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Shifting Landscapes: The Impact of Land Use and Land Cover Changes on Groundwater Sustainability in Anambra State, Nigeria (2017-2023)

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Abstract
Land Use and Land Cover (LULC) changes significantly impact groundwater resources, particularly in regions experiencing rapid urbanization and agricultural expansion. In Anambra State, Southeastern Nigeria, these dynamics are crucial for understanding groundwater availability and sustainability. This study aims to analyze the temporal changes in LULC between 2017 and 2023 in Anambra State and assess their implications on groundwater recharge and dynamics. The study utilizes remote sensing data and Geographic Information Systems (GIS) to map and analyze LULC changes over seven years. The LULC categories include Trees, Rangeland, Built Area, Crops, Water bodies, Flooded Vegetation, and Bare Ground. The data are statistically analyzed to determine trends and variations in land cover types. The results indicate a significant reduction in tree cover from 1,807.49 km² in 2017 to 1,345.35 km² in 2023, accompanied by an increase in built-up areas from 1,105.26 km² to 1,329.77 km². Cropland expanded considerably from 235.03 km² in 2020 to 437.04 km² in 2023. Rangeland coverage fluctuated, peaking at 1,700.13 km² in 2022 before decreasing to 1,345.51 km² in 2023. Water bodies remained relatively stable, while Flooded Vegetation saw a significant decline from 160.13 km² in 2019 to 22.07 km² in 2023. The reduction in tree cover and the expansion of built-up areas are likely to decrease groundwater recharge due to reduced infiltration and increased surface runoff. The expansion of croplands suggests increased groundwater extraction for irrigation, potentially leading to over-extraction and depletion of groundwater reserves. The variability in rangeland and flooded vegetation areas reflects changes in land management practices, which also influence groundwater dynamics. The study highlights the critical need for sustainable land management practices to protect groundwater resources in Anambra State. The observed LULC changes pose a significant threat to groundwater recharge, emphasizing the need for policies that balance development with groundwater conservation. This study provides a comprehensive temporal analysis of LULC changes over seven years and their direct implications on groundwater dynamics in a rapidly urbanizing region.

Keywords: *Groundwater Recharge, Remote Sensing, Southeastern Nigeria, Sustainable Land Management, Temporal Analysis*

1. Introduction

Land Use and Land Cover (LULC) changes are increasingly recognized as significant drivers of environmental and hydrological processes, particularly in the context of groundwater dynamics. As urbanization, agriculture, and deforestation accelerate globally, the natural landscapes that once played crucial roles in groundwater recharge are being altered (Olorunfemi et al., 2018). These changes have profound implications for groundwater availability, quality, and sustainability. Groundwater, which constitutes a major source of fresh water for domestic, agricultural, and industrial purposes, is highly sensitive to changes in the land surface. As land use and cover change, so too do the patterns of water infiltration, surface runoff, and groundwater recharge, leading to shifts in the availability and quality of groundwater resources (Aladejana et al., 2018; Xu et al., 2022).

Land Use refers to the human utilization of land for various purposes, such as agriculture, urban development, forestry, and recreation. Land Cover, on the other hand, describes the physical material present on the surface of the earth, such as vegetation, water bodies, and built environments (Rai et al., 2023). Over time, human activities have significantly altered the natural land cover, transforming forests into agricultural fields, grasslands into urban areas, and wetlands into industrial sites. These transformations are often driven by the need to accommodate growing populations, economic development, and industrialization (Koko et al., 2022).

The most common LULC changes include deforestation, urbanization, agricultural expansion, and the conversion of natural landscapes into built environments (Olorunfemi et al., 2018; Akaolisa et al., 2023). Deforestation, reduces the number of trees that can intercept rainfall, which affects the infiltration of water into the soil (Omolabi & Fagbohun, 2019). Urbanization replaces permeable soils with impermeable surfaces like roads and buildings, significantly reducing groundwater recharge while increasing surface runoff (Rowland & Ebuka, 2024). Agricultural expansion, particularly when it involves irrigation, can lead to the over-extraction of groundwater, further stressing the aquifers (Hassan et al., 2019). These changes not only alter the quantity of groundwater but also affect its quality, as pollutants from agricultural runoff, industrial discharges, and urban waste can contaminate groundwater supplies (Onwuka et al., 2018). The relationship between LULC changes and groundwater dynamics is complex and multifaceted. Key processes influenced by LULC changes include groundwater recharge, surface runoff, and evapotranspiration. Each of these processes is crucial to maintaining the balance of groundwater resources.

Groundwater recharge refers to the process by which water from precipitation, rivers, and lakes infiltrates the ground and replenishes aquifers. Natural landscapes, such as forests and grasslands, are typically effective at facilitating groundwater recharge due to their permeable soils and vegetative cover (Asiwaju-Bello et al., 2020). However, when these landscapes are altered by urbanization or deforestation, the rate of groundwater recharge can be significantly reduced. Urban areas with extensive concrete and asphalt surfaces prevent rainwater from infiltrating the soil, leading to decreased recharge rates. Deforestation can result in soil compaction and reduced infiltration capacity, further diminishing groundwater recharge (Ifediegwu, 2019).

Surface runoff occurs when rainfall or irrigation water flows over the land surface instead of infiltrating into the ground. LULC changes, particularly urbanization and deforestation, tend to increase surface runoff. Impermeable surfaces, such as pavements and buildings, create barriers to water infiltration, causing more water to run off into rivers and streams rather than percolating into the ground (Musa et al., 2018). This increased runoff not only reduces groundwater recharge but can also lead to flooding, erosion, and the contamination of surface water bodies, which can subsequently impact groundwater quality.

Evapotranspiration is the sum of evaporation from land and water surfaces and transpiration from plants. Vegetation plays a crucial role in regulating evapotranspiration rates, and changes in land cover can alter these rates significantly. Deforestation, Reduces the amount of water transpired by plants, which can lead to increased soil moisture and surface runoff, thereby reducing groundwater recharge. Conversely, agricultural expansion may increase evapotranspiration if it involves the introduction of crops that consume large amounts of water, potentially leading to groundwater depletion.

This study aims to examine the temporal changes in Land Use and Land Cover (LULC) between 2017 and 2023 in Anambra State, Nigeria, and assess their implications for groundwater recharge and dynamics. By utilizing remote sensing data and Geographic Information Systems (GIS), the study will map and analyze LULC changes over the seven-year period. The research seeks to understand how these changes influence groundwater resources, providing critical insights into sustainable water management and planning in the region.

2. Research area

Anambra State is situated in the southeastern region of Nigeria, strategically positioned between latitudes 6°25’ and 7°15’ North and longitudes 6°00’ and 7°00’ East. This geographical placement places Anambra within the heart of the Niger Delta Basin, an area known for its rich natural resources and significant economic activities. The state shares its boundaries with Kogi State to the north, Enugu State to the east, Imo State to the southeast, Rivers State to the southwest, and Delta State to the west. The capital city of Anambra is Awka, which serves as the administrative and political hub of the state. A comprehensive map illustrating the geographical location of Anambra State within Nigeria is provided in Figure 1. This figure comprises two parts: (a) a map of Nigeria highlighting the position of Anambra State among other states, and (b) a detailed map of Anambra State itself, showcasing water bodies and transportation networks.

