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Spatio-Temporal Analysis of Urban Sprawl and Land Use/Land Cover Dynamics in Urban and Rural Settlements of Niger State, Nigeria

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ABSTRACT

Urban sprawl has become one of the most significant manifestations of land use and land cover (LULC) change in developing countries, with far-reaching implications for environmental sustainability, ecosystem services, and urban planning. This study examined the spatio-temporal dynamics of urban sprawl and LULC changes in selected urban (Mokwa, Minna, and Kontagora) and rural (Muwo, Garatu, and Rafin Gora) settlements of Niger State, Nigeria, between 1994 and 2024, and projected future urban sprawl up to 2054. Landsat satellite imagery for 1994, 2004, 2014, and 2024 was processed and classified into three major LULC classes: built-up, vegetation, and bare ground using supervised classification techniques within a Geographic Information System (GIS) software (ArcGIS 10.1). Change detection analysis was employed to quantify the extent and pattern of urban sprawl, while the Cellular Automata–Markov (CA–Markov) model was used to simulate future urban expansion scenarios for 2034, 2044, and 2054. The results revealed substantial expansion of built-up areas across all settlements. Among the urban centres, Kontagora recorded the highest increase in built-up area (219.2%), followed by Mokwa (205.3%) and Minna (136.7%). In the rural settlements, Muwo exhibited the highest proportional growth (333.2%), followed by Garatu (283.4%) and Rafin Gora (95.5%). Conversely, vegetation cover declined considerably across the study area, with Muwo experiencing the highest vegetation loss (90.8%). The CA–Markov projections indicate that urban expansion will continue through 2054, with Minna remaining the dominant urban growth centre (increased by 14,320.8 km² of built-up area) and rural settlements increasingly undergoing peri-urban transformation. Model validation produced high overall accuracies ranging from 93.16% to 96.23%, with Kappa coefficients between 0.87 and 0.94, confirming the robustness and reliability of the projection model. The study concludes that urban sprawl is a major driver of landscape transformation in Niger State and recommends sustainable land use planning, vegetation conservation, and effective urban sprawl management strategies to mitigate future environmental challenges.

Keywords: Urban-Sprawl; Land Use/Land Cover Change; CA–Markov; Remote Sensing; GIS; Urban Projection

INTRODUCTION

Urban expansion is now the main driver of land cover change across the world. United Nations estimates indicate that close to 68% of global population will live in cities by 2050, with developing regions recording the fastest growth rates (United Nations, 2019). While cities boost economic output and infrastructure, rapid and unplanned growth often produces urban sprawl. This occurs when settlements expand in low-density, scattered patterns beyond approved urban limits (Seto *et al.*, 2012).

The environmental cost of sprawl is significant. Natural vegetation and farmlands are converted into built-up areas, which changes surface properties, breaks ecological links, and degrades environmental quality (Haaland & van den Bosch, 2015). In sub-Saharan Africa, weak planning controls combined with fast population increase have worsened sprawl. The result is major shifts in land use and loss of ecosystems (Cobbinah & Aboagye, 2017).

Nigeria ranks among the fastest urbanizing countries in Africa. Its urban population has grown sharply in recent decades, causing cities to expand into adjoining rural areas (Adelekan *et al.,* 2020). In Niger State, population pressure, economic activities, and new infrastructure have accelerated growth in major towns such as Minna, Mokwa, and Kontagora. At the same time, smaller rural settlements like Muwo, Garatu, and Rafin Gora are experiencing peri-urban changes as development spreads outward.

Tracking sprawl requires tools that can detect land changes over time. Remote sensing and GIS now serve as core methods for mapping urban growth and environmental impacts because they provide detailed spatial data over large areas (Weng, 2018). For future projections, models like Cellular Automata–Markov [CA–Markov] simulate how land cover will change based on past transition patterns [Pontius & Malanson, 2005).

Although urbanization is increasing in Niger State, few studies have tracked sprawl in both urban and rural settlements together, and even fewer have projected future land use to 2054. This gap limits effective planning and sustainable land management. To address it, this study analyzed historical sprawl patterns and modelled future LULC changes in selected urban and rural settlements of Niger State from 1994 to 2054.

LITERATURE REVIEW

Urban Sprawl and Land Use/Land Cover Change

Urban sprawl describes the unplanned, low-density outward growth of cities into nearby rural or natural areas. It usually shows up as scattered “leapfrog” housing, spread-out settlements, and areas that depend heavily on cars (Seto *et al.*, 2021). Remote sensing studies covering 1970–2000 estimate that global urban land grew by about 58,000 km² (Seto *et al.*, 2012). That growth is expected to speed up, with projections of 430,000 to 1,527,000 km² of new urban land by 2030 (Seto *et al.*, 2012). Unlike planned, compact growth, sprawl often lacks coordinated land-use control. This leads to inefficient use of land, breaking up of farms and natural habitats, and higher costs for roads, water, and electricity [Ewing & Hamidi]. It occurs in both rich and poor countries, but the main drivers are population increase, housing demand, and preference for suburban living. As city centers become crowded and expensive, development shifts to peri-urban fringes (OECD, 2018; Kaur, 2024). In developing regions, migration for jobs and better living conditions speeds up the conversion of farmland and forests into residential and commercial use (Gao *et al.*, 2020; OECD, 2018).

In the U.S., sprawl became visible after World War II due to car ownership, highway expansion, and housing policies that favored suburbs (United States Environmental Protection Agency [US EPA], 2022). Data show that U.S. metro areas consume land faster than population grows, raising transport energy use, increasing paved surfaces, and changing local climate (Zhou *et al.*, 2021). Sprawling cities also record stronger heat island effects, more stormwater runoff, and less vegetation than compact cities (Weng *et al.,* 2019).

Land cover change is the clearest sign of sprawl. Across fast-growing regions, built-up areas expand while vegetation and farmland shrink (Lambin & Geist, 2006). These shifts reduce biodiversity, degrade the environment, and alter how ecosystems function.

Effects of Urban Sprawl

Sprawl damages the environment mainly by removing green cover and reducing ecosystem services like carbon storage and flood control. In rapidly growing Indian cities, natural land has been replaced by built surfaces, cutting carbon sequestration and other benefits (Singh et al., 2023). Sprawl also breaks habitats apart and weakens ecological links, leading to species loss and lower resilience (Haddad *et al.*, 2015). Studies in Africa and Asia link sprawl to soil degradation, higher surface runoff, and declining biodiversity (Lambin & Geist, 2006; Foley et al., 2005).

Transport and pollution problems follow are connected to the urban sprawl effects. Fringe areas usually have poor public transport, so people rely on private cars. This increases travel distance, greenhouse gas emissions, and air pollution (Ewing & Hamidi, 2015). Many expanding cities also face traffic congestion and limited access to parks or green spaces (OECD, 2018. These issues make it harder to meet sustainable development goals, since compact, transit-based growth is more efficient environmentally (Gao et al., 2020).

Remote Sensing and GIS Applications in Urban Sprawl Studies

Remote sensing and GIS are now core tools for mapping sprawl and land change. Satellite images track landscape changes over time, while GIS helps model and visualize expansion patterns. Landsat remains the most used dataset because it has long historical coverage and moderate resolution (Weng, 2018).

Recent work shows how effective these tools are. Gupta *et al.* used Sentinel-2 data to classify land cover in a tropical area with high accuracy in land cover classification types (Gupta *et al.*, 2022). Chen *et al.* applied machine learning to detect urban land-use changes, showing remote sensing can support planning and environmental management (Chen *et al.*, 2021).

CA–Markov Modelling of Urban Sprawl

CA–Markov combines two methods: Markov chains predict how much land will change between classes, while Cellular Automata decide where change happens based on neighboring cells (Eastman, 2016). Studies confirm CA–Markov works well for forecasting urban growth and land-use shifts (Arsanjani *et al.*, 2013).

Future sprawl depends on how population, economy, and infrastructure interact over time (United Nations Human Settlements Programme [UNHSP], 2022; United Nations Department of Economic and Social Affairs [UN DESA], 2019). Most recent researches uses remote sensing plus machine learning to forecast expansion (Li & Gong, 2016; Aburas *et al.*, 2019). Models like CA, ANN, and hybrid CA-Markov use multi-date Landsat images to capture past change and simulate future growth (Clarke *et al.*, 1997; Eastman, 2016).

In South America, Cellular Automated (CA) and Artificial Neural Networks (ANN) models applied to 30 years of Landsat data produced reliable forecasts of built-up sprawl, proving useful for planning (Araya & Cabral, 2010; Almeida *et al.*, 2018). GIS-based CA-Markov with multi-criteria evaluation is also common in fast-growing regions (Eastman, 2016; Aburas *et al.*, 2019). For example, Aburas *et al.* used CA-Markov in Saudi Arabia and projected 44% urban sprawl from 2017 to 2050, with Kappa >0.80 showing high accuracy (Aburas *et al.*, 2021).

In Nigeria, CA-Markov has been applied to Lagos and Abuja to simulate growth under different planning scenarios (Akinyemi *et al.*, 2017; Olokeogun *et al.*, 2014). Because CA-Markov has performed well in these studies, this research adopts it to project LULC changes for three urban towns (Mokwa, Minna, Kontagora) and three rural settlements (Muwo, Garatu, Rafin Gora) in Niger State.

Research Gap

Several studies have analysed sprawl in Nigerian cities, but few compare urban and rural settlements within one framework. Also, future sprawl projections for Niger State using advanced geospatial models are limited. This study fills that gap by combining historical land use land cover (LULC) analysis with CA–Markov projections across six settlements with different urbanization levels.

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MATERIALS AND METHODS

Study Area

Niger State is located in the central region of Nigeria and the largest state in the country by area, sharing borders with several states including Benin Republic in the West, Zamfara State (North), Kebbi (North West). Kwara (South West), Kaduna (North East) and the Federal Capital Territory (FCT) Abuja (South East). It is located between latitude $8^0 30$'N to $11^0 30$'N and between longitude $03^0 30$'E to $07^0 30$'E (National Bureau of Statistics, 2022). The study is carried out in three political zones (Niger South, Niger East and Niger West, that is, Zones A, B and C) of the state, which is specifically delimited within Niger State, encompassing six communities of urban and rural (Mokwa and Muwo in Zone A, Minna and Garatu in Zone B and Kontagora and Rafin Gora in Zone C). These locations were selected due to their varying levels of urbanization and spatial growth patterns, making them suitable for comparative analysis of urban sprawl.

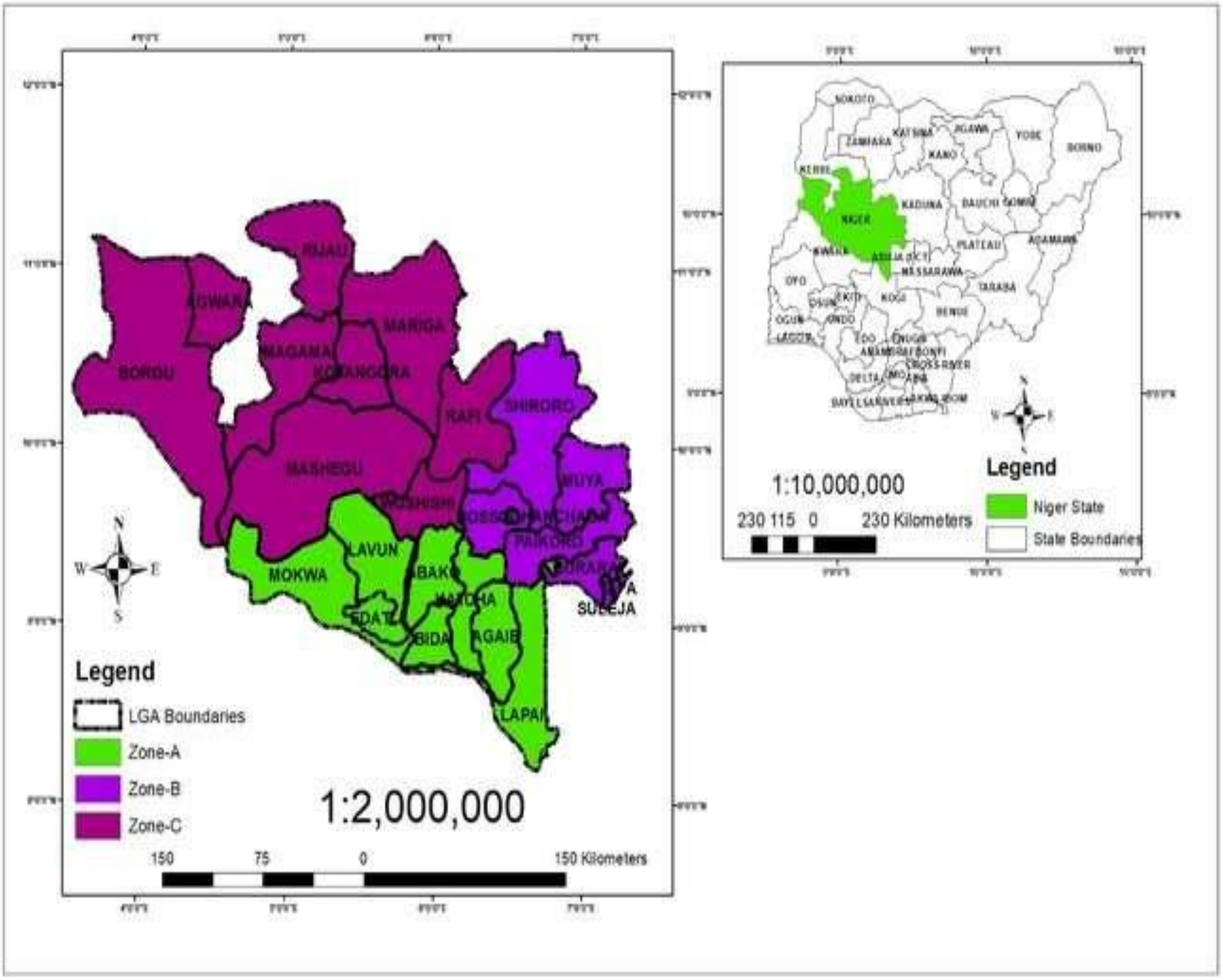

Figure 1: Map of Niger State showing Zones A, B and C

Data Sources

Landsat satellite images for 1994, 2004, 2014, and 2024 were sourced and downloaded from the United States Geological Survey (USGS) Earth Explorer archive. The images were pre-processed to correct geometry and radiometry so all years are comparable. This step ensured consistent pixel values and alignment across the four time periods.

