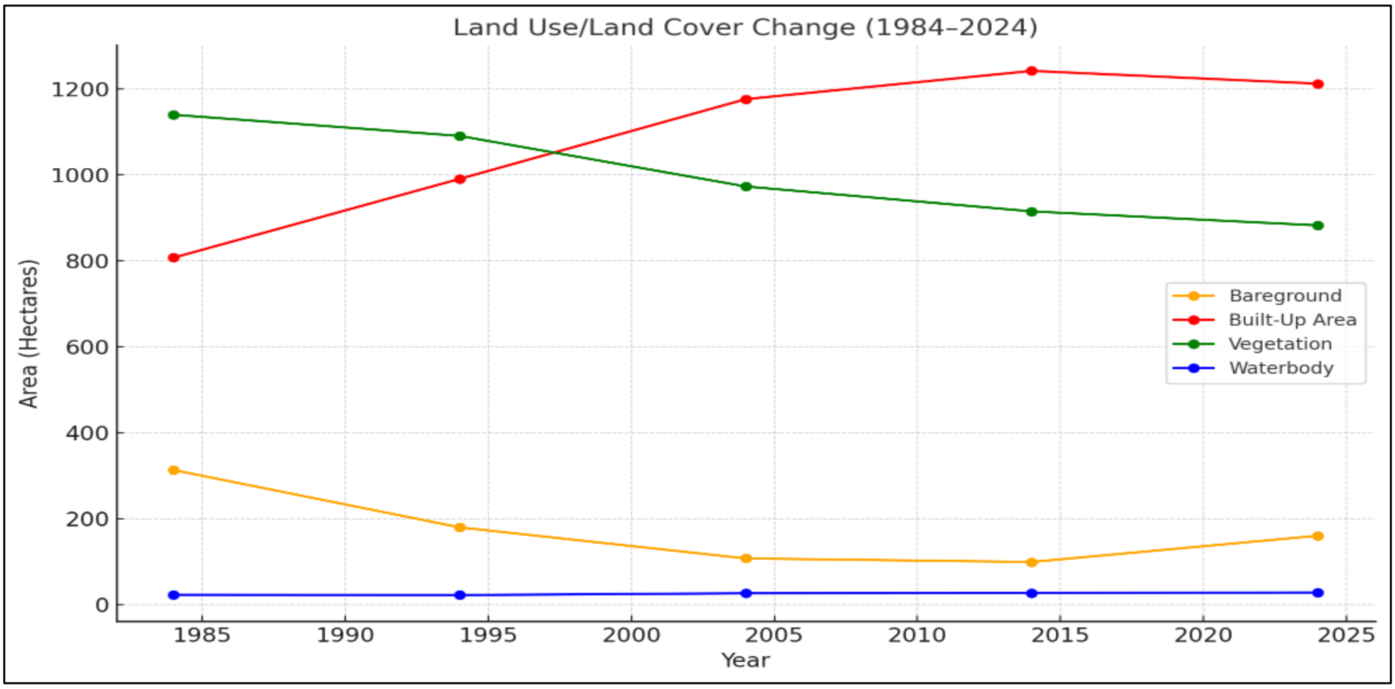

Fig 5 LULC Distribution of Onitsha Section of Nkisi River Watershed Between (1984-2024)

