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Research Article

Spatiotemporal Dynamics of Land Use/Land Cover Change and Their Impacts on Ecosystem Fragmentation and Habitat Quality in Kaduna Millennium City, Nigeria

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ABSTRACT

Land use and land cover (LULC) changes are recognized as significant drivers of ecosystem transformation, often resulting in profound modifications of ecosystem services. Kaduna Millennium City, like other rapidly urbanizing regions, is experiencing dynamic shifts in land utilization that threaten environmental sustainability and community well-being. This research proposes to detect, analyze, and assess the implications of LULC changes on ecosystem services using geospatial and field survey techniques. The study used multitemporal Landsat images from 2004 to 2024. The images were classified using the Support Vector Machine (SVM) algorithm in ArcGIS Pro 2.5. Ecosystem fragmentation was carried out using Fragstats 4.3, while Habitat Quality was assessed using the InVEST habitat quality model. The results revealed notable urban expansion, with built-up areas, bare lands, and water bodies increasing by 14.73 km², 9.99 km², and 0.02 km², respectively, while grassland and vegetation declined by 18.95 km² and 5.79 km². Fragmentation analysis showed increased patch and edge densities alongside decreases in contagion, aggregation, Shannon diversity indices, indicating heightened ecosystem fragmentation. Habitat quality assessments between 2004 and 2024 revealed substantial degradation: areas with poor habitat quality expanded by 24.64 km², while those with excellent habitat quality shrank by 24.82 km². The study highlights the ecological consequences of rapid urbanization and provides insights for sustainable urban and environmental planning. The study concludes that the structural shift disrupts ecological equilibrium, potentially harming biodiversity and the supply of key ecosystem services, such as carbon sequestration, air purification, and water management.

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1 Introduction

Urbanization is a key concern for both emerging and developed countries worldwide. Unchecked urbanization has been linked to the expansion of both formal and informal settlements, economic development, improved transportation networks, and industrialization (Magidi & Ahmed, 2019). Urbanization, often known as urban sprawl, is the spread of metropolitan areas with developed urban centres that have influenced neighboring regions (Dey et al., 2021). As cities grow, additional land use and land cover types, such as croplands and tree cover outside metropolitan areas, will be transformed, potentially leading to environmental difficulties (Mohammadreza et al., 2022). Thus, during urbanization, urban boundaries expand haphazardly, implicitly replacing large areas of rural land (Long et al., 2023).

Urban sprawl has been linked to increased consumption of natural resources, particularly in developed cities. According to a UN estimate (2015), 27% of Africa's population has resided in cities since 1990. This ratio rose to 37% in 2014 and is expected to reach 55% by the year 2050 (Magidi & Ahmed, 2019). Nigeria is among the most urbanized regions in sub-Saharan Africa, with an annual urbanization rate of 3.5% (World Bank, 2023). According to Statista (2024), Nigeria's urban population share will increase to 53.52 per cent in 2022. This process of urbanization is responsible for extending communities and for the development of infrastructure to accommodate the rising population (Zhang et al., 2023).

Considering the global net change, land-use change has nearly doubled, from 17% to 32% of Earth's land area (Winkler et al., 2021). Over the last millennia, humans have modified more than 75% of Earth's terrestrial area (Arneth et al., 2019). Furthermore, an assessment of Earth's land cover and land use over the first 20 years of the century revealed a drop in worldwide tree cover extent and an increase in cropland and human settlements (Potapov et al., 2022). Satellite data show that globally, urban areas are growing by 3,230 km² annually (Li et al., 2021), increasing from 157,733 km² in 2000 to around 470,632 km² in 2020 (Shi et al., 2023). Although land use and land cover are constantly changing, the rapid pace of this change is what we are experiencing today (Das et al., 2023). Recently, towns and cities in developing countries are experiencing unprecedented changes in both functions and areal coverage (Badamasi et al., 2022).

However, over time, the impact of human activities and land use on ecosystem services has been escalating (Nijhum et al., 2021). The United Nations Millennium Ecosystem Assessment Report indicates that extensive human activities resulting from rapid urbanization, industrialization, and contemporary agriculture have

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degraded approximately 60% of ecosystem services, jeopardizing regional ecological security and resource sustainability (Wang & Bai, 2025). Ecosystem services refer to the paramount benefits that the natural environment provides to people, encompassing resources, ecological significance, climate regulation, and cultural and spiritual enrichment (Zoeller & Cumming, 2023). Additionally, the interplay between natural factors and human activity has led to challenges such as species extinction and biodiversity loss (Hamza et al., 2023). Consequently, understanding these intricate relationships is essential for developing regional sustainable management plans and ecological conservation measures.

As urbanization and economic growth accelerate, the problem of ecological degradation has become increasingly prominent. An undisturbed ecosystem can preserve its vitality and functionality under external stressors while delivering human well-being through ecosystem services (Hernández-Blanco et al., 2022). Furthermore, the dynamics of LULC have emerged as important elements that support changes in the ecological environment and the numerous functions and services offered by ecosystem productivity (Edwin et al., 2024). Specifically, LULC has been identified as the primary source of ecosystem service degradation (Verburg et al., 2011).

