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Assessing The Impact Of Urban Encroachment On The Riparian Zones Of Mando, Kaduna State, Nigeria

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Abstract

This study assessed the urban encroachment and its ecological consequences in Mando, Kaduna, Nigeria, from 2004 to 2024, with a focus on the impacts on surrounding water bodies and riparian ecosystems. A multi-temporal remote sensing approach was adopted leveraging Landsat Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), and Operational Land Imager (OLI) imagery processed within ENVI and ArcGIS. This enabled the detailed mapping of land use/land cover (LULC) dynamics, the quantification of encroachment into hydrological features, and changes in riparian vegetation density was analysed. The result revealed a pronounced trajectory of urbanization: built-up areas expanded dramatically from 112.3 hectares (6.3%) in 2004 to 592.02 hectares (33.2%) by 2024. This assembly of impervious surfaces has fundamentally altered hydrological processes, increasing surface runoff and facilitating the direct transport of untreated pollutants into adjacent river systems. Furthermore, the natural riparian buffer has been severely degraded, declining from 226.4 hectares (12.7%) to 83.8 hectares (4.7%), thereby diminishing its capacity for flood regulation and ecological filtration. A subsequent buffer analysis confirmed that much of this unplanned development now lies within a high-risk 100-meter flood zone, emphasizing the acute susceptibility of both the resident population and the aquatic environment. The findings emphasize that unchecked urban sprawl in Mando poses a direct and escalating threat to water resource integrity. Consequently, this research advocates for the immediate implementation of integrated land-use planning, the formal delineation and restoration of riparian corridors, enhanced regulatory enforcement for new developments, and the promotion of community-based stewardship programs to safeguard the ecological region.

Keywords: Land-use, Urban Expansion, Water bodies, Ecosystem, Mapping, Susceptibility.

1.0 Introduction

Riparian zones are the transitional interfaces between terrestrial and aquatic ecosystems and represent some of the most ecologically dynamic and functionally significant landscapes in the world. These vegetated corridors along river channels perform essential hydrological and ecological functions, including bank stabilization, sediment filtration, nutrient cycling, floodwater attenuation, and the provision of critical wildlife habitats (Abubakar and Farouk, 2023). Their vegetative cover acts as a natural buffer, intercepting pollutants from overland flow, maintaining water quality, and regulating microclimatic conditions which is very vital for aquatic biota. The integrity of riparian ecosystems is therefore essential to the health and sustainability of river systems and the human communities that depend upon them (Adejumo and Osunwale, 2024).

Globally, riparian zones have come under increasing pressure from anthropogenic activities, with urbanization emerging as a primary driver of

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their degradation and loss (Adogamhe, 2024). As human populations expand and development intensifies, the conversion of natural landscapes into urban areas leads to the disintegration and removal of these sensitive ecotones. This transformation profoundly affects ecosystem functioning and presents formidable sustainability challenges across sectors such as water resources management, flood control, and biodiversity conservation (Akinbiola *et al.,* 2025). The ecological consequences of riparian degradation are particularly acute in developing regions where rapid urbanization often outpaces the capacity for environmental planning and regulation.

In Nigeria, the situation has become increasingly alarming. As the seventh most populous country globally, with projections indicating growth from 208 million in 2020 to 419 million by 2058 , Nigeria experiences quick population growth that exerts immense pressure on land cover and natural resources (Dossa *et al.,* 2025) . This demographic expansion has triggered substantial modifications in land use nationwide, with river basins experiencing particularly significant land cover changes resulting in biodiversity loss and environmental degradation (Dossa *et al.,* 2025). The demand for land for urban development has led to unplanned and extensive reclamation of wetlands, encroachment on natural drainage channels, and unrestrained deforestation along water courses. These uncontrolled expansions have serious consequences for environmental quality, including increased flooding vulnerability and compromised water resources integrity (Ezekwe *et al.,* 2021).

Research across Nigerian cities has documented the increasing threat to riparian ecosystems. In Osogbo city, studies revealed that riparian vegetation declined at rates of 2.63% per annum between 1986 and 2000, with built-up areas expanding from 9% to 41% of the study area by 2015, consuming most of the narrow riparian strips along river channels (Fabiyi and Daudu, 2025). Similarly, investigations in the Calabar River demonstrated that stations with sparse riparian vegetation showed markedly different substrate characteristics siltier and sandier compared to areas with dense riparian coverage, with important consequences for aquatic macroinvertebrate communities and overall river health (Garba *et al.,* 2023). The Wuye River in Abuja provided further evidence that unplanned urban settlements adjacent to water bodies exhibit elevated nitrate concentrations and intensified turbidity levels, indicating compromised water quality directly linked to riparian degradation (Jankaro Larai *et al.,* 2023).

The implication of riparian vegetation along Nigeria Rivers cannot be over emphasized especially the River Ogun and its effect on many Rivers in Nigeria which needs an urgent attention and further studies (Fashae *et al.,* 2023)

Kaduna State, the geographical focus of this study, characterizes these national trends. The Kaduna Metropolis has undergone substantial land use transformations driven by settlement expansion and agricultural activities, identified as the primary drivers of wetland changes in the area (Jijuwa Ijafiya *et al.,* 2023). Geospatial analysis of the metropolis between 1986 and 2023 revealed that built-up areas increased by 194.9 km², while riparian vegetation suffered a loss of 28.6 km² and marshlands declined by 15 km². These changes underscore the vulnerability of riparian ecosystems within the region and highlight the urgent need for systematic assessment of urban encroachment patterns.

