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ASSESSING THE IMPACT OF LAND COVER AND LAND USE CHANGE ON URBAN INFRASTRUCTURE RESILIENCE IN ABUJA, NIGERIA: A CASE STUDY FROM 2017 TO 2022

OCENA WPŁYWU ZMIAN POKRYCIA I UŻYTKOWANIA GRUNTÓW NA ODPORNOŚĆ INFRASTRUKTURY MIEJSKIEJ W STOLICY NIGERII, ABUDŻY: STUDIUM PRZYPADKU Z LAT 2017-2022

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Abstract

The remarkable feature of rapid urbanisation, which has fundamentally altered the distribution of land cover and land use (LULC), is what sets the contemporary era apart. The impact of these modifications on the resilience of Abuja's metropolitan infrastructure from 2017 to 2022 is examined in this study. Our study examined the dynamic changes in LULC using information from remote sensing, geospatial analysis software, and land cover categorization techniques. The findings indicate major changes in Abuja's topography, including a decrease in the number of water bodies, a decrease in the number of trees, the expansion of urban areas, changes in agricultural land use, and fluctuations in the amount of grazing land. The previously mentioned changes have significant consequences for urban infrastructure resilience, affecting various sectors such as water supply, transportation, housing, utilities, and food distribution systems. The infrastructure supporting water supply and sanitation may be severely stretched as the number of water bodies decreases, affecting the quantity and quality of accessible water supplies. As metropolitan areas expand, greater strain is placed on transportation infrastructure, exacerbating traffic congestion and complicating road maintenance difficulties. Changes in agricultural land use can have an impact on food production and distribution, hence affecting food security. Deforestation can cause ecological deterioration, affecting a variety of aspects such as temperature regulation, biological diversity, and atmospheric purity. Adaptive approaches, green infrastructure, and adopting sustainable urban design can all strengthen the resilience of urban infrastructure, according to this study. The significance of renewable energy adoption, community participation, green building laws, the establishment of public-private partnerships, integrated water resource management, and data-driven decision-making is emphasised. Improving legal frameworks that prioritise resilience and sustainability is critical. It is critical to have a complete grasp of the complicated links between changes in LULC, and the resilience of urban infrastructure in order to enable educated urban design and decision-making processes. Policymakers and urban planners may address and minimise the negative consequences of climate change while improving the overall quality of life in cities by using sustainable development practises. The findings of this study have the potential to dramatically improve Abuja's people's well-being and sustainability, especially given the variety of urban difficulties they encounter.

Keywords: geospatial analysis, infrastructure resilience, remote sensing, sustainability, urbanization

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Streszczenie

Współczesną erę wyróżnia niezwykle szybka urbanizacja, która zasadniczo zmieniła rozkład pokrycia terenu i użytkowania gruntów (LULC). W niniejszym badaniu przeanalizowano wpływ tych zmian na odporność infrastruktury metropolitalnej Abudży w latach 2017-2022. Dynamiczne zmiany LULC zbadano przy użyciu informacji z teledetekcji, oprogramowania do analizy geoprzestrzennej oraz technik kategoryzacji pokrycia terenu. Wyniki wskazują na poważne zmiany w topografii Abudży, w tym spadek liczby zbiorników wodnych, spadek liczby drzew, ekspansję obszarów miejskich, zmiany w użytkowaniu gruntów rolnych i wahania w ilości pastwisk. Zmiany te mają znaczące konsekwencje dla odporności infrastruktury miejskiej, wpływając na różne sektory, takie jak zaopatrzenie w wodę, transport, mieszkalnictwo, usługi komunalne i systemy dystrybucji żywności. Infrastruktura wspierająca zaopatrzenie w wodę i urządzenia sanitarne może być poważnie obciążona, ponieważ malejąca liczba zbiorników wodnych odbija się na ilości i jakości dostępnych zasobów wody. Wraz z rozwojem obszarów metropolitalnych rośnie obciążenie infrastruktury transportowej, co zwiększa natężenie ruchu i komplikuje utrzymanie dróg. Zmiany w użytkowaniu gruntów rolnych wpływają na produkcję i dystrybucję żywności, a tym samym na bezpieczeństwo żywnościowe. Wylesianie może powodować pogorszenie stanu środowiska, wpływając na regulację temperatury, różnorodność biologiczną i czystość atmosfery. Według naszych badań podejście adaptacyjne, zielona infrastruktura i przyjęcie zrównoważonego projektowania urbanistycznego mogą wzmocnić odporność infrastruktury miejskiej. Podkreśla się znaczenie energii odnawialnej, udziału społeczności, przepisów dotyczących zielonego budownictwa, ustanowienia partnerstw publiczno-prywatnych, zintegrowanego zarządzania zasobami wodnymi i podejmowania decyzji w oparciu o dane. Kluczowe znaczenie ma poprawa ram prawnych, które powinny priorytetowo traktować kwestie odporności miejskiej oraz zrównoważonego rozwoju. Świadome projektowanie urbanistyczne i procesy decyzyjne możliwe są jedynie przy zrozumieniu skomplikowanych powiązań między zmianami w LULC a odpornością infrastruktury miejskiej. Zastosowanie praktyk zrównoważonego rozwoju umożliwi decydentom i urbanistom zminimalizowanie negatywnych konsekwencji zmian klimatycznych oraz podniesienie ogólnej jakości życia w miastach. Wyniki tego badania mogą potencjalnie znacznie poprawić dobrobyt i zrównoważony rozwój mieszkańców Abudży, zwłaszcza biorąc pod uwagę różnorodność napotykanych przez nich trudności miejskich.