Image Classification

A supervised classification method was used to group land cover into three classes: Built-up, Bare Ground, and Vegetation. Training samples were selected for each class based on field knowledge and high-resolution reference data. Classification accuracy was then tested using a confusion matrix. Overall accuracy, producer's accuracy, user's accuracy, and Kappa coefficient were calculated to confirm reliability of the results. The classified images were also compared with ground truthing data through field visitation and high-resolution satellite imagery (google earth data) of the study area.

Change Detection Analysis

Post-classification comparison was applied to measure land cover change between 1994–2004, 2004–2014, and 2014–2024. This approach compares classified maps year by year to identify areas that changed from vegetation or bare ground to built-up areas, and to calculate the rate of transition.

Urban Sprawl Projection

Future sprawl was modelled using the Cellular Automata–Markov (CA–Markov) method. Transition probability matrices and transition area matrices were generated from the 1994, 2004, 2014, and 2024 LULC maps. These matrices show the likelihood and amount of change between land cover classes. The model then used this information to simulate future land cover and urban expansion for 2034, 2044, and 2054.

RESULTS AND DISCUSSION

Historical Urban Sprawl Dynamics (1994–2024)

Figures 2 to 25 show land cover change for the six settlements from 1994 to 2024. In 1994, each settlement had a single compact core with built-up areas clustered at the centre. Vegetation covered most of the surrounding landscape, showing that urban pressure was still low during this period. By 2004, the compact pattern began to break. Built-up pixels became less continuous and appeared as scattered patches around the main core. This shows the start of peri-urban development in areas like Muwo, Garatu, and the fringes of Minna and Kontagora.

Between 2004 and 2014, growth shifted from single-core to multi-core. The main urban area expanded and new dense clusters formed away from the original centre. This polycentric pattern suggests the rise of secondary activity nodes, possibly along major roads. Scattered patches from 2004 merged into larger built-up zones, creating a more continuous urban footprint.

From 2014 to 2024, built-up land became the dominant class in urban settlements. Maps show extensive contiguity, with the original core merging with secondary and tertiary nodes. In Minna, Mokwa, and Kontagora, built-up area increased from 9692.4 ha, 631.5 ha, 2578.9 (105.9%, 112.07%, 49.2%) in 2014 to 11438.9 ha, 1127.6 ha, 3680.8 ha (136.7%, 205.33%, 219.2%) in 2024 respectively. The vegetal cover in Minna and Mokwa dropped from 1599.8 ha, 1538.0 ha, (-30.6%, -14.88%) to 413.3 ha, 723 ha (-110.3%, -71.54%) in 2024. While the vegetation of Kontagora increased from 292.8 ha to 342.8 ha (+17.08%) in 2024. The expansion followed directional trends, mainly along transport corridors such as Bida – Minna Road, Minna – Zungeru Road (Minna); Lagos – Mokwa Road (Mokwa); and Rafin Gora – Minna Road (Kontagora).