Mando, located within the Kaduna urban landscape, represents a critical case study for examining the interface between urban development and riparian conservation. Like many peri-urban settlements in Nigeria, Mando has experienced significant growth without corresponding planning frameworks to protect its hydrological features. The absence of designated buffer zones and limited regulatory oversight has allowed construction activities to approach river channels, increasing both environmental risks and community susceptibility to flooding events. This pattern mirrors observations from Ibiono-Ibom, where urbanization was identified as modifying the structure and morphology of landscapes, with population growth directly related to massive infrastructural development encroaching on all other land spaces, including riparian vegetation and wetlands (Olokeogun *et al.,* 2020).

The methodological approaches employed in previous Nigerian riparian studies provide valuable frameworks for this investigation. Remote sensing and Geographic Information Systems (GIS) techniques have proven effective in detecting temporal trends in riparian vegetation degradation and quantifying urban encroachment patterns. Studies have successfully utilized Landsat imagery (TM, ETM+, and OLI sensors) coupled with vegetation indices such as NDVI to assess changes in riparian density over multi-decadal periods (Morán-Alonso *et al.,* 2025) . Buffer analysis, typically employing 100-meter corridors around river channels, has been instrumental in delineating areas of high ecological sensitivity and quantifying the magnitude of settlement encroachment into flood-prone zones. These geospatial techniques enable rigorous assessment of land use/land cover dynamics and provide empirical evidence for policy

formulation (Nabiollahi *et al.,* 2024).

Despite the growing body of research on riparian degradation in Nigerian urban centers, site-specific studies for rapidly developing areas like Mando remain limited. The scarcity of localized research hampers the identification of critical areas requiring conservation interventions and obstructs the development of targeted management strategies (Orimoogunje *et al.,* 2021). Yet such studies are essential to fostering sustainable development, mitigating biodiversity loss, and combating environmental degradation in alignment with the Sustainable Development Goals (SDGs), particularly Goal 6 (Clean Water and Sanitation), Goal 11 (Sustainable Cities and Communities), and Goal 15 (Life on Land) (Panjala *et al.,* 2022).

This study addresses this knowledge gap by conducting a comprehensive evaluation of urban development encroachment on the riparian zones of Mando, Kaduna State. By documenting the spatial and temporal patterns of land use change, quantifying the extent of riparian vegetation loss, and assessing the proximity of settlements to water bodies, the research aims to generate evidence that can inform sustainable land use planning and riparian conservation strategies. The findings will contribute to the broader understanding of urbanization impacts on sensitive ecosystems in Nigeria and support efforts to balance development needs with environmental protection in the Kaduna region.

2.0 Methodology

2.1 Description of the Study Area

Mando is a rapidly urbanizing peri-urban settlement located in Igabi LGA of Kaduna state, Nigeria. It is positioned along the Kaduna-Lagos highway, a major transportation corridor that significantly influences its growth. Mando lies to the northwest of Kaduna metropolis, serving as a gateway into the city from the western region. The geographical coordinates of the study area are approximately between: 10°32'N and 10°36'N latitude and 7°22'E and 7°26'E longitude

The strategic location of Mando near key infrastructures, such as the Kaduna International Airport, Nigerian Defense Academy (NDA), and Federal College of Forestry Mechanization, has contributed to the rapid land-use transformation, making it an ideal case study for urban expansion and environmental impact analysis. The terrain of Mando is relatively flat to gently undulating, with elevations ranging from 600 to 650 meters above sea level. The dominant soil types include ferruginous tropical soils, which support both natural vegetation and agricultural activities. However, rapid urbanization and infrastructure development have led the study area to soil degradation, increased surface runoff, and erosion risks.

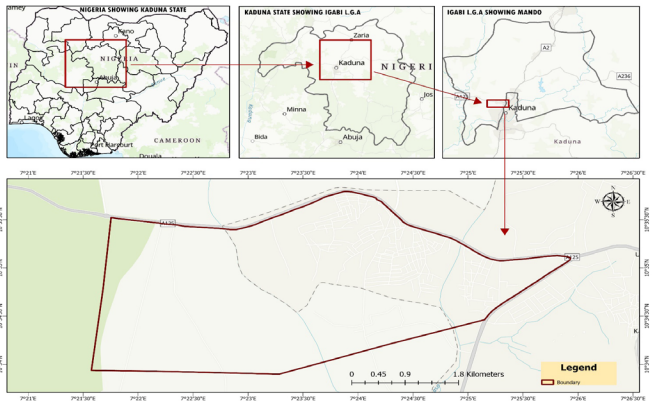


Figure 1 Map of Kaduna showing the Study Area

2.2 Materials

Materials used for the study include; Satellite Imagery: Multi-temporal, cloud-free satellite images (Landsat 8/9, Sentinel-2) for two epochs (2010 and 2023) to perform land use/land cover (LULC) classification and calculate changes in impervious surface area. Ancillary Geospatial Data: High-resolution base maps, digital elevation models (DEMs) (SRTM, ALOS), soil maps, and administrative boundaries for the study area. These were sourced from national agencies or open portals like USGS Earth Explorer, ArcGIS Pro, Topographic map, Landsat 7 and 8 TM, ETM+ and OLI Imagery etc.