Few studies have examined land use and land cover distribution in relation to ecosystem services in Kaduna. For example, Abubakar et al. (2025) examined the influence of land-use changes on the ecosystem in the Niger River Basin. Similarly, Musa and Abubakar (2024) monitored urban growth and landscape fragmentation in Kaduna, Nigeria, using multitemporal Landsat imagery to assess urban expansion and degradation of various landscapes in the metropolis. However, the study only focused on habitat quality, ignoring other aspects of ecosystem services. On the other hand, Abubakar and Abdussalam (2024) conducted a geospatial analysis of land-use changes and wetland dynamics in Kaduna Metropolis. However, the study focused only on wetland ecosystems and did not consider transitions between different LULC classes. Mande (2020) assessed land-use and land-cover distribution in Kaduna Metropolis, focusing on the impact of climate change on land-surface temperatures.

LULC changes, driven by population growth, agriculture, and urbanization, can lead to ecosystem degradation, biodiversity loss, and diminished ecosystem services, including water regulation, climate regulation, and food provision. Reliable LULC change detection is essential for evaluating the resulting impacts and guiding sustainable development. Thus, this study aims to assess land-use and land-cover change and their impacts on ecosystem services in Kaduna Millennium City, Chikun LGA

2 Materials and Methods

2.1 Study Area

The Kaduna Millennium City is located within Kaduna town, the capital of Kaduna State. The area lies within the geographic coordinates of Latitudes 10° 29' N to 10° 34' N and Longitudes 07° 30 06' E to 007° 30.33' E (Figure 1). The location covers a total landmass of 37.31 km². The climate of the study area, located in Kaduna State, Nigeria, is classified as a tropical savanna climate (Köppen climate classification *Aw*) (Ojonuba et al., 2025). This climate type is characterized by distinct wet and dry seasons (Abubakar et al., 2024). The wet season typically lasts from April to October, with the peak rainfall occurring between June and September. During this period, temperatures are relatively high, ranging from 25°C to 35°C. The dry season, on the other hand, lasts from November to March. This season is characterized by lower rainfall and drier conditions (Ahmad et al., 2025).

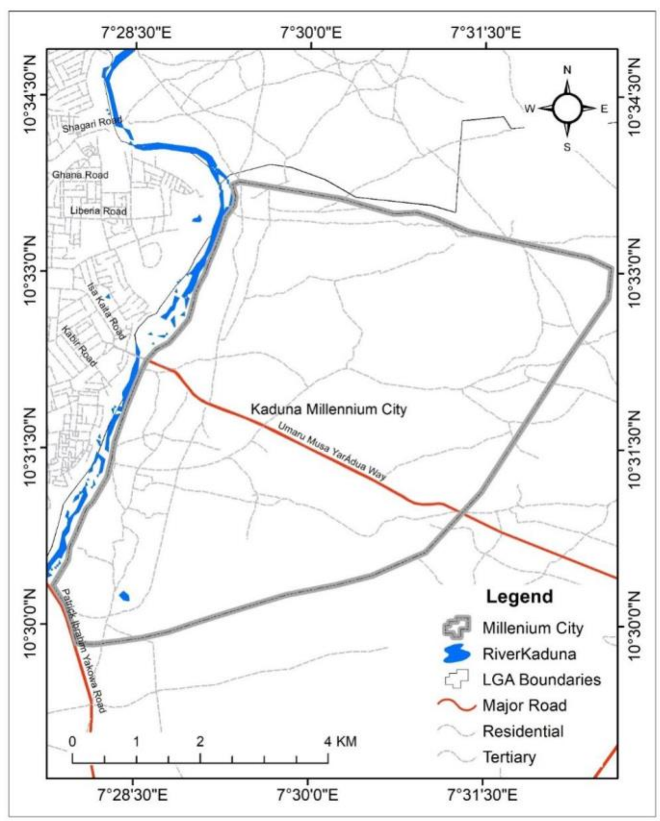


Figure 1: Map of the Study Area
Source: Modified from GRID3 Nigeria, 2025

Kaduna Millennium City has an average elevation of 607m above sea level. Both surface water and groundwater drain the terrain. The noticeable streams in the study area include Dan-Hono Stream and Kubai Stream, both of which drain into the river Kaduna. The relief of the area is characterized by undulating plains and gentle slopes, consisting of peneplains with eroded flat tops, often capped by layers of indurated laterites (Omeiza & Dogara, 2018).

Soil fertility in the area can vary, with some areas suitable for agriculture and others requiring additional inputs or management practices (FAO, 2017; Saleh, 2015). The study area lies within the Guinea savanna ecological zone of Nigeria. A mix of grassland, savanna woodland, and scattered trees typically characterises the vegetation in the area. Common tree species found in the region may include Acacia, Baobab, Shea, and Mahogany, among others (Oguntoyinbo et al., 1978). Human activities such as agriculture, urbanization, and deforestation can impact the natural vegetation cover in the area. Some areas may have undergone land clearing for agricultural purposes, resulting in a mix of farmlands and patches of natural vegetation.

2.2 Data Sources

The types of data used in this study and their sources are presented in Table 1.

Table 1: Types and Sources of Data

S/N	Data	Source	Relevance
1.	Landsat Imageries (MSS, ETM, and OLI/TIRS from 2004 to 2024)	United States Geological Survey Agency (USGS)	- Land Use and Land Cover Analysis - Computing remote sensing indices (NDVI, NDWI) to be used in the Land Change Modeler
2.	DEM - Shuttle Radar Topography Mission (SRTM)	USGS	This will be used to determine the elevation, slope, and distance to streams/rivers, which will serve as input to the Habitat Quality Model.
3.	Road Networks	GRID-3 Nigeria	Will be used as input in the InVEST Habitat Quality Model

Source: Author's Compilation, 2024

The characteristics of the Landsat Imagery used in this study are presented in Table 2.