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

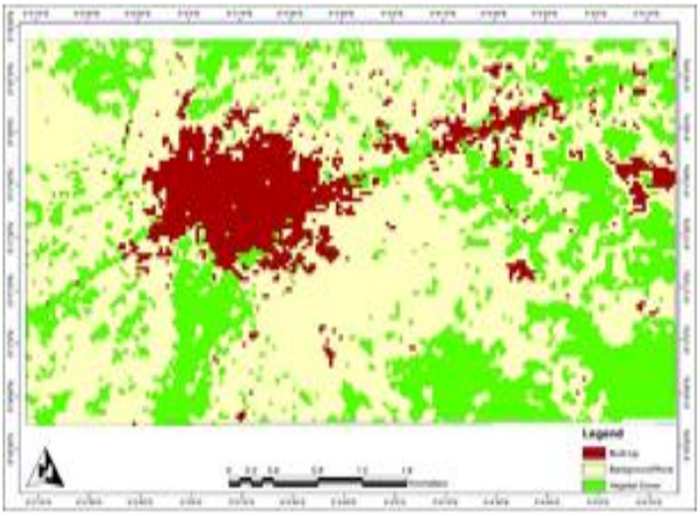

Figure 2: 1994 Mokwa LULC

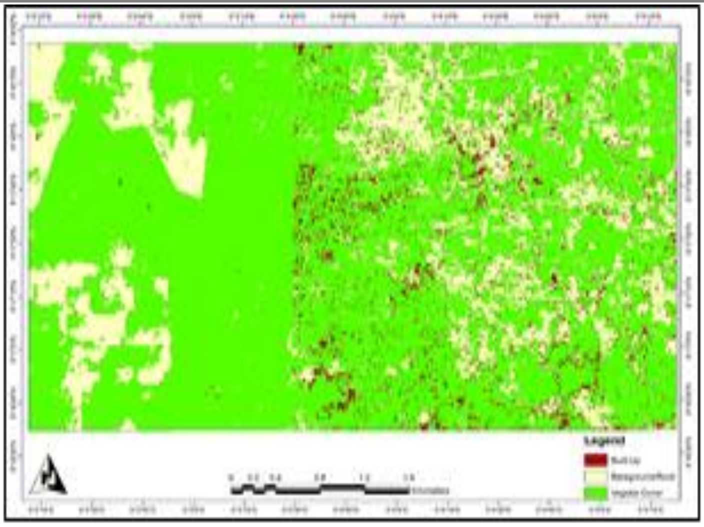

Figure 3: 2004 Mokwa LULC

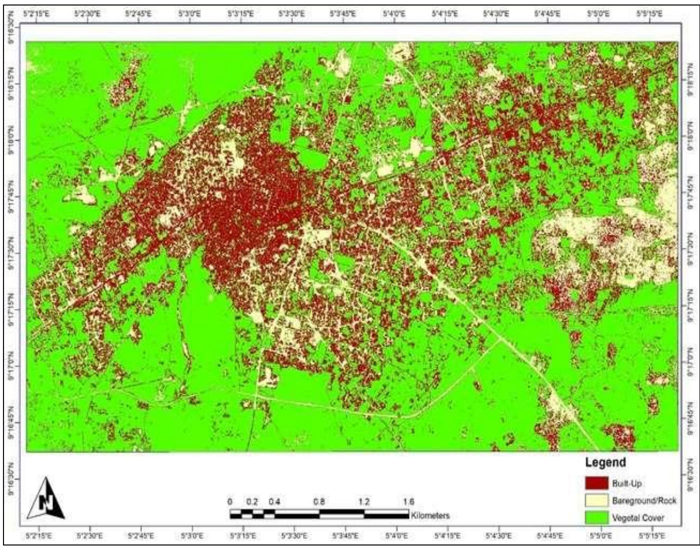

Figure 4: 2014 Mokwa LULC

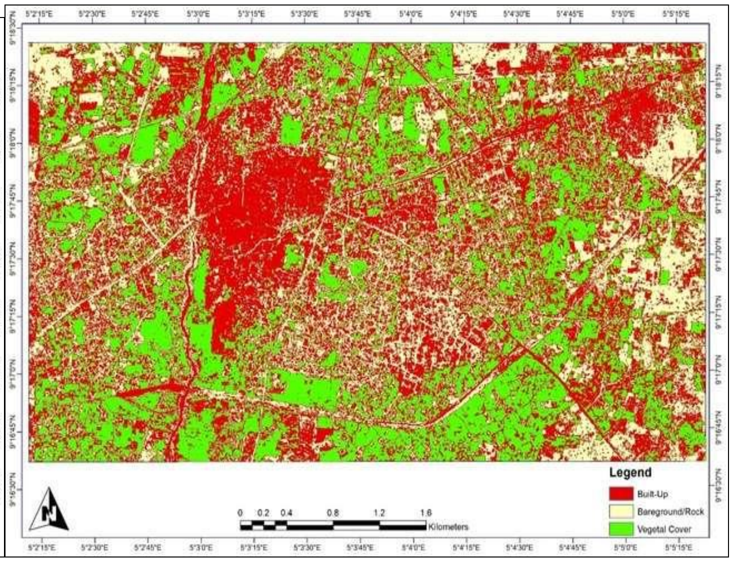

Figure 5: 2024 Mokwa LULC

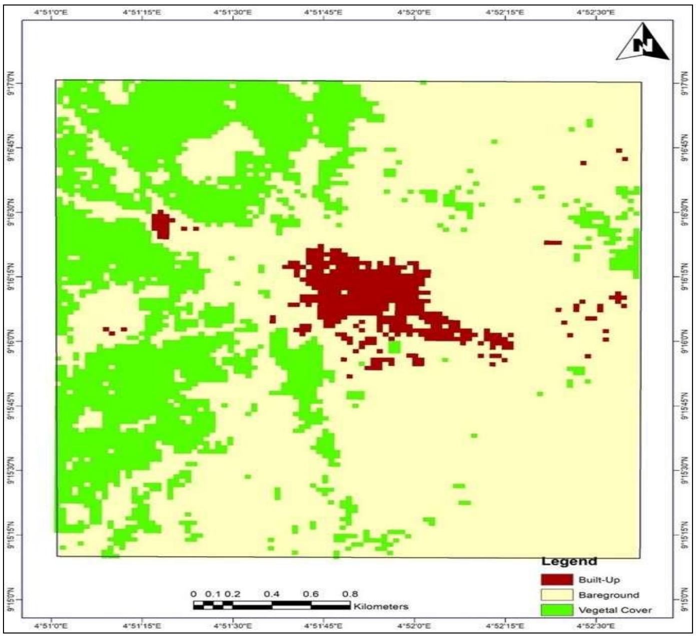

Figure 6:1994 Muwo LULC

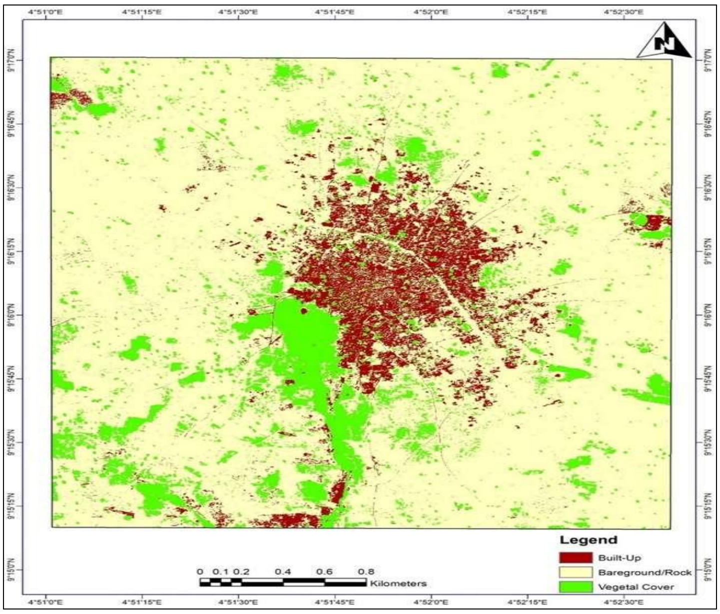

Figure 7: 2004 Muwo LULC

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

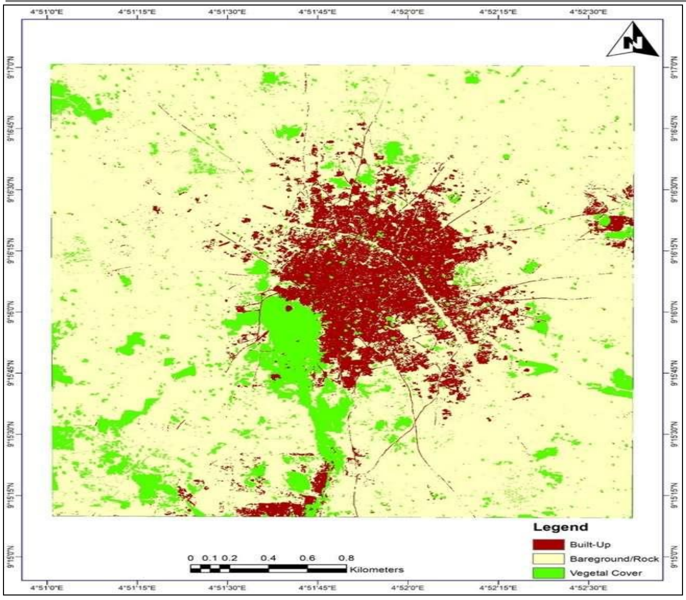

Figure 8: 2014 Muwo LULC

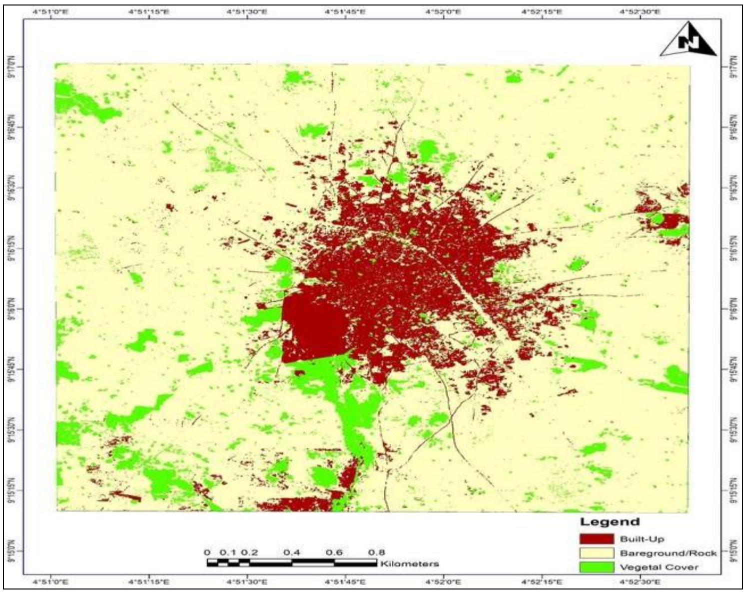

Figure 9: 2024 Muwo LULC

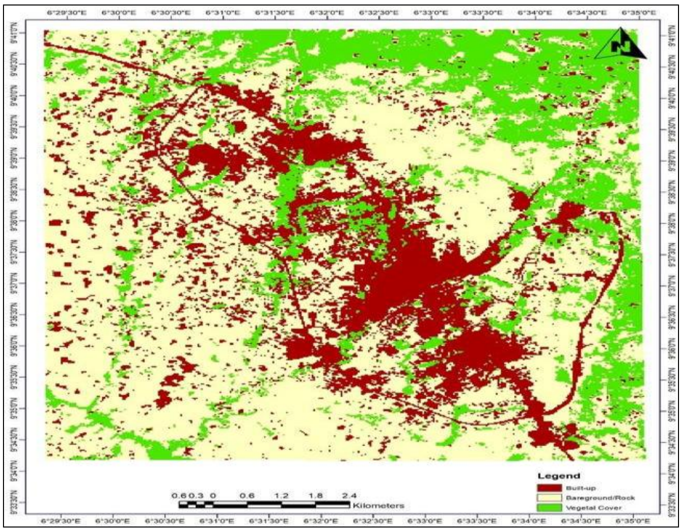

Figure 10: 1994 Minna LULC

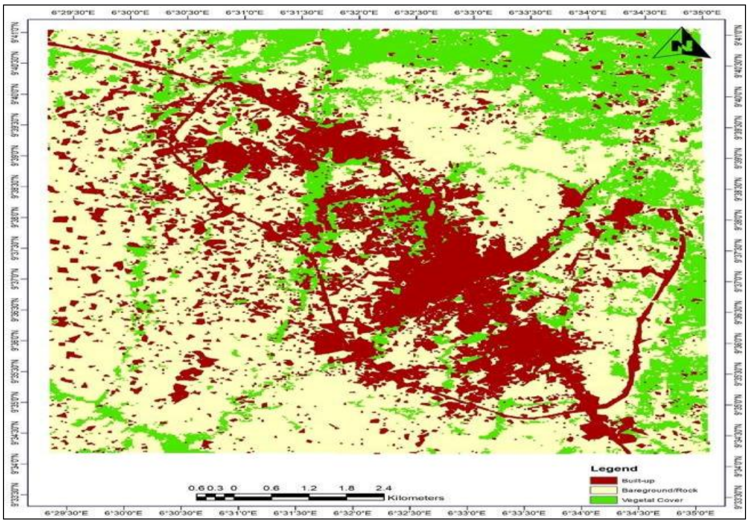

Figure 11: 2004 Minna LULC

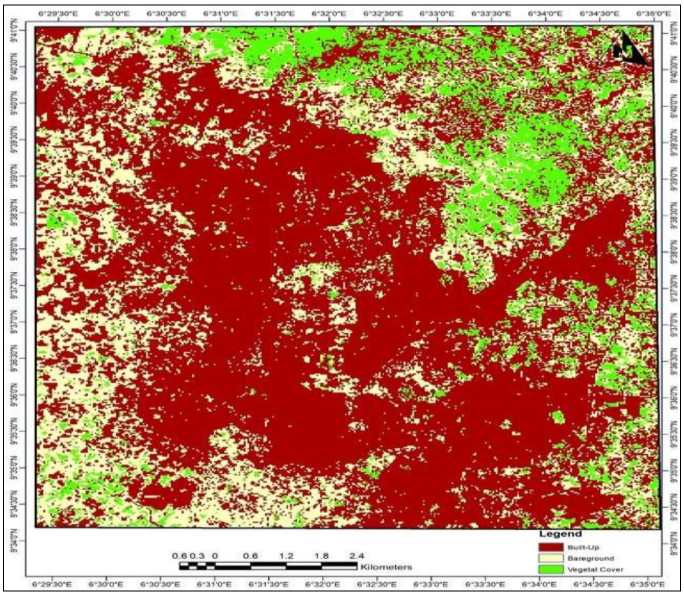

Figure 12: 2014 Minna LULC

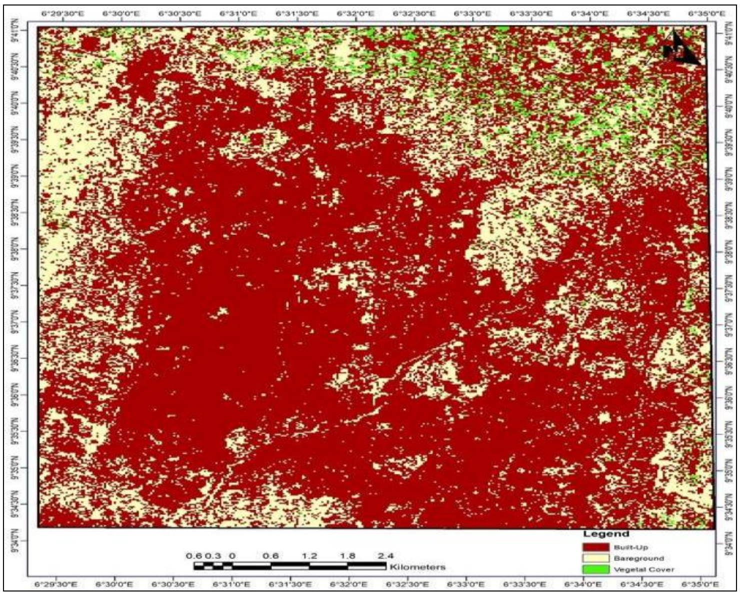

Figure 13: 2024 Minna LULC

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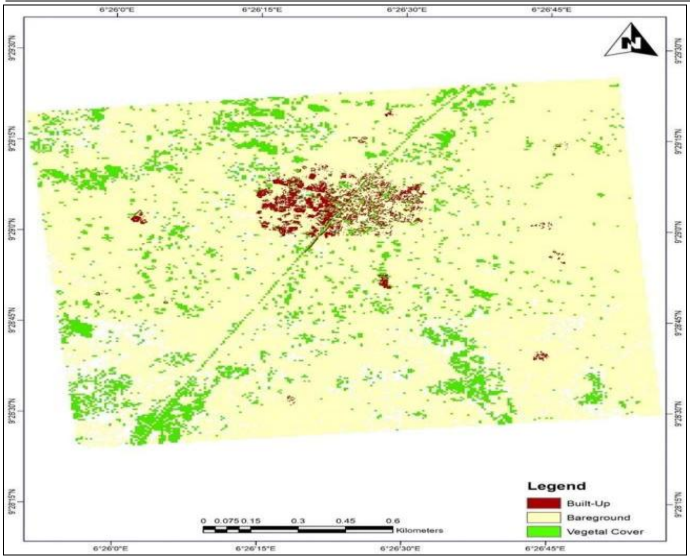


