Adamawa State University Global Journal of Geography and Environmental Sciences
(ADSU-GJGES)
Volume 06 Issue 1, 2026
ISSN: 2651-3830 (Print); 2756-4142 (Online)

Website: gjges.adsu.edu.ng *Email:* gjges@adsu.edu.ng

ORIGINAL RESEARCH ARTICLE

Evaluation of Settlement Encroachment into River Floodplains and Land Use Transformation, A Four-Decade Geospatial Analysis of the Ngadda River Corridor, Maiduguri, Nigeria

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DOI: https://doi.org/10.64290/gjges.v6i1.41

ARTICLE INFO

Article History:
Received 29th April 2026
Revised 3rd May 2026
Accepted 10th May 2026

Keywords:
- Settlement Encroachment;
- River Floodplains;
- Land use and Transformation;
- Ngadda floodplain;
- Maiduguri

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ABSTRACT

Settlement encroachment into river floodplains represents a critical challenge to sustainable urban development in rapidly growing African cities. This study examines the spatial patterns and environmental implications of settlement expansion within the River Ngadda floodplain in Maiduguri, Borno State, Nigeria, spanning the period 1985–2025. The research adopts a mixed-methods approach, integrating geospatial analysis of multi-temporal satellite imagery Landsat 5 TM, Landsat 7,8 & 9 ETM+ were used, with structured questionnaire surveys (n = 381) and field observations. Land use/land cover (LULC) transformations were quantified using ArcGIS 10.5, with GPS-facilitated ground-truthing ensuring classification accuracy. Results indicate a substantial transformation of the floodplain landscape, as built-up areas increased from 20.3% in 1995 to 54.9% in 2025, representing a 63.19% expansion. In contrast, vegetation declined from 46.4% to 24.0%, alongside significant reductions in bare surfaces, reflecting the loss of natural land covers. Additionally, water surface area increased by 172.38%, suggesting intensified flooding linked to reduced infiltration and increased surface runoff. Survey findings further reveal that 75% of respondents perceived continuous settlement expansion, while 80% reported increased flood frequency and intensity. Population growth and weak regulatory enforcement were identified as major drivers of encroachment. The study concludes that persistent floodplain encroachment has degraded ecological integrity and heightened flood vulnerability. It therefore recommends strict land-use regulation, integrated floodplain management, and sustainable housing strategies to enhance urban resilience.

Introduction

Settlement encroachment into river floodplains has emerged as a critical environmental and urban management challenge across the globe (Seto et al., 2011). Furthermore, rapid urbanization, population growth, and increasing demand for land have intensified pressure on environmentally sensitive areas, particularly river corridors and floodplains. The United Nations Department of Economic and Social Affairs projects that approximately 68% of the world's population will reside in urban areas by 2050; a trend that continues to accelerate land transformation and unregulated spatial expansion, especially in developing countries (UN DESA, 2019).

ADSU-GJGES, 6(1) 96 – 112, May 2026
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Consequently, floodplains that historically functioned as natural buffers for flood regulation and ecological balance are increasingly being converted into residential, commercial, and infrastructural land uses.

Globally, cities such as Jakarta, Bangkok, and Houston demonstrate how settlement expansion into floodplain environments disrupts natural hydrological systems (Douglas et al., 2008). Thus, encroachment into these zones has been associated with increased surface runoff, reduced groundwater recharge, loss of vegetation cover, and heightened flood vulnerability. Moreover, the replacement of permeable land surfaces with impervious materials such as concrete and asphalt alters natural drainage patterns, leading to frequent flooding, environmental degradation, and declining water quality (Shuster et al., 2005). Therefore, these experiences underscore the importance of preserving floodplains to maintain sustainable urban ecosystems.

Urban Ecological Theory explains cities as dynamic socio-ecological systems shaped by human activities, spatial competition, and environmental interactions (Park et al., 1925; Alberti, 2005; Grimm et al., 2008). Thus, urban expansion, including settlement encroachment into floodplains, leads to significant ecological changes such as vegetation loss and land cover transformation. Consequently, it highlights the role of population pressure, land demand and weak planning systems in driving environmental degradation.

The Hydrological Response Model, on the other hand, explains how these land use changes affect water movement within a watershed. Specifically, it shows that natural surfaces promote infiltration, while urban impervious surfaces increase surface runoff and flood risk (Shuster et al., 2005). Therefore, settlement encroachment disrupts natural drainage systems, reduces flood storage capacity, and intensifies flooding (Ahmed & Yusuf, 2017; Nwankwo et al., 2024).

Consequently, Urban Ecological Theory explains the causes of urban expansion, while the Hydrological Response Model explains its hydrological impacts, making both essential for understanding floodplain encroachment.