2.3. Methods

2.3.1 Research Design

The study primarily utilizes remote sensing and geographic information systems (GIS) for spatial analysis, supported by field observation and validation.

2.3.2 Data Collection

The primary data types include Landsat Imagery (Thematic Mapper, TM, Enhanced Thematic Mapper Plus, ETM $^{+}$ and Operational Land Imager, OLI for 2004. 2014 and 2024) for and-use/cover mapping and change detection. Satellite imagery forms the backbone of this research, providing the raw data for mapping Land Use/Land Cover (LULC) and detecting the changes over time. Landsat imagery was used with a band combination of 543 for sensors was selected for the Image classification analysis.

2.3.3 Data Pre- processing

Before analysis, the acquired satellite images were pre-processed using the steps below and a combination of ENVI 4.5 and ArcGIS (ArcMap)

- Geometric Correction/ Georeferencing: Ensures all images aligned accurately with a common coordinate system (WGS 1984)
- Image Sub-setting: Clipping the satellite images to the precise extent of the Mando study area boundary, performed in ArcGIS.
- Layer Stacking/Band combination: Combining relevant spectral bands of the multispectral imagery to create composite images suitable for classification, often done in ENVI.

2.3.4 Land Use/Cover Classification and Mapping

A supervised classification method was utilized in ENVI 4.5 to derive LULC maps for 2004, 2014, and 2024. Classification Scheme: Based on the study objectives and visual interpretation of the imagery, the following land use/cover classes were defined; Settlement, Farmland, Vegetation (non-riparian), Water body and Bare-land. In Training Sample Collection, each image representative training samples (pixels known to belong to each class) were identified based on visual interpretation, existing maps, and general knowledge of the area, done with ENVI 4.5. Classification Algorithm: The Maximum Likelihood algorithm was employed within ENVI 4.5 to classify the pixels of each image into the defined land use/ cover classes. Post-Classification Processing: Minor misclassifications were corrected using manual editing and filtering techniques, potentially using tools in both ENVI4.5 (for raster editing) and ArcGIS (for vector conversion and refinement), to improve the overall accuracy and visual coherence of the land use/cover maps.

2.3.5 Urban Expansion Analysis

The spatial and temporal dynamics of urban expansion were assessed using the derived LULC maps within the ArcGIS environment: The areal extent (in hectares or square kilometers) of the ‹Settlement› class was quantified for each of the three study years (2004, 2014, and 2024). Change detection analysis, specifically post-classification comparison, was performed to identify and quantify the transitions between LULC classes, with a focus on the conversion of other land uses to ‹Settlement›. A thematic map illustrating the chronological progression of settlement growth was generated, depicting areas settled by 2004, new settlements between 2004 and 2014, and further expansion between 2014 and 2024.

2.3.6 Assessment of Urban Encroachment on Water Bodies

The extent of urban development impacting on hydrological features was evaluated using ArcGIS. The Settlement layers from the LULC maps were spatially overlaid with the vector layers representing the Drainage Network and Waterbody features.

2.3.7 Evaluation of Riparian Corridor Condition

The condition of riparian corridors was assessed primarily by examining the extent and changes in ‘Vegetation’ and ‘Waterbody’ classes immediately adjacent to the drainage network in the land use/cover maps for 2004, 2014, and 2024. Separate “Riparian Condition” maps were generated, highlighting the presence of water and riparian vegetation for each study year.

3.0 Results/Findings

3.1 Results

3.1.1 Urban Expansion and Land Use/Cover Change

The Urban expansion and landuse/cover change comprises of Landuse/Cover Area Statistics (Table 1), settlement land area (Table 2) and vegetation land area (Table 3) in the study area.

Table 1 Land Use/Cover Area Statistics

Land Use Class	Area in 2004(ha)	Percentage (%) in 2004	Area in 2014 (ha)	Percentage (%) in 2014	Area in 2024(ha)	Percentage (%) in 2024
Settlement	112.3	6.29	340.59	19.09	592.02	33.05
Vegetation	226.4	12.68	137.3	7.70	83.8	4.68
Farmland	570.62	31.97	527.8	29.59	458.2	25.58
Bare Land	857.7	48.05	759.6	42.58	641.9	35.83
Water body	18.1	1.01	18.72	1.05	15.51	0.87
Total	**1785.12**	**100**	**1784.01**	**100.01**	**1791.43**	**100.01**

Hint: The percentage of each land use class was calculated using the following formula:

Percentage (%) = (Area of Land Use Class / Total Study Area) × 100

Table 2 Settlement land area

Year	Percentage (%)	Settlement (ha)
2004	6.3	112.3
2014	19.1	340.59
2024	33.2	592.02

Table 3 Vegetation Land Area in Mando

Year	Percentage (%)	Vegetation (ha)
2004	12.7	226.4
2014	7.7	137.3
2024	4.68	83.8

Figure 2.0 presents the satellite imagery for the study area across the three time points: 2004, 2014, and 2024. The progression from 2004 (Figure 2.0), where greenish hues are more widespread, to 2014 (Figure 3.0) and culminating in 2024 (Figure 4.0), where magenta/purple tones indicative of development become increasingly dominant, visually underscores the significant urban expansion and reduction in vegetative cover that has occurred over the two-decade period.