Table 2: Characteristics of the Landsat images needed

Satellite	Sensor	Path/Row	Date
Landsat 7	ETM+	189/053	2004/03/15
Landsat 8	OLI/TIRS	189/053	2014/12/21
Landsat 9	OLI/TIRS	189/053	2024/03/29

2.3 Data Processing

All the images were geo-referenced correctly. Removing the influence of the atmosphere is a critical preprocessing step in analyzing images of surface reflectance. Thus, in radiometric corrections, dark-subtraction was performed to eliminate atmospheric scattering in an image by subtracting a background pixel value from each band. Additionally, the Focal Analysis on ERDAS Imagine 2014 was used to remove the scanline error on Landsat 7.

2.4 Data Analysis

2.4.1 Land use and land cover analysis

The Support Vector Machine (SVM) supervised classification algorithm on ArcGIS Pro 2.5 was used to classify land use into five major classes. The land use classes were bare land, built-up areas, cultivated lands, tree cover, and water bodies (Table 3). The SVM was used because it is highly reliable and is suitable for index-based classification (Laliberte et al., 2007; Phiri et al., 2020).

Table 3: Land cover categories

Land Use Class	Description
Bare land	Any exposed soil layer, landfills, or excavated areas
Built Areas	Residential, institutional, industrial, roads, rail, etc.
Grassland	Cultivated areas, croplands, and grasslands.
Vegetation	Natural (undisturbed) vegetation, tree cover
Water Bodies	Rivers, streams, lakes, and reservoirs.

For this study, two steps were involved in the classification. The first stage was to select the training samples from the false-color composite (band combinations 5,4,3 on Landsat 8 and 4,3,2 on Landsat 4-7). This was saved as the signature file (.sig). Furthermore, the signature file was trained using the Landsat image to create a classifier definition file. The second stage involves using classifier definition file (.ecd) to classify the images into five (5) different land use and land cover classes.

For every given period, changes in square kilometres were computed and examined for each of the land use and land cover classifications. The percentage of LULC change (trend) for each LULC class is given using Equation (i).

$$Percentage\ of\ LULC\ change = \frac{(A_2 - A_1)}{A_1} \times 100 \qquad (i)$$

Dividing the percentage of LULC change by the time interval, i.e., 1990–2007 (17 years), 2007–2024 (17 years), and 1990–2024 (34 years), the rate of individual LULC change per year was determined using Equation (ii).

$$\text{Annual rate of change } (\%) = \frac{(A_2 - A_1)}{A_1(t_2 - t_1)} \times 100 \qquad (ii)$$

where time t_1 and t_2 are the initial and final periods, while A_2 and A_1 are the area coverage for the initial and final periods, respectively.

This study used a land-use transfer matrix to show land-use/land-cover change between 1990 and 2024. The matrix illustrates the dynamic interconversion of various LULC types over time in a particular region. Additionally, it can precisely show how the different categories are changing and how the structural characteristics of LULC change. This was computed according to Equation iii (Xu et al., 2022).

$$G_{xy} = \begin{bmatrix} G_{11} & G_{12} & \dots & G_{1n} \\ G_{21} & G_{22} & \dots & G_{2n} \\ \dots & \dots & \dots & \dots \\ G_{n1} & G_{n2} & \dots & G_{nn} \end{bmatrix} \qquad (iii)$$

where n refers to the quantity of LULC types; x and y (x, y = 1, 2, …, n) denote the LULC types in the initial and last stages, respectively; and G_{xy} indicates the conversion area from LULC category x to LULC category y.

2.4.2 *Fragmentation of Ecosystem in Kaduna Millennium City*

Fragstats 4.3 was used to examine land fragmentation in ecological areas. The indices used to assess ecosystem health in this study are shown in Table 4.

Table 4: Ecosystem Fragmentation Metrics

S/N	Name	Index	Ecosystem
1.	Patch Density	PD	A high patch density may signify fragmentation, potentially impacting species movement, resource availability, and ecological processes.
2.	Edge Density	ED	Edge density is crucial for understanding the interface between ecosystems, as it can affect species interactions, microclimate conditions, and edge effects.
3.	Simpson's Diversity Index	SIDI	SIDI = 0 when the landscape contains only 1 patch (i.e., no diversity). SIDI approaches 1 as the number of different patch types (i.e., patch richness, PR) increases and the proportional distribution of area among patch types becomes more equitable.
4.	Contagion	CONTAG	Contagion can signify the interconnectivity of ecosystems. Elevated contagion indicates a terrain characterized by a limited number of extensive, interconnected areas, which might be advantageous for species that require substantial habitat.
5.	Shannon's Diversity Index	SHDI	Higher diversity indices often signify a more varied environment, capable of sustaining a broader array of species and ecological activities.
6.	Aggregation Index	AI	Aggregation refers to the tendency of patch types to be spatially aggregated; that is, to occur in large, aggregated or "contagious" distributions.