In Africa, urbanization is occurring on an unprecedented and largely unplanned scale. Furthermore, many cities across Sub-Saharan Africa are characterized by informal settlements expanding into flood-prone areas due to poverty, rural–urban migration, weak planning institutions, and inadequate enforcement of land use regulations (Cobbinah et al., 2015). Consequently, floodplain ecosystems in cities such as Accra, Lagos, and Dar es Salaam have experienced significant degradation, marked by vegetation loss, soil erosion, water pollution, and increased flood disasters (Agyemang et al., 2017; UNEP, 2018). Thus, these developments often result in severe alterations to pre-existing land use and land cover patterns, thereby undermining ecosystem services and urban resilience.

Nigeria reflects these broader continental and global dynamics. Moreover, the country has witnessed rapid urban growth, with its urban population increasing from about 17.5% in 1960 to over 52% by 2022 (NBS, 2022). Consequently, this rapid expansion has placed considerable pressure on natural landscapes, particularly river floodplains. Furthermore, in many Nigerian cities, floodplains that historically functioned as natural drainage and flood control zones have been converted into built-up areas without adequate planning or environmental impact assessment. Hence, such land use transformations have disrupted natural hydrological processes, leading to increased flooding, sedimentation, and land degradation (Ogunyemi et al., 2018; Yakubu &

Garba, 2019). Notably, the 2012 nationwide flood disaster further highlighted the consequences of unchecked settlement encroachment and poor land use management in floodplain areas (NEMA, 2012).

In Maiduguri, the capital of Borno State, settlement encroachment into floodplain environments has been intensified by unique socio-economic and security-related factors. Furthermore, prolonged insurgency in the region has triggered large-scale displacement of populations from rural communities into the city, resulting in rapid, unplanned, and informal settlement growth (Ahmed et al., 2018). Consequently, the River Ngadda, a major urban river in Maiduguri, and its surrounding floodplain have been particularly affected. Moreover, areas that were previously characterized by natural vegetation, agricultural land, and open spaces have increasingly been transformed into residential and commercial developments (Baba et al., 2017). Thus, this transformation represents a significant alteration of pre-existing land use and land cover conditions along the river corridor.

The encroachment into the River Ngadda floodplain has led to notable environmental consequences. Furthermore, the loss of vegetation cover and the expansion of impervious surfaces have altered the river's natural flow regime, increased surface runoff, and reduced groundwater recharge. Consequently, these changes have contributed to more frequent and severe flooding events during the rainy season, as well as increased sedimentation and erosion along the riverbanks (Ahmed & Yusuf, 2017; Nwankwo & Abdullahi, 2023). Moreover, indiscriminate waste disposal and untreated effluent discharge into the river have degraded water quality and threatened aquatic ecosystems.

Notwithstanding the growing body of research on urban floodplain encroachment, there remains a paucity of localized empirical evidence focusing specifically on Maiduguri and the River Ngadda floodplain. Furthermore, the unique influence of conflict-induced displacement on settlement patterns further distinguishes Maiduguri from other Nigerian cities. Therefore, this study seeks to evaluate the extent of settlement encroachment into the River Ngadda floodplain and examine its effects on pre-existing land use and land cover in Maiduguri, Borno State.

The aim of this study is to evaluate settlement encroachment into the River Ngadda floodplain and its effect on pre-existing land use/land cover in Maiduguri, Borno State. The specific objectives are to: map flood-prone zones along the Ngadda River section of the study area; ascertain the trend of settlement encroachment into the Ngadda floodplain over the last four decades; examine the major pre-existing land use/land cover types affected by settlement encroachment; and analyze the effects of settlement encroachment on the affected land uses.

Materials and Methods

Study Area

Maiduguri, the administrative capital of Borno State in northeastern Nigeria, occupies a key geographical position within the Lake Chad Basin (between latitudes 11°46'30" N and 11°52'30" N of the equator and between longitudes 13°06'00" E and 13°12'00" E of the Prime Meridian), at an average elevation of approximately 320 m above sea level (Njihia et al., 2024). The city covers a land area of roughly 105.5 km², with its metropolitan area extending into adjacent settlements in Jere and Konduga Local Government Areas (Jibril et al., 2023).

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The climate falls under the hot semi-arid (BSh) Köppen classification, with annual average temperatures of 29-30°C and annual rainfall of 500-630 mm concentrated between June and September (Jibril et al., 2023). The relief is predominantly flat to gently undulating, resulting in slow surface water flow and poor natural drainage. The Ngadda River, a seasonal watercourse traversing the city from west to east, represents the primary hydrological feature, feeding into Lake Alau and playing crucial roles in agricultural irrigation and groundwater recharge (Njihia et al., 2024).

The study focuses specifically on communities situated along the River Ngadda corridor, including Fori, Gwange, Bulabulin, Hausari, and Gamboru, selected due to their proximity to the river and documented exposure to flood risks associated with settlement encroachment.