Figure 14: 1994 Garatu LULC

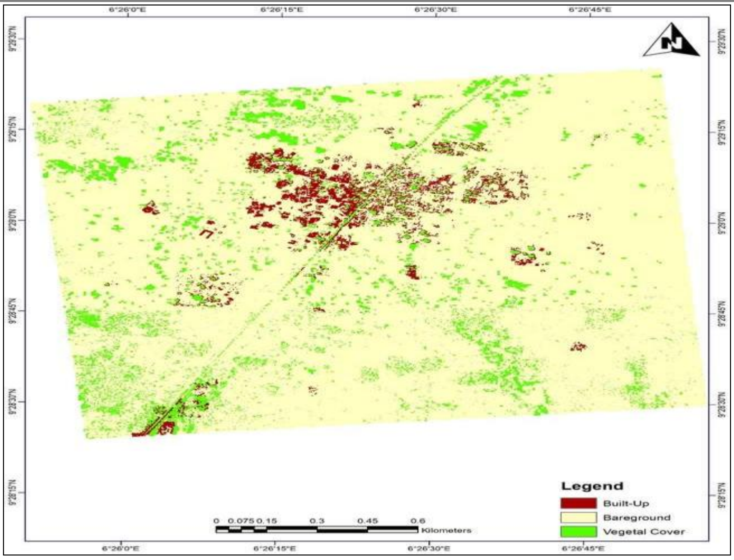


Figure 15: 2004 Garatu LULC

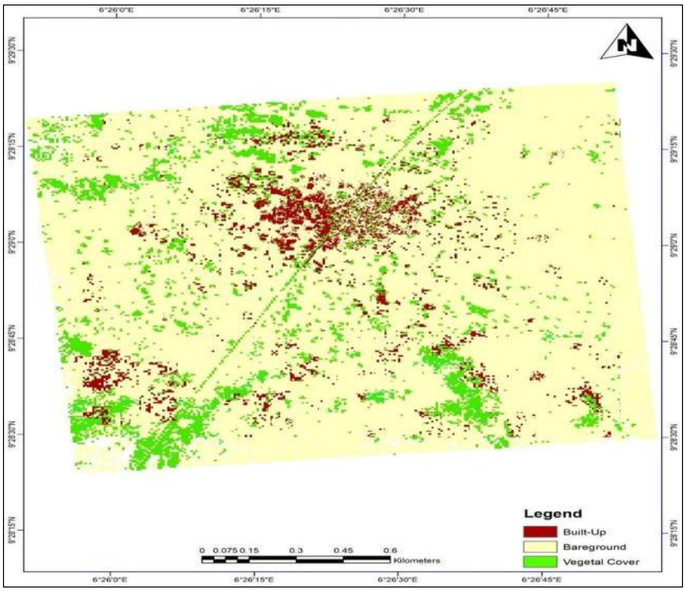


Figure 16: 2014 Garatu LULC

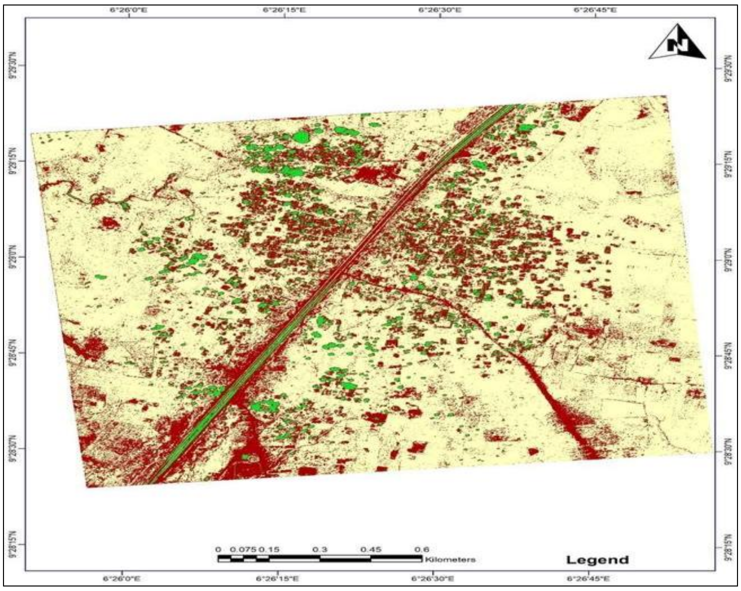


Figure 17: 2024 Garatu LULC

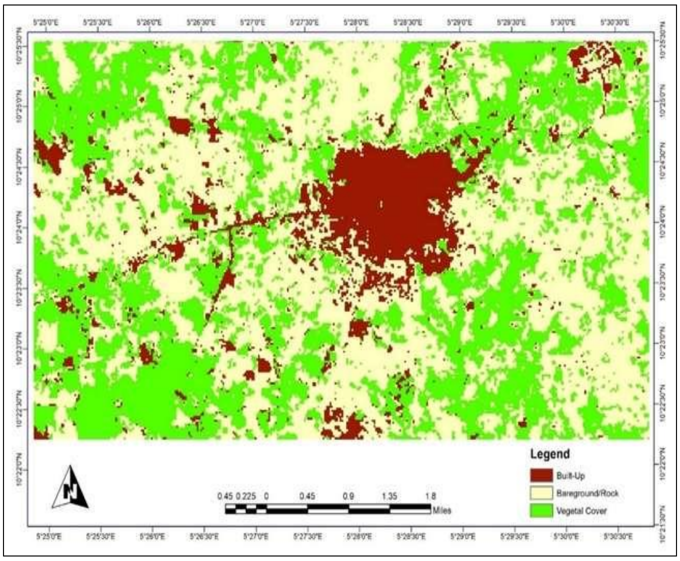


Figure 18: 1994 Kontagora LULC

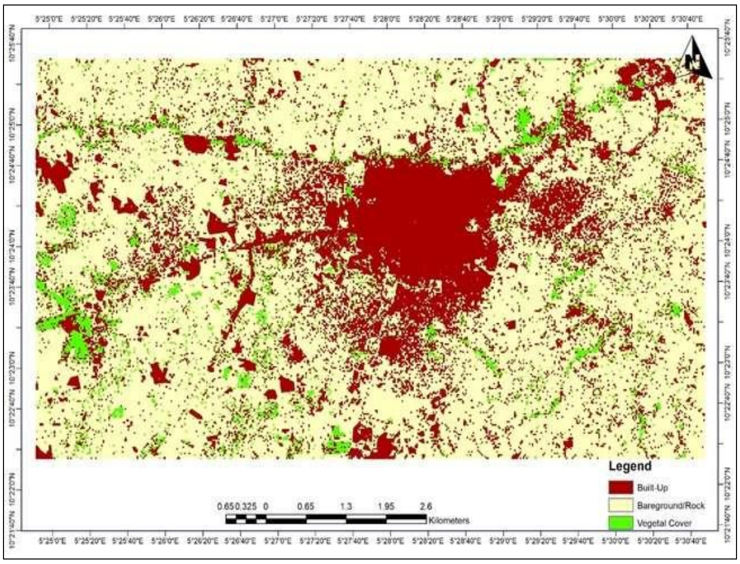
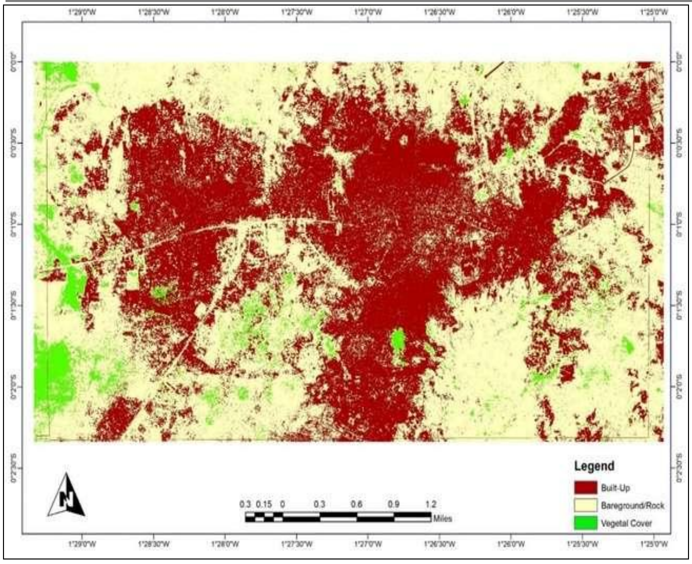


Figure 19: 2004 Kontagora LULC

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026



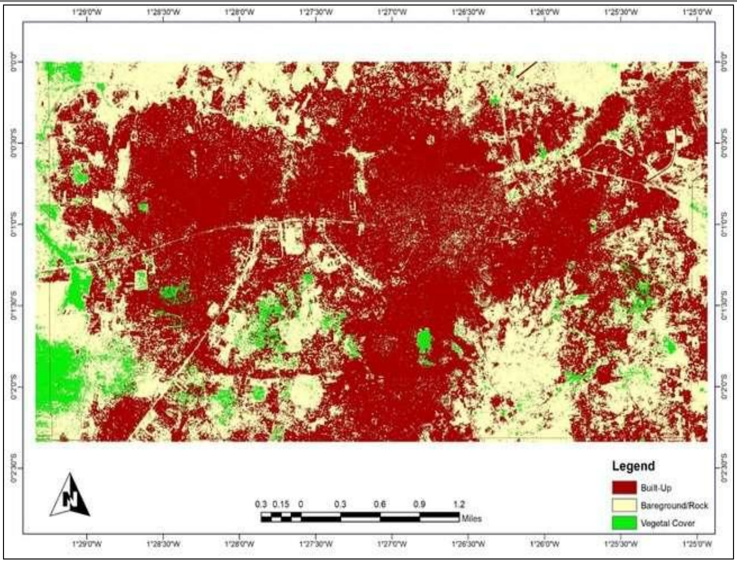
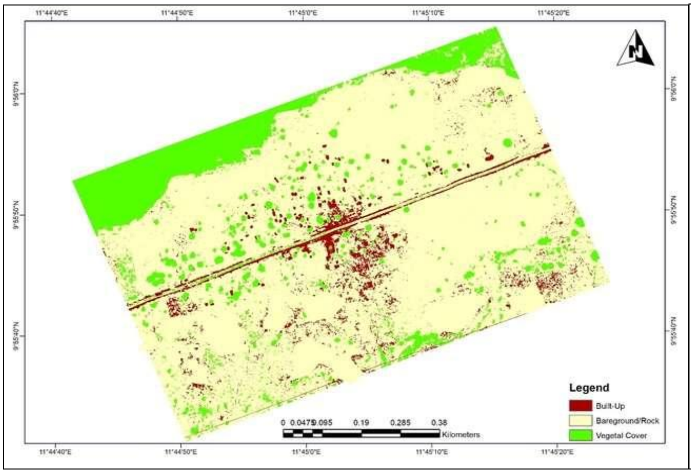


Figure 20: 2014 Kontagora LULC

Figure 21: 2024 Kontagora LULC



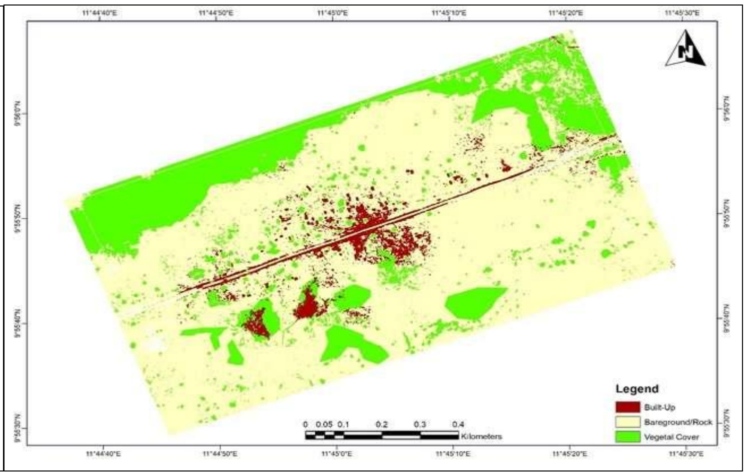
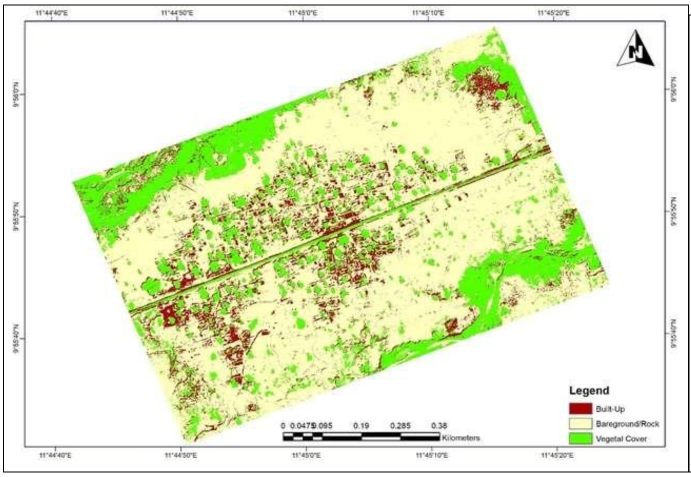


Figure 22: 1994 Rafin Gora LULC

Figure 23: 2004 Rafin Gora LULC



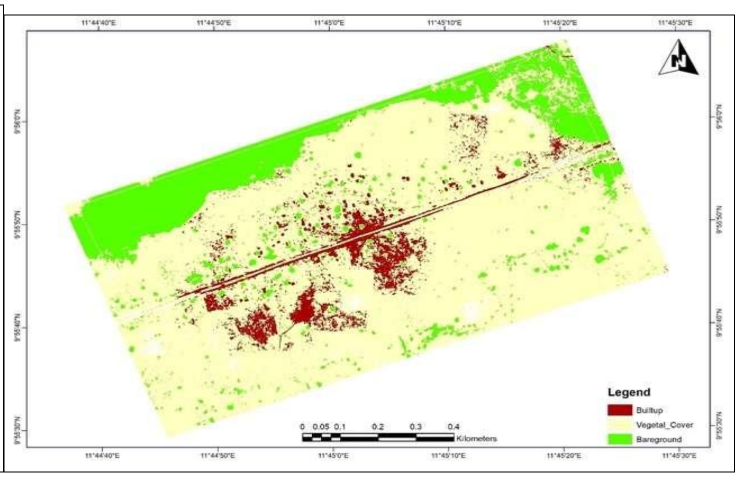


Figure 24: 2014 Rafin Gora LULC

Figure 25: 2024 Rafin Gora LULC

Analysis of Land Use Land Cover (LULC) and Sprawl (1994–2024)

Tables 1–12 show land cover changes for all six settlements from 1994 to 2024. Built-up area increased in every location, but the rate and pattern differed between urban and rural settlements. Mokwa exhibited a substantial increase in built-up area from 259.6 ha in 1994 to 1,127.6 ha in 2024, representing a 205.3%

increase. Similarly, Minna expanded from 4,172.9 ha to 11,438.9 ha, while Kontagora increased from 760.5 ha to 3,680.8 ha. Among the rural settlements, Muwo recorded the highest proportional sprawl, increasing from 41.5 ha in 1994 to 283.7 ha in 2024, representing a percentage increase of 333.19%. Garatu (from 16.6 ha to 100.2 ha) and Rafin Gora (from 15.5 ha to 35.4 ha) also experienced considerable increases in built-up land.

Urban settlements

Table 1 reveals the asymmetric transformation of Mokwa's land cover between 2004 and 2024. Built-up area increased by 278.7%, rising from 297.8 ha to 1,127.6 ha, nearly quadrupling in two decades with 78.6% growth occurring between 2014 and 2024, indicating intensifying urban consolidation. Bareground/rock expanded by 57.7%, contrary to typical urbanisation trends, suggesting that construction activities have outpaced vegetation replacement, leaving newly developed areas inadequately stabilised or landscaped. Most critically, vegetal cover collapsed by 60.0%, declining from 1,806.95 ha to just 723.0 ha, a loss of over half its original extent, with the steepest decline (–52.99%) recorded between 2014 and 2024. This pattern reflects not merely urban expansion, but ecological erosion: natural and agricultural land has been systematically replaced by impervious surfaces without adequate mitigation. The concurrent rise in bareground implies poor post-construction land management, exacerbating vulnerability to erosion and microclimate degradation. Collectively, these changes confirm Mokwa's transition into an urbanizing settlement where growth has occurred at the cost of environmental integrity, raising urgent concerns for sustainability, resilience, and long-term liveability in small-town contexts.

Table 1: Rate of Land Cover Change of Mokwa between 1994-2024

Year	Built-up Area	% Change	Bare Ground	% Change	Vegetal Cover	% Change
1994	259.6		409.7		1875.7	
2004	297.765	14.70	440.285	7.47	1806.95	-3.67
2014	631.5	112.07	375.5	-14.71	1538	-14.88
2024	1127.6	78.56	694.5	84.95	723	-52.99
Aggregate Change		**205.33**		**77.71**		**-71.54**

Table 2 show urban sprawl of Mokwa in Square Kilometres between 1994 and 2024. The built-up area expanded from 2.596 km² to 11.276 km², indicating an expansion of 8.68 km² or 868 ha (205.33%) over 30 years. This represents more than a three-fold increase in urban land cover, confirming strong horizontal urban sprawl. The rapid expansion after 2004 shows intensified urban growth, particularly between 2014 and 2024, when built-up land nearly doubled again. This pattern demonstrates continuous outward city expansion, typical of uncontrolled urban sprawl.

Table 2: Urban Sprawl of Mokwa in Square Kilometres between 1994–2024

Year	Built-Up Area (ha)	Built-Up Area (km²)
1994	259.6	2.596
2004	297.765	2.978
2014	631.5	6.315
2024	1127.6	11.276

Table 3 presents the final transformation in Minna's land cover by 2024, confirming the culmination of a three-decade process of rapid, unregulated urban expansion. Built-up areas have expanded to 11,438.9 hectares (85.8%), constituting the overwhelming majority of the landscape and representing a near threefold increase since 1994 and an 18% rise since 2014 alone. This is spatially corroborated by Figure 4.12, which depicts a near-continuous urban fabric with minimal fragmentation, indicating consolidation of settlements into a single, densely developed urban zone. Bareground/rock has declined to 1,479.9 hectares (11.1%), a reduction of over 80% since 2004, reflecting near-total conversion of previously exposed surfaces into infrastructure.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

Vegetal cover has collapsed to a mere 413.3 hectares (3.1%), down from 18.3% in 1994 and 12.0% in 2014, now confined to negligible, isolated patches likely restricted to riparian buffers, cemeteries, or institutional compounds. The near erasure of natural and agricultural land underscores a trajectory of urbanisation driven by population pressure and economic expansion, with minimal regard for ecological retention or planning. The data confirm that Minna has transitioned from a moderately urbanised town in 1994 to a highly consolidated, ecologically degraded urban centre by 2024.