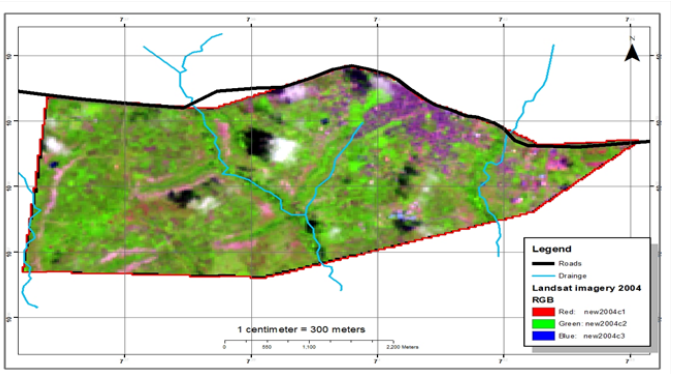


Figure 2 Satellite Imagery of Mando Study Area showing Landscape Transformation 2004

The analysis of land use/cover maps and settlement change over the 20-year period (2004-2024) as shown in Figures 5.0, 6.0, 7.0, and 8.0 clearly indicates a significant and progressive urban expansion in Mando. The statistics presented in Table 1.0 shows that; in 2004, as depicted in Figure 5.0 settlement areas were present but somewhat dispersed. Large areas were characterized by farmland, vegetation, and bare land; by 2014 (Figure 6.0) settlement areas had visibly increased, infilling spaces between older settlements and expanding outwards and by 2024 (Figure 7.0), settlement areas dominated large portions of the study area, forming more contiguous built-up areas.

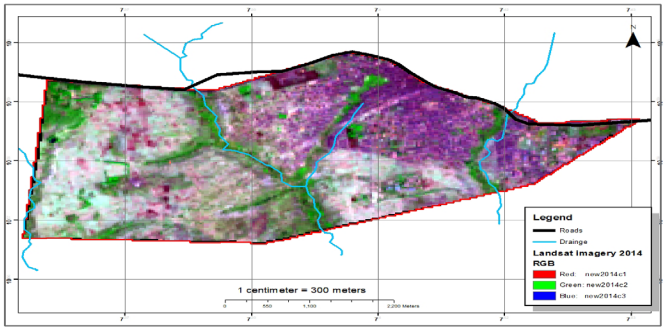


Figure 3 Satellite Imagery of Mando Study Area showing Landscape Transformation 2014

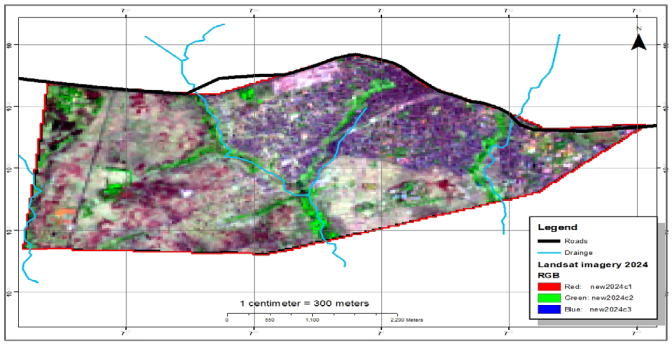


Figure 4 Satellite Imagery of Mando Study Area showing Landscape Transformation 2024