2.4.3 *Influence of Land Use and Land Cover Changes on Ecosystem Services in Kaduna Millennium City*

The InVEST habitat quality model was used to examine changes in habitat quality, which is a critical indicator of ecosystem health. The InVEST model is a robust framework for evaluating and quantifying ecosystem services (Abubakar et al., 2025). InVEST can simulate and predict the effects of various management techniques and land-use changes on ecosystem services by combining GIS and land-use data with ecological models, thereby assisting in sustainable development and environmental protection decision-making.

In this study, both climatic and surface parameters were addressed. This enabled the assessment of how surface water output, carbon storage, habitat quality, and soil retention vary across different locations within Kaduna Millennium City, accounting for their distinct biological characteristics.

2.4.4 *Threats Table*

The threat factors that significantly affect habitat quality in the Kaduna Millennium City are shown in Table 5.

Table 5: Threats Table

MAX_DIST	WEIGHT	THREAT	DECAY	DESCRIP	BASE_PATH	CUR_PATH	FUT_PATH
10	1	Urban24	exponential	Urban/developed		Urban24_c.tif	Urban24_f.tif
3	1	Roads1	linear	Primary roads		Roads1_c.tif	Roads1_f.tif
1	0.7	Roads2	linear	Secondary roads		Roads2_c.tif	Roads2_f.tif

2.4.5 Sensitivity Table

The suitability of each land use and land cover class was ranked, and their sensitivity to the threat factors was examined via expert knowledge. Table 6 shows the felicity and sensitivity of different land use classes, including urban areas, and primary and secondary roads, to threats. The ability of the land use type to support habitat quality is ranked 1 and 0, with 1 indicating suitability (grasslands and water bodies) and 0 indicating a lack of suitability (bare lands and built-up areas). Each land use sensitivity and anthropogenic activity was evaluated from 0 to 1, with 0 indicating no sensitivity and 1 indicating the maximum sensitivity. Wetlands and forests have the highest sensitivity to road and rail construction.

Table 6: Sensitivity Table

LULC	NAME	HABITAT	Urban24	Roads1	Roads2
1	Bare	0	0.6	0.4	0.3
2	Built Up	0	0.5	0.3	0.2
3	Grassland	1	0	0	0
4	Water Bodies	1	0.3	0	0

3 Results and Discussion

3.1 Spatial and temporal changes of land use and land cover in Kaduna Millennium City

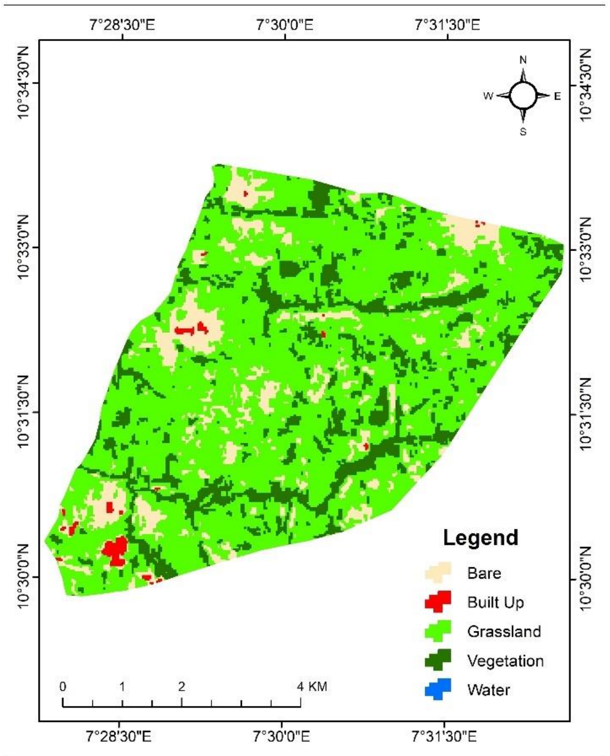
Table 7 presents the spatial and temporal variation of land use and land cover in Kaduna Millennium City.

Table 7: Land use and land cover distribution in Kaduna Millennium City (2004-2024)

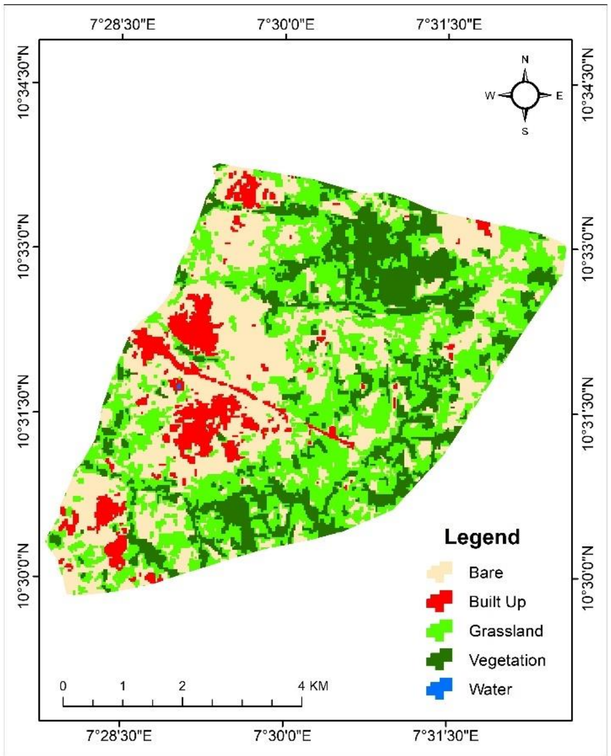
	2004		2014		2024	
Land Use / Land Cover	Area	Percentage	Area	Percentage	Area	Percentage
Bare	5.03	13.48	14.57	39.05	15.02	40.26
Built-Up	0.29	0.77	2.74	7.34	15.02	40.26
Grassland	26.20	70.22	12.94	34.68	7.24	19.42
Vegetation	5.79	15.53	7.06	18.92	0.00	0.00
Water	0.00	0.01	0.00	0.01	0.02	0.06
Total	37.31	100	37.31	100	37.31	100

Table 7 demonstrates significant landscape changes over the two decades. Grassland had the highest area in 2004, covering 70.22% of the entire area. This is followed by natural vegetation, covering 15.53%. Bare lands covered 13.48% of the study area, while built-up areas and water bodies covered 0.77% and 0.01% respectively. This is illustrated in Figure 2a.