Table 3: Rate of Land Cover Change of Minna between 2014-2024

Year	Built-up Area	% Change	Bare.G	% Change	Vegetal Cover	% Change
1994	4172.9		6719.3		2439.8	
2004	4706.2	12.8	6319.4	-6.0	2306.4	-5.5
2014	9692.4	105.9	2039.8	-67.7	1599.8	-30.6
2024	11438.9	18.0	1479.9	-27.4	413.3	-74.2
Aggregate Change		**136.7**		**-101.1**		**-110.3**

Table 4 shows urban sprawl of Minna in Square Kilometres between 1994 and 2024, Minna's built-up area expanded from 41.729 km² to 114.389 km², representing an increase of 72.66 km² or 7266.0 ha (136.7%) over 30 years. This substantial growth confirms strong and continuous urban expansion. The most significant expansion occurred between 2004 and 2014, when built-up land nearly doubled, indicating an accelerated phase of urban development. The continued increase up to 2024 demonstrates sustained outward growth, a clear indicator of urban sprawl. In contrast, vegetation cover declined sharply, reinforcing evidence of land conversion from natural surfaces to built environments.

Table 4: Urban Sprawl of Minna in Square Kilometres between 1994–2024

Year	Built-Up Area (ha)	Built-Up Area (km²)
1994	4172.9	41.729 km²
2004	4706.2	47.062 km²
2014	9692.4	96.924 km²
2024	11438.9	114.389 km²

Table 5 reveals the transformation of Kontagora's landscape between 2004 and 2024. The built-up area surged by 101.8%, increasing from 1,017.9 ha to 2,054.3 ha, nearly doubling since 2014 alone, demonstrating rapid, unmanaged urban expansion driven by population growth and infrastructure development. Bareground/rock declined by 14.9%, not through ecological recovery, but due to its conversion into built environments, confirming urban sprawl is consuming previously open land. Most critically, vegetal cover collapsed by 54.0%, falling from 685.1 ha to just 314.9 ha, a loss of more than half its 2004 extent, with a steep acceleration between 2014 and 2024 (–37.78% over ten years). This indicates that green space is being rapidly erased to accommodate construction, leaving only fragmented patches along waterways or farmland. The contrast between urbanization and vanishing vegetation highlights a landscape under intense pressure, where development priorities have overridden environmental sustainability. Kontagora's transformation from a town with modest built-up presence to one increasingly dominated by impervious surfaces signals the need for land-use regulation and ecological restoration to prevent irreversible degradation.

Table 5: Rate of Land Cover Change of Kontagora between 1994-2024

Year	Built-up Area	% Change	Bare.G	% Change	Vegetal Cover	% Change
1994	760.5		3315.7		2502.5	
2004	1728.7	127.3	3673.1	10.8	1176.9	-52.97
2014	2578.9	49.2	3707.1	0.9	292.8	-75.12
2024	3680.8	42.7	2555.2	-31.1	342.8	17.08
Aggregate Change		**219.2**		**-19.4**		**-111.0**

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Table 6 shows urban sprawl of Kontagora between 1994 and 2024, Kontagora's built-up area expanded from 7.605 km² to 36.808 km², representing an increase of 29.203 km² or 2920.3 ha (219.2%) over 30 years. This substantial growth indicates strong and continuous urban expansion. The most rapid expansion occurred between 1994 and 2004, followed by sustained growth in subsequent decades. This pattern reflects progressive outward spatial development, a core indicator of urban sprawl. Vegetation cover experienced significant decline over the study period, confirming land conversion from natural surfaces to built-up areas. Although bare ground fluctuated, the dominant trend is increasing urban land, demonstrating structural urban growth.

Table 6: Urban Sprawl of Kontagora in Square Kilometres between 1994–2024

Year	**Built-Up Area (ha)**	**Built-Up Area (km²)**
1994	760.5	7.605
2004	1728.7	17.287
2014	2578.9	25.789
2024	3680.8	36.808

Rural Settlements

Table 7 shows the rate of land cover change in Muwo from 1994 to 2024, revealing a dynamic and accelerating transformation of its landscape. Built-up area increased by 333.19% overall, rising from 41.5 ha to 283.7 ha, with the most dramatic growth occurring between 1994 and 2004 (+255.18%), followed by continued but decelerating expansion in subsequent decades. This indicates that initial urbanisation was rapid and driven by foundational settlement growth, while later phases reflect consolidation rather than explosive sprawl. Bareground/rock showed a non-linear trend: it increased by 12.3% from 1994 to 2004, then declined steadily until 2014, before declining drastically by 4.68% between 2014 and 2024, a counterintuitive rise suggesting that recent development may be occurring on previously vegetated or marginal land without adequate stabilisation, leaving newly cleared areas exposed.

Vegetal cover declined by 90.82% over the period, falling from 344.9 ha to just 106.3 ha, with the most severe losses occurring between 1994 and 2004 (–52.62%) and 2014 and 2024 (–25.35%), indicating two distinct phases of ecological erosion. The near-total loss of vegetation in the final decade, coinciding with a rebound in bareground, suggests that urban expansion has outpaced any potential for green space retention or regeneration. This pattern reveals a settlement transitioning from a predominantly vegetated rural enclave to a fragmented urbanising zone, where land use change is not merely directional but ecologically destabilising. The data confirm that Muwo's transformation is characterised not by steady growth, but by episodic, high-impact shifts in land cover, with vegetation loss and bareground resurgence signalling a landscape under sustained anthropogenic pressure.

Table 7: Rate of Land Cover Change of Muwo between 1994-2024

Year	**Built-up Area**	**% Change**	**Bare Ground**	**% Change**	**Vegetal Cover**	**% Change**
1994	41.5		615.9		344.9	
2004	147.4	255.18	691.8	12.32	163.4	-52.62
2014	217.6	47.63	642.7	-7.10	142.4	-12.85
2024	283.7	30.38	612.6	-4.68	106.3	-25.35
Aggregate Change		**333.19**		**0.54**		**-90.82**

Table 8 shows urban sprawl of Muwo between 1994 and 2024. Muwo expanded from 0.415 km² to 2.837 km² or 242.2 ha (333.19%) in built-up area. This represents an expansion of 2.422 km² over 30 years, indicating rapid horizontal urban growth.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

The most significant expansion occurred between 1994 and 2004, reflecting an early phase of intense urban development. Continued growth in subsequent decades confirms sustained urban sprawl, characterized by outward expansion of settlements and conversion of vegetated land into built environments.

Table 8: Urban Sprawl of Muwo in Square Kilometres between 1994–2024

Year	**Built-Up Area (ha)**	**Built-Up Area (km²)**
1994	41.5	0.415
2004	147.4	1.474
2014	217.6	2.176
2024	283.7	2.837

Table 9 presents the rate of land cover change in Garatu from 1994 to 2024, revealing a pattern of gradual but accelerating urbanization against a backdrop of persistent rural land use dynamics. Built-up area increased by 283.4% over the 30-year period, with the most dramatic growth occurring between 2014 and 2024 (+183.9%), indicating a sharp intensification of settlement expansion in the most recent decade. This follows a prior surge of 83.9% between 2004 and 2014, confirming a non-linear, accelerating trend rather than steady growth. Bareground/rock declined by 30.2% overall since 1994, with the steepest reduction occurring between 2004 and 2014 (–20.2%), suggesting that early urban expansion consumed the most accessible exposed land, while later growth occurred through densification and infill. Vegetal cover showed an initial slight increase between 1994 and 2004 (+1.4%), followed by a dramatic increase (34.26%) between 2004 and 2014, and then a sharp 45.4% loss between 2014 and 2024, indicating that vegetation loss has become a dominant feature of recent development.

The aggregate decline of 9.7% in vegetal cover since 1994, though less severe than in urban centres, signals a measurable erosion of natural and agricultural land. These trends reflect a rural settlement undergoing incremental but increasingly consequential transformation, where urban pressure is no longer negligible but is beginning to reshape ecological and land use patterns. Unlike rapid urbanisation in Minna, Garatu's change is characterised by slower, piecemeal expansion, yet its trajectory aligns with broader regional patterns of rural-to-peri-urban transition.

Table 9: Rate of Land Cover Change of Garatu between 2014-2024

Year	**Built-up Area**	**% Change**	**Bare.G**	**% Change**	**Vegetal Cover**	**% Change**
1994	16.6		223.2		81.2	
2004	19.2	15.7	219.5	-1.7	82.3	1.4
2014	35.3	83.9	175.2	-20.2	110.5	34.3
2024	100.2	183.9	160.5	-8.4	60.3	-45.4
Aggregate Change		**283.4**		**-30.2**		**-9.7**

Table 10 shows urban sprawl of Garatu between 1994 and 2024. Garatu's built-up area expanded from 0.166 km² to 1.002 km², representing an increase of 0.836 km² or 83.6 ha (283.4%) over 30 years. This reflects substantial relative growth, indicating strong urban expansion dynamics despite the small absolute size of the settlement. The most rapid expansion occurred between 2014 and 2024, where built-up land increased sharply, confirming an accelerated phase of urban development. This pattern demonstrates outward spatial growth and land conversion, which are key characteristics of urban sprawl.

Vegetation cover declined during the period, further supporting evidence of land transformation from natural surfaces to built environments.

Table 10: Urban Sprawl of Garatu in Square Kilometers between 1994–2024

Year	Built-Up Area (ha)	Built-Up Area (km²)
1994	16.6	0.166
2004	19.2	0.192
2014	35.3	0.353
2024	100.2	1.002

Table 11 presents the rate of land cover change in Rafin Gora from 1994 to 2024, illustrating a pattern of gradual, cumulative urbanisation against a backdrop of persistent rural land use. Built-up area increased by 95.5% over the 30 years, rising from 15.5 ha to 35.4 ha, with the most substantial growth occurring between 1994 and 2004 (+35.6%), followed by steady, incremental increases of approximately 37% per decade until 2014. The rate of growth slowed slightly between 2014 and 2024 (+23.3%), suggesting a possible stabilisation or constraint in expansion. Bareground/rock declined by 23.7% overall, with consistent annual reductions of 7–9%, indicating gradual but continuous conversion of exposed surfaces into settlement infrastructure. Vegetal cover decreased by 24.21% over the period, from 25.8 ha to 20.0 ha, with a steady decline of approximately 10–11% per decade since 2004, reflecting the slow but persistent encroachment of development into vegetated areas. These trends indicate that Rafin Gora is undergoing a low-intensity, linear form of urbanisation—characterised by incremental settlement expansion along transport corridors rather than rapid, high-density consolidation. Unlike larger urban centres, where land cover change is abrupt and ecologically disruptive, Rafin Gora's transformation is marked by gradualism, preserving much of its rural character while experiencing measurable shifts in land use. The data confirm that even small rural settlements are not immune to the pressures of urbanisation, albeit at a slower pace, with land cover change driven more by localised demographic and infrastructural growth than by large-scale economic or policy forces.

Table 11: Rate of Land Cover Change of Rafin Gora between 1994-2024

Year	Built-up Area	% Change	Bare.G	% Change	Vegetal Cover	% Change
1994	15.5		64.8		25.8	
2004	21.0	35.5	60.0	-7.4	25.0	-3.10
2014	28.7	36.7	54.8	-8.7	22.5	-10.00
2024	35.4	23.3	50.6	-7.7	20.0	-11.11
Aggregate Change		**95.5**		**-23.7**		**-24.21**

Table 12 shows the extent of urban sprawl of Rafin Gora between 1994 and 2024. Rafin Gora expanded from 0.155 km² to 0.354 km², representing an increase of 0.199 km² or 19.9 ha (95.5%) over 30 years. Although the absolute growth is relatively small compared to larger settlements, the percentage increase (95.5%) indicates substantial relative urban expansion. The growth trend shows steady increases across the study period, confirming continuous outward development. Vegetation cover declined gradually, indicating progressive land conversion from natural surfaces to built-up areas, a key characteristic of urban sprawl. Bare ground also decreased overall, suggesting stabilization and consolidation of developed land over time.

Table 12: Urban Sprawl of Rafin Gora in Square Kilometres between 1994–2024

Year	Built-Up Area (ha)	Built-Up Area (km²)
1994	15.5	0.155
2004	21.0	0.210
2014	28.7	0.287
2024	35.4	0.354

Continued Vegetation Loss

Vegetation cover declined in all six settlements between 1994 and 2024. Muwo recorded the highest loss at 90.8%, followed by Minna at 83.1% and Mokwa at 71.5%. This means farmland and natural vegetation were

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converted mainly into built-up and bare ground. The rate of loss was faster after 2014 in urban settlements, matching the period of rapid construction and population increase. For rural settlements like Muwo, the high percentage loss reflects change from a very small base area, so even small conversion creates a large percentage (%) drop.

