

Geospatial Assessment of Land Use/Land Cover Dynamics in Wukari–Donga, Taraba State, Nigeria: Implications for Erosion Vulnerability

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Abstract- *Land-use/land-cover (LULC) change is an important component of landscape transformation and may influence environmental conditions relevant to soil-erosion vulnerability. This study assessed the spatial and temporal dynamics of LULC in the Wukari–Donga area of Taraba State, Nigeria, for 2000, 2010 and 2024, and examined their potential implications for erosion vulnerability. Multi-temporal Landsat imagery, supported by Sentinel-2 imagery for training-sample identification and verification, was processed in ArcGIS Pro. Seven LULC classes—water, trees/savanna woodland, flooded vegetation, cropland, built-up area, bare ground and rangeland—were mapped using supervised Maximum Likelihood Classification. Area statistics, percentage changes and cross-tabulation were used to assess the spatial extent and temporal dynamics of the classes. In 2024, rangeland was the dominant class, covering 4,249.71 km² (60.94%), followed by cropland (1,285.25 km²; 18.43%) and trees/savanna woodland (1,240.68 km²; 17.79%). Between 2000 and 2024, tree/savanna woodland declined by 52.76% and cropland by 30.66%, whereas rangeland increased by 75.08%. Built-up area, bare ground, flooded vegetation and water bodies increased by 2,077.56%, 3,595.26%, 587.17% and 31.85%, respectively, although the large relative increases in built-up area and bare ground reflected their very small initial extents. LULC change was not uniform: cropland and tree cover increased between 2000 and 2010 but declined substantially during 2010–2024, while rangeland followed the opposite trajectory. The results demonstrate substantial landscape reorganization and identify changes in vegetation, cultivated and exposed surfaces that may influence erosion vulnerability. The findings provide a geospatial basis for sustainable land-use planning and soil-resource management in the Wukari–Donga area.*

Keywords: *Land-use/land-cover change; Remote sensing; Geographic Information System (GIS); Soil erosion vulnerability; Wukari–Donga.*

I. INTRODUCTION

Land cover refers to the biophysical materials and features occupying the Earth's surface, including vegetation, water bodies, bare soil, rocks, buildings and roads; whereas land use refers to the human activities, arrangements and management practices through which land is utilized for particular social and economic purposes, such as cultivation, grazing, timber extraction, conservation and settlement (IPCC, 2022; Sleeter et al., 2018). Land-use/land-cover change (LULCC) therefore describes changes in land-cover classes and/or land-use categories and management over time, resulting from changes in land use, natural conditions, or their interaction (IPCC, 2022). These changes may be driven by anthropogenic activities, including deforestation, agricultural expansion or intensification, urbanization and other forms of land management, as well as by natural and climate-related processes such as drought, wildfire, flooding and other ecological or geomorphological disturbances (Lambin et al., 2001; Chen et al., 2012; Sleeter et al., 2018).

Land-use and land-cover (LULC) changes are important components of global environmental change because they transform and reorganize natural and human-dominated landscapes, with consequences for biodiversity, carbon storage, hydrological processes, soil properties and ecosystem services (Foley et al., 2005; Hasan et al., 2020). Understanding their spatial and temporal dynamics is therefore essential for environmental monitoring, natural-resource management and sustainable land-use planning. LULC change results from interacting demographic,

socioeconomic, institutional, technological and environmental factors. Population dynamics, agricultural expansion, settlement development, infrastructure and economic opportunities can influence land-use decisions and the resulting landscape patterns (Lambin et al., 2001). Assessment of LULC change should consequently consider the magnitude, direction and spatial pattern of land-cover transitions, which help reveal the processes underlying landscape transformation (Pontius et al., 2004).

Changes in vegetation cover and land use can alter infiltration and surface runoff and consequently influence soil erosion processes (Negese, 2021). Vegetation cover helps protect the soil surface from raindrop impact, enhance infiltration and reduce runoff velocity and sediment transport (Negese, 2021). However, soil erosion results from the interaction of rainfall, soil properties, topography, cover management and support practices rather than LULC alone (Phinzi & Ngetar, 2019). Therefore, LULC assessment provides an important basis for identifying changes in surface conditions that may influence erosion vulnerability.

