Land Use Classification and Predictive Modeling of Urban Growth Impacts on the Environment in Minna Metropolis, Niger State, Nigeria

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ABSTRACT

This study investigates the land use and land cover (LULC) changes in Minna Metropolis, Niger State, Nigeria, from 2015 to 2024, emphasizing the impacts of urban growth on the environment. Employing remote sensing and Geographic Information System (GIS) techniques, the research utilizes high-resolution satellite imagery to conduct a comprehensive classification of land use across four critical years: 2015, 2018, 2021, and 2024. The analysis reveals a significant increase in built-up areas, which expanded from 28.68 km² (15.51%) in 2015 to 69.98 km² (37.85%) in 2024, indicating rapid urbanization and infrastructural development driven by population growth and economic activities. In contrast, agricultural land, while remaining the predominant land cover, exhibited a slight decline from 140.20 km² (75.81%) in 2018 to 129.01 km² (69.75%) in 2024, reflecting the pressures of urban encroachment. Furthermore, vegetation cover experienced a notable decrease, dropping from 15.39 km² (8.32%) in 2021 to 5.17 km² (2.80%) in 2024, underscoring the environmental challenges associated with urban expansion, such as habitat loss and reduced biodiversity. The study also employs predictive modeling to forecast land use changes for 2034, projecting a further increase in built-up areas to 101.83 km² (55.08%), alongside a corresponding decline in agricultural and vegetative land. This forecast highlights the potential for continued urban sprawl and its implications for local ecosystems. The findings underscore the urgent need for sustainable urban planning strategies that incorporate remote sensing and GIS methodologies to monitor and manage urban growth effectively. By doing so, stakeholders can mitigate the adverse effects of urbanization on the environment and ensure the preservation of vital ecosystems in Minna Metropolis, thereby promoting a balanced approach to development and environmental conservation.

Key words: Remote Sensing, GIS, Urban Growth, Predictive Modelling, Land Use

INTRODUCTION

Urbanization has been progressing at an unprecedented pace across the globe, leading to vast land cover changes. This rapid growth of the urban regions poses vast opportunities and challenges for sustainable development in a country's future (Busho et al., 2021). Urbanization is a major cause of the conversion of agricultural land into the built-up area due to rapid economic growth, new industrial zones, and migration from rural areas toward towns and cities around the world (Rahman et al., 2023). The rapid urbanization of the world is a phenomenon that has been observed over the past few decades, with more than half of the global population currently residing in urban areas. This trend is projected to continue, with an estimated 68% of the global population expected to live in urban areas by 2050. This rapid urban growth, driven by population growth and socio-economic development, is leading to significant urban sprawl (Getu and Bhat, 2021).

In Nigeria, urbanization has accelerated over the past few decades, driven by population growth, economic opportunities, and rural-to-urban migration in which Minna Metropolis, the capital of Niger State, is no exception to this trend, experiencing substantial urban expansion that poses challenges to its environmental integrity.

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Understanding the dynamics of land use change and its environmental impacts is crucial for effective urban planning and sustainable development.

The evolving landscape of urban areas worldwide indicates that the future of our planet is increasingly urban. Cities across the globe, particularly in less developed nations, are experiencing significant changes, with a notable trend toward urban growth and expansion (Rikko, 2016). The United Nations has projected that by 2030, a larger portion of the global population will reside in urban areas rather than rural ones, predominantly in Asia and Africa, which are currently among the least urbanized regions (Abdulkadir et al., 2019; Sustainable Development Solutions Network, 2012). In Sub-Saharan Africa, Nigeria stands out with the highest urban population proportion, accounting for 52.764% (The World Bank Data, 2022; Rowland, 2016). This unprecedented population surge exerts considerable pressure on land resources due to human activities related to housing, infrastructure development, food production, and natural resource extraction. However, land resources are becoming increasingly limited globally due to ongoing exploitation and mismanagement (Fikadu, 2022; Gessese, 2018). The rapid urban population growth has led many cities worldwide to experience heightened land consumption driven by increased demand, as evidenced by city boundaries frequently extending into surrounding areas (Nicolau et al., 2019; UN-Habitat, 2018; Seto et al., 2011).