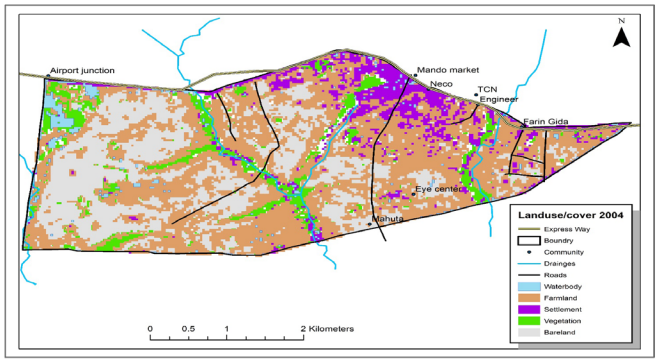


Figure 5 Land Use/Cover in Mando, 2004

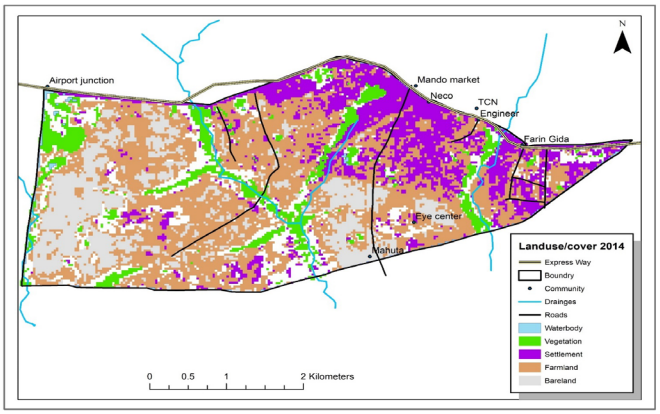


Figure 6 Land Use/Cover in Mando, 2014

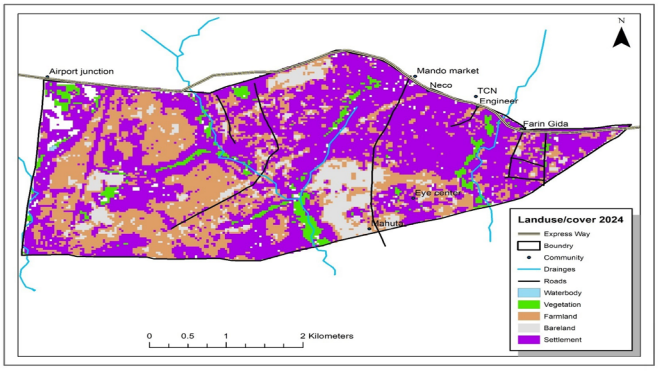


Figure 7 Land Use/Cover in Mando, 2024

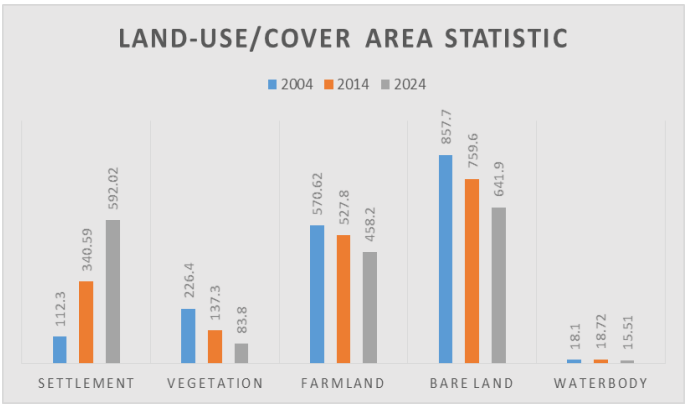


Figure 8 Area of Land Use/Cover Classes in Mando (2004, 2014, and 2024)

The massive and rapid growth of settlements in Mando means the city is under great pressure. With so much farmland and natural land replaced by buildings, there is less space to grow food locally, and essential services like water and electricity are likely stressed, pugnacious and struggling to keep up with the demand. The loss of green spaces also makes the city hotter and less pleasant to live in.

Figure 8.0 visually depicts the land-use/cover area statistics for Mando across the study years 2004,

2014, and 2024, presenting a compelling overview of the changing landscape. The bar chart format facilitates a direct visual comparison of the area covered by each land use class over time, highlighting key trends in urban expansion and land cover conversion

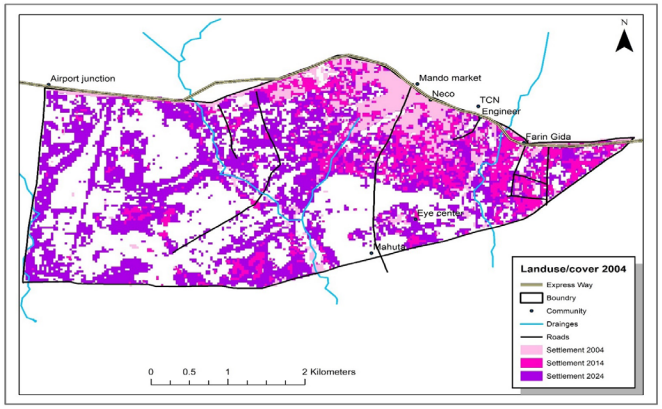


Figure 9 Settlement Expansion in Mando (2004, 2014, and 2024)

3.1.2 Encroachment of Urban Development on Water Bodies

Evaluation of the land use/cover maps as shown in Figures 5.0, 6.0 and 7.0 respectively alongside the drainage network indicates a clear trend of urban development encroaching on areas adjacent to water bodies. This indicates that; in 2004 as indicated in Figure 5.0), settlements were generally situated at a distance from the main drainage channels; by 2014 (Figure 6.0), new settlements were observed developing closer to these drainage channels and by 2024 (Figure 7.0), settlements have expanded significantly, with many new developments in immediate proximity to the mapped drainage lines, reducing the natural space previously separating urban areas from water bodies. This encroachment is visually evident when comparing the settlement expansion (Figure 9.0) with the location of drainages.

The finding that new homes are being built right up against rivers and drainage channels has created a direct and immediate danger. These settlements are now in the path of future floods, putting lives and property at extreme risk. It also means that pollution and waste from these homes flow straight into the water, contaminating it for everyone downstream.