The relationship between LULC dynamics and erosion vulnerability has been widely studied. Studies have demonstrated that changes in vegetation and other land-cover conditions can be associated with differences in runoff and soil-erosion processes (Negese, 2021). LULC information has been integrated with soil-erosion assessment. Obiahu and Elias (2020) combined remote sensing, GIS and the Revised Universal Soil Loss Equation to investigate the relationship between LULC change and soil erosion in the Upper Eyiohia River catchment. Such studies reinforce the need for reliable spatial information on LULC where changes in vegetation, cultivated land, exposed surfaces and built-up areas may alter the environmental conditions relevant to soil conservation.

The development of satellite remote sensing and geographic information systems (GIS) has greatly enhanced the ability to observe and analyse LULC dynamics (Makhdumi et al., 2025). Remote sensing provides repeated observations of the Earth's surface over broad geographical areas, while GIS provides tools for spatial data management, classification, overlay analysis, change detection and visualization. The combination of these technologies enables researchers

to characterize land-cover conditions at different points in time and to identify the location and nature of landscape transitions (Treitz & Rogan, 2004). Multi-temporal satellite imagery is particularly valuable because it allows changes to be examined consistently across extended periods. The development of increasingly sophisticated remote-sensing datasets and analytical approaches has further expanded the capacity to characterize land change in terms of its location, timing, magnitude and spatial pattern (Zhu et al., 2022). In Nigeria, the application of remote sensing and GIS to LULC assessment has expanded considerably in response to increasing environmental and land-management challenges. A systematic review of Nigerian LULC research by Alegbeleye et al. (2024) identified substantial growth in LULC studies and demonstrated the wide application of satellite imagery, GIS and classification techniques for investigating land-cover transformation across different regions and environmental settings.

Taraba State, located in northeastern Nigeria, contains diverse agricultural, savanna, riparian and settlement landscapes that are subject to continuing interactions between human activities and environmental processes. A comprehensive assessment of LULC dynamics is particularly important for Wukari–Donga area of southern Taraba because the landscape supports agricultural activities, settlements, vegetation resources, water bodies and other land uses whose spatial distribution and condition may change over time. Understanding the direction and magnitude of these changes is important not only for documenting landscape transformation but also for interpreting the environmental implications of changing land-surface conditions. In particular, identifying transitions involving vegetation, cultivated land, bare surfaces and built-up areas can provide useful information for understanding changes in soil protection, surface exposure and runoff conditions that may be relevant to erosion vulnerability.

Despite the growing body of research on LULC in Nigeria and Taraba State, there remains a need for an integrated assessment of the Wukari–Donga area using a consistent classification framework and comparable observation periods. A study that evaluates the combined landscape using a common geospatial framework can therefore provide a clearer

understanding of the spatial distribution, magnitude and direction of LULC transitions. Such information can also provide an appropriate basis for discussing the potential environmental implications of landscape transformation, including its relevance to erosion vulnerability. Therefore, this study assesses LULC dynamics in the Wukari–Donga area of Taraba State, Nigeria, by mapping major LULC categories, quantifying their spatial changes, identifying major transition pathways, and examining the spatial pattern of landscape transformation. The study also considers the potential implications of these changes for erosion vulnerability, providing a geospatial basis for sustainable land and soil-resource management.

II. MATERIALS AND METHODS

1. Study Area

Taraba State lies in northeastern Nigeria along the Nigeria–Cameroon border, approximately between $6^{\circ}25'N$ – $9^{\circ}30'N$ and $9^{\circ}30'E$ – $11^{\circ}45'E$. It is bordered by Nasarawa and Plateau States to the west, Bauchi and Gombe to the north, Adamawa to the northeast, Benue to the southwest, and Cameroon to the south and southeast (Oruonye & Adebayo, 2015). The state has an undulating terrain, with low forest in the south and grassland in the north, and its hydrology is dominated by the Benue and Donga Rivers (Imadojemu, 2024). Annual rainfall is approximately 1,100–1,250 mm, with

the wet season generally extending from May to October (NiMET, 2019).