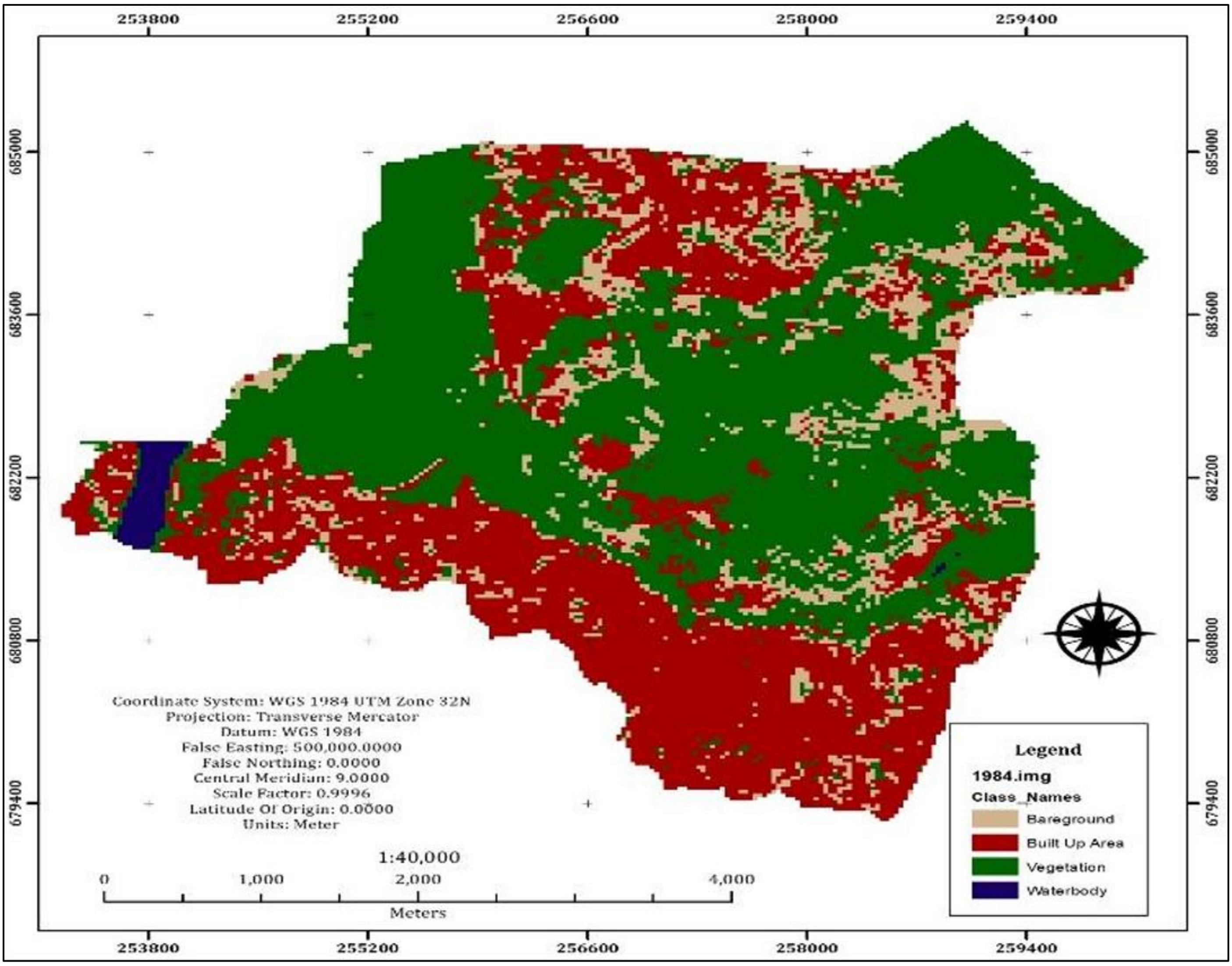

Fig 6 Landcover/Land use Map of Onitsha Section of Nkisi River Watershed in 1984

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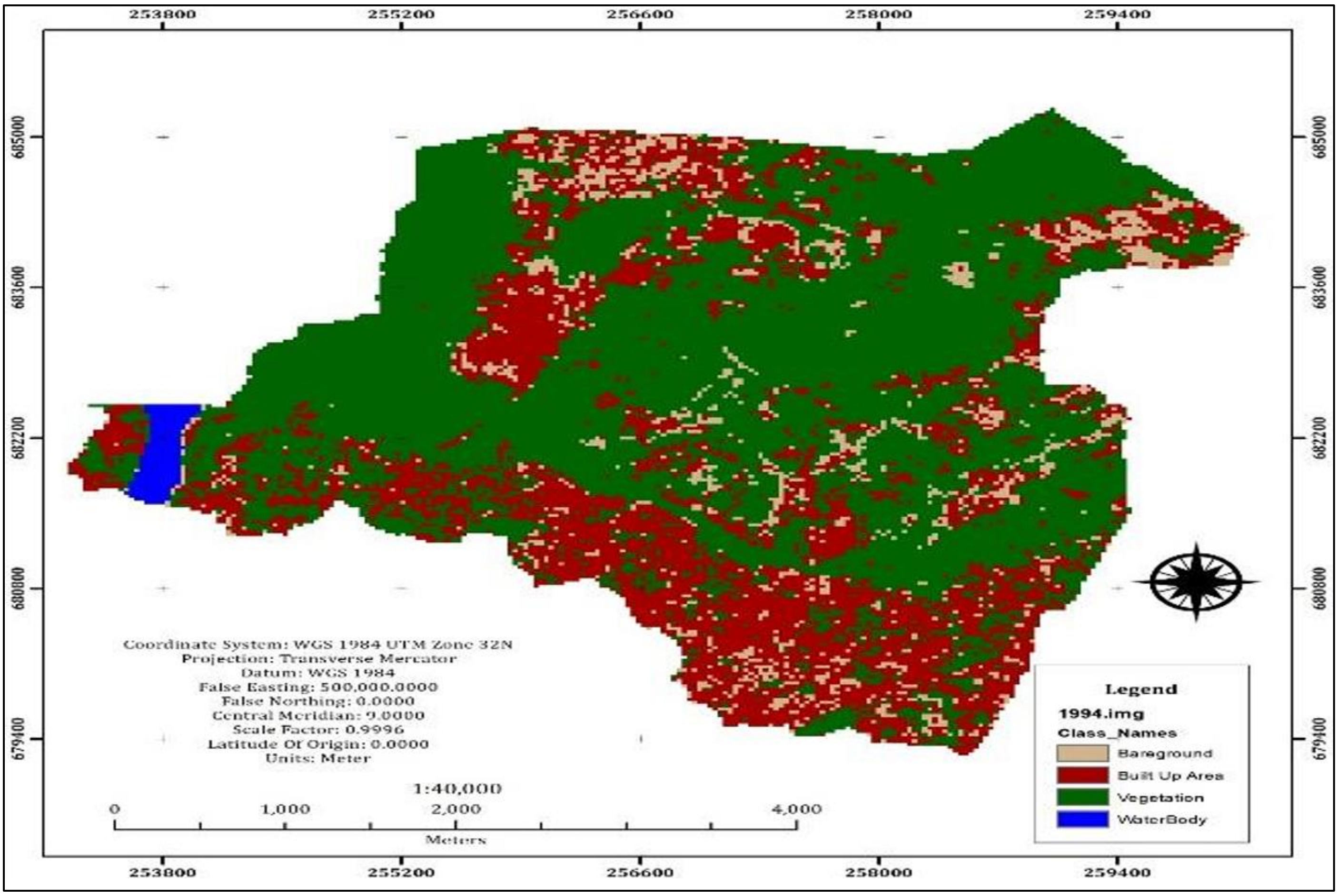