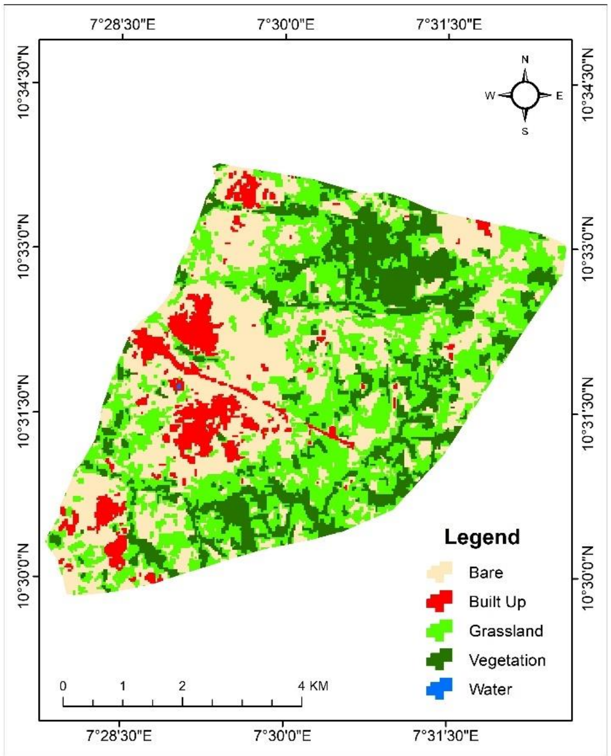
In 2004, 70.22% of the total acreage was covered in grasslands, with bare land and vegetation accounting for 13.48% and 15.53%, respectively. At just 0.77%, built-up areas were few; water bodies were practically non-existent. This means the area was mostly natural or semi-natural, with limited human development. However, by 2014, grassland had reduced significantly to 34.68%, while bare land had surged sharply to 39.05%, and built-up areas had extended to 7.34%. Vegetation also witnessed a slight increase to 18.92%, but water bodies remained minimal. These changes reflect a pattern of land degradation, urbanization, and even deforestation or land clearing for development (Akpu et al., 2017). This result is illustrated in Figure 2b. By 2024, built-up areas and bare lands covered 40.26% each, followed by grassland at 19.42%. Water bodies also significantly increased to 0.06%, while vegetation completely disappeared. This result is illustrated in Figure 2c. This result is similar to the findings of Abubakar and Abdussalam (2024), who reported a persistent increase in built-up areas and a decrease in vegetation cover during the study period. The complete loss of vegetation and the reduction in grassland indicate severe environmental deterioration, potentially leading to biodiversity loss, reduced carbon storage, and increased vulnerability to climate change impacts (Mdluli et al., 2022)



a) 2004



b) 2014



c) 2024

Figure 2: Land use land cover distribution in Kaduna Millennium City (2004 to 2024)

3.2 Land use and land cover transitions in Kaduna Millennium City

Table 8 reveals the transitions between land use and land cover classes across the three epochs in this study (2004-2014, 2014-2024, and 2004-2024).

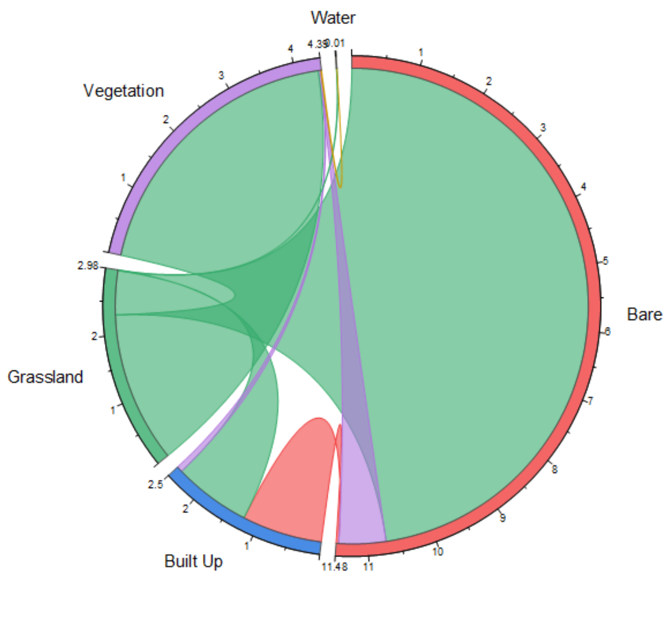
Table 8: LULC Matrix

Period	LULC Class	Bare	Built-Up	Grassland	Vegetation	Water
2004-2014	Bare	-	1.231	0.670	0.029	-
	Built-Up	0.04	-	0.01	0.00	-
	Grassland	10.72	1.18	-	4.34	0.00
	Vegetation	0.72	0.09	2.30	-	-
	Water	-	-	-	0.01	-
2014-2024	Bare	-	8.51	0.87	-	-
	Built-Up	0.10	-	0.01	-	0.02
	Grassland	6.98	3.31	-	-	-
	Vegetation	2.75	0.59	3.72	-	0.01
	Water	-	0.01	-	-	-
2004-2024	Bare	-	3.31	0.20	-	-
	Built-Up	0.03	-	0.00	-	0.02
	Grassland	10.93	10.39	-	-	0.01
	Vegetation	2.54	1.09	2.16	-	-
	Water	-	-	0.01	-	0.01