Southern Taraba comprises Takum, Wukari, Donga, Ussa and Ibi LGAs, together with Yangtu Special Development Area. The region lies approximately between $8^{\circ}30'N$ – $9^{\circ}30'N$ and $8^{\circ}30'E$ – $10^{\circ}30'E$ and covers about 14,099 km² (Aboki et al., 2020). It has a tropical climate with distinct wet and dry seasons, Guinea savannah vegetation, and a predominantly agrarian economy, with about 80% of inhabitants engaged in rain-fed agriculture (Aboki et al., 2020).

The study area lies within the Upper Benue Trough, a Cretaceous inland sedimentary basin associated with the West and Central African Rift System (Genik, 1993; Benkhelil, 1989). The basin comprises sedimentary formations overlying Precambrian basement rocks and is structurally characterized by faults, folds, fractures and shear zones (Obaje, 2009; Zaborski et al., 1998). Groundwater occurrence is mainly controlled by lithology, stratigraphy and geological structures, with permeable sandstone units such as the Bima Formation providing important groundwater storage and transmission, while shale and clay-rich formations generally act as aquitards (Okochi et al., 2025). Figure 1 shows map of the study location.

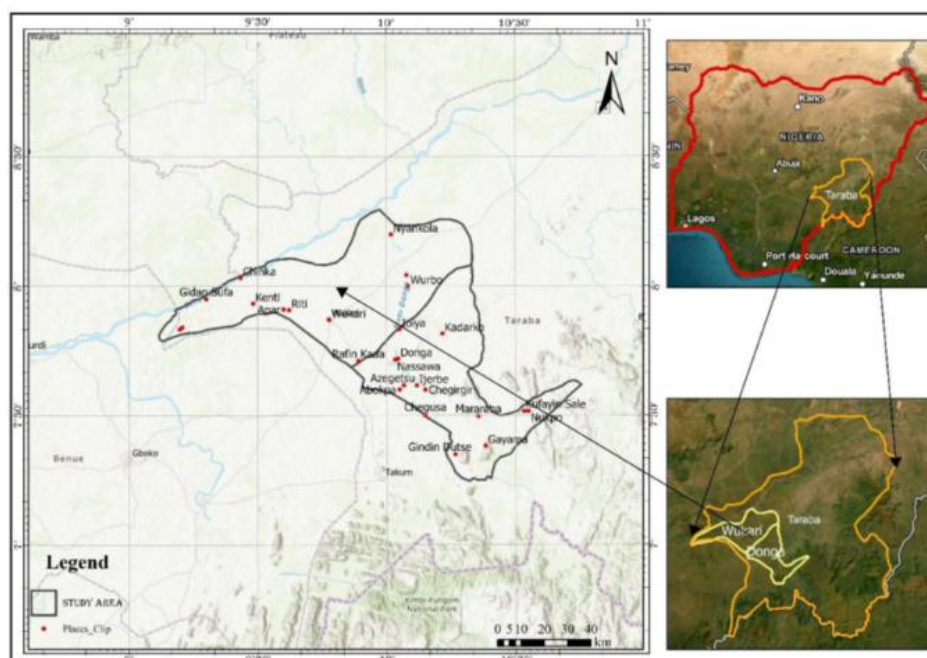


Figure 1: Map of Taraba State Showing the Study Area (Insert-Map of Nigeria) Source: Author

2. Remote Sensing and LULC Classification

Multi-temporal Landsat and Sentinel-2 imagery were used to characterize LULC conditions in the Wukari–Donga study area for 2000, 2010 and 2024. Landsat imagery served as the primary dataset for LULC classification, while Sentinel-2 imagery was used to support the identification and verification of training samples. Sentinel-2 provides multispectral observations at 10, 20 and 60 m spatial resolutions, offering additional spatial and spectral information for land-cover discrimination (Drusch et al., 2012).