Słowa kluczowe: analiza geoprzestrzenna, odporność infrastruktury, teledetekcja, zrównoważony rozwój, urbanizacja

1. INTRODUCTION

Cities have become key social change agents in an era of unprecedented global urbanisation. Because of the increasing expansion of metropolitan regions, both the physical settings and patterns of human habitation are changing dramatically (Nuissl & Siedentop, 2020). These changes affect more than just the surface of cities; they also affect basic infrastructure and interact with crucial elements that maintain our modern life. In this environment, assessing changes in LULC and their consequences for the robustness of urban infrastructure appears as an important and intriguing area of research (Alp et al., 2020; Noi et al., 2021).

Urbanisation has emerged as one of the most noteworthy characteristics of the twenty-first century, the modern time (Hölscher & Frantzeskaki, 2021). As the world's population congregates in metropolitan areas, cities face continual challenges in caring for, housing, and assuring the well-being of their residents. Changes in LULC that precede urban expansion are usually caused by a variety of variables, including population growth, economic development, and shifting societal demands. These improvements, however, come at a significant cost and pose a serious threat to the stability of urban infrastructure (Rode, 2013). This covers vital networks responsible for delivering basics including energy distribution, water supply, sewage treatment, transportation, and other services.

The word "land cover" refers to the apparent aspects of the Earth's surface, such as farms, forests, water bodies, and urban infrastructure. The term "land use" refers to how a plot of land is used; it might be used for residential, commercial, industrial, agricultural, or other permissible purposes. These two interconnected principles have a significant impact on how cities evolve and take shape. Changes in LULC have a substantial impact on urban infrastructure, which in turn determines how vulnerable it is to various stresses such as population increase, climate change, and natural disasters (Akaolisa et al., 2023).

Changes in LULC in metropolitan areas are driven by a number of factors, including population growth, economic expansion, and technological advancements. Land cover changes refer to changes in the physical properties of the land, such as the transformation of vegetated zones into impermeable surfaces (Naikoo et al., 2020; Lamichhane & Shakya, 2021). Changes in land use, on the other hand, refer to changes in the way land is used, such as transitioning from residential to commercial or from agricultural to industrial.

Urban infrastructure includes a variety of systems such as energy, telecommunications, water supply, sewerage, and transportation. These systems are linked because their resilience is critical to ensuring the general well-being of city dwellers (Gonçalves & Villena-Manzanares, 2021). Resilience refers to an infrastructure's ability to successfully absorb, adapt to, and recover from a variety of disruptive events and long-term stresses. The need of analysing infrastructure resilience in order to improve urban sustainability and catastrophe preparedness is emphasised in research conducted by (Mottahedi et al., 2021).

It is critical to have a good understanding of the intricate connections between changes in LULC, as well as the resilience of urban infrastructure, in order to enable sensible urban design. Land cover changes, namely the addition of impermeable surfaces, can result in urban heat island effects, which can have an impact on public health, transportation systems, and energy usage (Nwakaire et al., 2020; Vujovic et al., 2021). It explains how switching from a residential to a mixed-use zoning plan affects a variety of aspects, including traffic flow, accessibility, and public transportation use.

Many academic research has been conducted to study how changes in LULC affect urban infrastructure resilience (Aliyu et al., 2023; Bernard & Bilal, 2023). Changes in land cover, notably an increase in impermeable surfaces, may make floods and heat-related difficulties more likely, according to the findings of a study conducted by Derdouri et al., (2021), Singh et al., (2022), Ramzan et al., (2022), Bernard & Bilal, (2023) and Ha & Nguyen, (2023). These changes may weaken the resilience of transportation, power, and water supply systems, making it more difficult for them to withstand and recover from comparable disasters. The consequences of land use changes, such as the move to mixed-use development, on transport infrastructure have shown variable results, highlighting the necessity for assessments tailored to specific scenarios.

Adoption of sustainable urban development is critical in raising the general standard of life in urban areas while mitigating the negative effects of climate change. It is impossible to exaggerate the importance of resilient urban infrastructure in reducing disaster risk and increasing the general well-being of urban dwellers. Policymakers and urban planners can utilise the study's key results to inform their decisions. By embracing these notions, policymakers and planners can effectively promote sustainability and economic progress. They can also improve infrastructure to better manage environmental challenges, strengthen a city's ability to endure extreme events, and ultimately provide a good standard of living for its residents. The goal of this study is to conduct a thorough examination of the influence of changes in LULC on the resilience of urban infrastructure.

2. GEOGRAPHICAL AND DEMOGRAPHIC OVERVIEW OF THE STUDY AREA

The topography of Abuja exemplifies a well-coordinated blend of purposeful urban architecture and natural beauty. The disputed territory is located in central Nigeria at around 8.532°N to 9.337°N latitude and 6.745°E to 7.545°E longitude. The city centre is positioned on the visually beautiful Jos Plateau, part of the broader Guinea Savanna region. The region's gently sloping hills and valleys provide spectacular views of the surrounding agricultural area (Enoguanbhor et al., 2019; Shuaibu & Kara, 2019).