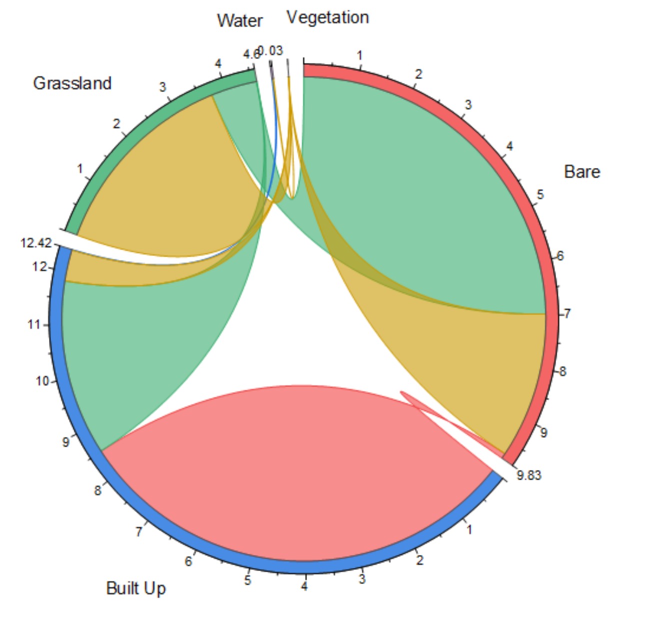
From Table 8, the transition between 2004 and 2014, grassland lost 10.72 km² to Bare land and 4.34 km² to Vegetation. This suggests land degradation or overgrazing in some areas and vegetation regrowth in others. Similarly, vegetation transitioned into grassland 2.30 km² and Bare land 0.72 km², with a smaller transition 0.09 km² to Built-Up areas, suggesting deforestation and habitat degradation. Bare land transitioned to Built-Up areas 1.231 km² and Grassland 0.670 km². Indicating urban expansion and some natural land regeneration. Water bodies remained stable, with negligible transition to Vegetation 0.01 km², suggesting minimal loss. This is shown in Figure 3a.

Between 2014 and 2024, the rapid expansion of Built-Up areas occurred. 8.51 km² of bare land, 3.31 km² of grassland, and 0.59 km² of vegetation all transitioned to built-up areas. This indicates a significant expansion of built-up areas and infrastructural development in the area. Grassland and vegetation continued to decrease, with 6.98 km² of grassland converted to bare land. Vegetation also lost 2.75 km² to Bare land and 3.72 km² to grassland, suggesting deforestation and ecosystem fragmentation. Water bodies experienced minimal transition, with 0.01 km² converted to built-up areas. This is shown in Figure 3b.

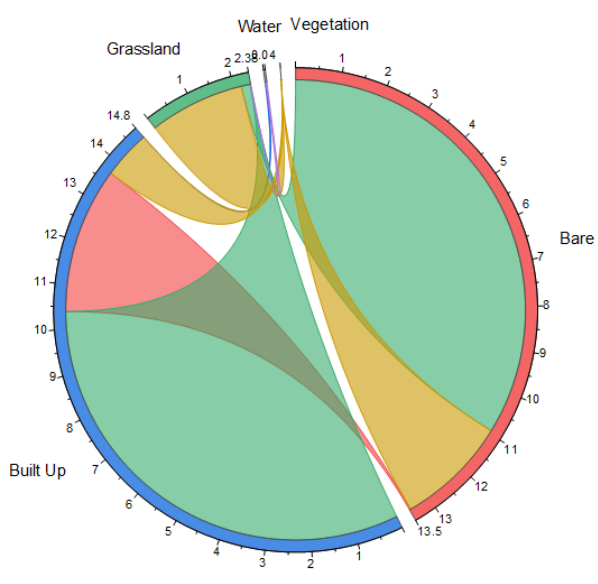
For the entire study period (2004-2024), grassland experienced the highest encroachment with 10.93 km² converted to bare land, and 10.39 km² converted to built-up areas. Areas with natural vegetation disappeared, with 2.54 km² converted to Bare land, 1.09 km² to built-up, and 2.16 km² to Grassland. Water bodies remained largely stable with minor transitions to Built-Up and Grassland. This is shown in Figure 3c.



a) 2004-2014



b) 2014-2024



c) 2004-2024

Figure 3: Land use transition matrix in Kaduna Millennium City (2004 to 2024)

3.3 Ecosystem Fragmentation in Kaduna Millennium City

Table 9 revealed the changes in patch density, edge density, contagion index, Shannon Diversity Index in Kaduna Millennium City.