The satellite imagery was imported into ArcGIS Pro and subjected to the required preprocessing, including atmospheric correction, mosaicking where necessary, and clipping to the study-area boundary. Seven LULC classes were defined: water, trees/savanna woodland, flooded vegetation, cropland, built-up area, bare ground and rangeland. Training samples were generated for each class using the imagery and knowledge of the study landscape, with Sentinel-2 imagery providing supplementary information for sample identification and verification. A supervised Maximum Likelihood Classification (MLC) was then applied to the Landsat imagery to assign pixels to the defined LULC classes based on their spectral characteristics (Otukei & Blaschke, 2010).

The classified rasters were refined using the Majority Filter and Boundary Clean tools to reduce isolated pixels and improve spatial coherence. All spatial datasets were standardized to a common 30-m spatial resolution, projection, extent and raster alignment, with the DEM used as the snap raster for subsequent raster operations. The resulting LULC maps were used to

determine the spatial distribution and extent of each class for the three observation years.

For each observation year, the area of each LULC class was calculated in square kilometres and as a percentage of the total study area. Temporal changes were quantified for the 2000–2010, 2010–2024 and 2000–2024 periods using:

$$\% \text{ Change} = [(A_{i2} - A_{i1}) / A_{i1}] \times 100$$

where A_{i1} and A_{i2} represent the area of a given LULC class at the beginning and end of each period, respectively. Cross-tabulation of the classified maps was used to identify the spatial distribution and major transition pathways among LULC classes, including persistence, gains and losses, following the approach of Pontius et al. (2004).

Finally, the LULC classes were assigned corresponding RUSLE (Revised Universal Soil Loss Equation) C-factor values based on published soil-erosion studies. The resulting C-factor layer was subsequently incorporated into the erosion-vulnerability assessment to evaluate the contribution of land cover and management conditions to potential soil erosion.

III. RESULTS

1) Spatial Distribution and Temporal Dynamics of LULC

Figures 2, 3, and 4 shows the LULC classification for the study area for years 2000, 2010, and 2024 respectively; while Table 1 shows the spatial extent and net change of LULC for the study period.