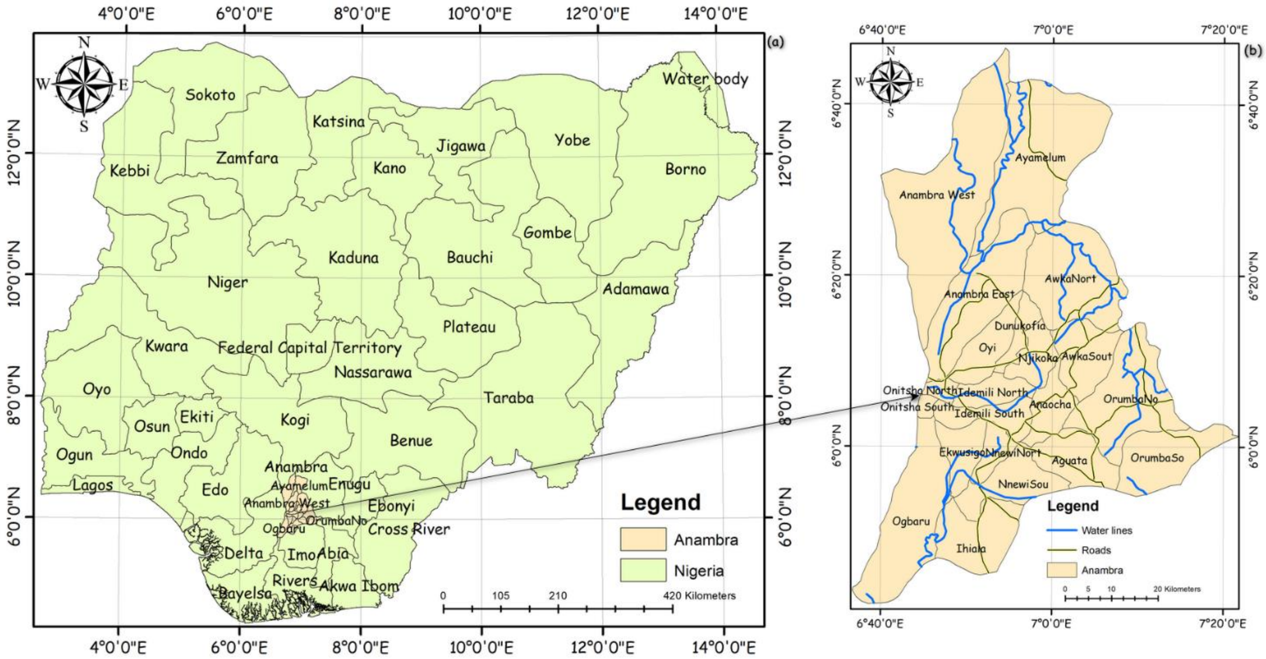

Figure 1: Geographical Location and Detailed Map of Anambra State, Southeastern Nigeria

Anambra State is characterized by a well-developed transportation network that enhances mobility within the state and provides crucial links to other parts of Nigeria. The state is crisscrossed by federal and state highways connecting major cities and towns, including Awka, Onitsha, Nnewi, and Ekwulobia(Echendu, 2020). Onitsha, one of the largest commercial hubs in West Africa, is home to the renowned Onitsha Main Market, drawing traders and buyers from across the region. Additionally, the state is accessible via railways and waterways, with the Onitsha River serving as a vital route for goods and passengers. The A3 highway further boosts connectivity to neighboring states and urban centers, fostering economic activity (Obi-Ani & Isiani, 2020). The state's topography is predominantly low-lying, with gently undulating plains, fertile floodplains, and a network of rivers, creeks, and swamps, particularly in the Niger Delta region. These features contribute to rich alluvial soil, making Anambra highly suitable for agriculture, while also influencing local climate, drainage, and groundwater dynamics.

Anambra is one of Nigeria's most urbanized states, with significant portions of the population residing in cities like Awka, Onitsha, and Nnewi. Onitsha is known for its bustling markets, while Nnewi, dubbed the "Japan of Africa," is a center of manufacturing and entrepreneurship. Rapid urbanization, driven by population growth, industrialization, and economic opportunities, has led to the expansion of built-up areas. This urban sprawl impacts LULC changes, influencing groundwater recharge and sustainability by increasing impermeable surfaces and altering hydrological cycles.

The geological framework of Anambra State is primarily influenced by its location within the Benue Trough, a significant geological formation in Nigeria. The state’s geology is characterized by a succession of sedimentary rocks, including sandstones, shales, and clays, which play a crucial role in determining groundwater availability and quality(Ukpai et al., 2021). The sedimentary layers act as aquifers, with varying degrees of permeability and storage capacity. In some areas, the presence of volcanic ash deposits and laterite layers affects the porosity and permeability of the subsurface, influencing groundwater flow and recharge rates (Omietimi et al., 2021). The state's geology is marked by the presence of mineral resources such as limestone, which supports local industries like cement manufacturing. Understanding the geological composition is essential for effective groundwater management, as it dictates the interaction between surface water and groundwater, aquifer recharge mechanisms, and potential contamination pathways (Ukpai et al., 2021).

The accessibility to groundwater in Anambra State is influenced by both natural and anthropogenic factors. The state's abundant rainfall and river systems contribute to natural groundwater recharge, while urbanization and agricultural activities impact the sustainability of these resources. Over-extraction for domestic, agricultural, and industrial use, coupled with pollution from agricultural runoff and urban waste, poses significant challenges to groundwater quality and availability (Ukpai et al., 2021). Sustainable groundwater management practices, including proper land use planning, pollution control measures, and the protection of recharge areas, are imperative to ensure the long-term viability of groundwater resources in the state.

3. Methodology

3.1 Data Acquisition

High-resolution satellite imagery from the USGS Earth Explorer platform served as the primary data source, offering a detailed view of LULC changes throughout the specified period. Complementary historical LULC data from the USGS provided classifications into categories such as agricultural land, forests, urban areas, and water bodies (Olorunfemi et al., 2018). The data processing phase involved several meticulous steps to ensure readiness for analysis. For spatial data manipulation and analysis, ArcGIS—a robust GIS software suite—was utilized, facilitating the examination of spatial patterns and trends. This comprehensive approach aims to enhance understanding of the impacts of land use changes on environmental and geological conditions in Anambra State.

3.2.1 LULC Classification and Change Analysis

The preprocessed satellite images were classified into various land use/land cover (LULC) categories using supervised classification techniques. To achieve this, training samples representing different land cover types—such as vegetation, water, and urban areas—were collected. A maximum likelihood classifier was then applied to the images for categorization (Chughtai et al., 2021). The accuracy of the classification was evaluated through ground truth data and accuracy metrics, including the Kappa coefficient, to ensure the reliability of the results.