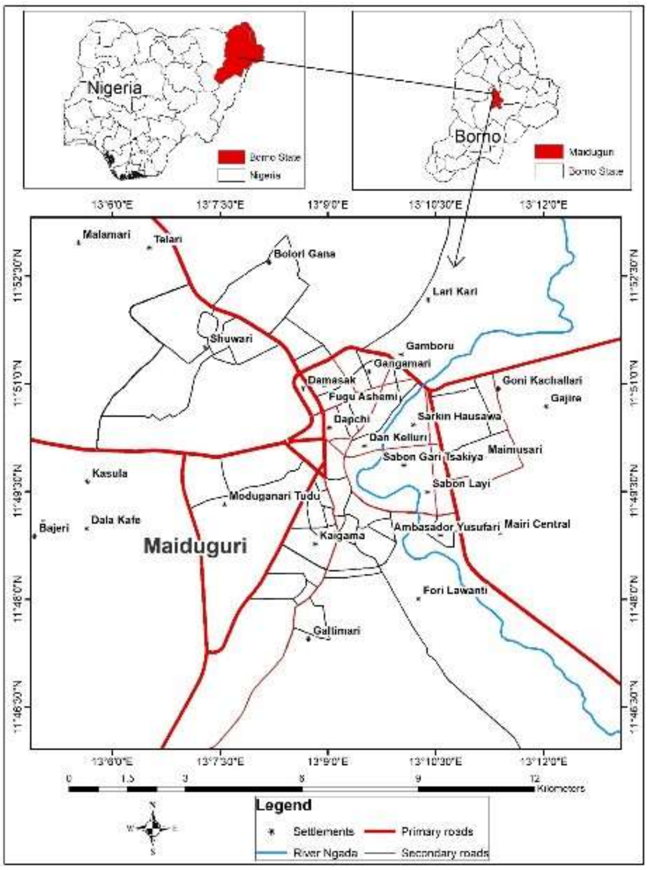

Figure 1: The Study Area

Data Sources and Collection

This study utilized a mixed-methods research design, integrating primary empirical data with secondary geospatial and institutional records to facilitate a comprehensive assessment of settlement dynamics. Primary data acquisition was executed through the administration of structured questionnaires to a sample of 400 respondents, identified via simple random sampling across riparian communities situated along the River Ngadda corridor. The determination of this sample size was predicated on the Yamane (1967) formula to ensure statistical rigor and population representativeness.

Empirical field validation was conducted using Garmin eTrex 30 GPS receivers to

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facilitate ground-truthing and verify the spectral accuracy of the land cover classifications. The secondary geospatial framework relied upon a multi-decadal chronological suite of satellite imagery retrieved from the United States Geological Survey (USGS) Earth Explorer platform. Specifically, the study utilized Landsat 5 Thematic Mapper (TM), Landsat 7 (ETM+) for the 1995 and 2005 datasets, Landsat 8 operational Land Imager (OLI) for the 2015 epoch, and Landsat 8 + 9 OLI-2 for the 2025 analysis. These datasets were further integrated with historical cartographic maps, longitudinal meteorological data, and statutory policy frameworks sourced from the Borno State Ministry of Land and Surveys and the Nigeria Hydrological Services Agency (NIHSA).

Analytical Methods

Geospatial analysis was conducted using ArcGIS 10.5 to process satellite imagery and generate land use/land cover maps. Change detection techniques compared imagery from 1995, 2005, 2015, 2025 to quantify settlement expansion in hectares. Supervised classification using the maximum likelihood algorithm was used to differentiate land cover categories including built-up areas, vegetation, agricultural land, wetlands, and bare surface.

Quantitative survey data were coded in Microsoft Excel and analyzed using SPSS Version 23. Descriptive statistics including (means and standard deviations) summarized respondent demographics and perceptions.

Buffer analysis in ArcGIS delineated flood-prone zones at 500m (high risk), 1000m (moderate risk), and 1500m (low risk) intervals from the river channel. Qualitative data from open-ended questionnaire responses were thematically coded to identify key drivers of encroachment and community proposed mitigation strategies.

Results

Demographic Characteristics

Out of the 400 (100%) questionnaires distributed to the respondents in the study area, 381 (95%) were completed, returned, and considered valid for analysis, whereas 19 (4.7%) were not returned. The survey sample comprised 381 respondents with the following characteristics: 55% male and 45% female; age distribution dominated by 26-40 years (37.5%); educational attainment primarily secondary (37.5%) or tertiary (42.5%); occupations predominantly farming (30%) and trading (25%); and length of residence predominantly 11–20 years (30%). These demographics indicate a sample of educated, economically active residents with substantial local experience, positioning them to provide informed perspectives on flood-related and land-use changes.

Perception of Flood Risks

Spatial analysis identified three distinct flood-risk zones along the River Ngadda (Figure 2). The High Vulnerability zone (Pink) occurs closest to the river channel, representing areas most frequently inundated during the rainy season. The vulnerability zone (Yellow) extends outward and experiences flooding during intense rainfall or prolonged runoff. The low vulnerability zone (Blue) lies furthest from the river but remains vulnerable under extreme flood events.