Table 9: Ecosystem Fragmentation

Year	PD	ED	CONTAG	SHDI	SIDI	AI
2004	7.21	65.30	53.61	1.24	0.69	90.66
2014	12.22	93.59	49.32	1.05	0.64	86.48
2024	16.75	128.82	42.43	0.84	0.46	81.45

From Table 9, the patch density (PD) showed a steady increase (+9.54), suggesting that larger habitat patches are being fragmented into smaller patches. This can be attributed to urban expansion and deforestation. An increase in edge density (ED) by 63.52 suggests the creation of more habitat edges due to fragmentation. A decreasing CONTAG value (-11.19) indicates the dispersal of more land cover types, instead of large continuous patches. Lower CONTAG means habitats are more fragmented, reducing ecological connectivity and increasing habitat isolation. A declining SHDI (-2.0873) indicates a decrease in land cover diversity. This implies a reduction in habitat types, which will affect biodiversity and ecosystem resilience.

Table 9 also revealed that, similar to the Shannon Diversity Index, a diminishing SIDI (-0.2216) indicates a reduction in landscape diversity. This indicates that fewer dominant habitat types are prevailing, perhaps leading to a decline in ecological equilibrium and species diversity. This reduction is probably due to rapid urbanization in Kaduna Millennium City. The persistently decreasing AI (9.2087) indicates that fewer habitat patches are aggregated but more scattered. This confirms that habitats are more fragmented and can reduce species diversity by inhibiting movement and reducing habitat connectivity. Changes in ecosystem fragmentation are shown in Figure 4.

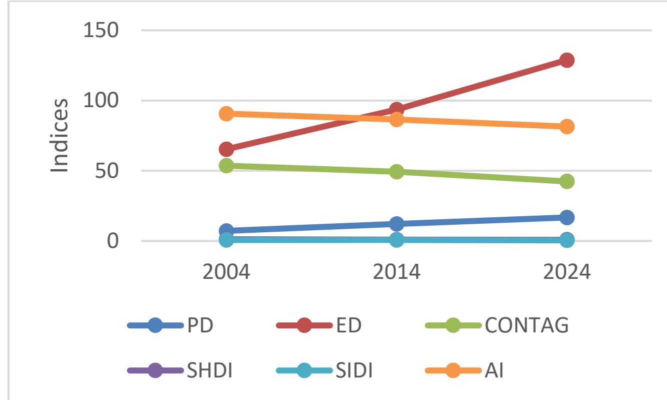


Figure 4: Ecosystem fragmentation indices

3.4 Habitat Quality Assessment

Changes in habitat quality in Kaduna Millennium City were assessed from 2004 to 2024 using the InVEST habitat quality model. The result is shown in Table 10.

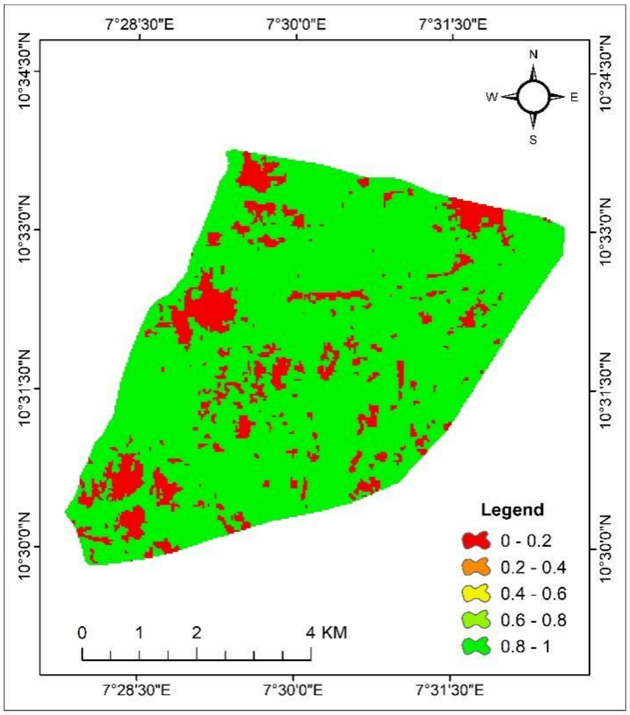
Table 10: Habitat Quality in Kaduna Millennium City

HQ Class	2004		2014		2024	
	Area	Percentage	Area	Percentage	Area	Percentage
I	4.04	10.83	16.15	43.31	28.67	76.91
II	0.20	0.54	1.10	2.95	1.30	3.49
III	0.01	0.03	0.00	0.00	0.10	0.27
IV	1.01	2.71	0.00	0.00	0.00	0.00
V	32.03	85.90	20.04	53.74	7.21	19.33
Total	**37.29**	**100**	**37.29**	**100**	**37.28**	**100**