To examine the LULC changes over the six-year period, a change detection analysis was conducted. This involved comparing classified LULC maps from 2017 and 2023 using post-classification comparison techniques. The analysis entailed overlaying the LULC maps to identify and quantify changes in land cover, measured by the differences in the extent of each land cover type between the two years. The data analysis phase integrated the processed data to evaluate the spatial distribution of LULC changes, as well as their groundwater impacts. Various analytical techniques and equations were used to assess these factors comprehensively (Gashaw et al., 2018). The LULC change analysis quantified the extent of changes across different land cover types from 2017 to 2023, employing specific equations to detail the shifts in land use.

$$\Delta LULC = LULC_{2023} - LULC_{2017} \quad (1)$$

where $LULC_{2023}$ and $LULC_{2017}$ denote the areas of each land cover type in 2023 and 2017, respectively. The changes were illustrated through maps and statistical summaries to reveal trends and patterns in land use dynamics.

4. Results and Discussion

4.1 Implications of LULC Changes on Groundwater Dynamics

Table 1 presents the LULC distribution for Anambra State, South Eastern Nigeria, in 2023. The spatial map of LULC (Figure 2) further illustrates these changes. The study reveals significant variations in LULC, which have implications for groundwater dynamics.

The predominant LULC types are Trees (1345.35 km²) and Rangeland (1345.51 km²), each covering a substantial portion of the state's area. Built Area also occupies a large extent (1329.77 km²), indicating urban expansion. Crops cover 437.04 km², reflecting the importance of agriculture in the region. Water bodies account for 96.15 km², while Flooded Vegetation and Bare Ground are limited to 22.07 km² and 16.63 km², respectively. Figure 2, the spatial map of LULC in 2023, visually represents these land cover changes and their spatial distribution across the state.

Table 1: LULC Types and Areas in Anambra State, 2023

LULC Type (2023)	Area (km²)
Water	96.15
Trees	1345.35
Flooded Vegetation	22.07
Crops	437.04
Built Area	1329.77
Bare Ground	16.63
Rangeland	1345.51

The dominance of Trees and Rangeland suggests that the state still maintains significant green cover, which is vital for groundwater recharge (Arowolo et al., 2018). However, the large extent of Built Area raises concerns. Urbanization often leads to reduced infiltration rates due to impermeable surfaces, thereby limiting groundwater recharge. The presence of 437.04 km² of Crops also indicates that agriculture is a major land use, which can contribute to both groundwater recharge and depletion, depending on the irrigation practices employed.

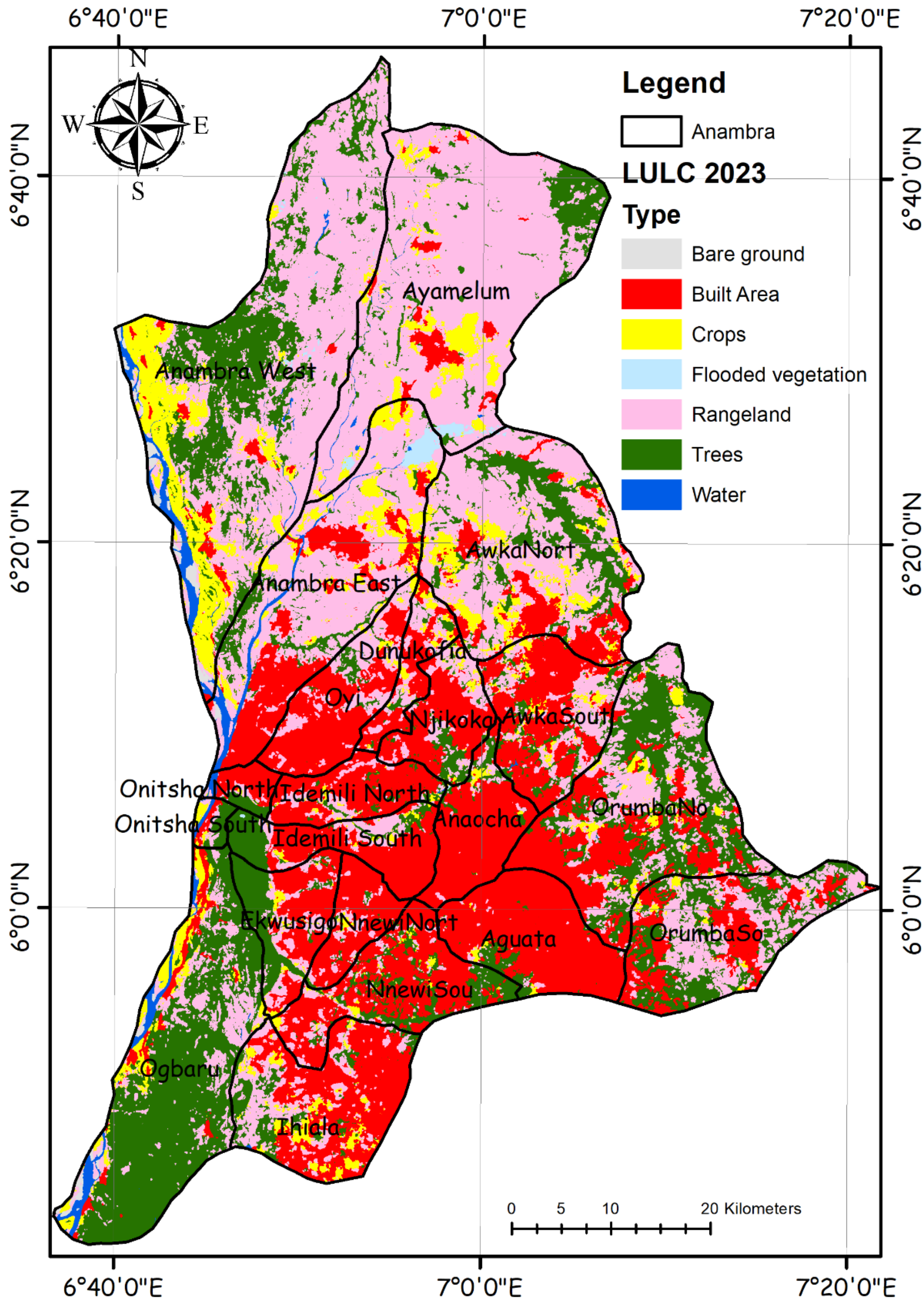

Figure 2: Spatial map of LULC 2023 within Anambra

The observed LULC changes have critical implications for groundwater in Anambra State. The reduction in natural vegetation, particularly Trees, due to urban expansion (Built Area) can negatively affect groundwater recharge rates (Emenike et al., 2020). The minimal area occupied by Water and Flooded Vegetation may indicate limited natural groundwater recharge sources. Therefore, the increasing urbanization and agricultural activities could pose a threat to groundwater availability, necessitating sustainable land management practices to ensure long-term groundwater security.

Table 2 presents the LULC distribution in Anambra State, South Eastern Nigeria, for the year 2022. The analysis reveals that the predominant LULC types include Rangeland (1700.13 km²), Built Area (1284.37 km²), and Trees (1156.74 km²), while Water bodies (96.91 km²), Flooded Vegetation (51.89 km²), and Bare Ground (16.18 km²) constitute the least covered areas. Figure 3 provides a spatial map of these LULC distributions.