Rapid pace of urbanization is believed to be a global problem that has led to dramatic change in land use practices in most developing nations of the world. Such expansion has encouraged residential development, leading to urban sprawl and consequently damaged the environment. Balogun et al. (2011) submitted that urban populations in developing countries have grown by 40% between 1900 and 1975. The trend will continue adding approximately 2 bilion people to the urban population of the presently less developed nations for the next 30 years.

Land Use/Land Cover Change (LULCC) resulting from human activities is a well-recognized global phenomenon that has significantly transformed the Earth's terrestrial surface. Over the period from 1960 to 2019, approximately one-third of the Earth's land area underwent alterations (Winkler et al., 2021).

Context of Urban Sprawl Study

To establish a comprehensive understanding of urban sprawl, it is essential to consider four key areas: resource optimization, environmental aspects, economic effects, and quality of life.

Resource Optimization: Urban sprawl frequently leads to unplanned land use, resulting in the dispersion of development across extensive areas and escalating infrastructure costs for utilities, transportation, and services. A thorough understanding of urban sprawl is vital for managing resources more effectively (Hamidi et al., 2015).

Environmental Aspects: The environmental repercussions of urban sprawl can be significant, including the loss of agricultural land, increased pollution, and heightened energy consumption due to longer commutes (Abdel Jawad and Nagy, 2023). Analyzing urban sprawl is crucial for identifying these impacts and formulating strategies for mitigation and sustainable development.

Economic Effects: Urban sprawl can lead to increased infrastructure costs and reduced tax revenues per unit of land. It may also contribute to economic segregation and a decline in property values in certain areas. Understanding the economic implications of sprawl is essential for effective land use planning and development policies (Zhang et al., 2022).

Quality of Life: Urban sprawl can negatively affect quality of life by exacerbating traffic congestion, extending commute times, increasing air pollution, and diminishing green spaces and community cohesion. Studying urban sprawl is necessary to grasp its multifaceted impacts on the environment, economy, society, and individual well-being, and to devise strategies for fostering more sustainable, equitable, and vibrant cities (Tsuyoshi et al., 2023).

Over the past four decades, Oman has experienced significant socio-economic changes, marked by a rapid shift from rural to urban lifestyles, which has intensified the consumption of natural resources, particularly land, water, and oil (Hamad, 2019). Each city has its own land use constraints, and not all available land is suitable

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for development or residential purposes. This has led to a preference for multi-level housing systems over single-family homes. Additionally, the number and height of buildings are often subject to restrictions due to economic or environmental considerations.

Population density can manifest in various forms, and the distribution of this density across a specific area is referred to as urban sprawl. As populations grow, cities tend to expand laterally beyond their official jurisdictional boundaries, a phenomenon commonly known as urban sprawl (Shaw, 2005). There are several types of sprawl, including continuous sprawl, which is concentric around the city; leapfrog sprawl, which spreads irregularly and discontinuously; and ribbon sprawl, which develops in a linear fashion along roads and pathways.

The study has examined the following research questions and objectives: What are the current land cover status of Minna metropolis? What is the future trend of land cover in the study area? The objectives include analyzing the urban land cover and existing land use changes in Minna metropolis for 2015 – 2024 and predicts its urban growth trend from 2024 to 2034**.**

Study Area

Minna, the capital of Niger State is located between Longitude 3^0 3' 0" E and 7^0 2' 0" N and Latitudes 8^0 2'0" N and $11^{\circ 0}$ 3' 0" N. Minna is about 135km away from the Federal Capital Territory and 300km away from Kaduna city. Within Niger State, it is about 90km away from Bida, 100km away from Suleja and about 130km from Kontagora. The town lies on a relatively high land with a site height of between 240m-270m above sea level. It is surrounded by a range of hills that stretch from north east westward towards Bosso and Tudun Fulani (Sanusi, 2006). The town is dissected at the lower part by River Suka and its tributaries. In the Southeast part of the town lays River Chanchaga which has been dammed to provide water for the greater part of the town.

Figure 1: Map of the Study Area

METHODOLOGY

This study employs a multi-faceted methodology to analyze land use and land cover (LULC) changes in Minna Metropolis, Niger State, Nigeria, from 2015 to 2024. The methodology consists of the following key components:

Data Acquisition and Processing

The data used for this research included Sentinel-2 images sourced from the Copernicus Open Access Hub (https://scihub.copernicus.eu) for the years 2015, 2018, 2021, and 2024. The data were collected in the dry season to ensure cloud-free photos and achieve a seasonal effect. Numerous factors, including sensor calibration, air absorption, scattering, and illumination geometry, frequently influence the spectral images acquired by satellite sensors. Radiometric and geometric corrections were applied to the images to adjust for the numerous surface reflectance fluctuations caused by the acquiring system.