Fig 7 Landcover/Landuse Map of Onitsha Section of Nkisi River Watershed in 1994

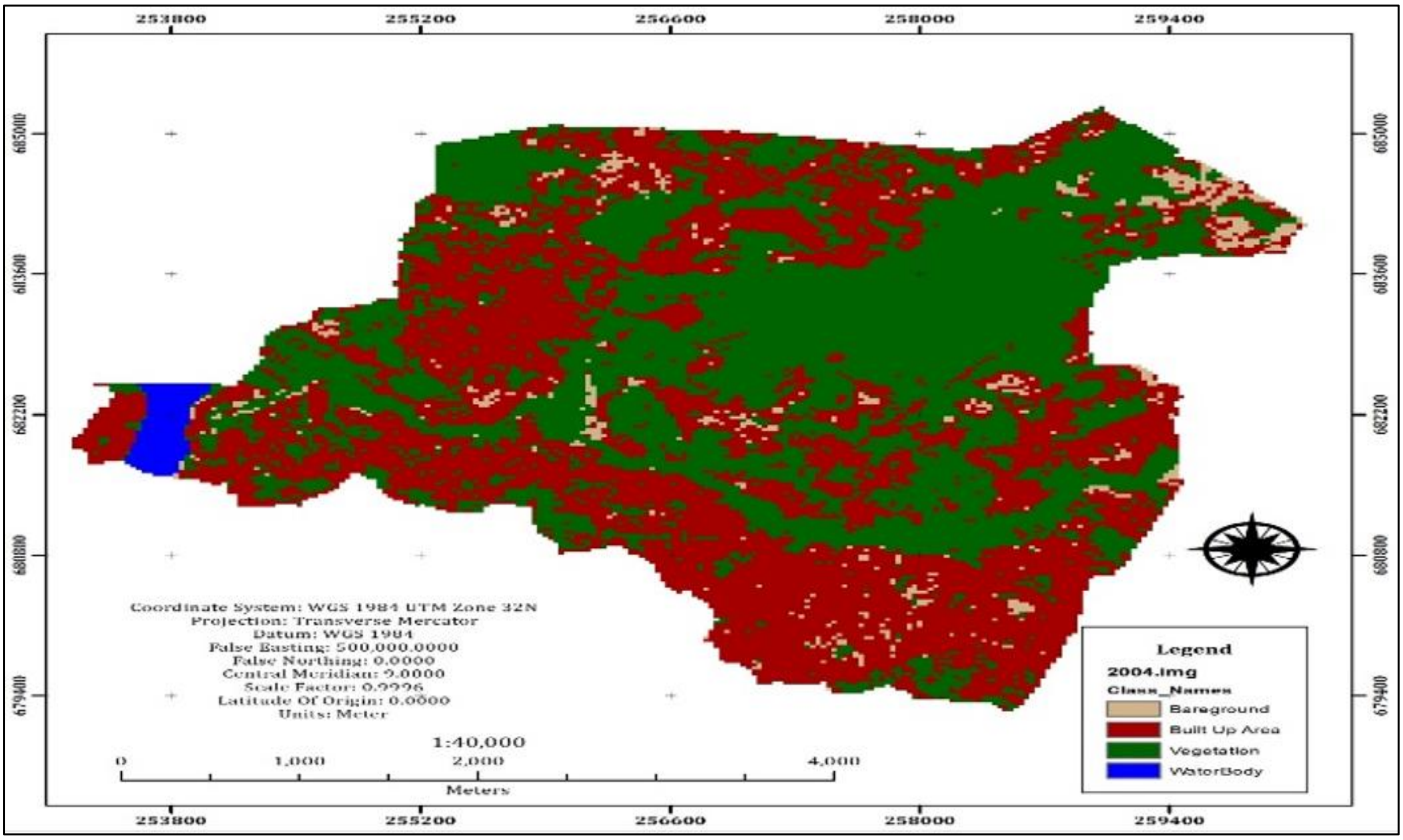

Fig 8 Landcover/Landuse Map