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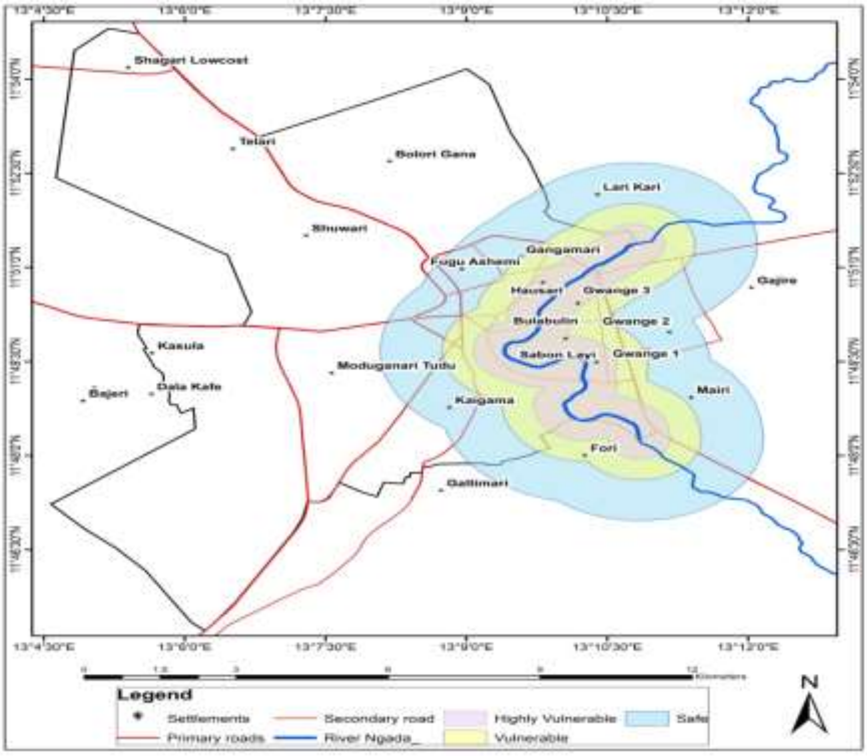

Figure 2: Flood risk zone

Table 1: Perceptions of Flood Risks (n=381)

Statement	**Mean**	**SD**
Flooding frequently occurs along lower sections	3.91	1.02
Settlements along floodplain are vulnerable	3.81	1.05
Poor drainage contributes to flooding	3.71	1.08
Built-up expansion reduced flood absorption	3.80	1.06
Seasonal flooding disrupts livelihoods	3.91	1.02
Cluster Mean	**3.83**	**1.05**

The findings on perceptions of flood-prone zones (n = 381) indicate that respondents generally agreed that flooding is a significant and recurring issue in the area, as reflected in the high cluster mean of 3.83 (SD = 1.05). The results show strong agreement that flooding frequently occurs along lower sections (Mean = 3.91, SD = 1.02) and that seasonal flooding disrupts livelihoods (Mean = 3.91, SD = 1.02), highlighting the regularity and socio-economic impact of flooding. Respondents also agreed that settlements along the floodplain are highly vulnerable (Mean = 3.81, SD = 1.05) and that built-up expansion has reduced natural flood absorption capacity (Mean = 3.80, SD = 1.06), suggesting that human activities

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contribute to increased flood risks. Additionally, poor drainage was perceived as a major factor contributing to flooding (Mean = 3.71, SD = 1.08). The relatively moderate standard deviations indicate some variation in responses, but overall, the results reflect a shared perception that both environmental and human factors increase flood vulnerability and its impact on communities.

Table 2: Trend of Settlement Encroachment (n=381)

Statement	Mean	SD
Settlements expanded into floodplain over decades	3.78	1.12
Expansion noticeable in last 40 years	3.75	1.10
Population growth is major driver	3.80	1.11
Government policies/insurgency contributed	3.48	1.20
Weak enforcement encourages encroachment	3.83	1.08
Cluster Mean	**3.73**	**1.14**

The findings on the trend of settlement encroachment (n = 381) indicate that respondents generally agreed that settlement

expansion into floodplains is increasing. This is supported by the cluster mean of 3.73, which shows overall agreement, while the standard deviation of 1.14 indicates moderate variation in responses. Specifically, respondents agreed that settlements have expanded into floodplains over decades (Mean = 3.78, SD = 1.12) and that this expansion has become more noticeable in the last 40 years (Mean = 3.75, SD = 1.10). Population growth was identified as a major driver of encroachment (Mean = 3.80, SD = 1.11), while weak enforcement of regulations was perceived as the most significant contributing factor (Mean = 3.83, SD = 1.08). Although respondents also agreed that government policies and insurgency contributed to settlement encroachment (Mean = 3.48, SD = 1.20), this factor recorded the lowest level of agreement and showed greater variation in opinions. The result shows that settlement encroachment into floodplains is a growing concern largely driven by population increase and weak regulatory enforcement.