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Land Use Classification: Utilizing supervised classification techniques, the study categorizes land use into distinct classes, including built-up areas, agricultural land, vegetation, bare ground, and water bodies. Training samples are selected based on ground truth data and expert knowledge to ensure accurate classification.

Geographic Information System (GIS) Analysis: GIS software is employed to analyze and visualize the classified land use data. The softwares used include QGIS version 3.34.0, ARCGIS 10.9, Microsoft version 2019. Spatial analysis techniques are used to assess the distribution and extent of each land cover type, allowing for a comprehensive understanding of land use dynamics.

Change Detection Analysis: Change detection techniques are applied to identify and quantify the changes in land use and land cover between the selected years (2015-2024). This analysis highlights trends in urbanization, agricultural land use, and vegetation cover.

Predictive Modeling: A predictive model is developed to forecast future land use changes for the year 2034. This model incorporates historical data trends and urban growth patterns to estimate potential changes in built-up areas, agricultural land, and vegetation cover.

Impact Assessment: The environmental impacts of urban growth are assessed by analyzing the implications of land use changes on local ecosystems, biodiversity, and agricultural productivity. This assessment provides insights into the sustainability of urban development in Minna Metropolis

RESULT AND DISCUSSION

The results obtained from the investigation and land use land cover analysis carried out in the study area based on the research-specific objectives are highlighted in this chapter. The results are obtained through careful analysis of the data obtained while carrying out the study; the outputs are presented through maps and tables.

Analysis of land use and land cover classification of 2015 satellite imagery For Minna

Figure 2 shows the study area's land use and land cover map for 2015. It reveals that farmland was the most dominant land cover feature, covering about 124.34 square kilometers (67.29%) of the area. This is followed by bare ground, which covers an area of 50.48 square kilometers (27.31%) of the total land mass of the area, primarily located in the southern and western parts of the study area.

In addition, built-up areas cover an area of 28.68 square kilometers (15.51%), mainly found in the northern part of the map and small patches throughout other sections of the area, indicating significant urban development. Vegetation covers an area of 12.86 square kilometers (6.96%), predominantly in the southern and eastern sections of the study area. Finally, water bodies cover a total land area of 0.61 square kilometers (0.33%), with rivers flowing from the northern to the western section of the study area. The total land area of the study area is 184.95 square kilometers.

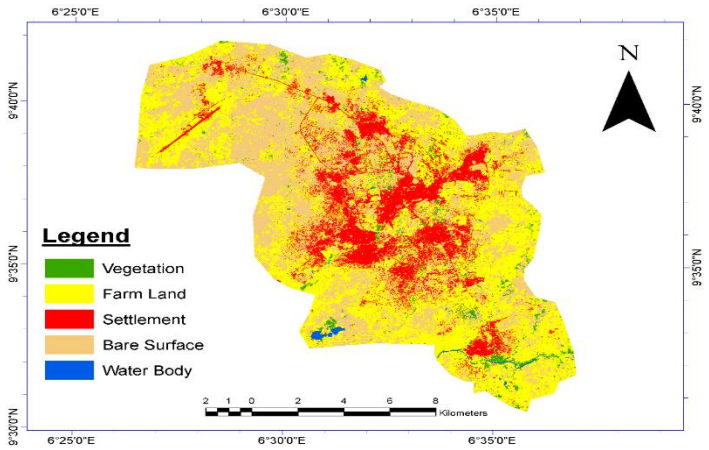

Figure 2: Minna 2015 Land use and Landcover distribution map generated from Sentinel

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Source: Author's Analysis, 2024.