of Onitsha Section of Nkisi River Watershed in 2004

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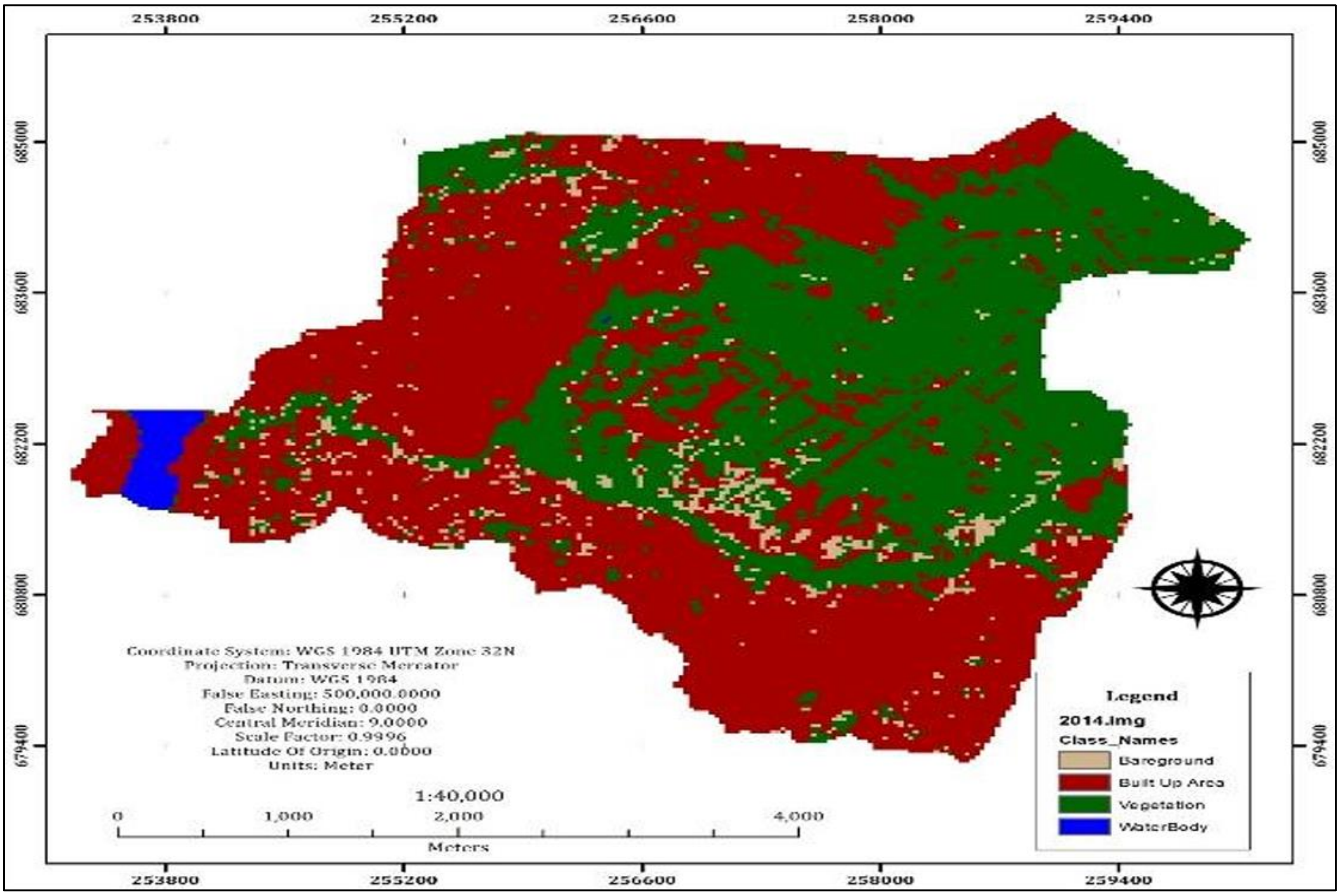