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Table 3: Pre-Existing Land Use/Land Cover Affected (n=381)

Statement	Mean	SD
Natural vegetation replaced by structures	3.78	1.12
Agricultural farmlands converted to built-up	3.75	1.10
Grazing lands and wetlands lost	3.80	1.11
Road construction disrupted natural cover	3.65	1.14
Riparian vegetation cleared for development	3.78	1.12
Cluster Mean	**3.75**	**1.12**

The findings on pre-existing land use and land cover affected (n = 381) show that respondents generally agreed that significant changes have occurred in the natural environment, as indicated by the cluster mean of 3.75 (SD = 1.12). The results reveal that grazing lands and wetlands have been lost (Mean = 3.80, SD = 1.11), while natural vegetation has been replaced by structures (Mean = 3.78, SD = 1.12) and riparian vegetation cleared for development (Mean = 3.78, SD = 1.12), indicating substantial environmental modification due to human activities. Respondents also agreed that agricultural farmlands have been converted to built-up areas (Mean = 3.75, SD = 1.10), reflecting increasing urban expansion and land-use change. Additionally, road construction was perceived to have disrupted natural land cover (Mean = 3.65, SD = 1.14), though with slightly lower agreement compared to other factors. The moderate standard deviations suggest some variation in responses; however, the results indicate a shared perception that development activities have significantly altered natural land cover, contributing to environmental degradation and loss of ecological resources.

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Table 4: Effects of Settlement Encroachment (n=381)

Statement	Mean	SD
Flood frequency/intensity increased	3.91	1.02
Vegetation loss caused soil erosion	3.83	1.08
Wetlands destroyed, biodiversity reduced	3.78	1.12
Farmland reduction affected agriculture	3.75	1.10
Encroachment poses long-term risks	3.91	1.02
Cluster Mean	**3.84**	**1.07**

The results on the effects of settlement encroachment (n = 381) indicate that respondents generally agreed that settlement expansion has significant environmental and socio-economic consequences. The cluster mean of 3.84 with a standard deviation of 1.07 shows a high level of agreement and moderate variation in responses, suggesting a shared perception among respondents. Specifically, respondents agreed that flood frequency and intensity have increased due to settlement encroachment (Mean = 3.91, SD = 1.02), indicating that development in sensitive areas may be worsening flood conditions. Similarly, there was strong agreement that encroachment poses long-term risks (Mean = 3.91, SD = 1.02), highlighting concerns about future environmental sustainability and safety. The findings also show that vegetation loss has contributed to soil erosion (Mean = 3.83, SD = 1.08), while the destruction of wetlands has reduced biodiversity (Mean = 3.78, SD = 1.12), suggesting significant ecological impacts. In addition, respondents agreed that reduction in farmland has negatively affected agricultural activities (Mean = 3.75, SD = 1.10), indicating implications for food production and livelihoods. The findings reveal that settlement encroachment is perceived to have serious environmental effects, including increased flooding, land degradation, biodiversity loss, and reduced agricultural productivity, with potential long-term risks to sustainable development.

Table 5: Land Use/Land Cover Changes (1995–2025)

Features	Area 1995 (ha)	2005 (ha)	2015 (ha)	2025 (ha)	Changes in(ha) 1995-2025	Percentage (%)
Water	288.00	346.50	431.55	784.44	496.44	172.38
Bare Surface	1,701.00	1,548.00	1,398.60	924.93	776.07	-45.62
Vegetation	3,762.00	3,474.00	3,081.78	2,417.22	1344.78	-35.75
Built-up	4,068.00	4,716.00	5,853.60	6,638.76	2570.76	63.19

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The analysis of land use/land cover (LULC) changes along the Ngadda River floodplain from 1995 to 2025 reveals a clear transformation driven by sustained settlement encroachment and its associated environmental impacts. Over the 40-year period, the floodplain experienced a significant expansion of built-up areas, which increased by 2,570.76 hectares (63.19%), making it the most dominant and rapidly growing land-use class. Consequently, this growth occurred at the direct expense of natural land covers, particularly vegetation and bare surfaces, which declined by 1,344.78 hectares (−35.75%) and 776.07 hectares (−45.62%), respectively. As a result, the progressive loss of these permeable and ecologically functional surfaces indicates a transition from a naturally regulated floodplain system to a highly modified, human-dominated landscape.

Furthermore, a notable outcome of this transformation is the substantial increase in water surface area, which expanded by 496.44 hectares (172.38%) over the study period. In effect, this near threefold rise in floodplain inundation reflects the hydrological consequences of land cover change, particularly the reduction in infiltration capacity, increased surface runoff, and disruption of natural drainage systems. More importantly, the accelerated increase observed between 2015 and 2025 further suggests that the cumulative effects of urban expansion have reached a threshold where flood dynamics are being significantly altered.