2018 Satellite Imagery LULC Classification for Minna

The land use and land cover (LULC) map of Minna in 2018 (Figure 3) demonstrates that agricultural land remained the primary land cover, increasing from 124.34 square kilometers (67.29%) in 2015 to 140.20 square kilometers (75.81%) in 2018. These agricultural areas were widely distributed, with a higher concentration in the central region of the study area. The extensive cultivation suggests a significant agricultural engagement by the local population, likely due to fertile soil conditions. Vegetation cover declined from 12.86 square kilometers (6.96%) in 2015 to 8.49 square kilometers (4.59%) in 2018, primarily located in the southern and eastern parts of the study area. Conversely, built-up areas experienced substantial growth, expanding from 28.68 square kilometers (15.51%) in 2015 to 41.09 square kilometers (22.21%) in 2018, indicating significant urbanization and infrastructural development. Bare ground areas decreased from 50.48 square kilometers (27.31%) in 2015 to 26.49 square kilometers (14.33%) in 2018, likely due to increased anthropogenic activities and land development. Water bodies experienced a slight increase, covering 0.71 square kilometers (0.38%) in 2018, up from 0.61 square kilometers (0.33%) in 2015. The total land area of the study area remains 184.97 square kilometers.

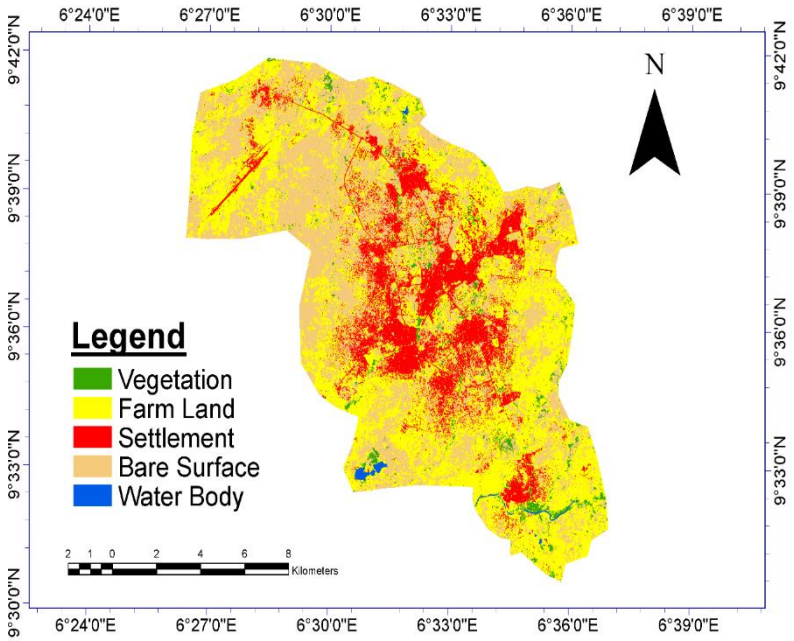

Figure 3: Minna 2018 Land use and Landcover distribution map generated from Sentinel

Source: Author's Analysis, 2024

Analysis of land use and land cover classification of 2021 satellite imagery for Minna

The land use and land cover (LULC) map of Minna in 2021 (Figure 4) shows that farmland remained the most prevalent land cover, although it slightly decreased from 140.20 square kilometers (75.81%) in 2018 to 130.28 square kilometers (70.45%) in 2021. These agricultural areas are widely dispersed, particularly in the central part of the study area, indicating that agriculture continues to be a significant land use activity. Vegetation cover increased from 8.49 square kilometers (4.59%) in 2018 to 15.39 square kilometers (8.32%) in 2021, found primarily in the southern and eastern sections. Built-up areas continued to expand, growing from 41.09 square kilometers (22.21%) in 2018 to 44.25 square kilometers (23.92%) in 2021, highlighting ongoing urbanization and development. Bare ground areas remained relatively stable, slightly increasing from 26.49 square kilometers (14.33%) in 2018 to 26.42 square kilometers (14.28%) in 2021, indicating minimal changes in areas without vegetation or significant human development. Water bodies saw a minor decrease, covering 0.64 square kilometers (0.34%) in 2021, down from 0.71 square kilometers (0.38%) in 2018. The total land area of the study area remains 184.97 square kilometers.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue VI June 2025