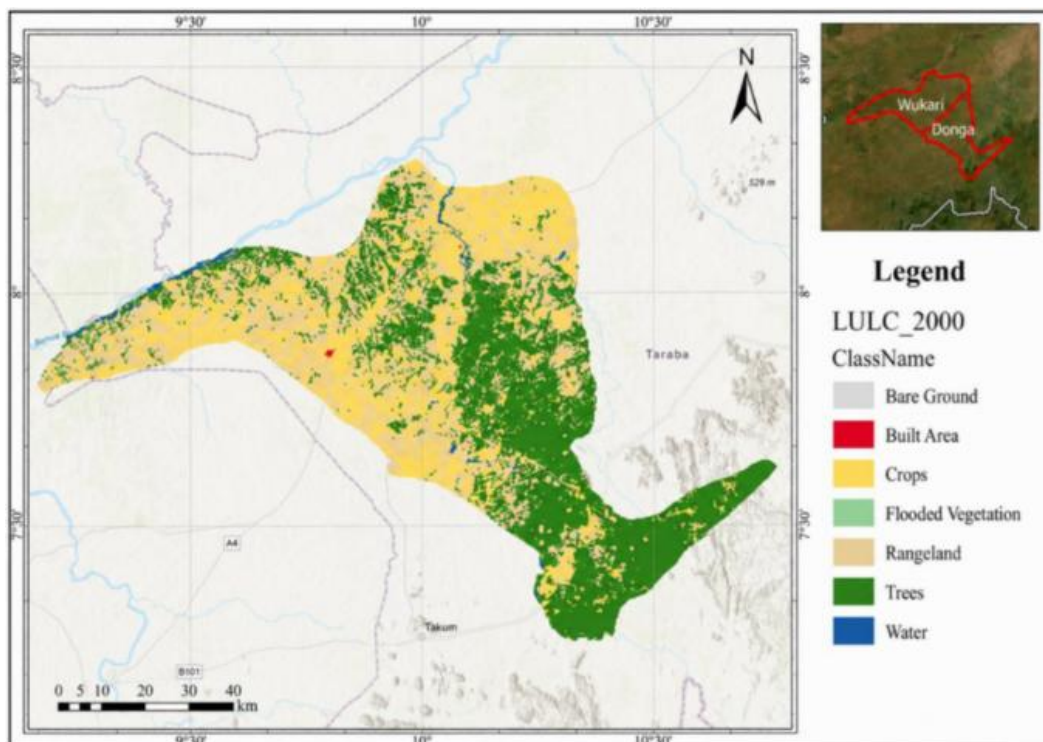


Figure 2: LULC Classification for Year 2000

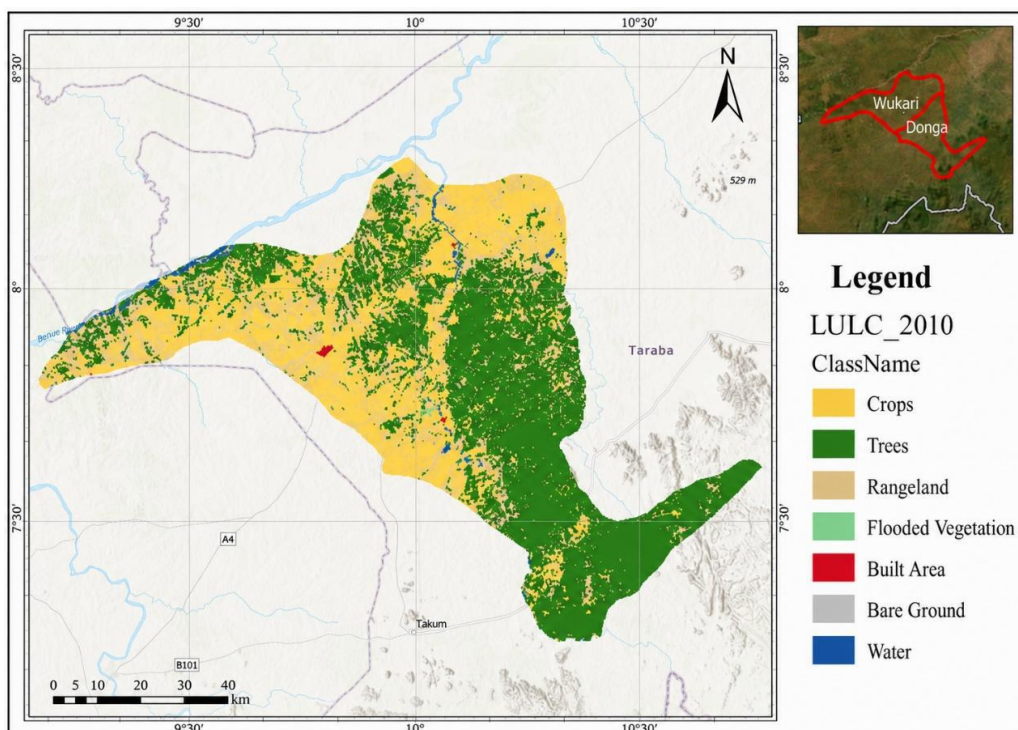


Figure 3: LULC Classification for Year 2010

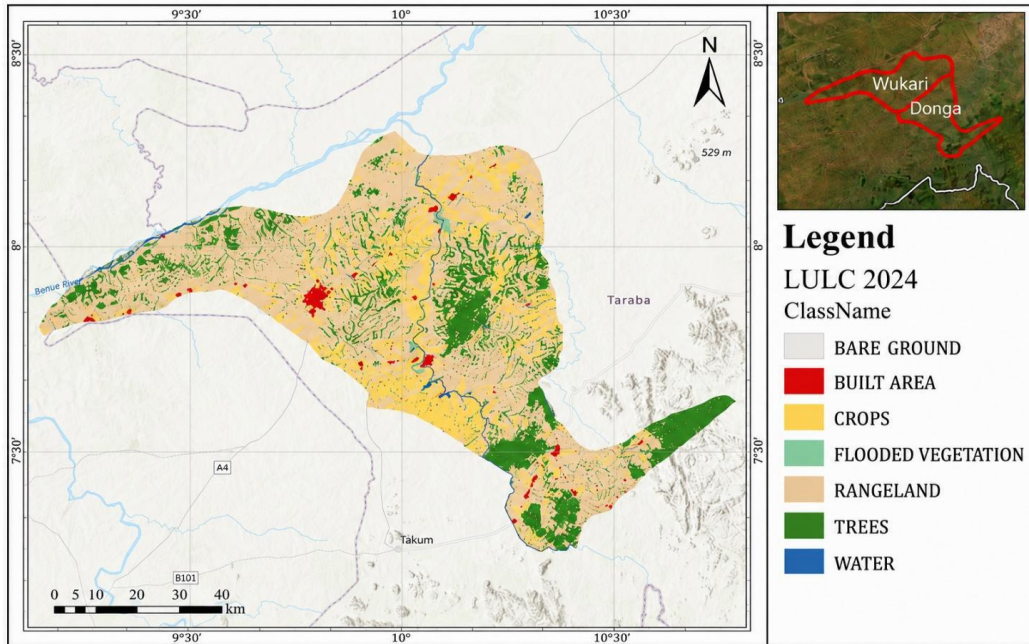


Figure 4: LULC Classification for Year 2024

Table 1: Spatial extent and net change of LULC classes in Wukari–Donga, 2000–2024

LULC class	2000 area (km ²)	2010 area (km ²)	2024 area (km ²)	Net change (km ²)	Change (%)
Crops	1,853.63	2,129.21	1,285.25	−568.38	−30.66
Trees	2,626.47	3,122.17	1,240.68	−1,385.78	−52.76
Rangeland	2,427.27	1,632.20	4,249.71	+1,822.44	+75.08
Flooded vegetation	3.21	20.16	22.04	+18.83	+587.17
Built-up area	3.84	9.83	83.62	+79.78	+2,077.56
Bare ground	0.38	0.37	13.91	+13.53	+3,595.26
Water	59.58	59.62	78.55	+18.97	+31.85

The LULC classification revealed a heterogeneous landscape comprising seven major classes: water, trees/savanna woodland, flooded vegetation, cropland, built-up area, bare ground and rangeland. In 2024, rangeland was the dominant class, covering 4,249.71 km² (60.94%) of the study area, followed by cropland at 1,285.25 km² (18.43%) and trees/savanna woodland at 1,240.68 km² (17.79%). Built-up areas, water bodies, flooded vegetation and bare ground occupied 83.62 km² (1.20%), 78.55 km² (1.13%), 22.04 km² (0.32%) and 13.91 km² (0.20%), respectively. The 2000 and 2010 classifications represent the initial and intermediate stages of the landscape trajectory, respectively, while the 2024 classification shows substantial re-

organization of the spatial structure, particularly the expansion of rangeland and contraction of tree cover and cropland.

Between 2000 and 2024, tree/savanna woodland experienced the largest absolute decline, decreasing from 2,626.47 km² to 1,240.68 km², a loss of 1,385.78 km² (52.76%). Cropland also declined from 1,853.63 km² to 1,285.25 km², representing a reduction of 568.38 km² (30.66%). In contrast, rangeland increased by 1,822.44 km² (75.08%), becoming the dominant LULC class in 2024. The other classes also increased over the study period: built-up area expanded from 3.84 to 83.62 km², bare ground from 0.38 to 13.91 km², flooded

vegetation from 3.21 to 22.04 km², and water bodies from 59.58 to 78.55 km². The very large percentage increases in built-up area and bare ground should, however, be interpreted in relation to their very small initial areas.