Fig 9 Landcover/Landuse Map of Onitsha Section of Nkisi River Watershed in 2014

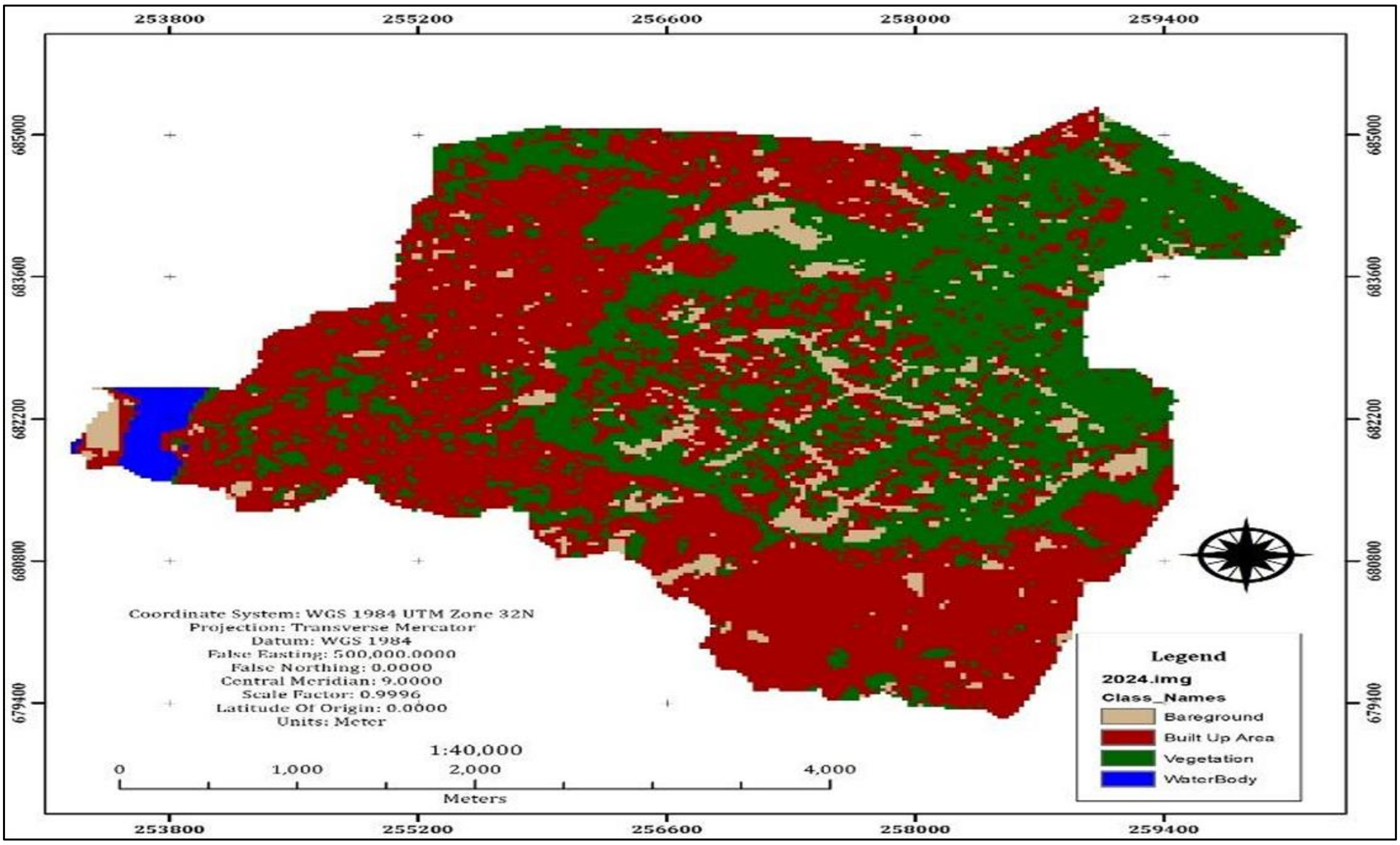

Fig 10 Landcover/Landuse Map of Onitsha Section of Nkisi River Watershed in 2024

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Between 1984 and 1994, the Built-Up Area increased from 807.12 ha (35.36%) to 990.33 ha (43.39%), representing an expansion of approximately 183.21 ha. This growth occurred mainly in the southern and central regions of the map, as depicted in Figures 4 and 5. The Vegetation class slightly declined from 1139.40 ha (49.92%) to 1090.20 ha (47.76%), while Bare ground areas reduced sharply from 313.02 ha (13.71%) to 179.73 ha (7.87%), indicating active reclamation of open land for development or agricultural expansion. The Waterbody class remained relatively stable, showing a negligible reduction from 22.95 ha to 22.23 ha.