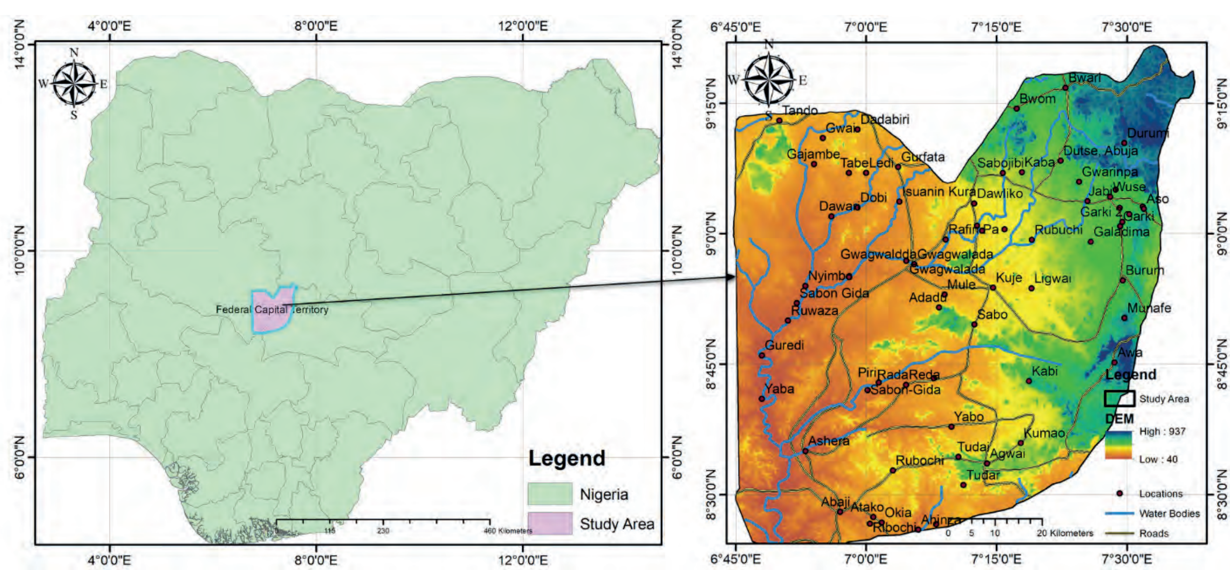

Fig. 1. Map of Nigeria and Digital Elevation Model of the Study Area

The Aso Rock, a massive rock that rises abruptly upwards from the surrounding land, is one of Abuja's most noticeable topographical features. Aso Rock is included in Nigeria's national emblem due to its significance as a landmark and symbolic value as a representation of the city. The rock adds a particular visual appeal to the cityscape by serving as a magnificent feature behind a number of significant government buildings.

Because of the city's ideal position, a wide range of agricultural activities are conceivable, promoting the creation of a diverse food market. Furthermore, the Usuma Dam created a reservoir in Abuja, which offers a critical supply of clean drinking water to the local people. Furthermore, the Gurara Falls, which are located near the city, provide people with the opportunity to engage in leisure activities and find solace in wildlife (Momoh et al., 2022).

As of January 2022, Abuja's population had increased significantly, which has been attributed to urbanisation, government centralization, and the availability of employment possibilities. Since it became the country's capital in 1991, Abuja has welcomed a varied population representing many different ethnic groups. Because of the presence of foreign embassies and government institutions in the city, government personnel and diplomats are concentrated in the city, which has a significant impact on the local economy and society (Zubair et al., 2015). Abuja has a big number of young people, which has numerous ramifications in the domains of work and education. However, as a result of urbanisation, a number of issues have arisen, including strain on existing infrastructure, a housing shortage, and traffic congestion. As a result, in order to stimulate growth and enhance overall living standards, sustainable solutions must be devised (Aniekwe & Igu, 2019).

Abuja is a metropolis that has been meticulously planned and separated into zones, each serving a specific demography and performing specific functions. The CBD is home to a multitude of government buildings, diplomatic offices, and business enterprises distinguished by modern skyscrapers and manicured green spaces. Garki is defined as a community with both residential and commercial sectors, as well as a variety of facilities such as malls and various types of housing. Asokoro is an affluent suburb mostly inhabited by diplomats and government officials. Wuse is best defined as a bustling metropolitan district with a vibrant street scene that includes both commercial and residential areas. The plethora of expensive mansions, diplomatic embassies, and sumptuous amenities attest to Maitama's affluence. As a result of development, the Gwagwalada neighbourhood has grown dramatically.

3. METHODOLOGY

Because of the improved availability and accessibility of remote sensing data, the use of satellite imaging and geospatial analysis tools to explore changes in LULC has expanded recently. The study is notable because it employs European Space Agency (ESA) Sentinel-2 data with a 10-meter resolution, allowing for a more detailed analysis of the topography. Using data preparation techniques enhances image quality and removes errors, resulting in more accurate results (Kumar et al., 2021; Agdas & Yenen, 2023). Furthermore, the well-known geospatial analytics tool ArcGIS 10.8 offers a reliable approach to identify and study land cover data.