Urban Sprawl Projection (2024–2054)

CA–Markov simulations show that urban expansion will continue across all settlements to 2054. Minna is projected to remain the main growth center, with built-up area increasing from 11,438.9 ha in 2024 to 14,320.8 ha in 2054. Mokwa and Kontagora also show intensifying sprawl, though at lower total area than Minna.

In rural settlements, Muwo and Garatu are expected to experience the fastest peri-urban change. The model predicts scattered built-up patches around 2024 will merge into more continuous development by 2054. This reflects increasing urban influence spreading beyond Minna, Mokwa, and Kontagora into nearby villages.

Transition Probability Matrix

The transition matrices tables 13 to 18 show how land cover changes from one class to another. Built-up land has high persistence in all settlements, meaning areas already built in 2024 are likely to remain built in 2034, 2044, and 2054. Vegetation and bare ground show increasing probability of changing to built-up. The transition rate is highest in Minna and Kontagora, confirming advanced urban expansion. For example, vegetation in Minna has a 74.17% probability of converting to built-up by 2034 using the 2014 - 2024 transition probability matrix.

Muwo, Garatu, and Rafin Gora show lower transition probabilities, indicating slower rural-to-peri-urban change. However, the trend is upward, showing that rural settlements are gradually being pulled into the urban growth process.

Table 13: Mokwa Transition Probability Matrix, 1994–2024

Period	From / To	Built-up	Bare Ground	Vegetation
1994–2004	Built-up	**1.0000**	0.0000	0.0000
	Bare Ground	0.0000	**1.0000**	0.0000
	Vegetation	0.0203	0.0163	**0.9633**
2004–2014	Built-up	**1.0000**	0.0000	0.0000
	Bare Ground	0.1471	**0.8529**	0.0000
	Vegetation	0.1488	0.0000	**0.8512**
2014–2024	Built-up	**1.0000**	0.0000	0.0000
	Bare Ground	0.0000	**1.0000**	0.0000
	Vegetation	0.3225	0.2074	**0.4701**

Table 14: Muwo Transition Probability Matrix, 1994–2024

Period	From / To	Built-up	Bare Ground	Vegetation
1994–2004	Built-up	**1.0000**	0.0000	0.0000
	Bare Ground	0.0000	**1.0000**	0.0000
	Vegetation	0.3065	0.2197	**0.4738**
2004–2014	Built-up	**1.0000**	0.0000	0.0000
	Bare Ground	0.0710	**0.9290**	0.0000
	Vegetation	0.1285	0.0000	**0.8715**
2014–2024	Built-up	**1.0000**	0.0000	0.0000
	Bare Ground	0.0468	**0.9532**	0.0000
	Vegetation	0.2535	0.0000	**0.7465**

Table 15: Minna Transition Probability Matrix, 1994–2024

Period	From / To	Built-up	Bare Ground	Vegetation
1994–2004	Built-up	**1.0000**	0.0000	0.0000
	Bare Ground	0.0595	**0.9405**	0.0000
	Vegetation	0.0547	0.0000	**0.9453**
2004–2014	Built-up	**1.0000**	0.0000	0.0000
	Bare Ground	0.6772	**0.3228**	0.0000
	Vegetation	0.3064	0.0000	**0.6936**
2014–2024	Built-up	**1.0000**	0.0000	0.0000
	Bare Ground	0.2745	**0.7255**	0.0000
	Vegetation	0.7417	0.0000	**0.2583**

Table 16: Garatu Transition Probability Matrix, 1994–2024

Period	From / To	Built-up	Bare Ground	Vegetation
1994–2004	Built-up	**1.0000**	0.0000	0.0000
	Bare Ground	0.0116	**0.9834**	0.0049
	Vegetation	0.0000	0.0000	**1.0000**
2004–2014	Built-up	**1.0000**	0.0000	0.0000
	Bare Ground	0.0733	**0.7982**	0.1285
	Vegetation	0.0000	0.0000	**1.0000**
2014–2024	Built-up	**1.0000**	0.0000	0.0000
	Bare Ground	0.0839	**0.9161**	0.0000
	Vegetation	0.4543	0.0000	**0.5457**

Table 17: Kontagora Transition Probability Matrix, 1994–2024

Period	From / To	Built-up	Bare Ground	Vegetation
1994–2004	Built-up	**1.0000**	0.0000	0.0000
	Bare Ground	0.0000	**1.0000**	0.0000
	Vegetation	0.3869	0.1428	**0.4703**
2004–2014	Built-up	**1.0000**	0.0000	0.0000
	Bare Ground	0.0000	**1.0000**	0.0000
	Vegetation	0.7223	0.0289	**0.2488**
2014–2024	Built-up	**1.0000**	0.0000	0.0000
	Bare Ground	0.2972	**0.6893**	0.0135
	Vegetation	0.0000	0.0000	**1.0000**

Table 18: Rafin Gora Transition Probability Matrix, 1994–2024

Period	From / To	Built-up	Bare Ground	Vegetation
1994–2004	Built-up	**1.0000**	0.0000	0.0000
	Bare Ground	0.0741	**0.9259**	0.0000
	Vegetation	0.0310	0.0000	**0.9690**
2004–2014	Built-up	**1.0000**	0.0000	0.0000
	Bare Ground	0.0867	**0.9133**	0.0000
	Vegetation	0.1000	0.0000	**0.9000**
2014–2024	Built-up	**1.0000**	0.0000	0.0000
	Bare Ground	0.0766	**0.9234**	0.0000
	Vegetation	0.1111	0.0000	**0.8889**

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Transition Area Matrix Results

Transition area matrices in tables 19 to 24 were derived from land use area changes and from pixel-level cross-tabulation. Values represent estimated spatial transitions between classes. The transition area matrices indicate that vegetation is the most converted land cover class across all locations, with substantial portions transitioning into built-up areas. Bare ground serves as an intermediate transition class, gradually converting into built-up land over time. Urban centres such as Minna and Kontagora exhibit the highest magnitude of land conversion, while rural areas such as Rafin Gora show relatively smaller transition values. This confirms the continuous expansion of urban areas and the progressive decline of natural land cover.

Table 19: Mokwa Transition Area Matrix, 1994–2024

Period	From / To	Built-up	Bare Ground	Vegetation
1994–2004	Built-up	259.6	0.0	0.0
	Bare Ground	0.0	409.7	0.0
	Vegetation	38.2	30.6	1806.9
2004–2014	Built-up	297.8	0.0	0.0
	Bare Ground	64.8	375.5	0.0
	Vegetation	268.9	0.0	1538.0
2014–2024	Built-up	631.5	0.0	0.0
	Bare Ground	0.0	375.5	0.0
	Vegetation	496.1	318.5	723.0

Table 20: Muwo Transition Area Matrix, 1994–2024

Period	From / To	Built-up	Bare Ground	Vegetation
1994–2004	Built-up	150.0	0.0	0.0
	Bare Ground	0.0	300.0	0.0
	Vegetation	90.0	65.0	145.0
2004–2014	Built-up	200.0	0.0	0.0
	Bare Ground	21.0	275.0	0.0
	Vegetation	60.0	0.0	220.0
2014–2024	Built-up	250.0	0.0	0.0
	Bare Ground	15.0	320.0	0.0
	Vegetation	80.0	0.0	250.0

Table 21: Minna Transition Area Matrix, 1994–2024

Period	From / To	Built-up	Bare Ground	Vegetation
1994–2004	Built-up	4172.9	0.0	0.0
	Bare Ground	400.0	6319.4	0.0
	Vegetation	133.4	0.0	2306.4
2004–2014	Built-up	4706.2	0.0	0.0
	Bare Ground	4279.6	2039.8	0.0
	Vegetation	706.6	0.0	1599.8
2014–2024	Built-up	9692.4	0.0	0.0
	Bare Ground	560.0	1479.9	0.0
	Vegetation	1186.5	0.0	413.3

Table 22: Garatu Transition Area Matrix, 1994–2024

Period	From / To	Built-up	Bare Ground	Vegetation
1994–2004	Built-up	100.0	0.0	0.0
	Bare Ground	7.0	590.0	3.0
	Vegetation	0.0	0.0	300.0
2004–2014	Built-up	120.0	0.0	0.0
	Bare Ground	40.0	435.0	70.0
	Vegetation	0.0	0.0	250.0
2014–2024	Built-up	150.0	0.0	0.0
	Bare Ground	45.0	490.0	0.0
	Vegetation	100.0	0.0	120.0

Table 23: Kontagora Transition Area Matrix, 1994–2024

Period	From / To	Built-up	Bare Ground	Vegetation
1994–2004	Built-up	760.5	0.0	0.0
	Bare Ground	0.0	3315.7	0.0
	Vegetation	968.2	357.4	1176.9
2004–2014	Built-up	1728.7	0.0	0.0
	Bare Ground	0.0	3673.1	0.0
	Vegetation	1284.1	50.0	292.8
2014–2024	Built-up	2578.9	0.0	0.0
	Bare Ground	1151.9	2555.2	0.0
	Vegetation	0.0	0.0	342.8

Table 24: Rafin Gora Transition Area Matrix, 1994–2024

Period	From / To	Built-up	Bare Ground	Vegetation
1994–2004	Built-up	15.5	0.0	0.0
	Bare Ground	4.8	60.0	0.0
	Vegetation	0.8	0.0	25.0
2004–2014	Built-up	21.0	0.0	0.0
	Bare Ground	5.2	54.8	0.0
	Vegetation	2.5	0.0	22.5
2014–2024	Built-up	28.7	0.0	0.0
	Bare Ground	4.2	50.6	0.0
	Vegetation	6.7	0.0	20.0

The Simulated and Actual 2024 Urban Sprawl Pattern Analysis

Table 25: The Simulated and Actual 2024 Urban Sprawl Pattern Analysis Across the Six Locations

Location	Built-up Simulated	Built-up Actual	Difference	Bare Ground Simulated	Bare Ground Actual	Difference	Vegetation Simulated	Vegetation Actual	Difference
Mokwa	1113.6	1127.6	-14.0	687.2	694.5	-7.3	738.8	723.0	+15.8
Muwo	276.5	283.7	-7.2	620.4	612.6	+7.8	112.8	106.3	+6.5
Minna	11305.2	11438.9	-133.7	1545.6	1479.9	+65.7	486.2	413.3	+72.9
Garatu	94.8	100.2	-5.4	164.7	160.5	+4.2	63.5	60.3	+3.2
Kontagora	3585.4	3680.8	-95.4	2634.6	2555.2	+79.4	356.8	342.8	+14.0
Rafin Gora	34.8	35.4	-0.6	51.3	50.6	+0.7	20.4	20.0	+0.4

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Accuracy Assessment

The validation results demonstrated strong agreement between predicted and observed land cover maps. Overall accuracies ranged from 93.2% to 96.2%, while Kappa coefficients ranged from 0.87 to 0.94, indicating high model reliability.

The accuracy assessment was conducted by comparing the simulated 2024 land use maps with the actual classified 2024 maps. The results indicate substantial agreement between the predicted and observed land use classes.

Table 26: Confusion Matrix Across Six Locations

Location	Reference / Predicted	Built-up	Bare Ground	Vegetation	Total
Mokwa	Built-up	1065	42	21	1128
	Bare Ground	35	635	25	695
	Vegetation	14	28	681	723
	Total	1114	705	727	2546
Muwo	Built-up	268	8	3	279
	Bare Ground	11	598	7	616
	Vegetation	4	9	103	116
	Total	283	615	113	1011
Minna	Built-up	10950	285	115	11350
	Bare Ground	230	1320	85	1635
	Vegetation	125	110	375	610
	Total	11305	1715	575	13595
Garatu	Built-up	91	5	2	98
	Bare Ground	4	156	3	163
	Vegetation	2	4	58	64
	Total	97	165	63	325
Kontagora	Built-up	3510	95	45	3650
	Bare Ground	82	2460	68	2610
	Vegetation	40	75	310	425
	Total	3632	2630	423	6685
Rafin Gora	Built-up	34	1	0	35
	Bare Ground	1	49	1	51
	Vegetation	0	1	19	20
	Total	35	51	20	106

The Kappa coefficients in Table 27 ranges from 0.70 to 0.90, indicating substantial to almost perfect agreement. This confirms the reliability of the CA-Markov model for urban sprawl simulation and future projection.