The temporal trajectory indicates that LULC change was not uniform throughout the study period. Between 2000 and 2010, cropland and tree cover increased by approximately 14.87% and 18.87%, respectively, while rangeland declined by 32.76%. During 2010–2024, the direction of change was markedly different: cropland declined by 39.64%, tree cover by 60.26%, whereas rangeland increased by 160.37%. Thus, the net changes observed between 2000 and 2024 conceal substantial intermediate transformations. This highlights the importance of examining land-change trajectories and cross-tabulation to distinguish persistence, gains, losses and transition pathways rather than relying solely on initial-to-final differences (Pontius et al., 2004).

IV. DISCUSSION

1. LULC Dynamics

The observed decline in vegetation cover is broadly consistent with findings from studies conducted within the study area and its surroundings. Gabriel and Zemba (2017) reported declining vegetation cover alongside increasing built-up and bare-land areas in Donga LGA, although differences in observation years, classification schemes and spatial extent limit direct comparison. Similarly, Light and Aremu (2026) reported a decline in vegetation cover in Wukari LGA between 2004 and 2024, accompanied by expansion of urban and agricultural land uses. Awwal et al. (2025) also reported declining dense vegetation and increasing farmland and built-up areas in Wukari, together with a reduction in ecosystem carbon stocks. Collectively, these studies provide broader local evidence of continuing landscape transformation.

The decline in tree/savanna woodland accompanied by the expansion of rangeland represents an important change in the composition of vegetated land rather than simply a complete loss of vegetation. Although rangeland, trees and flooded vegetation continued to occupy a substantial proportion of the landscape in 2024, the marked reduction in tree-dominated cover indicates a shift in vegetation structure. This distinction

is environmentally relevant because woody vegetation and grass-dominated rangeland may differ in canopy interception, litter accumulation, rooting characteristics and surface protection. However, the LULC results alone do not establish the specific processes responsible for these transitions.

Cropland likewise exhibited a marked temporal shift, with an initial expansion followed by substantial contraction. The initial increase may be associated with agricultural expansion, whereas the subsequent decline could reflect conversion to rangeland, settlement growth, land abandonment or other land-use restructuring; these pathways would require transition-matrix analysis or additional socioeconomic evidence for confirmation. The expansion of built-up land indicates substantial growth in settlement and infrastructure, although it remained a relatively small proportion of the total landscape in 2024. Similarly, bare ground occupied only 0.20% of the study area but recorded a large relative increase because of its very small initial extent. These changes indicate increasing spatial heterogeneity in the landscape and provide an important basis for examining their implications for erosion vulnerability.

2. LULC Dynamics and Erosion Vulnerability

The observed LULC trajectory has important implications for erosion vulnerability because the composition of the land surface changed substantially between 2000 and 2024. Tree/savanna woodland declined by 52.76%, while rangeland increased by 75.08%; built-up area expanded from 3.84 to 83.62 km² and bare ground from 0.38 to 13.91 km². These changes represent a re-organization of vegetated, cultivated and disturbed surfaces that may influence rainfall interception, surface roughness, infiltration and runoff. Though LULC change alone does not determine erosion response, which is also controlled by rainfall erosivity, soil properties, topography and land-management practices (Negese, 2021; Taye et al., 2023), understanding the relationship between land use and erosion is crucial for developing effective watershed management strategies (Maximus, 2025).

The decline in tree/savanna woodland in year 2024 as compared to year 2000 is particularly relevant because vegetation intercepts rainfall, reduces raindrop impact, enhances infiltration and contributes to soil

stabilization. Negese (2021) reported that expansion of cultivated land at the expense of forest, shrubland and grassland was generally associated with increased soil erosion, sediment yield and surface runoff. Similarly, Taye et al. (2023) reported an increase in mean annual soil loss in the Alage watershed alongside changes in cropland, bare land, built-up areas and protective vegetation, while significant association has been reported among land use land cover change, climate and geomorphological conditions to soil erosion (Aneseyee et al. 2020; Meshe et al., 2012). Thus, the substantial reduction in tree cover observed in Wukari–Donga represents a change in surface conditions that may increase soil exposure and erosion susceptibility where other erosion-controlling factors are also favourable.