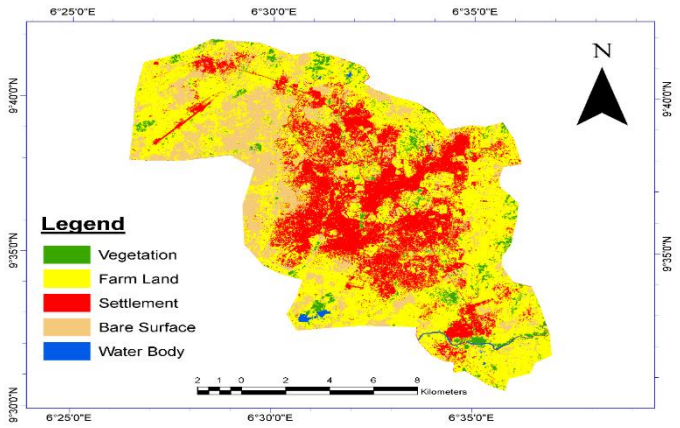

Figure 4: Minna 2021 Land use and Landcover distribution map generated from Sentinel

Source: Author's Analysis, 2024

Analysis of land use and land cover classification of 2024 satellite imagery for Minna

The land use and land cover (LULC) map of Minna in 2024 (Figure 5) indicates that farmland remains the most dominant land cover, though it has slightly decreased from 130.28 square kilometers (70.45%) in 2021 to 129.01 square kilometers (69.75%) in 2024. These agricultural areas are still widely distributed, especially in the central region, showing the persistence of agriculture as a major land use.

Vegetation cover has significantly decreased from 15.39 square kilometers (8.32%) in 2021 to 5.17 square kilometers (2.80%) in 2024, now found primarily in scattered patches. Built-up areas have continued to expand dramatically, increasing from 44.25 square kilometers (23.92%) in 2021 to 69.98 square kilometers (37.85%) in 2024, reflecting ongoing urbanization and infrastructural development.

The bare ground has reduced from 26.42 square kilometers (14.28%) in 2021 to 12.15 square kilometers (6.57%) in 2024, likely due to the conversion of these areas into built-up or agricultural land. Water bodies have seen a slight increase, covering 0.68 square kilometers (0.37%) in 2024, up from 0.64 square kilometers (0.34%) in 2021. The total land area of the study area remains 184.97 square kilometers.

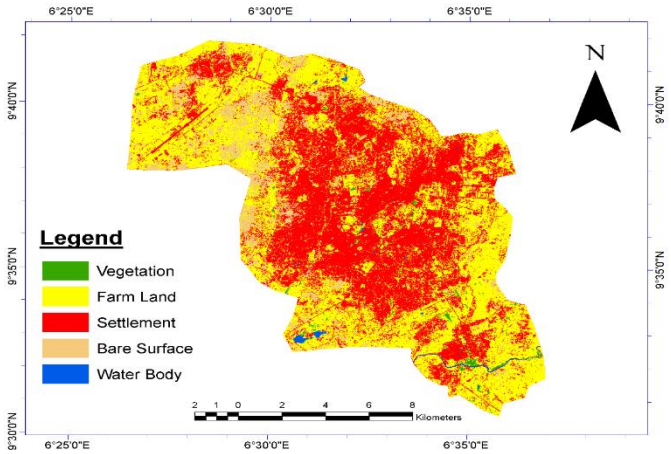

Figure 5: Minaa 2024 Land use and Landcover distribution map generated from Sentinel

Source: Author's Analysis, 2024

The data presented in the table 1 captures dynamic land use and land cover (LULC) transformations from 2015 to 2024, offering insights into how human activity and natural processes have reshaped the landscape. The classifications include Built-Up Area, Agricultural Land, Vegetation, Bare Ground, and Water Body. These

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue VI June 2025

transformations reveal significant urban expansion, marginal changes in agriculture, notable reductions in bare ground and vegetation, and relative stability in water bodies.

Urban Expansion

Built-up areas experienced the most significant growth over the period. From 28.68 km² (15.51%) in 2015, the urban footprint increased to 69.98 km² (37.85%) by 2024. This 144% increase in spatial extent reflects intense urbanization, possibly driven by population growth, infrastructure development, and expansion of residential and commercial areas. The increase was especially marked between 2021 and 2024, with a jump of over 25 km² in built-up land.

Agricultural Land Dynamics

Agricultural land showed a fluctuating but overall stable trend. It increased from 124.34 km² (67.29%) in 2015 to 140.20 km² (75.81%) in 2018, then slightly declined to 129.01 km² (69.75%) by 2024. The initial expansion may have been due to land conversion from bare ground and vegetation to croplands. However, the slight decline after 2018 suggests competition for land with expanding urban areas, or possibly changes in farming practices or land degradation.