Table 2: LULC Type Distribution in Anambra State, 2022

LULC Type	Area (km²)
Water	96.91
Trees	1156.74
Flooded Vegetation	51.89
Crops	286.29
Built Area	1284.37
Bare Ground	16.18
Rangeland	1700.13

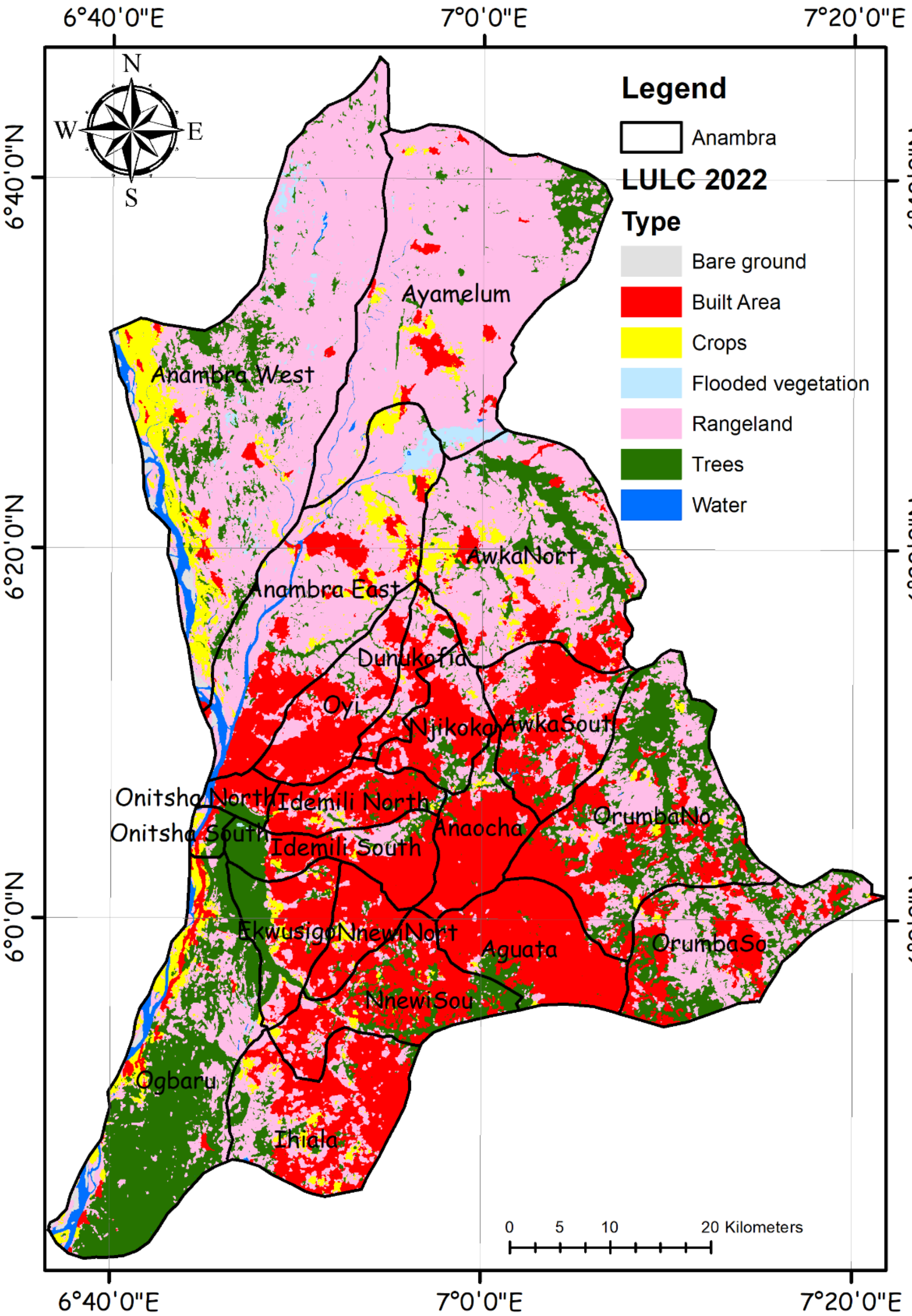

Figure 3: Spatial Map of LULC in Anambra State, 2022

Conversely, the substantial coverage of Built Areas (1284.37 km²) poses a considerable threat to groundwater recharge. Urbanization, characterized by impermeable surfaces like roads and buildings, impedes water infiltration, leading to increased surface runoff and reduced groundwater recharge. This scenario can exacerbate the risk of water scarcity, especially during dry seasons, as groundwater is a crucial source of water for many communities in Anambra State.

Moreover, the presence of Cropland (286.29 km²) may lead to groundwater contamination due to the potential leaching of agricultural chemicals like fertilizers and pesticides. The runoff from these areas could introduce pollutants into the aquifers, degrading water quality and posing risks to public health. Flooded Vegetation and Water bodies, while relatively small in area, indicate zones of potential groundwater recharge, particularly in regions where seasonal flooding occurs (Ashaolu et al., 2020). However, excessive flooding, likely influenced by climate change and human activities, could lead to groundwater contamination through the mixing of surface pollutants.

The LULC analysis for Anambra State in 2021 reveals significant implications for groundwater resources. As illustrated in Table 3, tree cover dominates the landscape, covering 1,675.10 km², followed by built areas and rangeland, with 1,248.06 km² and 1,246.47 km², respectively. The extensive tree coverage is crucial for groundwater recharge, as trees facilitate infiltration and reduce surface runoff. However, the large built area, which is nearly as extensive as rangeland, presents a challenge for groundwater sustainability. Impervious surfaces in built-up areas can significantly reduce infiltration rates, leading to decreased groundwater recharge and increased surface runoff, which can exacerbate flooding during heavy rains (Salele et al., 2023).

Table 3: LULC Type in Anambra State, South Eastern Nigeria (2021)

LULC Type (2021)	Area (km²)
Water	99.16
Trees	1675.10
Flooded Vegetation	12.89
Crops	294.60
Built Area	1248.06
Bare Ground	16.21
Rangeland	1246.47

Moreover, the presence of 294.60 km² of cropland and 16.21 km² of bare ground can further influence groundwater dynamics, as agricultural activities may lead to increased water extraction and potential contamination from agrochemicals. The relatively small area of flooded vegetation (12.89 km²) suggests localized waterlogging, which could either enhance groundwater recharge or contribute to surface water stagnation, depending on soil permeability. Figure 4, the spatial map of LULC in 2021, highlights these spatial distributions and underscores the need for sustainable land management practices to protect groundwater resources in Anambra State.