It has been proved that supervised classification systems can correctly classify various types of land cover. The accuracy of the categorization can be improved further by employing high-resolution images to confirm training data from field surveys. Post-classification comparison is a popular way for assessing how LULC has changed over time (Akaolisa et al., 2023). This method compares categorise land cover maps created over a range of time periods.

4. DATA PROCESSING

The use of training data to guide a computer system on how to classify pixels in a photograph into multiple land cover categories is a major component of supervised classification algorithms. Using supervised classification algorithms, Sentinel-2 photos were sorted into different land cover classes, including forests, aquatic bodies, farms, and urban areas. The training data for the study came from field surveys, and it was confirmed using high-resolution images (Zhang et al., 2021). The main purpose of this stage was to ensure that the training dataset accurately reflected the variety of land cover types found in the specified research location. Using high-resolution photos to assess the training set improved classification accuracy.

Post-classification comparison requires studying classed land cover maps from many temporal eras to detect variations in LULC throughout time. The post-classification comparison method was employed in this study to find disparities in LULC in Abuja, Nigeria. Maps of land cover, separated into numerous categories, were compared across time periods to find sites where major changes in land cover occurred (Asenso et al., 2020; Otoo et al., 2021). Post-classification comparison analysis is a useful method for analysing changes in LULC over time since it makes it easier to discover patterns and understand the underlying causes of these changes. It also makes it straightforward to identify places that are undergoing significant change and those that may require support for successful land use management (Twisa & Buchroithner, 2019).

This study employed supervised classification methods and post-classification analysis to precisely classify Sentinel-2 imagery into multiple land cover classes and identify temporal oscillations in LULC. The previously mentioned methodology is quite useful in tracking environmental changes and identifying areas that require action for effective land use change management.

5. RESULT AND DISCUSSION

Table 1 and Figure 2 depict an evaluation of changes in LULC within Abuja between 2017 and 2022. These images provide crucial insights into the dynamic changes that are taking place in the city's physical landscape.

The observed variations in the size of water bodies may be due to dynamic changes in precipitation patterns and the implementation of water management strategies. The observed reduction in water area between 2017 and 2022 could be attributable to rising urbanisation and climate change, both of which frequently necessitate the reclamation of water bodies for development. The observed drop in the number of Tress areas over time is most likely due to deforestation and urban growth. Reduced tree cover has a negative impact on the environment, including lower biodiversity, higher temperatures, and poorer air and water quality (Sun et al., 2022).

Submerged plant life changes have the potential to serve as indicators of changes in hydrological patterns and urbanisation processes. The changes could have a significant influence on adjacent ecosystems and increase the risk of flooding, necessitating adaptation and mitigation measures (Hussein et al., 2020). Changes in land usage and farming practises may be the cause of reported crop area fluctuations. Changes in agriculture may have a significant impact on a number of aspects, including food security, rural wellbeing, and the long-term sustainability of land resources. The consistent rise in developed regions indicates the prevalence of urbanisation and the concurrent construction of infrastructure (Chou et al., 2015). This trend indicates greater population numbers, increased economic activity, and higher living standards. It may, however, create new issues, such as greater demand for resources and services. Changes in land usage and land reclamation efforts may result in differences in the number of exposed ground surfaces. These modifications could have an impact on habitat loss, land degradation, and soil erosion. Increased rangeland area could be influenced by urban encroachment as well as land-use practises (Du et al., 2019). Because the region has historically relied on pastoralism, changes in animal grazing supplies have a substantial impact.

The loss of tree cover and the expansion of built-up areas may result in environmental degradation, a decrease in biodiversity, and an increase in climate-related difficulties. Aquatic system modifications can have a significant impact on the availability of water resources and surrounding ecosystems. The expansion of urbanised areas reflects the city's rising population and economic activities, necessitating the creation of necessary amenities and infrastructure (Grêt-Regamey et al., 2020). Crop area changes can have an impact on food production, agricultural sustainability, and the economic well-being of rural populations, among other things. Differences in exposed soil and rangeland areas indicate changes in land use and future land management plans, which affect ecosystems and farming practises. Maintaining an eye on these developments is critical for

Table 1. Dynamic LULC Landscape of the study area between 2017 to 2022

LULC Type	Area (km^2)						Change (%)				
	2017	2018	2019	2020	2021	2022	17/18%	18/19%	19/20%	20/21%	21/22%
Water	32.57	37.27	41.84	41.64	38.25	39.94	14.44	12.26	-0.47	-8.14	4.42
Trees	2631.65	2467.32	2205.70	1952.04	1863.01	1468.26	-6.24	-10.60	-11.50	-4.56	-21.19
Flooded vegetation	0.93	1.99	2.98	1.05	0.33	0.65	113.67	49.44	-64.83	-68.51	97.98
Crops	2299.93	2399.10	2447.10	2228.69	2441.37	2359.55	4.31	2.00	-8.93	9.54	-3.35
Built Area	535.77	573.88	614.73	638.67	665.69	712.10	7.11	7.12	3.90	4.23	6.97
Bare ground	1.80	1.53	2.37	3.12	2.67	1.30	-15.20	55.03	31.43	-14.36	-51.24
Rangeland	1850.49	1872.03	2038.41	2487.91	2318.60	2771.32	1.16	8.89	22.05	-6.81	19.53