Vegetation Decline

Vegetation cover declined substantially over the observed period, dropping from 12.86 km² (6.96%) in 2015 to just 5.17 km² (2.80%) in 2024. This decline may reflect deforestation, urban encroachment, or agricultural expansion. A brief resurgence occurred in 2021 (15.39 km², 8.32%), which could be attributed to afforestation efforts or seasonal variations in land classification, but this gain was quickly reversed by 2024.

Reduction in Bare Ground

Bare ground reduced significantly from 50.48 km² (27.31%) in 2015 to 12.15 km² (6.57%) in 2024. This consistent decline aligns with increases in built-up areas and, to a lesser extent, agricultural land, indicating that previously unused or undeveloped land has been increasingly put to use.

Stability of Water Bodies

The spatial extent of water bodies remained relatively constant over the period, fluctuating only slightly between 0.61 km² (0.33%) in 2015 and 0.68 km² (0.37%) in 2024. This stability suggests minimal hydrological changes or effective water resource management, although the values are very low and may reflect either small-scale water bodies or seasonal availability.

Overall Trends

The total land area remained constant at 184.97 km² across all years, ensuring that observed changes are due to land cover conversions rather than spatial redefinitions. The dominant trend is the rapid urban expansion at the expense of bare ground and vegetated areas, signaling increasing anthropogenic pressure on the landscape.

Table 1: Percentage of land Use and Land Cover in Minna (2015,2018,2021, and 2024)

Classification	**2015**		**2018**		**2021**		**2024**	
Category	**Rate (Km²)**	**Area (%)**	**Rate (Km²)**	**Area (%)**	**Rate (Km²)**	**Area (%)**	**Rate (Km²)**	**Area (%)**
Built-Up Area	28.68	15.51	41.09	22.21	44.25	23.92	69.98	37.85
Agricultural Land	124.34	67.29	140.2	75.81	130.28	70.45	129.01	69.75

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue VI June 2025

Vegetation	12.86	6.96	8.49	4.59	15.39	8.32	5.17	2.8
Bare Ground	50.48	27.31	26.49	14.33	26.42	14.28	12.15	6.57
Water Body	0.61	0.33	0.71	0.38	0.64	0.34	0.68	0.37
Total Area	**184.97**	**100**	**184.97**	**100**	**184.97**	**100**	**184.97**	**100**

Source: Author's analysis 2024

Simulation analysis of land use and land cover of Minna for 2034

Table 2. provides a forecast of the land use and land cover changes in Minna by the year 2034. The results suggest a marked increase in built-up areas from 69.98 km² (37.85%) in 2024 to 101.83 km² (55.08%). This substantial growth in urban areas highlights the ongoing trend of urbanization in the region.

Table 2: Predicted LULC for Minna in 2034

Category	Square Kilometers
Vegetation	2.89
Farm Land	105.74
Built-Up	101.83
Bare Ground	5.89
Water Body	0.65

Source: Author's analysis 2024

This forecast indicates a substantial increase in urban land cover over the next decade, primarily driven by accelerated population growth and the associated demand for housing, infrastructure, and services. As the urban population continues to rise, the need for expanded residential, commercial, and industrial spaces will intensify, leading to the rapid transformation of the landscape.

The expansion of urban areas is projected to occur in all cardinal directions—north, south, east, and west—throughout the study region. This widespread urban sprawl is expected to encroach significantly upon existing vegetation and agricultural lands, triggering a cascade of environmental consequences. One of the most immediate concerns is the reduction in arable farmland, which could lead to a decline in local food production capacity, increase reliance on imported food, and disrupt traditional livelihoods that depend on agriculture.

The shrinkage of agricultural land will also affect biodiversity and soil health, as monoculture practices and urban development replace diverse, ecologically functional landscapes. Additionally, vegetation cover is forecasted to decline markedly, mainly due to deforestation and the conversion of green spaces into built environments. This loss of natural vegetation may reduce carbon sequestration potential, worsen air quality, and elevate surface temperatures, exacerbating the urban heat island effect.

As urban construction accelerates, the amount of bare ground—areas cleared and exposed for development—is anticipated to rise. These exposed soils are more prone to erosion, dust generation, and water runoff, further stressing local ecosystems. Although water bodies are expected to remain relatively stable in terms of surface area, their ecological health could be indirectly affected by urban runoff, pollution, and altered hydrological patterns.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue VI June 2025

Overall, the projected urban expansion presents serious challenges to environmental sustainability and climate resilience. It underscores the urgent need for integrated urban planning strategies that balance development with ecological preservation, promote green infrastructure, and support sustainable land use practices.