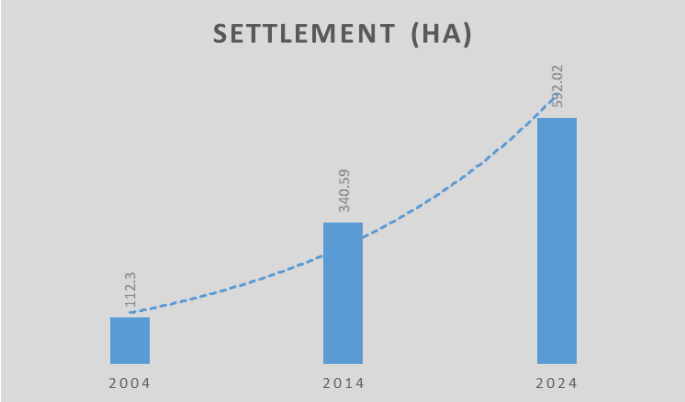


Figure 10 Increase in Settlement (2004, 2014 and 2024)

3.2 Discussion

3.2.1 Condition of Riparian Corridors and Buffer Zone Mapping

The encroachment of urban development has directly affected the condition of riparian corridors along water bodies in Mando. The state of these corridors, primarily assessed through the extent of riparian vegetation, is depicted in the riparian condition maps as shown in Figures 11.0, 12.0, and 13.0) for the years 2004, 2014, and 2024, respectively. Furthermore, in 2004, the Riparian Condition map as indicated in Figure 11.0 shows relatively extensive and connected stretches of riparian vegetation; by 2014 as indicated in Figure 12.0), there was a noticeable reduction and fragmentation of this riparian vegetation and by 2024 as indicated in Figure 13.0), the riparian vegetation is severely diminished and highly fragmented and Figure 14.0 shows the decline in Riparian vegetation area in the study area (Mando).

By destroying the natural vegetation along the riverbanks, Mando has lost its natural flood defense system. These plants once acted like a sponge, but now that they are gone, floods will be much more powerful and destructive. This has also destroyed vital homes for local wildlife and weakened the riverbanks, making them more likely to erode and collapse.

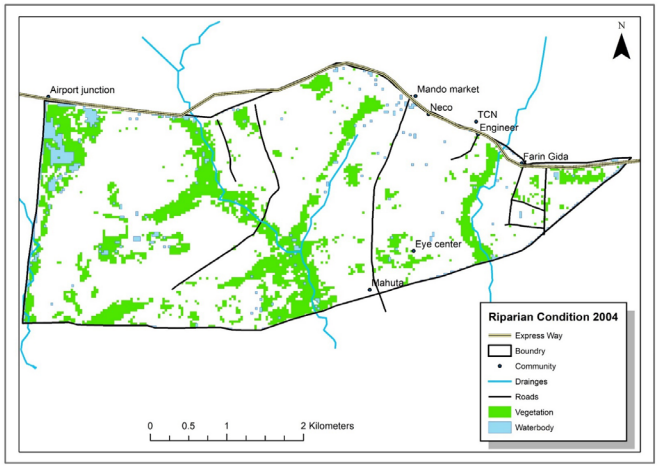


Figure 11 Riparian Condition in Mando, 2004

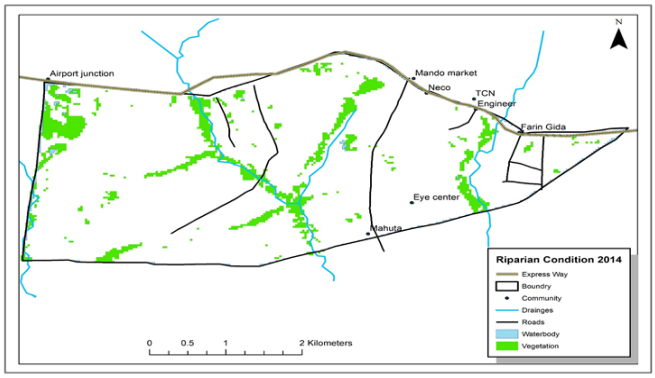


Figure 12 Riparian Condition in Mando, 2014

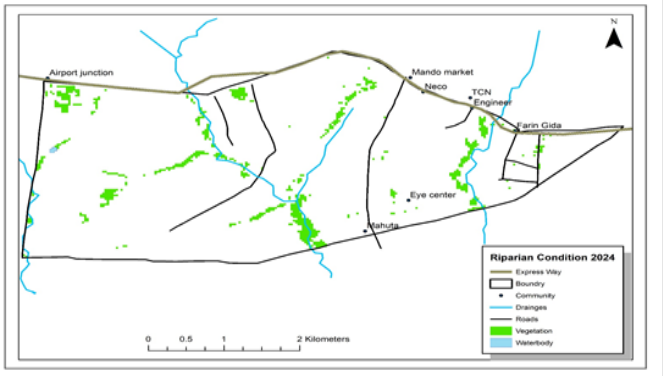


Figure 13 Riparian Condition in Mando, 2024

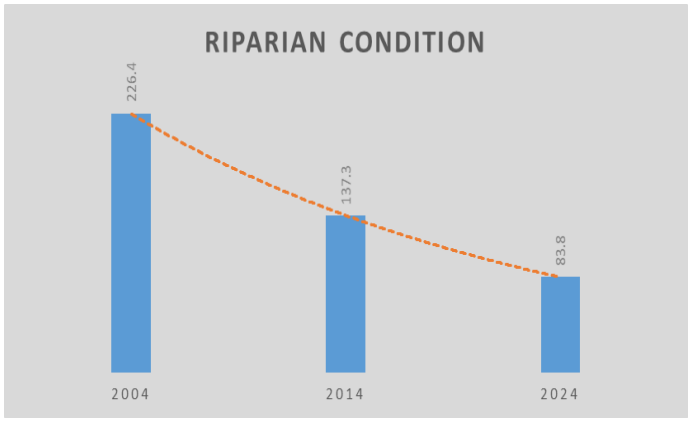


Figure 14 Decline in Riparian Vegetation Area in Mando (2004-2024)