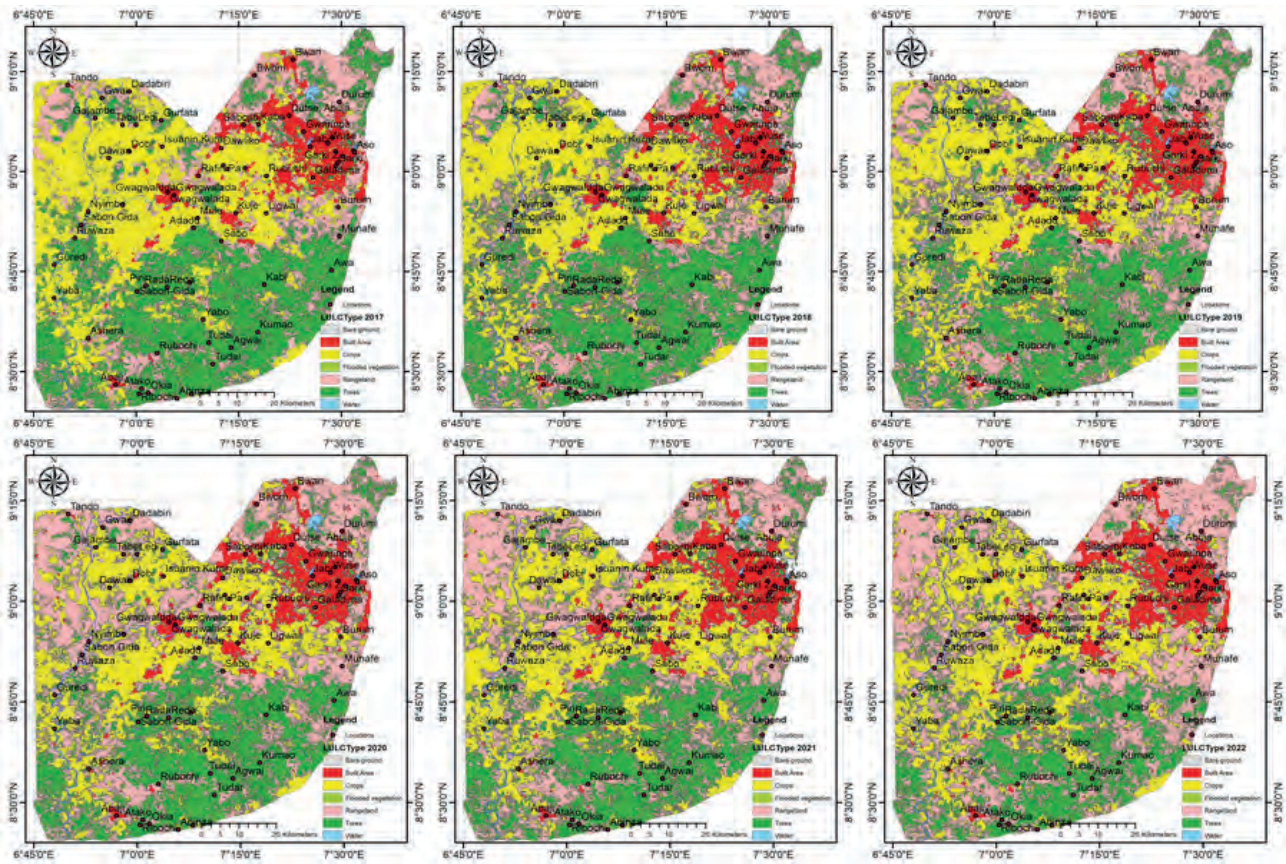

Fig. 2. LULC between 2017 to 2022 in the study area

resilience strategies and urban planning, particularly in the context of climate change. It is critical to ensure that ecosystems and infrastructure can adapt and respond to changing conditions.

The observed changes in LULC between 2017 and 2022 are being used to estimate the risk of critical infrastructure components in Abuja, Nigeria. The evaluation's findings give critical new information on the dangers and concerns that may develop as a result of these changes in LULC. In this work, we will examine vulnerability assessment in depth, with a focus on how changes in LULC affect infrastructure vulnerability. We will highlight significant discoveries as well as any concerns associated with this link.

Water availability and infrastructure resilience may be impacted by the urban region's lower water supply as a result of water area shrinking. The extension of built-up regions is a symptom of the phenomenon of urban expansion, which places increased demand on transport infrastructure. Traffic, road maintenance, and the need for public transport are three primary impediments (Faiyetole & Adewumi, 2023). The evolution of built-up areas has a significant impact on housing and utility infrastructure. It has an impact on issues such as housing scarcity and increased demand for utilities, particularly water and electricity. Variations in crop acreage may have an impact on the entire food supply chain as well as agricultural infrastructure. Changes in agricultural land allocation can have a considerable impact on food distribution and production.