A significant land transformation occurred between 1994 and 2004 (Figures 3 and 4), with Built-Up Area expanding further to 1175.77 ha (51.51%), marking an increase of 185.44 ha. Conversely, Vegetation cover declined to 972.68 ha (42.61%), reflecting a loss of 117.52 ha over the decade. The reduction in Vegetation corresponds with rapid urban encroachment and infrastructural development. Bare ground continued to decrease to 107.49 ha (4.71%), indicating conversion of previously unused land to urban or vegetative cover. The Waterbody area experienced a slight increase to 26.55 ha (1.16%), possibly due to improved detection accuracy or expansion of surface water through minor damming or wetland inundation.

During this decade, between 2004 and 2014 (Figures 6 and 7), Built-Up Area reached 1241.47 ha (54.39%), further confirming a persistent trend of urban expansion. Vegetation decreased to 914.75 ha (40.08%), representing continued deforestation and land clearance. Bare ground slightly decreased to 99.27 ha (4.35%), which could imply a relative stabilization in land development intensity. The Waterbody class also exhibited a marginal rise to 27.00 ha (1.18%), which might reflect hydrological changes or improvement in remote sensing detection due to higher image resolution.

From 2014 to 2024 (Figures 5 and 6), Built-Up Area exhibited a modest decline from 1241.47 ha (54.39%) to 1211.76 ha (53.09%), possibly reflecting saturation of urban growth or reclassification due to infill development. Vegetation continued its downward trend, decreasing to 882.18 ha (38.65%), while Bare ground increased from 99.27 ha (4.35%) to 160.29 ha (7.02%), indicating recent land clearing or abandoned development projects. The Waterbody class slightly increased to 28.26 ha (1.24%), which may relate to improved surface water management or wetland expansion.

Over the 40-year period, the landscape experienced substantial modification driven by anthropogenic and environmental factors. Built-Up Area expanded by 404.64 ha, rising from 35.36% in 1984 to 53.09% in 2024. This increase underscores accelerated urbanization and infrastructure development within the study area. Vegetation cover decreased by 257.22 ha, reducing from 49.92% to 38.65%, reflecting persistent pressure on natural land resources. Bare ground fluctuated across the decades but showed a net decline of 152.73 ha between 1984 and 2024, indicating that much of the previously open land was converted to either vegetative or built-up surfaces. Waterbody coverage remained relatively constant, with a minor increase of 1.31 ha.

The spatial patterns observed in Figures 6 to 7 demonstrate that urban expansion primarily occurred along transport corridors and lowland regions, while vegetation losses were concentrated in peripheral and upland areas. These transformations indicate a shift from predominantly vegetative and bare surfaces in 1984 toward a highly urbanized landscape by 2024.

VI. LAND USE/LAND COVER TRANSITION MATRIX AND RATE OF CHANGE ANALYSIS (1984–2024)

➢ *Transition Matrix*

To quantify the direction and magnitude of land use conversion among the four classes (Bare ground, Built-Up Area, Vegetation, and Waterbody), a post-classification comparison was performed using the 1984 and 2024 classified maps. The resulting transition matrix (Table1) illustrates how each class in 1984 transformed into other classes by 2024, expressed in hectares.

Table 1 Land Use/Land Cover Transition Matrix (1984–2024)

1984 Class → 2024 Class	**Bare ground (ha)**	**Built-Up (ha)**	**Vegetation (ha)**	**Waterbody (ha)**	**Total (ha)**
Bare ground	58.41	187.26	65.37	2.00	313.02
Built-Up Area	21.18	705.32	75.10	5.52	807.12
Vegetation	79.20	319.18	736.57	4.45	1139.40
Waterbody	1.50	0.00	20.73	0.72	22.95
Total (2024)	160.29	1211.76	882.18	28.26	2282.49

The matrix reveals that Vegetation experienced the most significant transitions, with 319.18 ha converted to Built-Up Area and 79.20 ha transformed to Bare ground. Bare ground loss to Built-Up Area (187.26 ha) also highlighted the intensity of infrastructural encroachment on previously open land. Only 736.57 ha of Vegetation in 1984 remained intact by 2024, representing a net vegetation persistence rate of 64.6 %. The Waterbody class showed remarkable stability, with over 90 % of its area retained.