3.2.2 Buffer Zone Mapping and Analysis

To provide a clear guideline for flood risk management, a 100-meter buffer zone was delineated along all major drainage channels, as illustrated in Figure 15.0. This buffer represents a scientifically recommended setback distance to protect both the water body and human settlements. However, the analysis reveals that this buffer is already heavily compromised by existing development. This means that these people are living in the most dangerous places. Their homes are now at high risk of being destroyed by floods. It also shows that building rules have been broken, and fixing this problem to protect the city in the future will be very difficult and expensive.

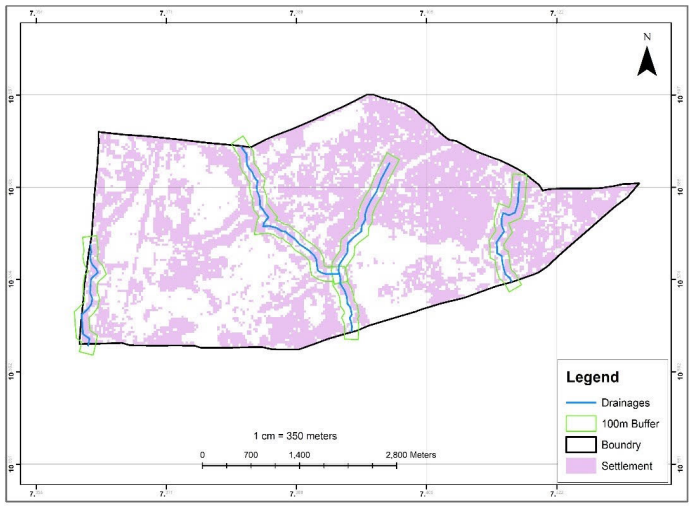


Figure 15 Mapped 100m Buffer Zone Showing Settlement Encroachment

4.0 Conclusion and Recommendations

4.1 Conclusion

The findings of this study finally established and affirmed that Mando has undergone rapid and substantial urban expansion between 2004 and 2024. This growth, largely unplanned and unregulated, is quantified by the significant increase in settlement areas from 112.30ha in 2004 to 592.02ha in 2024 as shown in Table 2.0. However, a direct consequence of this expansion has been the significant encroachment of urban development onto lands adjacent to water bodies. The primary implication of this trend is a drastically increased risk of severe flooding, placing lives and property in immediate danger. The mapping of a 100-meter buffer zone clearly identifies these encroached settlements as high-risk areas, transforming predictable rainfall into potential disasters.

Moreover, this encroachment has directly caused a severe degradation and marked loss of riparian vegetation. The area of riparian vegetation diminished from 226.4ha in 2004 to 83.8ha in 2024 as indicated and shown in Table 3.0. This loss has not only reduced the natural buffer capacity against flooding but has also compromised the ecological integrity of watercourses, leading to poorer water quality due to unfiltered runoff and a significant decline in local biodiversity. Furthermore, this study reveals a hazardous feedback loop where uncontrolled growth drives encroachment, which in turn destroys the very ecosystems that protect the city. The observed trends underscore an urgent need to break this cycle through strategic urban planning, effective development control measures, and proactive environmental management. Such interventions are critical not just to mitigate the adverse impacts of past expansion but to guide the future development of Mando towards a path of resilience, safety, and long-term sustainability.

4.2 Recommendations

Sequel to the findings of this study, the following key actions are recommended to address the challenges of urban expansion and environmental degradation in Mando:

1. There should be implementation of clear landuse plan by developing and enforcing landuse plan which will show clearly where new buildings are allowed and very importantly designate areas near rivers and drainage channels as no-build or restricted zones.
2. There should be establishment and protection of Riparian Buffer Zones which will mark out protective buffer zones along all the rivers and major drainage lines, prohibit any new construction or harmful activities within these zones which will safeguard water quality, reduce flood risk, and preserve the natural environment along waterways.
3. There should be commencement of projects to replant native trees and vegetation along riverbanks and drainage channels where natural cover has been lost in order to restore degraded riparian areas and this will help to stabilize riverbanks, improve water filtration, and bring back habitat for local wildlife.
4. There should be law that will strengthening the monitoring and enforcement which will increase regular checks by authorities to ensure that landuse plans and buffer zone restrictions are being followed and apply fair penalties for violations in order to ensure that protective measures are very effective and that illegal construction is stopped.
5. There should be a sensitization program for all residents to promote community awareness and participation which will educate local residents, community leaders, and developers about the importance of protecting water bodies and riparian areas which will involve them in planning and restoration efforts to build understanding and shared responsibility for sustainable practices, leading to better long-term care of the environment.