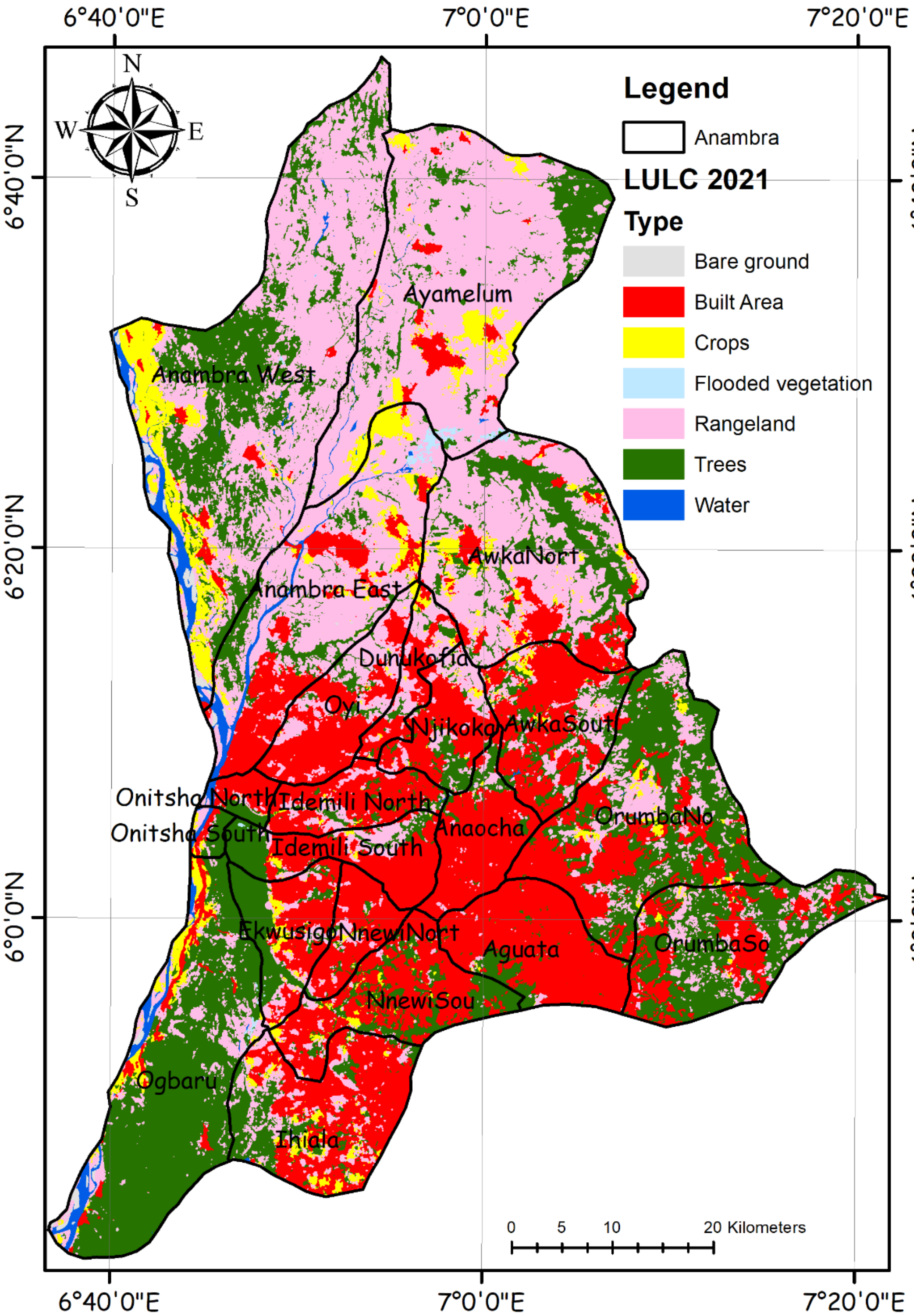

Figure 4: Spatial Map of LULC in Anambra State, 2021

Table 4 summarizes the LULC types in Anambra State, Southeastern Nigeria, for the year 2020. The dominant LULC types include Trees (1517.32 km²), Rangeland (1467.82 km²), and Built

Area (1229.16 km²). These findings indicate significant anthropogenic activities, particularly urbanization and agricultural expansion. The spatial distribution of these LULC types, as shown in Figure 5, highlights the extensive coverage of trees and rangeland, followed by built areas.

Table 4: LULC Types in Anambra State, 2020

LULC Type	Area (km²)
Water	96.53
Trees	1517.32
Flooded vegetation	30.84
Crops	235.03
Built Area	1229.16
Bare ground	15.80
Rangeland	1467.82

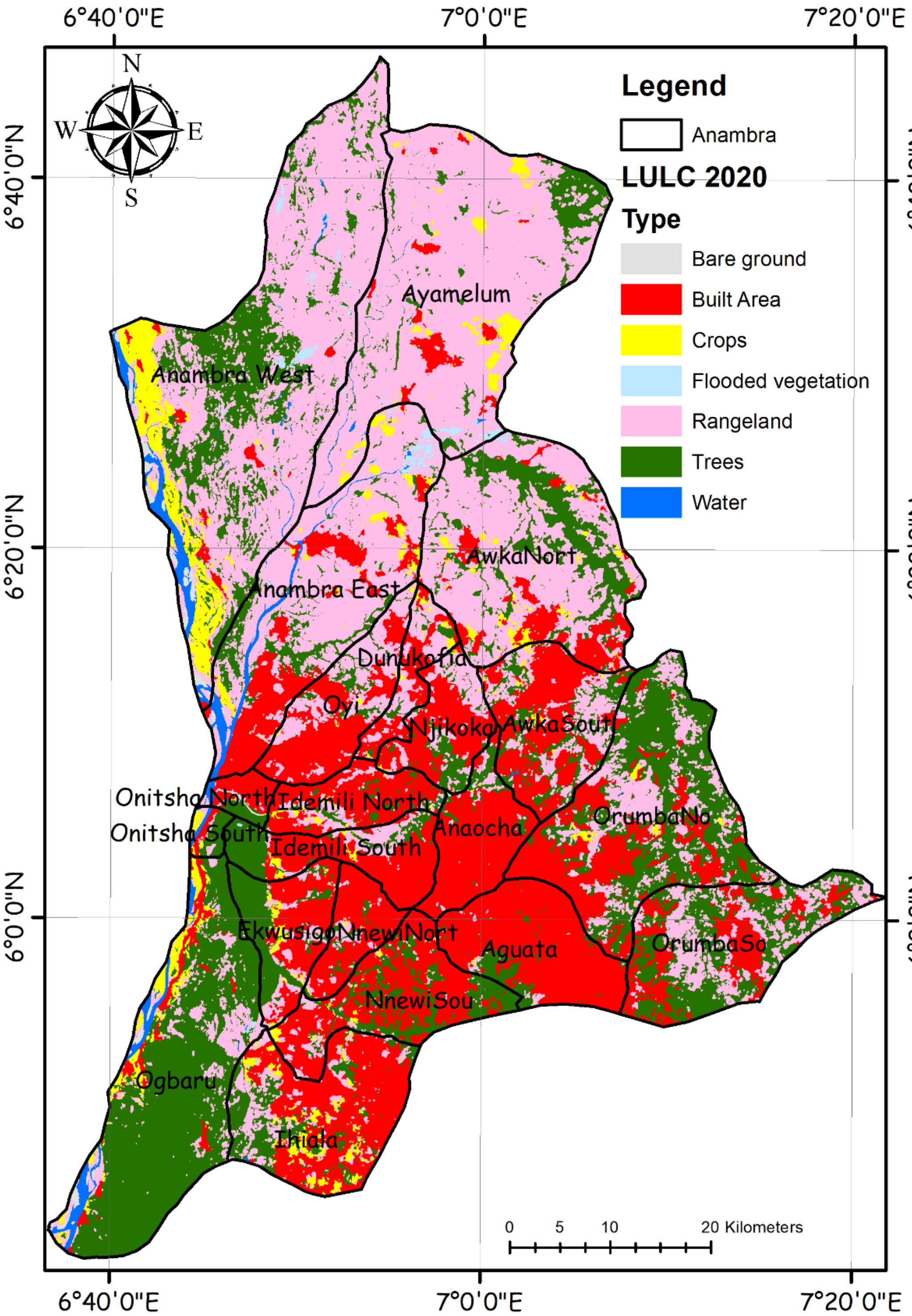

Figure 5: Spatial Map of LULC in Anambra State, 2020

The reduction in vegetative cover, particularly trees and rangeland, diminishes the area's capacity for water infiltration, increasing surface runoff and reducing groundwater recharge rates. The expansion of built areas, often characterized by impervious surfaces, further exacerbates this effect, leading to a decline in groundwater levels. The presence of flooded vegetation (30.84 km²) and water bodies (96.53 km²) may contribute to localized groundwater recharge; however, their limited extent compared to other LULC types suggests a minimal overall impact. Therefore, sustainable land management practices are crucial to mitigate the adverse effects of LULC changes on groundwater resources in Anambra State.