➢ *Rate of Change*

The annual rate of change (ARC) for each land-cover class was calculated using the formula in equation, the results is shown in table 2:

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Table 2 Annual Rate of Change (1984–2024)

Class	1984 Area (ha)	2024 Area (ha)	Net Change (ha)	Annual Rate (ha/yr)	% Change
Bare ground	313.02	160.29	–152.73	–3.82	–48.77 %
Built-Up Area	807.12	1211.76	+404.64	+10.12	+50.14 %
Vegetation	1139.40	882.18	–257.22	–6.43	–22.58 %
Waterbody	22.95	28.26	+5.31	+0.13	+23.14 %

The Built-Up Area class recorded the highest annual growth rate of approximately 10.12 ha yr^{-1}, consistent with rapid urbanization trends observed in the satellite-derived maps. Vegetation declined at an average rate of 6.43 ha yr^{-1}, while Bare ground decreased by 3.82 ha yr^{-1}, indicating gradual land conversion and stabilization of open surfaces. Waterbody changes were relatively minor, with a marginal increase of 0.13 ha yr^{-1}, indicating hydrological consistency over the study period.

The continuous expansion of Built-Up Area signifies progressive urban intensification, particularly between 1984 and 2014, when infrastructural projects and settlement growth accelerated. The loss of Vegetation is symptomatic of deforestation, agricultural expansion, and land clearing, while the fluctuating Bare ground class reflects alternating phases of land preparation, construction, and reclamation.

The results indicated a pronounced anthropogenic influence on land transformation, with direct implications for hydrological response, biodiversity, and environmental sustainability. The increase in Built-Up surfaces implies greater surface runoff potential and reduced infiltration capacity, which can exacerbate flooding and heat-island effects**.** Vegetation depletion threatens ecosystem services, soil stability, and local climate regulation. Conversely, the modest Waterbody increase indicates minimal but positive adjustments in local water management.

- *Drivers of Land Use/Land Cover (LULC) Change in the Onitsha Section of Nkisi River Watershed*

The Onitsha section of the Nkisi River watershed has experienced continuous modification of its land surface characteristics over the past four decades. The transformation reflected in the classified images and quantitative data (1984–2024) is predominantly attributed to anthropogenic drivers, although natural factors have also contributed to spatial variations in land use and land cover patterns. Understanding these drivers provides context for the observed landscape dynamics and supports policy recommendations for sustainable watershed management.

The principal drivers of LULC change within the Onitsha section of the Nkisi River watershed are human-induced and natural-environmental factors. The human-induced drivers have been dominant, corresponding with the observed increase in built-up area from 35.36% in 1984 to 53.09% in 2024, while vegetation declined from 49.92% to 38.65% over the same period.

- *Anthropogenic Drivers of LULC Change*

- *Urbanization and Population Growth*

The expansion of Onitsha as a commercial hub has exerted significant pressure on the watershed environment. Rapid population growth, accompanied by residential and commercial infrastructure development, has led to the conversion of vegetated and Bare ground areas into built-up surfaces. The city's role as a major economic and transportation node within South East Nigeria has intensified spatial expansion, with settlements extending toward the Nkisi River floodplain. The proliferation of housing estates, industrial layouts, and road networks is the most evident driver of built-up growth observed in the 1994–2024 period.

- *Deforestation*

The removal of forest and secondary vegetation has contributed substantially to vegetation loss. urban expansion has degraded large portions of the watershed. The decreasing vegetation cover from 1139.40 ha in 1984 to 882.18 ha in 2024 demonstrated a persistent deforestation trend. Government and private sector infrastructural initiatives, including road construction, drainage networks, and urban renewal projects, have altered natural land surfaces. Expansion of transport corridors, particularly linking Onitsha to Nkpor, Obosi, and Ogidi, has facilitated further urban encroachment into formerly vegetated and bare areas.

- *Sand Mining and Land Reclamation*

Unregulated sand mining and excavation along the Nkisi River and adjoining floodplains have altered surface morphology, leading to exposure of Bare ground and subsequent changes in land cover reflectance characteristics. Reclamation of flood-prone areas for residential use has also contributed to permanent surface modification and reduction in natural vegetation.

- *Natural and Environmental of LULC Change*

Although anthropogenic forces dominate, several natural factors influence LULC dynamics in the watershed.

- *Topography and Slope Gradient*

The undulating terrain and variable slope distribution within the watershed affect land-use allocation. Steeper slopes are less suitable for dense settlement but often subject to vegetation clearance for cultivation or erosion-prone construction. The lower plains adjacent to the Nkisi River support extensive urbanization due to their accessibility and gentle gradient.