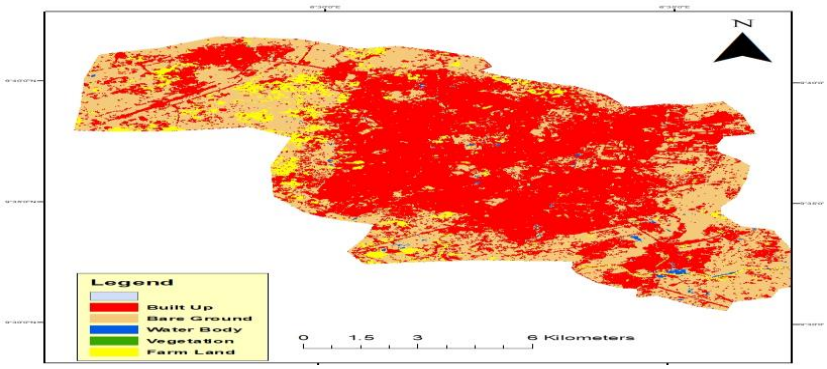

Figure 6: Simulated 2034 Land Use and Land Cover Map of Minna

Source: Author's analysis 2024

CONCLUSION

The findings of this study clearly demonstrate the profound impact of rapid urbanization on land use and land cover in Minna Metropolis between 2015 and 2024. The significant expansion of built-up areas, accompanied by the decline in agricultural and vegetative land, reflects a pattern of unplanned urban growth that poses serious environmental risks, including habitat loss and ecosystem degradation. The projected trend for 2034 suggests that, without strategic intervention, this trajectory will continue, potentially exacerbating environmental challenges. Therefore, this study emphasizes the critical importance of integrating remote sensing and GIS technologies into urban planning processes. Such integration will enable policymakers and stakeholders to make informed decisions, implement sustainable land management practices, and strike a necessary balance between urban development and environmental preservation in Minna and similar rapidly growing urban centers.

RECOMMENDATIONS

Based on the study's findings on land use and land cover (LULC) changes in Minna Metropolis from 2015 to 2024, the following are therefore recommended:

Implement Sustainable Urban Planning Policies

Authorities should prioritize the development of comprehensive urban master plans that guide expansion in a sustainable manner.

Zoning regulations should be updated to control the spread of built-up areas, especially in ecologically sensitive zones.

Establish Urban Green Belts and Buffer Zones

To counteract the 81.63% reduction in vegetation cover (from 15.39 km² in 2021 to 5.17 km² in 2024), designated green belts should be created to preserve biodiversity and maintain ecological balance.

Buffer zones between urban and agricultural land can reduce conflict and prevent encroachment.

Promote Smart Growth and Infill Development

Encourage high-density, mixed-use developments within existing urban areas to reduce pressure on undeveloped land.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue VI June 2025

Incentivize the redevelopment of underutilized spaces rather than expanding into agricultural zones, which have declined by 11.19 km² between 2018 and 2024.

Integrate Remote Sensing and GIS in Land Use Monitoring

Institutionalize the use of satellite imagery and GIS tools for real-time monitoring of land use changes.

These technologies can support early detection of illegal land conversion and guide policy enforcement.

Enhance Public Awareness and Community Engagement

Educate residents and stakeholders on the environmental impacts of unchecked urbanization.

Promote community-based initiatives for afforestation and land stewardship to restore lost vegetation.

Encourage Sustainable Agriculture and Land Management

Support agricultural practices that can coexist with urban expansion, such as vertical farming or agroforestry.

Protect existing farmlands through legislation and incentivize efficient land use practices to offset the 6.06% drop in agricultural land.

Develop and Enforce Environmental Regulations

Enforce environmental impact assessments (EIAs) for all major infrastructure projects.

Strengthen laws that regulate deforestation, land degradation, and urban sprawl.

Plan for Future Urban Growth

Given the forecasted rise in built-up area to 101.83 km² by 2034, proactive planning is needed now to mitigate future challenges.

Establish urban growth boundaries to manage sprawl and direct development toward sustainable zones.

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