The LULC analysis for Anambra State, Southeastern Nigeria, in 2019 reveals significant variability across different categories, as shown in Table 5. The spatial map of LULC in 2019 (Figure 6) indicates that the most extensive land cover type is trees, occupying 1,578.30 km², followed by rangeland (1,206.04 km²) and built areas (1,201.08 km²). The dominance of these categories suggests that urbanization and agricultural expansion have significantly influenced land cover patterns in the region.

Table 5: LULC Types and Areas in Anambra State, 2019

LULC Type	Area (km²)
Water	106.15
Trees	1578.30
Flooded vegetation	160.13
Crops	325.69
Built Area	1201.08
Bare ground	15.12
Rangeland	1206.04

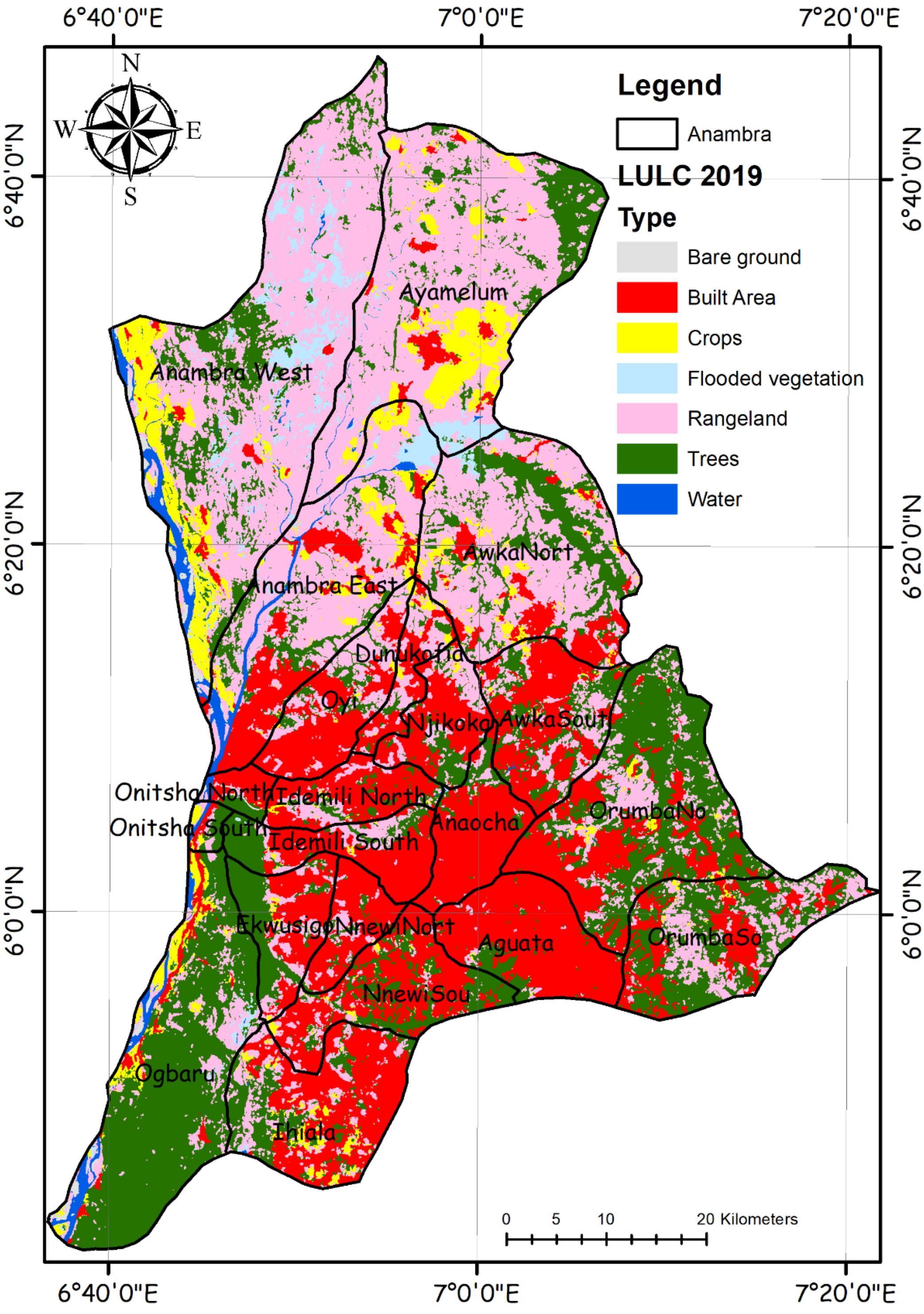

Figure 6: Spatial Map of LULC in Anambra State, 2019

The presence of flooded vegetation and water bodies, which occupy 266.28 km², highlights areas of high groundwater potential. However, the expansion of built-up areas may exacerbate groundwater depletion and quality deterioration. Sustainable land management practices are essential to balance development and groundwater conservation in the region.

Table 6 illustrates the LULC distribution in Anambra State, Southeastern Nigeria, for the year 2018, highlighting the implications of these changes on groundwater resources. The dominant LULC types include Trees (1,644.81 km²), Rangeland (1,410.67 km²), and Built Area (1,154.96 km²), followed by Crops, Water, Flooded Vegetation, and Bare Ground. Statistically, the substantial coverage of built areas, occupying approximately 21.29% of the total area, suggests significant urbanization, which is likely to increase impervious surfaces, reduce infiltration, and consequently affect groundwater recharge. The spatial distribution of these LULC types, depicted in Figure 7, shows concentrated urban growth that may lead to localized groundwater depletion due to over-extraction and reduced natural recharge.