The development of developed regions indicates a significant urbanisation trend. Although the previously described phenomenon has the potential to create economic opportunities, it also places strain on existing infrastructure, perhaps resulting in traffic bottlenecks, higher power costs, and difficulties in providing enough housing and services. Some of the consequences of forest canopy decline include decreased air and water quality as well as elevated temperatures (Bernard & Bilal, 2023). It is critical to consider how infrastructure aspects such as energy and transportation may impact people's health and well-being (Bianchini et al., 2021). Crop region variations may have an impact on agricultural infrastructure. Changes in the networks that produce and distribute food can have an impact on the infrastructure of supply chains as well as food security. Reduced water body size, which is a shift in aquatic ecosystems, can have a significant impact on sanitation and water supply systems, perhaps reducing the quantity and quality of accessible water. Rapid urbanisation and population growth can strain existing infrastructure, resulting in issues such as traffic, housing shortages, and increased demand for essential utilities such as power, water, and transportation. The loss of tree cover and the resulting ecological repercussions may have an impact on other sections of infrastructure, such as energy supply, air conditioning requirements, and transportation networks, worsening the state of the environment (Fan et al., 2022).

Understanding the city's ability to withstand and recover from shocks necessitates evaluating the robustness of existing urban infrastructure in light of observed changes in LULC. The spread of urban growth and the unequal distribution of land resources may put strain on transportation infrastructure. Problems such as traffic congestion, poor road conditions, and impediments to public transport may put the current transport system to the test (Gonçalves & Ribeiro, 2020). The relocation of metropolitan areas has a considerable influence on housing and utility infrastructure. Rapidly increasing metropolitan areas may face resilience challenges due to a lack of housing and increased demand for basics such as power and water. Variations in crop acreage may have an impact on the entire food supply chain as well as agricultural infrastructure. Building solid infrastructure in the agriculture business is crucial to assuring the stability and dependability of food security while also optimising supply chain processes.

Table 2. Impact of LULC changes between 2017 to 2022 in the study area on Urban Infrastructure Resilience

Major LULC Type Change	Area (Km^2)					
	2017	2018	2019	2020	2021	2022
Trees	2631.65	2467.32	2205.70	1952.04	1863.01	1468.26
Crops	2299.93	2399.10	2447.10	2228.69	2441.37	2359.55
Built Area	535.77	573.88	614.73	638.67	665.69	712.10
Rangeland	1850.49	1872.03	2038.41	2487.91	2318.60	2771.32

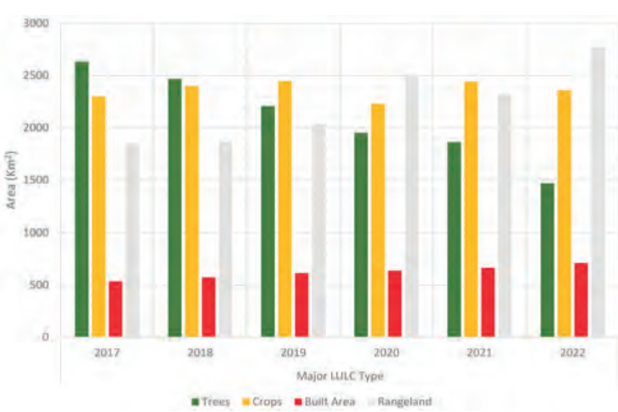

Fig. 3. Stack plot of major LULC Type change in the study area

Table 2 and Figure 3 show how changes in the LULC categories have a direct impact on the resilience of urban infrastructure. This is especially true when considering the "Built Area" category as a representative of urban infrastructure. The high growth in Built Area shows that metropolitan areas are growing in size, putting more burden on infrastructural services. Urbanisation frequently puts a strain on critical infrastructure and services such social amenities, water supply, transportation networks, and garbage disposal. The loss of natural land cover, particularly trees, as a result of development has the potential to affect environmental quality as well as the resilience of metropolitan areas to shocks.

Table 3 shows the correlation between various LULC in the study region from 2017 to 2022, providing insight into the dynamics of the relationship within the study area. The built area and range land have a high positive correction, indicating that development is encroaching on range areas, potentially affecting the natural ecology. Trees have a negative link with built area and rangeland, implying that there is less tree cover, implying a loss of green spaces and urban trees, which would have an impact on the urban heat island and air and water quality. Water and crops have a weak positive association. Tress with Crops and Bare terrain, Flooded Vegetation and Bare Ground, Crops with Built Area, Built Area with Bare Ground, and Bare Ground with Rangeland are all examples of bare terrain. These would affect irrigation operations and agricultural land near sources of water, indicating that there is a transition zone between urban areas and natural rangeland.

Table 3. Matrix correlation for LULC changes between 2017 to 2022 in the study area

	Water	Trees	Flooded vegetation	Crops	Built Area	Bare ground	Rangeland
Water	1.000						
Trees	–0.621	1.000					
Flooded vegetation	0.319	0.435	1.000				
Crops	0.111	-0.043	0.355	1.000			
Built Area	0.654	–0.993	–0.381	0.146	1.000		
Bare ground	0.431	–0.079	–0.037	–0.227	0.092	1.000	
Rangeland	0.570	–0.964	–0.514	–0.221	0.930	0.113	1.000

Reduced tree cover, an important component of green infrastructure, may have an impact on ecosystem services as well as urban heat islands. Changes in

Rangeland may also imply changes in land use practises, which may have additional consequences for adjacent ecosystems and urban growth.