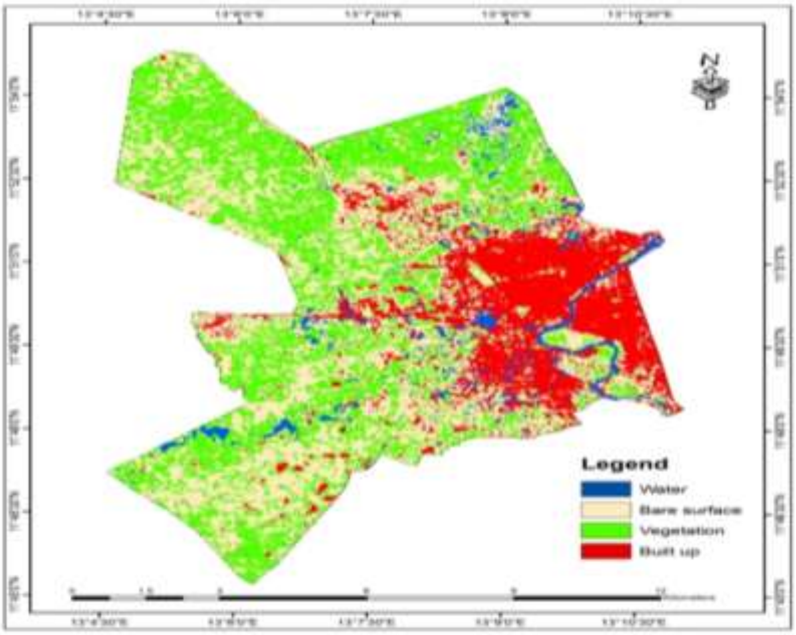

Figure 3: land use/land cover of Maiduguri, 1995-

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Table 6: land use/land cover Distribution for 1995

LULC Class	Area (ha)	Percentage (%)
Water	288.00	2.68
Bare Surface	1701.00	15.80
Vegetation	3762.00	34.94
Built up	4068.00	37.76
Total	**10765.53**	**100**

By 2005, vegetation had declined to 38.9%, while built-up areas rose to 32.1%, signaling early urban expansion likely fueled by population growth and increased demand for housing and commercial spaces. Bare surfaces also decreased as open lands were converted for development.

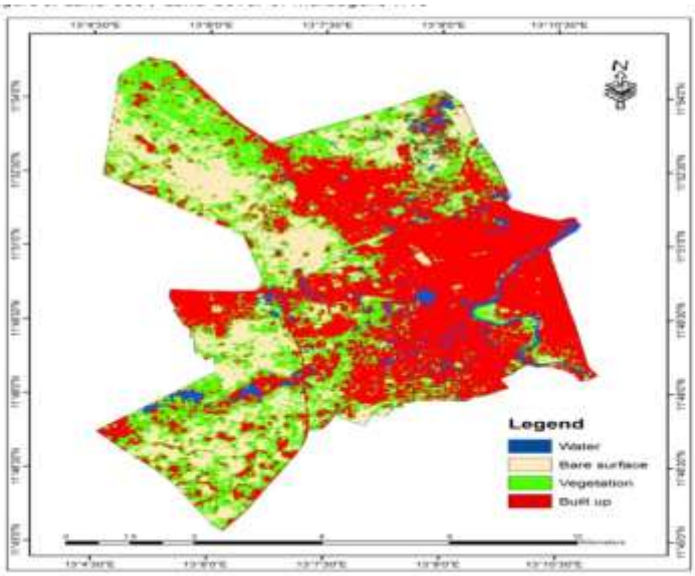

Figure 4: land use/land cover of Maiduguri, 2005-

Table 7: land use/land cover Distribution for 2005

LULC Class	Area (ha)	Percentage (%)
Water	346.50	3.22
Bare Surface	1548.00	14.38
Vegetation	3762.00	34.95
Built up	4068.00	37.45
Total	**10765.53**	**100**

The trend accelerated in 2015, with built-up areas reaching 43.4%, surpassing vegetation (31.3%). This marks a critical shift where urban land use became dominant, driven by infrastructure development, economic activities, and rural-urban migration.