Table 6: LULC Types and Area Distribution in 2018

LULC Type	Area (km²)
Water	95.79
Trees	1644.81
Flooded Vegetation	21.42
Crops	245.63
Built Area	1154.96
Bare Ground	19.22
Rangeland	1410.67

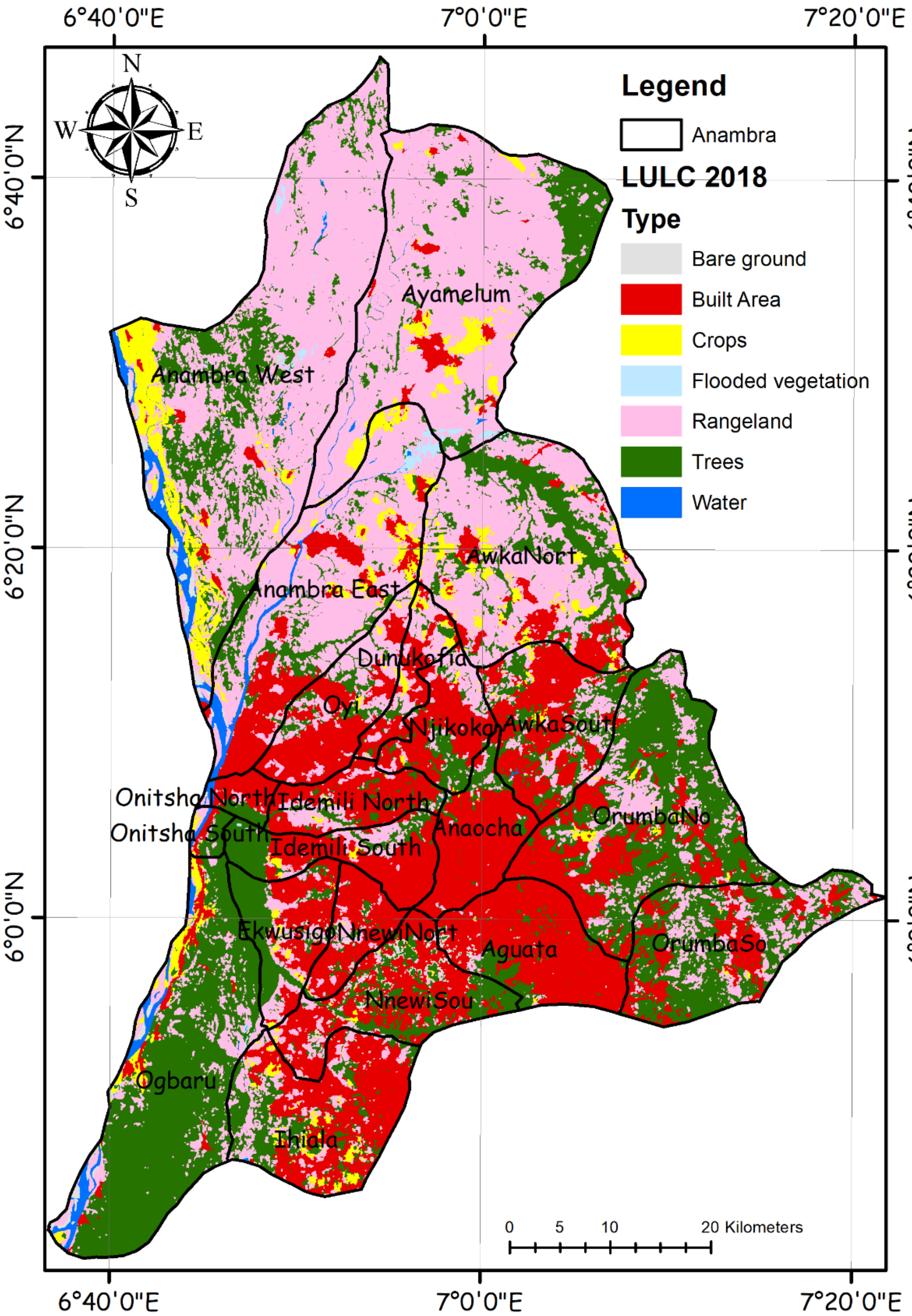

Figure 7: Spatial Map of LULC in 2018

Furthermore, the substantial area covered by trees and rangeland, constituting 30.33% and 26.00% respectively, plays a crucial role in maintaining groundwater levels through enhanced infiltration and reduced surface runoff. Conversely, the presence of 21.42 km² of flooded vegetation indicates areas vulnerable to waterlogging, which can lead to groundwater contamination. The variations in LULC types across the study area underscore the importance of sustainable land management practices to safeguard groundwater resources in Anambra State.

The LULC analysis of Anambra State in 2017 reveals a significant predominance of tree cover, occupying 1807.49 km², followed by rangeland and built areas, covering 1294.14 km² and 1105.26 km², respectively (Table 7). The implications of these findings on groundwater dynamics are profound. High tree coverage, while beneficial for recharging groundwater through infiltration, may also lead to excessive water uptake, potentially lowering the water table in the long term. The substantial built-up area, comprising 1105.26 km², poses a risk of reduced groundwater recharge due to increased surface runoff and impervious surfaces, contributing to urban flooding and diminishing aquifer levels. Agricultural activities, occupying 247.32 km², also impact groundwater through irrigation demands and potential contamination from agrochemicals.

Table 7: LULC Distribution in Anambra State, Nigeria (2017)

LULC Type	Area (km²)
Water	94.67
Trees	1807.49
Flooded vegetation	28.08
Crops	247.32
Built Area	1105.26
Bare ground	15.53
Rangeland	1294.14