- *Hydrological and Climatic Variability*

Seasonal flooding from the Nkisi River, coupled with intense rainfall events, has contributed to spatial alterations

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in land cover, particularly around low-lying zones. Fluctuations in precipitation intensity and runoff volume occasionally cause bank erosion, sediment deposition, and localized wetland formation, influencing land-use decisions and the persistence of Waterbody features.

The interplay between urban growth and environmental processes has produced a complex spatial mosaic characterized by alternating patches of built-up surfaces and residual vegetation. Between 1984 and 2024, the watershed transitioned from a predominantly vegetated landscape to an increasingly urbanized environment. The acceleration of built-up expansion, especially from 2004 to 2014, aligns with national patterns of urban growth in Nigerian cities where population density and commercial expansion have outpaced land-use regulation.

Natural factors such as hydrological changes have amplified the anthropogenic impacts by influencing where development occurs and how land cover transitions manifest. The cumulative effect of these drivers indicates that the Nkisi River watershed is undergoing intensive anthropogenic transformation, with direct implications for ecological balance, hydrological stability, and long-term land-use sustainability.

The results in Table 3 below show that respondents generally agree socio-economic factors strongly drive land use and land cover change (LULC), with a grand mean of 3.0 ± 1.0. Economic activities like trading and farming recorded the highest mean score (3.14 ± 0.95), indicating that livelihoods play a central role in shaping land use. Poverty and unemployment also ranked high (3.06 ± 0.93), highlighting how limited opportunities can lead to unsustainable land practices. Population growth (2.64 ± 1.00) and increasing infrastructure demand (2.61 ± 1.08) were identified as contributing factors, though with slightly less agreement. Overall, weak enforcement of land use regulations (2.90 ± 1.05) and broader socio-economic pressures collectively influence land use patterns in the study area.

Table 3 Respondent Responses on Socio-Economic Drivers of Land Use Change

S/N	Socio-Economic Drivers of Land Use Change	Mean ± SD	Remark
6	Population increase has contributed to LULC changes in the area	2.64 ± 1.00	Agree
7	Demand for infrastructure has increased land conversion	2.61 ± 1.08	Agree
8	Economic activities such as trading and farming influence land use changes	3.14 ± 0.95	Agree
9	Poverty and unemployment encourage unsustainable land use practices	3.06 ± 0.93	Agree
10	Weak enforcement of land use regulations contributes to land degradation	2.90 ± 1.05	Agree
	Grand Total	**3.0±1.0**	**Agree**

The results in Table 4 below indicate that respondents generally agree human activities significantly contribute to erosion, with a grand mean of 2.83 ± 1.18. Construction activities recorded the highest mean (3.13 ± 0.97), showing strong consensus that land clearing and poor erosion control drive soil loss. Bush burning and vegetation removal also ranked high (3.08 ± 0.87), highlighting the importance of vegetation in protecting soil stability. Other factors such as general human activities (2.74 ± 1.05), poor drainage systems (2.70 ± 1.06), and farming on slopes (2.67 ± 1.07) were also identified as contributors. Additionally, sand excavation along the Nkisi River (2.63 ± 1.05) was recognized as worsening erosion through riverbank disturbance and increased land degradation.

Table 4 Respondent Responses on Anthropogenic Activities and Erosion

S/N	Items on Anthropogenic Activities and Erosion	Mean ± SD	Remark
11	Human activities have increased erosion problems in this community	2.74 ± 1.05	Agree
12	Farming activities on slopes contribute to erosion in the area	2.67 ± 1.07	Agree
13	Bush burning and vegetation removal worsen erosion conditions	3.08 ± 0.87	Agree
14	Poor drainage systems increase waterflow problems	2.70 ± 1.06	Agree
15	Sand excavation along the Nkisi River has intensified erosion	2.63 ± 1.05	Agree
16	Construction activities have contributed to erosion in the area	3.13 ± 0.97	Agree
	Grand Total	**2.83±1.18**	**Agree**

VII. SUMMARY AND CONCLUSION

The analysis shows a clear transformation of the watershed from a largely vegetated landscape to a more urbanized environment, driven mainly by human activities. Vegetation has declined significantly while built-up areas have expanded, with urban growth concentrated along transport routes and near the Nkisi River. These changes are largely influenced by factors such as urbanization, population growth, infrastructure development, deforestation, and sand mining, alongside natural conditions like topography and drainage patterns. The soil, dominated by sandy loam properties, becomes highly vulnerable to erosion when disturbed, contributing to severe and uneven soil loss across the area. Overall, the study shows that human-driven land use changes are the primary cause of increased erosion, leading to environmental degradation and negative impacts on local livelihoods.

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