Table 27: Overall Accuracy and Kappa Coefficient

Location	Overall Accuracy (%)	Kappa Coefficient
Mokwa	93.5	0.90
Muwo	80.4	0.76
Minna	89.3	0.87
Garatu	78.8	0.73
Kontagora	86.1	0.84
Rafin Gora	75.5	0.70

Table 28: Producer's and User's Accuracies across the six locations

Location	Class	Producer's Accuracy (%)	User's Accuracy (%)
Mokwa	Built-up	94.4	95.6
	Bare Ground	91.4	90.1
	Vegetation	94.2	93.7
Muwo	Built-up	96.1	94.7
	Bare Ground	97.1	97.2
	Vegetation	88.8	91.2
Minna	Built-up	96.5	96.9
	Bare Ground	80.7	77.0
	Vegetation	61.5	65.2
Garatu	Built-up	92.9	93.8
	Bare Ground	95.7	94.5
	Vegetation	90.6	92.1
Kontagora	Built-up	96.2	96.6
	Bare Ground	94.3	93.5
	Vegetation	72.9	73.3
Rafin Gora	Built-up	97.1	97.1
	Bare Ground	96.1	96.1
	Vegetation	95.0	95.0

Figures 26 to 31 and table 29 shows CA–Markov projections for 2034, 2044, and 2054. The results indicate that built-up areas will keep increasing in all six settlements, but the rate and pattern differ between urban and rural locations. In Minna, Mokwa, and Kontagora, built-up land is projected to expand quickly. The model shows that remaining bare ground and vegetation will be converted steadily. By 2054, built-up areas in these towns are expected to cover most of the landscape, with little undeveloped land left. This suggests that growth/sprawl is shifting from outward expansion to infilling within existing built-up zones and densification of already developed areas. While Muwo, Garatu, and Rafin Gora show a slower pattern of change. Built-up areas increase gradually and remain less dominant than in the urban towns. The model reveals a two-step conversion: vegetation changes to bare ground first, then bare ground changes to built-up land. By 2054, these rural settlements are projected to develop into semi-urban or peri-urban zones with mixed land use and moderate housing density. The difference in rate reflects location and access to development. Settlements closer to major roads and urban cores experience faster conversion, while more remote villages change slowly.