The expansion of bare ground provides an additional indication of increased exposure of soil surfaces. Bare surfaces lack the protective vegetation cover that reduces rainfall energy and helps maintain soil structure, potentially increasing susceptibility to detachment and runoff-mediated transport. However, the large percentage increase in bare ground should be interpreted cautiously because the class occupied only 0.38 km² in 2000 and 13.91 km² in 2024. Consequently, the change indicates an increase in localized exposed surfaces rather than widespread conversion of the entire landscape to bare land. Its erosion implications will therefore depend on its spatial distribution, slope position, soil characteristics and rainfall conditions.

Although rangelands can provide effective soil protection where vegetation cover is continuous and grazing is appropriately managed, excessive grazing can reduce vegetation cover, compact the soil and increase runoff. Consequently, the erosion implications of the 75.08% increase in rangeland cannot be inferred from the LULC class label alone; they depend on vegetation condition, grazing intensity and management practices. This interpretation is consistent with the RUSLE cover-management concept, in which erosion response is influenced by the degree and condition of surface cover rather than land-cover category alone (Renard et al., 1997; Taye et al., 2018). The expansion of built-up surfaces may provide another pathway through which LULC change influences erosion vulnerability. Built-up and compacted surfaces can reduce infiltration and modify the concentration and routing of surface runoff, potentially increasing runoff

delivery to adjacent unprotected areas. Birhanu et al. (2024) identified agricultural and built-up areas as important contributors to erosion in the Dondor watershed, while Buraka et al. (2024) identified cultivated and bare areas occurring on steep and poorly vegetated terrain as important erosion hotspots in the Coka watershed. These findings indicate that the erosion implications of disturbed surfaces depend strongly on their spatial context and interaction with topography, rainfall and soil properties.

The temporal results further demonstrate that the LULC–erosion relationship is dynamic. Tree cover and cropland increased during 2000–2010 but declined substantially during 2010–2024, whereas rangeland followed the opposite trajectory. Evidence from the Yezat watershed similarly showed that improvements in vegetation cover following watershed-development and soil-and-water-conservation interventions were accompanied by reductions in mean annual soil loss (Tadesse et al., 2017). This suggests that changes in vegetation condition and conservation management can modify erosion susceptibility over time.

Evidence from other watershed studies also indicates that high erosion susceptibility commonly occurs where exposed or cultivated surfaces coincide with steep slopes, erosive rainfall and susceptible soils (Buraka et al., 2024; Maximus, 2025). Accordingly, the decline in tree cover and expansion of built-up and bare surfaces in Wukari–Donga constitute landscape conditions that may increase soil exposure and modify runoff pathways.

The findings therefore indicate that LULC change is an important component of erosion vulnerability in Wukari–Donga, but its influence is mediated by the broader physical and management environment. The observed transformation of tree cover, cropland, rangeland, built-up areas and exposed surfaces provides an important basis for understanding spatial differences in erosion susceptibility. Consequently, erosion management should integrate continued LULC monitoring with vegetation restoration, sustainable grazing and agricultural management, soil and water conservation, and spatial assessment of rainfall, soil and topographic controls. Integrating these variables within RUSLE and related geospatial models can provide a

more robust assessment of the magnitude and spatial distribution of erosion vulnerability.

V. CONCLUSION

The study demonstrates that the Wukari–Donga landscape underwent substantial spatial and temporal re-organization between 2000 and 2024, characterized by a 52.76% decline in tree/savanna woodland, a 30.66% decline in cropland and a 75.08% increase in rangeland, together with marked expansion of built-up and bare-ground surfaces. The contrasting trajectories between 2000–2010 and 2010–2024 show that the net changes over the full study period conceal important intermediate transformations. These changes indicate altered patterns of vegetation cover, cultivated land and exposed surfaces that may influence infiltration, runoff and erosion vulnerability. The findings therefore provide an important geospatial basis for continued LULC monitoring, sustainable land-use planning, vegetation restoration and integrated soil and water conservation in the Wukari–Donga area.

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