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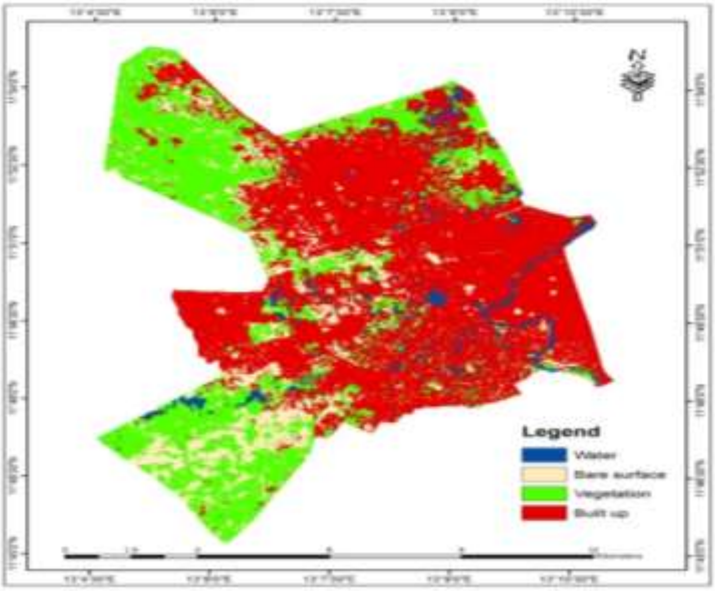

Figure 5: land use/land cover of Maiduguri, 2015

Table 8: land use/land cover Distribution for 2015

LULC Class	Area (ha)	Percentage (%)
Water	431.55	4.01
Bare Surface	1398.60	12.99
Vegetation	3081.78	28.63
Built up	5853.60	54.37
Total	**10765.53**	**100**

By 2025, built-up areas had expanded to 54.9% (325.65 km²), while vegetation and bare surfaces declined to 24.0% and 19.5%, respectively. Water bodies also decreased slightly, possibly due to environmental degradation or urban encroachment.

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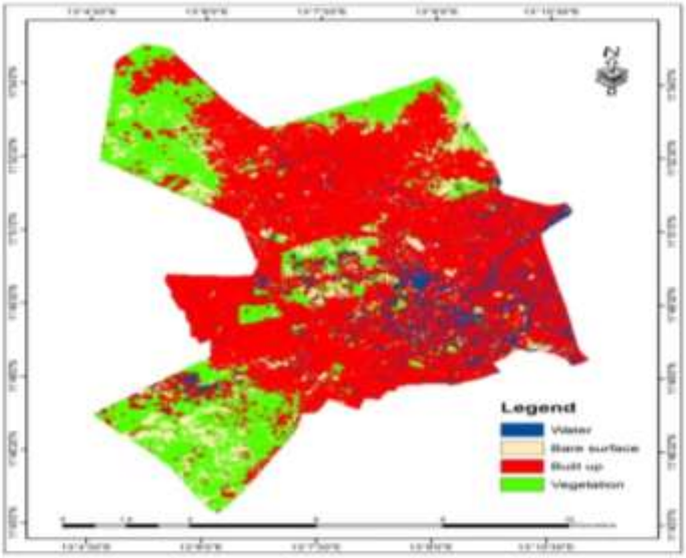

Figure 6: land use/land cover of Maiduguri, 2025-

Table 9: land use/land cover Distribution for 2025

LULC Class	Area (ha)	Percentage (%)
Water	784.44	7.29
Bare Surface	924.93	8.59
Vegetation	2417.22	22.45
Built up	6638.76	61.67
Total	**10765.35**	**100**

The 2025 classification results reveal a decisive shift in the landscape of Maiduguri, with the built-up area now constituting the dominant land cover at 61.67% (6,638.76 ha). This represents a steady and significant increase in anthropogenic surfaces at the expense of natural covers, underscoring the trajectory of rapid, often informal, urbanization.

The environmental implications of this spatial transition are profound: the substantial loss of green spaces and the corresponding expansion of impervious surfaces have fundamentally altered the local hydrological cycle. These transformations contribute to increased surface runoff, the intensification of urban heat islands (UHI), and heightened flooding risks, particularly for settlements proximal to the River Ngadda. These findings highlight a critical need for integrated, sustainable land-use planning that effectively balances urban developmental pressures with essential ecosystem conservation.

Discussion

Spatial Dynamics of Settlement Encroachment

The progressive expansion of settlements into the Ngadda floodplain between 1995 and 2025 aligns with established urban growth theories and empirical observations from other rapidly urbanizing African cities. The initial phase (1995) exhibited minimal encroachment, with settlements maintaining safe distances from the river channel reflecting traditional environmental knowledge and lower population pressure (Shettima et al., 2019). By 2005, moderate expansion into the floodplain became evident, corresponding with

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accelerated urbanization and increasing land demand. The final phase (2025) revealed extensive encroachment, with dense settlement clusters occupying previously protected floodplain zones.

This temporal pattern corroborates findings from Ibrahim et al. (2024), who documented similar progressive encroachment in other West African riverine communities. The statistically significant correlation between population growth and settlement expansion ($r=0.678$, $p<0.05$) confirms demographic pressure as the dominant driver, consistent with theoretical predictions from urban ecology literature (Alberti, 2005; Grimm et al., 2008).