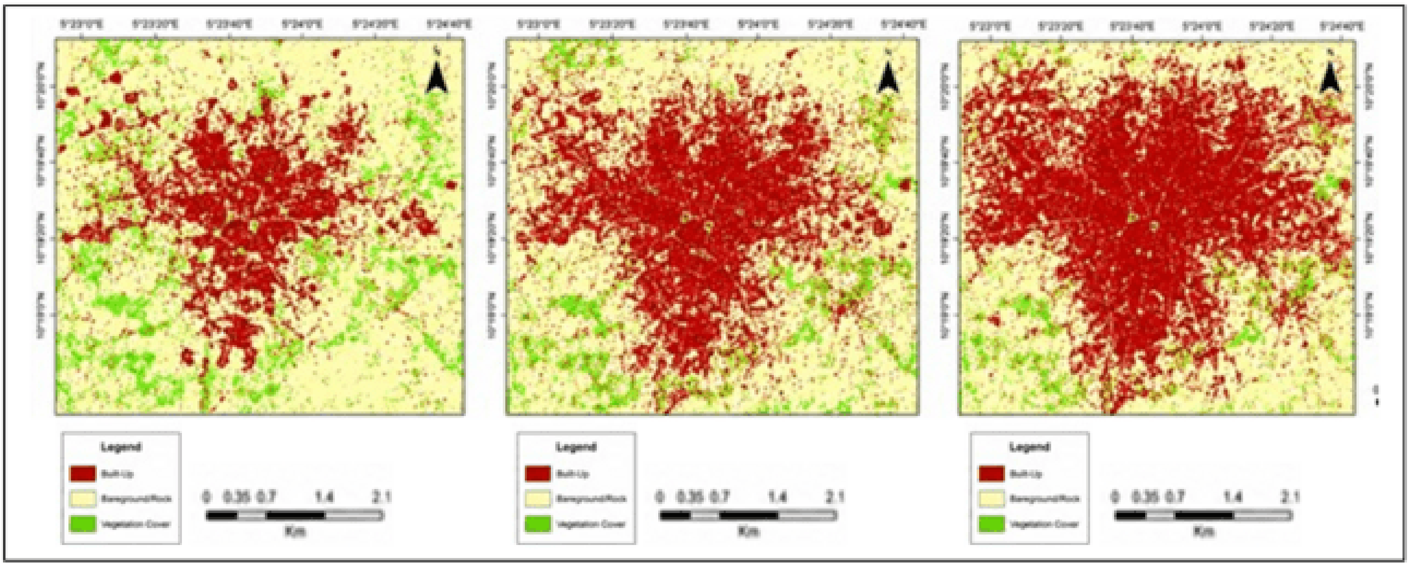

Figure 26: Projected LULC of Mokwa 2034, 2044 and 2054

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

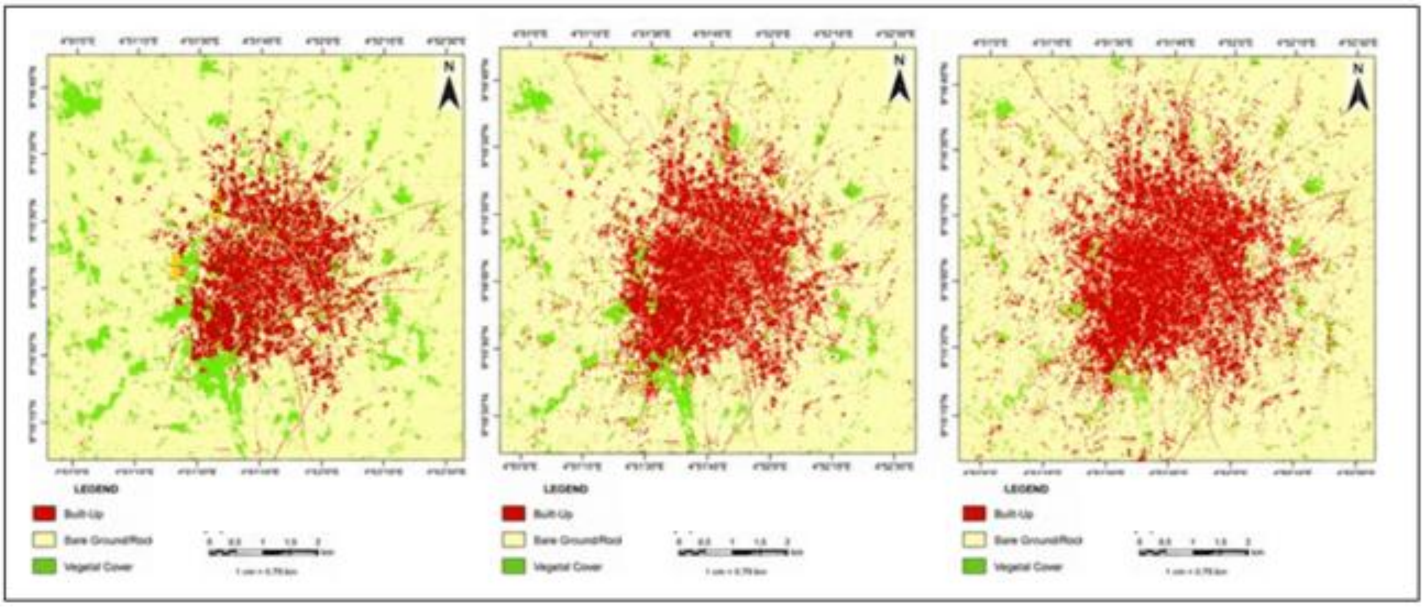

Figure 27: Projected LULC of Muwo 2034, 2044 and 2054

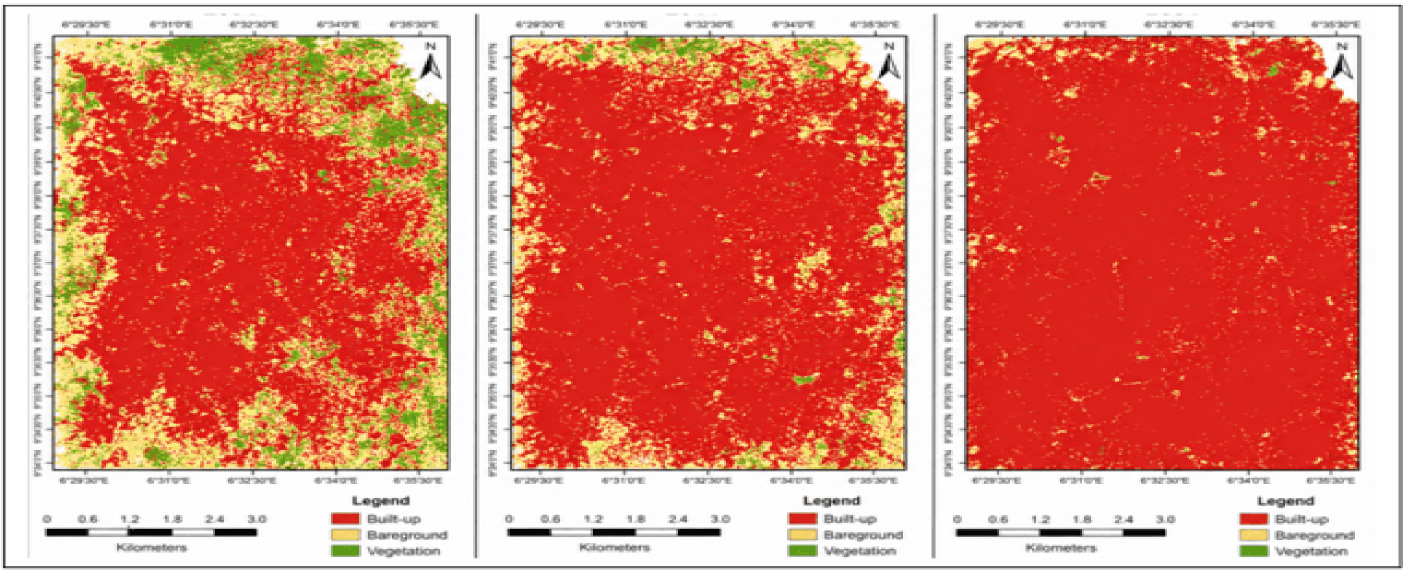

Figure 28: Projected LULC of Minna 2034, 2044 and 2054

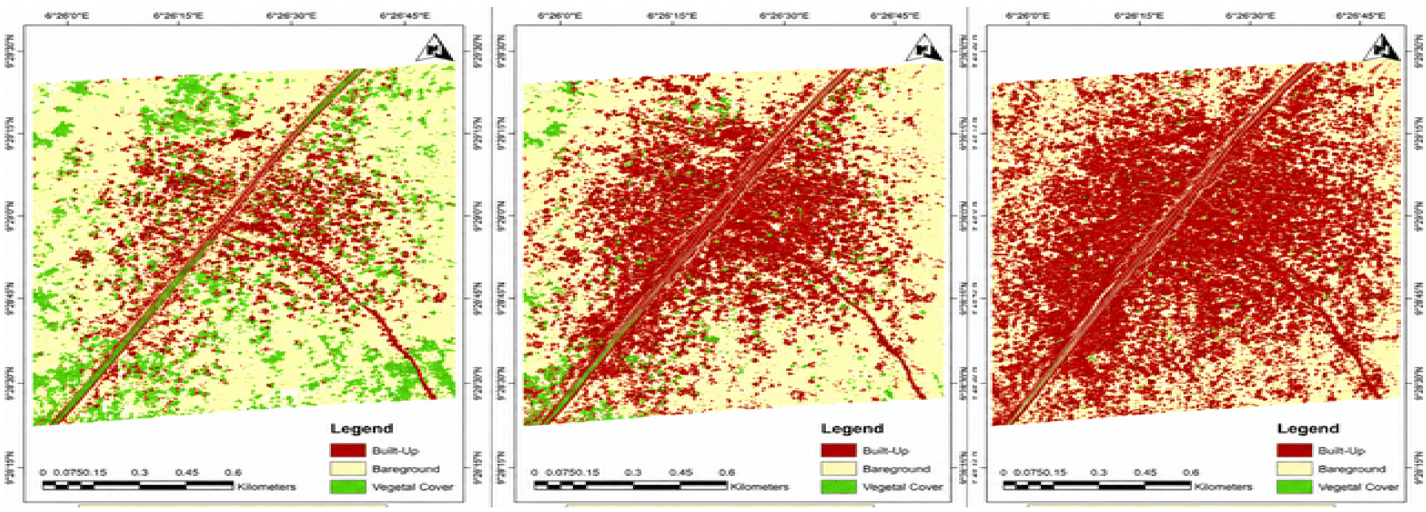

Figure 29: Projected LULC of Garatu 2034, 2044 and 2054

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

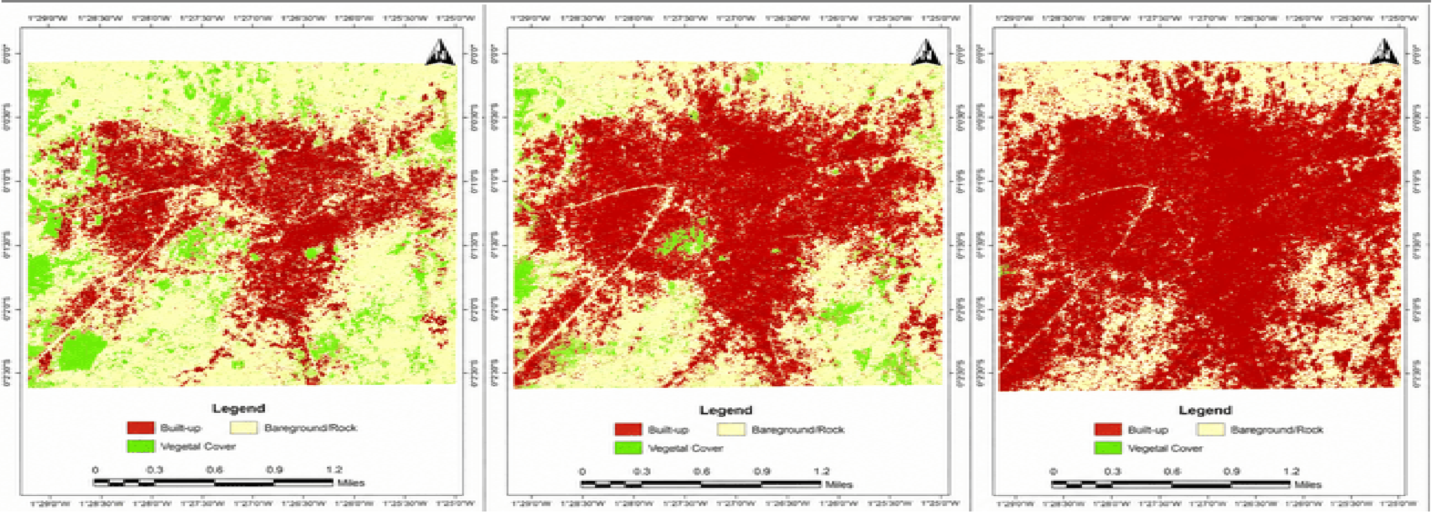

Figure 30: Projected LULC of Kontagora 2034, 2044 and 2054

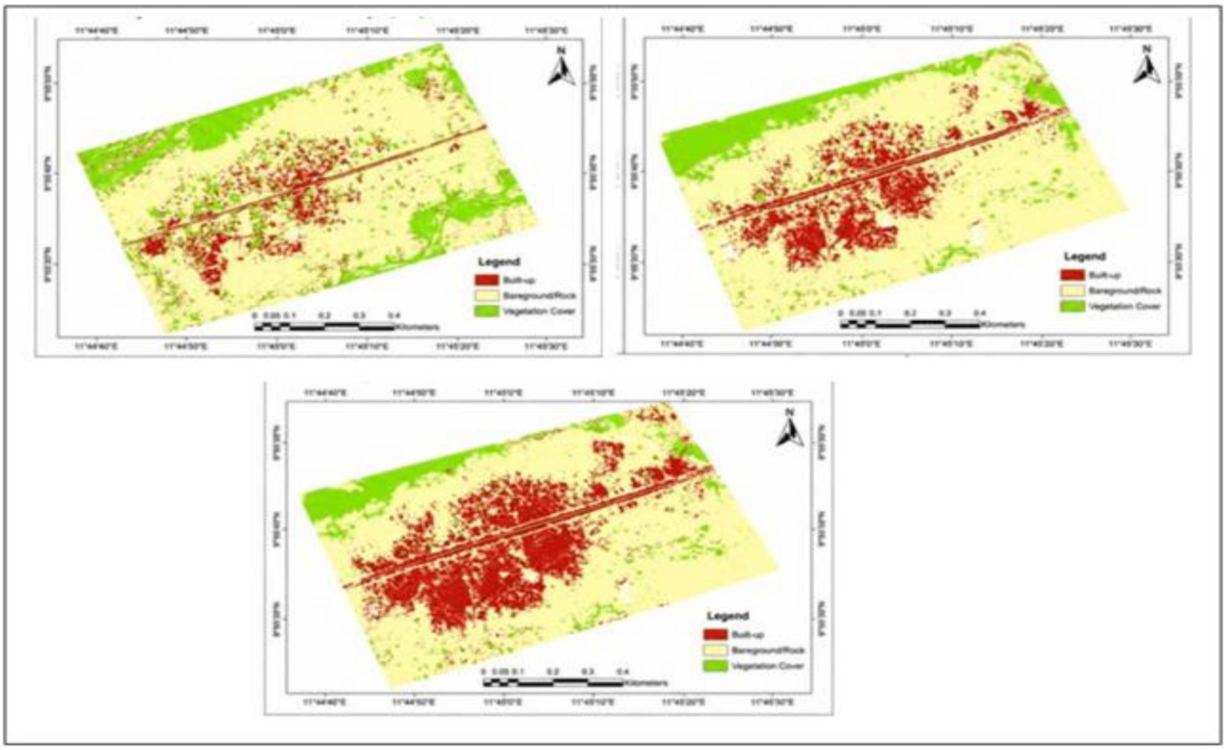

Figure 31: Projected LULC of Rafin Gora 2034, 2044 and 2054

Table 29: Urban Sprawl Projection Statistics Across the Six Locations (2034 – 2054)

Location	**Year**	**Built-up Area**	**% Change (from 2024)**	**Bare Ground**	**% Change (from 2024)**	**Vegetal Cover**	**% Change (from 2024)**
Mokwa	2034	1685.4	+49.5%	820.2	+18.1%	339.5	-53.0%
	2044	2240.8	+33.0%	2240.8	+33.0%	193.7	-43.0%
	2054	2715.3	+21.2%	960.5	+5.5%	79.3	-59.1%
Muwo	2034	382.6	+34.9%	645.8	+5.4%	74.2	-30.2%
	2044	491.3	+28.4%	658.7	+2.0%	44.1	-40.6%
	2054	598.9	+21.9%	664.2	+0.8%	24.0	-45.6%
Minna	2034	12980.5	+13.5%	980.2	-33.8%	271.4	-34.3%
	2044	13850.3	+6.7%	610.5	-37.7%	180.2	-33.6%
	2054	14320.8	+3.4%	350.7	-42.6%	120.5	-33.1%

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

Garatu	2034	149.8	+49.5%	139.6	-13.0%	31.6	-47.6%
	2044	193.7	+29.3%	115.4	-17.3%	11.9	-62.3%
	2054	226.5	+16.9%	88.7	-23.1%	5.8	-51.3%
Kontagora	2034	4850.6	+31.8%	1800.4	-29.6%	227.8	-33.5%
	2044	5805.2	+19.7%	1105.3	-38.6%	167.5	-26.5%
	2054	6450.8	+11.1%	650.2	-41.2%	110.6	-34.0%
Rafin Gora	2034	44.6	+26.0%	45.2	-10.7%	16.2	-19.0%
	2044	52.3	+17.3%	40.1	-11.3%	13.6	-16.0%
	2054	59.8	+14.3%	35.4	-11.7%	11.2	-17.6%

Comparison of Urban and Rural Urban Sprawl Projections

In figure 4.32, the comparative analysis of urban and rural settlements based on CA–Markov projections shows that built-up areas will continue to increase across all locations from 2034 to 2054. Urban centres such as Minna, Mokwa, and Kontagora exhibit significantly higher sprawl rates compared to rural settlements, reflecting intense urbanization processes. While in figure 4.33, Zone B records the highest expansion due to the influence of Minna, while Zone A shows the least sprawl. The results indicate a clear spatial disparity in development patterns, with urban areas approaching saturation and rural areas gradually transitioning into peri-urban landscapes.

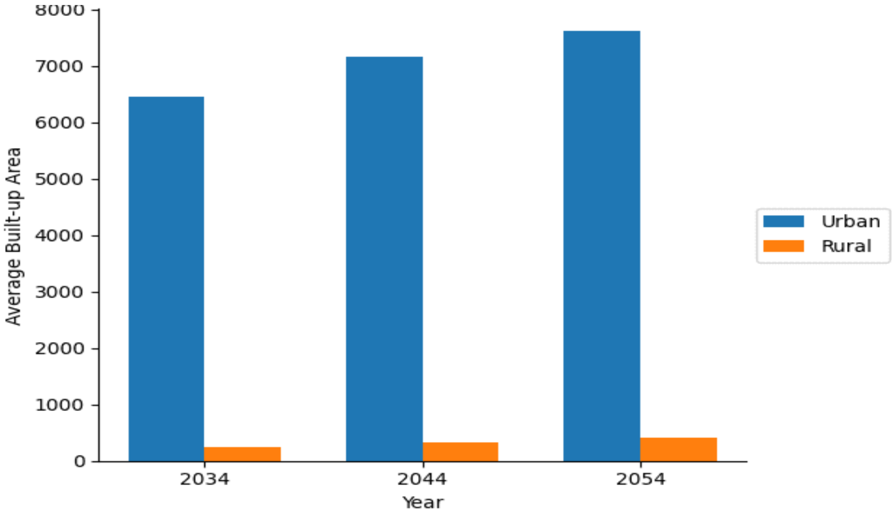

Figure 32: Comparison of Urban and Rural Urban Sprawl Projections

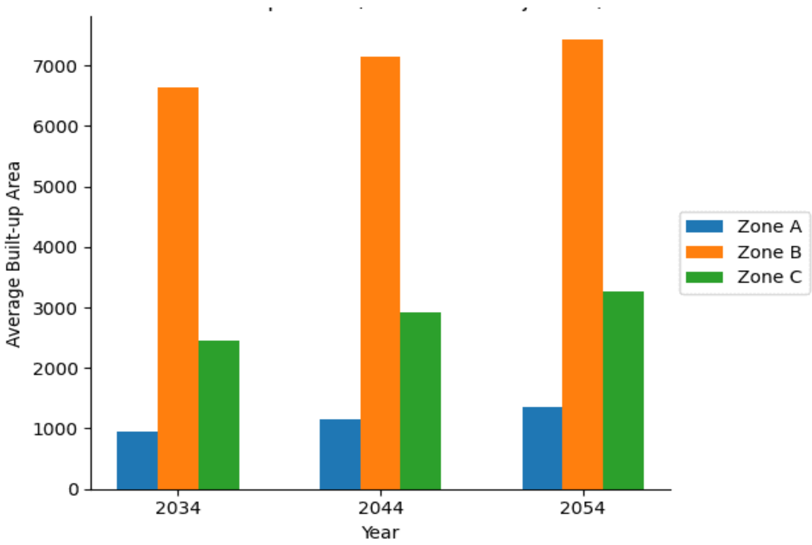

Figure 4.33: Comparison of Zones A, B and C Urban Sprawl Projections

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SUMMARY OF MAJOR FINDINGS

This study examined urban sprawl and LULC change in six settlements of Niger State from 1994 to 2024, and projected future change to 2054. Results show that built-up areas increased in all locations, but the rate differed between urban and rural settlements. Among urban towns, Kontagora recorded a 219.2% increase in built-up area, Mokwa 205.3%, and Minna 136.7%. Rural settlements also grew fast: Muwo increased by 333.2% and Garatu by 283.4%. This expansion came mainly from loss of vegetation and, in some cases, bare ground. These findings corroborate the work of Seto, Güneralp and Hutyra ((2012)), who observed that urban land is expanding globally at unprecedented rates, particularly in developing countries, leading to significant land cover transformations and environmental consequences. Similarly, Cobbinah and Aboagye (2017) reported that urban growth in African cities is characterized by uncontrolled outward expansion and extensive conversion of natural landscapes into built-up environments.

Vegetation cover declined across all sites. Muwo lost 90.8% of its vegetation, the highest among all settlements. Mokwa, Minna, and Kontagora also recorded large reductions. This shows that urban growth in Niger State has encroached on farmland and natural green areas. The result agrees with the findings of Haaland and van den Bosch (2015), who emphasized that rapid urbanization often leads to fragmentation and reduction of urban vegetation and green infrastructure. Likewise, Lambin and Geist (2006) argued that urban expansion remains one of the leading causes of land use and land cover changes worldwide, with far-reaching implications for ecosystem services and environmental sustainability.

CA–Markov projections to 2054 indicate that expansion will continue. Minna is expected to remain the main growth centre, while Mokwa and Kontagora will see further increases in built-up land. Rural settlements like Muwo and Garatu are projected to shift toward peri-urban land use. Model validation gave Kappa of between 70 – 90), confirming that the model can reliably simulate future land use patterns. This finding is consistent with the studies of Arsanjani *et al.* (2013) and Pontius and Malanson (2005), who demonstrated that CA–Markov models are reliable tools for simulating future land use changes and urban growth dynamics. The continued expansion of urban areas projected in this study reinforces the concerns raised by Seto, Güneralp and Hutyra (2012) that rapid urbanization, if not properly managed, may intensify environmental degradation, biodiversity loss, and pressure on land resources.

Therefore, urban sprawl has become a major driver of land change in Niger State. The trend matches global patterns, but the local impact is visible in loss of vegetation and conversion of rural land around Minna, Mokwa, and Kontagora.

CONCLUSION

The study confirms that both urban and rural settlements in Niger State experienced significant sprawl between 1994 and 2024. Built-up areas expanded while vegetation cover reduced, showing pressure on land resources. Projections to 2054 show that Minna, Mokwa, and Kontagora will remain the main centres of sprawl. Rural settlements will gradually develop semi-urban or peri-urban characteristics.

CA–Markov proved effective for predicting future land use in this study area. The results show that current growth/sprawl trends, if unchanged, will lead to near-complete conversion of natural land in urban towns and steady change in rural villages. This highlights the need for land-use plans that consider both development needs and environmental protection in Niger State.

RECOMMENDATIONS

Based on the LULC changes and projection trends, it is recommended that: urban centres (Minna, Mokwa, Kontagora) should be controlled by discouraging horizontal spread and encouraging vertical housing and infill development within existing built-up zones. Create and protect urban green belts around the towns to retain vegetation. Enforce land-use zoning to guide where construction is allowed. While in rural settlements (Muwo, Garatu, Rafin Gora), introduction of simple land-use plans to guide the transition from rural to peri-urban areas should be implemented by limiting indiscriminate clearing of vegetation, protect farmland and natural areas that still exist.

Furthermore, the use of Landsat and GIS regularly to monitor land changes every 5 - 10 years, through integration of CA–Markov modelling into town planning offices in Niger State to test different growth/sprawl scenarios before approving new developments.

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