References

Abubakar, L. M., & Farouk, A. A. (2023). Geospatial Analysis of Land Use Change and

Wetland Dynamics in Kaduna Metropolis, Kaduna - Nigeria. Research Square Platform LLC. https://doi.org/10.21203/rs.3.rs-3183200/v1.

Adejumo, S. A., & Osunwale, S. (2024). Urban Expansion and Loss of Watershed of

Eleyele Dam in Ibadan, Nigeria. CSID Journal of Infrastructure Development, 7(1). https://doi.org/10.7454/jid.v7.i1.1113

Adogamhe, P. (2024). Nigeria's Urban Transition: Trends, Patterns and Policy

Implications. African Journal of Economic and Management Studies. (Cited in Dossa et al., 2025)

Akinbiola, S. A., Alabi, A. T., Olubaju, A. E., & Ogundahunsi, O. E. (2025). Geospatial

Assessment and Multi-Criteria Land Suitability

Analysis for Irrigation. African Journal on Land Policy and Geospatial Sciences, 8(8), 1434-1445. https://doi.org/10.48346/IMIST.PRSM/ajlp-gs.v8i8.58201

Dossa, K. F., Miassi, Y. E., Bakary, S., & Ogou, F. K. (2025). Drowning in urban growth:

rethinking flood resilience and spatial equity in Lagos, Nigeria. Frontiers in Sustainable Resource Management, 4, 1659930. https://doi.org/10.3389/fsrma.2025.1659930

Ezekwe, C. I., & Anya, M. U. K. (2021). Landuse change and sediment yield in an

urbanized tropical deltaic catchment in Port Harcourt, South-South of Nigeria. International Journal of Hydrology Science and Technology, 11(3), 245-268. https://doi.org/10.1504/IJHST.2021.114538

Fabiyi, O. O., & Daudu, T. V. (2025). Spatial analysis of wetland dynamics and Sea level

rise effects on Nigerian coastal area: Case study of Ilaje local government area, Ondo state. Contemporary Issues in Planning and Environmental Studies, 1(2), 204217. https://doi.org/10.5281/zenodo.17867734

Fashae, O. A., & Obateru, R. (2023). Riparian vegetation along Nigeria Rivers: The River

Ogun example. In A. Faniran, L. K. Jeje, O. A. Fashae, & A. O. Olusola (Eds.), Landscapes and Landforms of Nigeria (pp. 175–190). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-17972-3_12

Garba, S. I., Ebmeier, S. K., Bastin, J. F., Mollicone, D., & Holden, J. (2023). Wetland

mapping at 10 m resolution reveals fragmentation in southern Nigeria. Wetlands Ecology and Management, 31, 329-345. https://doi.org/10.1007/s11273-023-09919-2

Jankaro Larai, S., Odofin, A. J., Lawal, B. A., & Onuigbo, I. C. (2023). GIS-Based

Irrigation Suitability Evaluation of Lapai-Agaie Irrigation Scheme, Niger State, Nigeria. Journal of Agripreneurship and Sustainable Development, 6(1), 41-46. https://doi.org/10.59331/jasd.v6i1.390

Jijuwa Ijafiya, D., Abubakar, U. Y., & Liman, A. B. (2023). Perceptions on the Impacts of

Morphological Changes on the Lower Course of River Mayo-Inne, Yola South, Adamawa State, Nigeria. FUDMA Journal of Sciences, 7(3), 215-223. https://doi.org/10.33003/fjs-2023-0703-1858

Morán-Alonso, N., Viedma-Guiard, A., Simón-Rojo, M., & Córdoba-Hernández, R.

(2025). Agricultural Land Suitability Analysis for Land Use Planning: The Case of the Madrid Region. Land, 14(1), 134. https://doi.org/10.3390/land14010134

Nabiollahi, K., M. Kebonye, N., Molani, F., Tahari-Mehrjardi, M. H., Taghizadeh-

Mehrjardi, R., Shokati, H., & Scholten, T. (2024). Assessment of Land Suitability Potential Using Ensemble Approaches of Advanced Multi-Criteria Decision Models and Machine Learning for Wheat Cultivation. Remote Sensing, 16(14), 2566. https://doi.org/10.3390/rs16142566

Olokeogun, O. S., Ayanlade, A., & Popoola, O. O. (2020). Assessment of riparian zone

dynamics and its flood-related implications in Eleyele area of Ibadan, Nigeria. Environmental Systems Research, 9(1), 6. https://doi.org/10.1186/s40068-020-00167-4

Orimoogunje, O. O. I., Adeleke, B. O., Dada, E., Shote, A. A., Eudoxie-Okafor, A. N., &

Nwayor, J. I. (2021). Dynamism of Landscape Transformation in Ibiono-Ibom, Akwa-Ibom State, Nigeria. Journal of Landscape Ecology, 14(1), 19-38. https://doi.org/10.2478/jlecol-2021-0002.

Panjala, P., Gumma, M. K., Ajeigbe, H. A., Badamasi, M. M., Deevi, K. C., & Tabo, R.

(2022). Identifying Suitable Watersheds across Nigeria Using Biophysical Parameters and Machine Learning Algorithms for Agri–Planning. ISPRS International Journal of Geo-Information,11(12),612. https://doi.org/10.3390/ijgi11120612.