The notable expansions in the "Water-Built Area" and "Crops-Built Area," as illustrated in Figure 4, indicate significant urban development. The current expansion has a significant impact on the spatial needs that accompany the growth of urban infrastructure. The transitions "Trees-Built Area" and "Rangeland-Built Area" show the process of converting natural regions into constructed settings, which may have an impact on biodiversity and green spaces. Changes in "Water-Trees" and "Water-Crops" have been seen as a result of changes in water bodies, which are significant for controlling urban water supply. Transitions associated to "Bare Ground" may indicate changes in the land's features, which may have an impact on soil production and quality.

Abuja's rapidly expanding urban area and population have placed significant strain on the city's existing infrastructure, particularly in the areas of utilities, housing, and transportation. To meet the increased demand for electricity, water, and transportation services, infrastructure resilience necessitates careful planning and investment. Growth in urban areas has exacerbated traffic congestion, demanding infrastructure expansion to improve resilience and the implementation of adaptive transportation management solutions.

The rapid pace of urbanisation and land-use changes can strain existing infrastructure, resulting in a variety of issues such as insufficient housing supply, transportation congestion, and inadequate utility availability. The difficulties listed above have the potential to reduce the citizens' overall standard of living. Changes in crop-growing regions can have an impact on local agricultural methods and the interdependent systems that assist distribute food. The economic fallout from fluctuations in food output may have a considerable influence on food security and lives (Okeleye et a., 2023). The decline in tree canopy and the resulting increase in air pollution may have a negative impact on public health. The overall health and well-being of individuals in impacted areas may be jeopardised because there is a link between poor air quality and the prevalence of respiratory and cardiovascular disorders. The loss of habitat caused by deforestation, as well as alterations

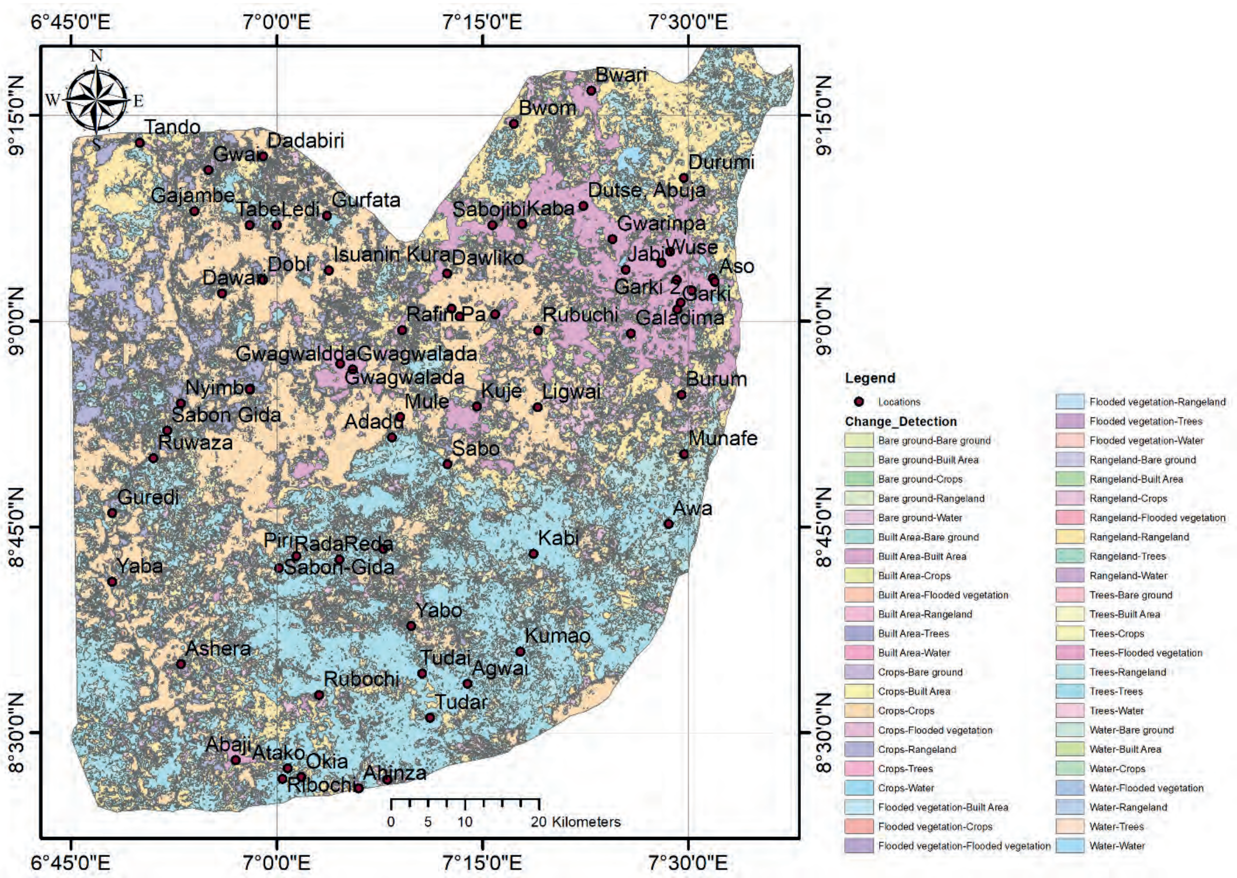

Fig. 4. LULC changes in the study area between 2017 to 2022

environment

to wetland ecosystems, may have a negative impact on biodiversity. As biodiversity declines, citizens may have less possibilities for leisure and education. Changes in aquatic ecosystems and decrease of water quality have serious implications for the supply of safe drinking water. Water quality preservation is critical for sustaining public health and increasing general welfare. The expansion of urban areas shows the presence of favourable economic conditions and the emergence of new work opportunities. Uncontrolled growth, on the other hand, can lead to urban issues such as unequal social conditions and inadequate urban development plans.