Land Use Transformation and Ecosystem Degradation

The systematic conversion of natural vegetation, agricultural farmlands, wetlands, and riparian buffers into built-up areas represents a fundamental alteration of the floodplain's ecological structure and functional integrity. As evidenced by the geospatial analysis, the decline of natural vegetation from 46.4% in 1995 to 22.45% in 2025 signifies a critical reduction in the landscape's permeable surface area. Simultaneously, the expansion of the built-up footprint to 61.67% by 2025 indicates that the majority of the study area is now dominated by anthropogenic infrastructure.

This observed shift in land cover percentages suggests significant hydrological implications. The substantial increase in impervious surfaces typically compromises the floodplain's natural water retention capacity, a process that is associated with accelerated surface runoff dynamics and the amplification of flood peaks during high-intensity rainfall events (Shuster et al., 2005; Jacobson, 2011).

While this research empirically quantifies the spatial magnitude of these transformations, the resulting disruptions to infiltration rates and groundwater recharge are inferred consequences of replacing natural ecological buffers with residential and commercial structures. These findings underscore the environmental cost of unchecked urban expansion, as the regulatory functions of the River Ngadda corridor are increasingly superseded by the hydrological pressures of urban runoff.

Socio-Economic Vulnerability and Environmental Justice

The concentration of informal settlements within high-risk flood zones disproportionately exposes low-income households and internally displaced persons to flood hazards an environmental justice concern highlighted in urban political ecology literature (Swyngedouw, 2004; Neef et al., 2018). The 80% agreement among respondents regarding increased flood frequency and intensity, coupled with agricultural productivity decline, indicates cascading socio-economic impacts that compound existing vulnerabilities.

These findings resonate with Douglas et al. (2008), who documented similar disproportionate exposure of poor and displaced populations to urban flood risks across multiple African cities. The Maiduguri case is distinguished by the additional pressure of conflict-induced displacement, which has intensified settlement expansion into hazard-prone areas beyond what demographic growth alone would predict.

Policy Implications and Management Strategies

The identification of weak enforcement of planning regulations as a key enabling factor (Mean=3.83) aligns with Yakubu and Garba (2019), who emphasized governance deficits in northern Nigerian urban planning. The predominance of community awareness and

ADSU-GJGES, 6(1) 96 – 112, May 2026
ISSN: 2705-1900 (Online); ISSN: 2251-0702 (Print)
Website: gjges.adsu.edu.ng *Email: gjges@adsu.edu.ng* *DOI:* https://doi.org/10.64290/gjges.v6i1.41

strict enforcement as recommended solutions (75% combined frequency) suggests that effective intervention requires both regulatory strengthening and participatory education approaches.

The study's findings support the integration of Nature-Based Solutions (NBS) and Water-Sensitive Urban Design (WSUD) into Maiduguri's urban planning framework, including permeable surfaces, vegetated swales, bioswales, and riparian buffer restoration (World Bank, 2021). Such approaches could partially restore floodplain functionality while accommodating necessary urban development.

Limitations and Future Research Directions

This study faced constraints including limited access to high-resolution historical satellite imagery for early study periods, security-related restrictions on field access to certain floodplain sections, and gaps in hydrological monitoring data. These limitations were mitigated through multi-source data integration and mixed-methods triangulation.

Future research should examine long-term socio-economic impacts of recurrent flooding, effectiveness of specific policy interventions, and comparative analysis with other insurgency-affected cities to develop transferable management frameworks.

Conclusions

This study demonstrates that settlement encroachment into the River Ngadda floodplain has been continuous, progressive, and environmentally disruptive over the past four decades. The conversion of natural vegetation, agricultural lands, wetlands, and riparian zones to built-up areas has fundamentally degraded the floodplain's hydrological and ecological functions, resulting in increased flood frequency and intensity, soil erosion, biodiversity loss, and reduced agricultural productivity.

Population growth emerged as the statistically significant primary driver of encroachment, though conflict-induced displacement and weak governance structures have accelerated the process beyond demographic pressure alone. The resulting environmental changes have disproportionately affected low-income and displaced populations, creating a nexus of environmental degradation and social vulnerability that threatens long-term urban sustainability.

The findings underscore the urgent necessity of: (1) strict enforcement of floodplain zoning regulations with clear demarcation of restricted zones; (2) provision of safe and affordable alternative housing outside flood-risk areas; (3) improvement of drainage and flood-control infrastructure; (4) restoration of degraded floodplain ecosystems through re-vegetation and wetland protection; (5) community awareness and education programs; and (6) enhanced institutional coordination among planning, environmental, and disaster management agencies.

Addressing settlement encroachment in Maiduguri requires recognizing floodplains as essential ecological infrastructure rather than vacant land available for development. Only through integrated, evidence-based management can the city reduce flood risks, protect ecosystem services, and ensure sustainable livelihoods for its growing population.

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ADSU-GJGES, 6(1) 96 – 112, May 2026
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