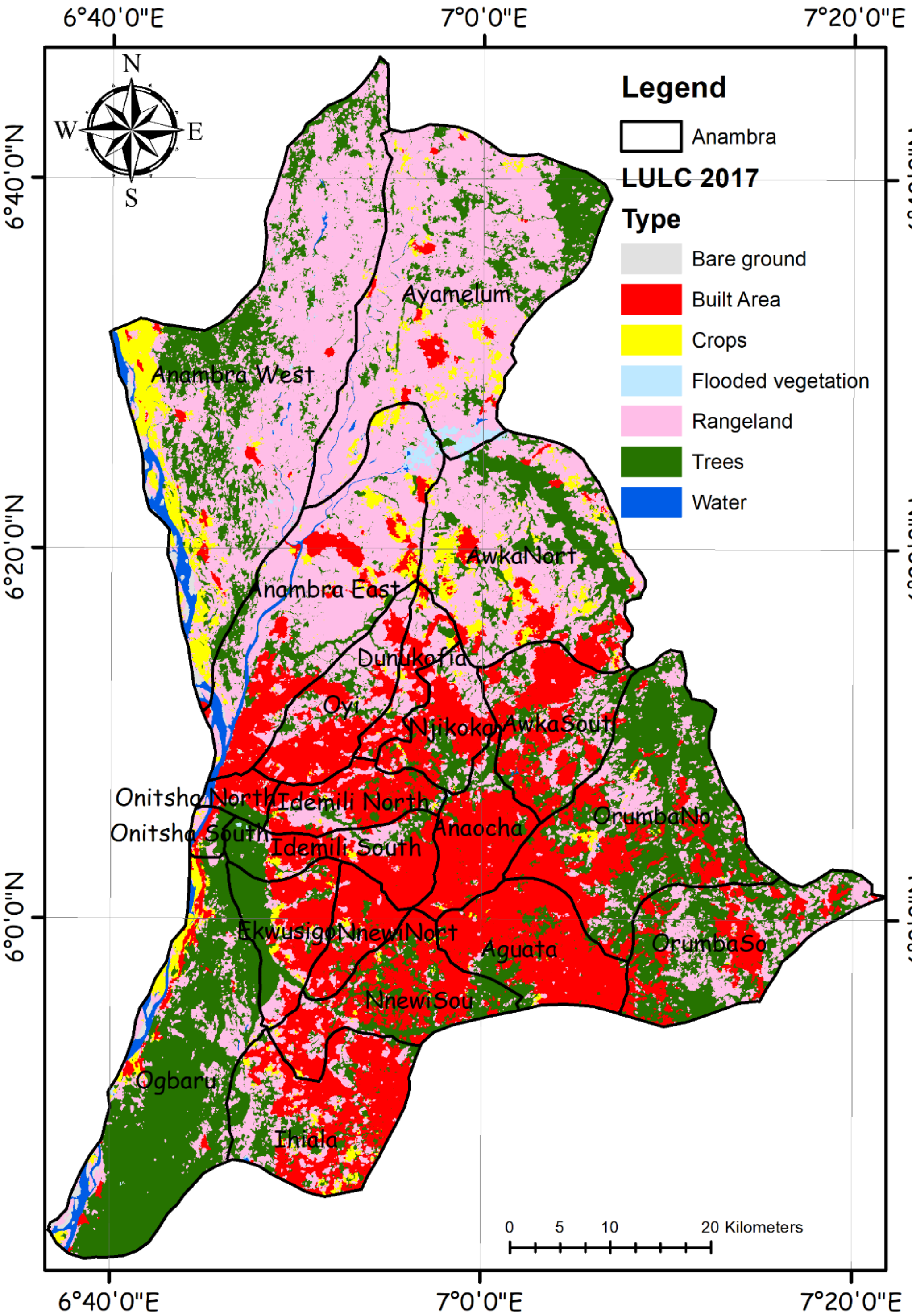

Figure 8: Spatial Map of LULC in 2017

Conversely, the minimal area of bare ground (15.53 km²) indicates limited direct soil exposure, which could otherwise contribute to increased evaporation and reduced groundwater infiltration. The spatial distribution of these LULC types is illustrated in Figure 8, highlighting critical areas for targeted groundwater management and conservation strategies.

4.2 LULC Changes (2017-2023)

Between 2017 and 2023, there has been a noticeable shift in various LULC types. The area covered by trees decreased dramatically from 1,807.49 km² in 2017 to 1,345.35 km² in 2023. This decline is accompanied by a significant increase in built-up areas, which expanded from 1,105.26 km² in 2017 to 1,329.77 km² in 2023. Similarly, the area dedicated to crops has seen a substantial increase, from 235.03 km² in 2020 to 437.04 km² in 2023. Rangeland, which covers substantial portions of Anambra State, fluctuated over the years, peaking at 1,700.13 km² in 2022 before decreasing to 1,345.51 km² in 2023. The water bodies, however, have remained relatively stable, with minor fluctuations, reflecting limited direct anthropogenic impact in these areas. The area under flooded vegetation has seen a significant decrease, from 160.13 km² in 2019 to just 22.07 km² in 2023, suggesting substantial drainage or land reclamation activities.

A statistical examination of the data reveals that the most consistent trend is the reduction in tree-covered areas, with a standard deviation of 213.77 km² across the seven-year period, indicating significant land clearance. Conversely, built-up areas show an upward trend with a relatively low standard deviation of 81.87 km², reflecting steady urban expansion. Cropland areas show a similar increase, with a substantial rise in area particularly between 2022 and 2023. The fluctuations in rangeland and flooded vegetation areas are also notable, with rangeland showing the highest variability (standard deviation of 187.89 km²) due to changes in agricultural practices and possible overgrazing.

The reduction in tree cover, particularly between 2017 and 2023, poses a major threat to groundwater recharge. Trees play a crucial role in the hydrological cycle by facilitating the infiltration of rainwater into the ground, which replenishes aquifers (Charles et al., 2019). The conversion of forested areas to built-up spaces, where impermeable surfaces dominate, leads to increased surface runoff, reducing the amount of water that percolates into the ground. This is likely to decrease the natural replenishment rates of groundwater, exacerbating water scarcity issues, especially during dry seasons. (Adhikari et al., 2020)

The significant increase in cropland from 2020 onwards suggests a greater reliance on groundwater for irrigation. This expansion, particularly in the absence of sustainable water management practices, can lead to over-extraction of groundwater resources. As croplands expand, the demand for water increases, often resulting in the depletion of groundwater reserves, especially if the extraction exceeds natural recharge rates (Zhang et al., 2018). Fluctuations in rangeland areas, which show a marked decrease in 2023 after peaking in 2022, could be associated with changes in land management practices, such as grazing intensity or conversion to other land uses. Overgrazing can lead to soil compaction, which reduces infiltration and further decreases groundwater recharge. However, proper management of rangelands could mitigate such effects by maintaining soil structure and promoting infiltration (Khalil et al., 2021).

The drastic reduction in flooded vegetation areas over the years, particularly from 2019 onwards, indicates significant land-use changes, possibly due to drainage for agriculture or urban expansion. Flooded vegetated areas, such as wetlands, are critical for groundwater recharge as they allow water to slowly seep into the ground. The loss of these areas could result in reduced groundwater recharge, impacting water availability for both agricultural and domestic use (Abdullateef et al., 2021).

5. Conclusion

LULC analysis for Anambra State from 2017 to 2023 highlights significant temporal changes with profound implications for groundwater dynamics. The observed reduction in tree cover, from 1,807.49 km² in 2017 to 1,345.35 km² in 2023, poses a substantial threat to groundwater recharge. Trees play a crucial role in facilitating the infiltration of rainwater into the ground, a process essential for replenishing aquifers. The continuous conversion of these areas into built-up spaces has led to an increase in impervious surfaces, which exacerbates surface runoff and limits the percolation of water into the ground, thereby reducing groundwater recharge rates. The expansion of croplands, particularly between 2020 and 2023, has increased the demand for groundwater, potentially leading to over-extraction. As agricultural activities expand, especially without the implementation of sustainable water management practices, the risk of groundwater depletion grows, which could have severe implications for water availability in the region. This situation is particularly concerning in the context of the rising trend of urbanization and the accompanying infrastructural development, as seen in the steady increase in built-up areas, which further limits the recharge potential of the region's groundwater reserves.

The fluctuating rangeland areas, which saw a marked decrease in 2023, may indicate changes in land management practices, such as overgrazing or conversion to other uses. Overgrazing can lead to soil compaction, reducing infiltration and thus further decreasing groundwater recharge. However, these effects could be mitigated with proper land management strategies that maintain soil structure and promote water infiltration. The drastic reduction in flooded vegetation areas from 160.13 km² in 2019 to 22.07 km² in 2023 indicates significant drainage or land reclamation activities, which may have long-term effects on groundwater recharge and quality. The decline in these natural recharge zones could result in decreased groundwater availability, exacerbating water scarcity issues, especially during dry seasons.

The findings underscore the need for sustainable land management practices in Anambra State to mitigate the adverse effects of LULC changes on groundwater resources. Protecting and restoring natural vegetation, implementing controlled urban expansion, and promoting sustainable agricultural practices are crucial for ensuring the long-term availability of groundwater. To safeguard groundwater resources in Anambra State, it is recommended to implement sustainable land management practices. This includes protecting natural vegetation, regulating urban expansion, and promoting efficient water use in agriculture. These strategies will help balance development with groundwater conservation, ensuring water security for future generations.

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