There is an opportunity to reduce the burden on infrastructure by implementing adaptable urban design principles that incorporate sustainable land use practises. Infrastructure systems can be made significantly more resilient by using sound zoning and urban planning practises. Transit infrastructure resilience can be strengthened by using adaptive measures such as better traffic management, greater public transit, and road repair programmes. Resilient water and power supply systems necessitate the allocation of resources for infrastructure upgrades and the implementation of effective utilities management practises. The implementation of adaptive agricultural practises, such as crop diversity and the adoption of sustainable farming techniques, could increase the resilience of the infrastructure sustaining food supply (Okeleye et al., 2023).

It is critical to implement and enforce inclusive land use plans that prioritise sustainable growth and the preservation of natural areas. Zoning restrictions are critical for regulating urban growth, fostering the development of green spaces, and conserving critical ecosystems. Implement afforestation and reforestation efforts to minimise deforestation and expand urban green spaces. Incorporating green infrastructure into urban design entails incorporating elements such as parks, tree-lined boulevards, and green roofs to enhance air quality and sustain biodiversity (Gavrilidis et al., 2019; Ronchi et al., 2020). Strengthen rules aimed at protecting and advancing long-term maritime environment management. Water conservation tactics and pollution control measures are critical for guaranteeing water quality preservation. Infrastructure resilience can be increased by improving design, maintenance, and adaptive measures, allowing it to withstand and recover from a variety of shocks. In order to successfully limit possible flooding threats, it is critical to prioritise the installation of sustainable urban drainage systems and flood management techniques (Tachaudomdach et al., 2018; Karamouz et al., 2019).

The goal is to develop climate-resilient urban development policies and strategies in order to effectively mitigate the rising risks connected with climate-related factors. It is recommended to use integrated water resource management techniques that incorporate sustainable urban drainage systems that take both water quantity and quality into account. To minimise carbon emissions, this idea encourages the widespread adoption of renewable energy sources as well as increased energy efficiency in infrastructure and buildings. The goal is to increase community engagement and understanding about sustainable land use practises, conservation projects, and disaster preparedness in order to build a resilient and knowledgeable population. Green building regulations, which encourage the construction of environmentally friendly and energy-efficient structures, must be implemented and carefully enforced in order to limit the harmful consequences of new construction on the environment. Encourage the formation of public-private partnerships to aid in infrastructure development, with a focus on resilient and sustainable projects that benefit both the public and private sectors equally. Provide a comprehensive framework for acquiring and tracking data on changes in land use, environmental markers, and infrastructure performance in order to provide meaningful information to guide decision-making procedures. In terms of urban expansion and planning, strengthen legislative frameworks that prioritise resilience, sustainability, and environmental preservation.

6. CONCLUSION

The changing patterns of LULC in Abuja have a substantial impact on the vulnerability of critical infrastructure assets. The observed loss in aquatic ecosystems poses a major danger to water supply and sanitary infrastructure, potentially resulting in a water deficit and decreasing water quality. The expansion of metropolitan regions places a significant strain on the transportation infrastructure, raising worries about road upkeep, traffic congestion, and the availability of public transportation. Given the implications for food security, crop area alterations on agricultural infrastructure and the food supply chain are cause for concern. Furthermore, the loss of tree canopy and submerged vegetation has significant ecological consequences that affect numerous infrastructure components such as atmospheric conditions, water reservoirs, and energy provision.

Abuja must assess the resilience of its urban infrastructure to address the challenges posed by urbanization and environmental changes. Sustainable land use planning, zoning regulations, green infrastructure, water conservation, afforestation, and adaptive measures are essential for reducing infrastructure demand and ensuring water quality preservation. Enforestation and reforestation efforts can mitigate deforestation effects and improve urban green spaces. Infrastructure resilience can be increased through design, maintenance, and adaptive measures.

To reduce flooding threats, sustainable urban drainage systems and flood management measures should be prioritized. Green building laws should be enforced to promote ecologically friendly and energy-efficient structures. Public transit, pedestrian-friendly infrastructure, and bicycle networks can alleviate traffic congestion and environmental damage caused by carbon emissions. Mixed-use projects can reduce commute time and promote conservation farming practices.

Establishing climate-resilient policies and approaches is crucial for mitigating climate change hazards. Integrated water resource management techniques should incorporate sustainable urban drainage systems, and renewable energy resources should be used to reduce carbon emissions. Increased community engagement and awareness of sustainable land use practices, conservation projects, and disaster preparedness can create a resilient citizenry. Collaborative efforts between public and private groups can help develop robust and sustainable infrastructure.

A comprehensive framework for acquiring and tracking information on land use, environmental indicators, and infrastructure performance can help make sound decisions. Abuja must act now to ensure a resilient and sustainable future for all parties involved.

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