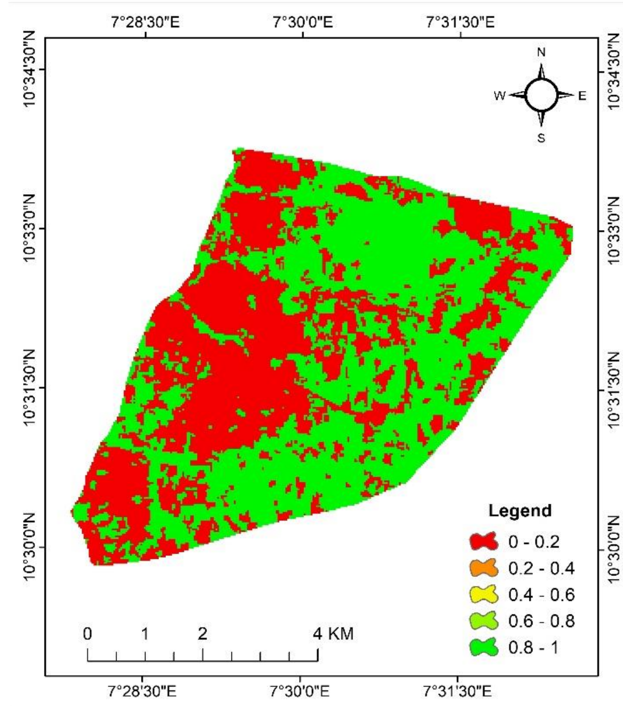
Table 10 revealed that in 2004, the study area was predominantly characterized by excellent habitat quality, with Class V (the best habitat quality) covering 32.03 km² (85.90%) of the total area. This means that the ecosystem remained relatively intact, with limited human disturbance and well-preserved natural habitats. However, Class I (the lowest habitat quality) accounted for 4.04 km² (10.83%), suggesting the presence of some degraded areas due to urban expansion. Intermediate habitat quality classes (II, III, and IV) occupied substantially smaller areas, with Class IV occupying 1.01 km² (2.71%), Class II occupying 0.20 km² (0.54%), and Class III occupying barely 0.01 km² (0.03%). While the overall habitat condition was acceptable, signs of degradation were already evident.

In 2014, there was a considerable drop in habitat quality, with Class V declining to 20.04 km² (53.74%), indicating habitat degradation. Class I (poor habitat) increased considerably to 16.15 km² (43.31%), signifying that degradation had intensified. Class IV disappeared entirely, whereas Class II increased slightly to 1.10 km² (2.95%), indicating that some areas were at an intermediate level of degradation. The complete phasing-out of Class III shows that significant degradation was either mitigated or absorbed into lower-quality habitat classes. The sharp decline in high-quality habitat reflects increased environmental stressors over the decade.

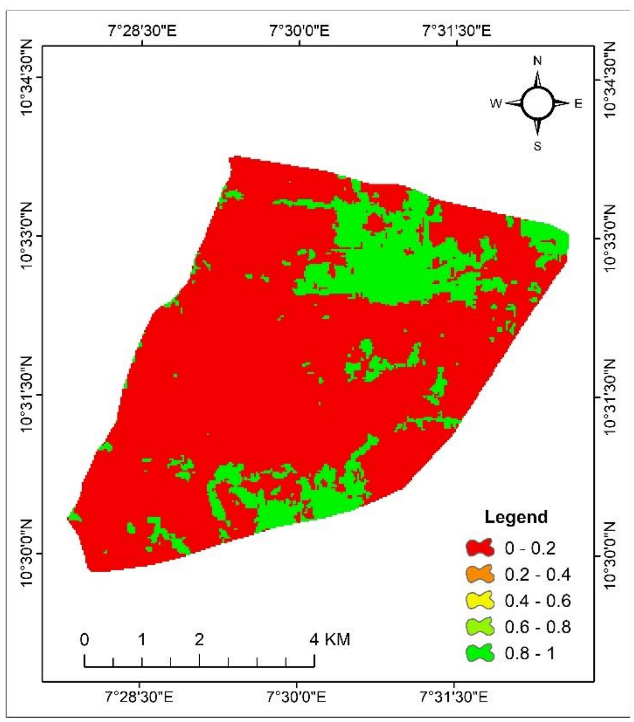
Finally, in 2024, habitat quality continued to decline, with Class V dropping further to 7.21 km² (19.33%), indicating a substantial loss of pristine natural ecosystems. Class I expanded dramatically to 28.67 km² (76.91%), revealing habitat degradation. Class II increased by 1.30 km² (3.49%), while Class III resurfaced to 0.10 km² (0.27%), indicating that some areas had become even more degraded. The full elimination of Class IV since 2014 indicates a shift in which moderately degraded regions either worsened or migrated into other land-use categories. This result is similar to the findings of Musa and Abubakar (2024), who reported a downward trend in ecosystem habitat quality in Kaduna Metropolis. These results are shown in Figure 5.



a) 2004



b) 2014



c) 2024

Figure 5: Habitat quality distribution in Kaduna Millennium City (2004 to 2024)

4 Discussion

Land-use and land-cover changes from 2004 to 2024 indicated habitat fragmentation and biodiversity loss. The transformation of vegetation into bare terrain and grassland indicates deforestation and habitat fragmentation (Yan et al., 2022). Furthermore, the loss of vegetation diminishes habitat quality, hence impacting biodiversity. The decreasing CONTAG and AI scores in the Fragstats results indicate heightened fragmentation. The study also found enhanced urbanization and infrastructure expansion (Bindajam et al., 2023). Thus, the continual expansion in built-up areas, largely from bare land, grassland, and vegetation, suggests fast urban sprawl (Aduko et al., 2025). This coincides with declining SHDI and SIDI values, suggesting habitat homogenization.

The study also revealed land degradation and a risk of desertification. Significant grassland-to-bareland conversion (10.93% over 20 years) indicates soil degradation, potentially due to overgrazing or declining plant cover. This coincides with the growing Patch Density (PD) and Edge Density (ED), indicating fragmented landscapes. However, water bodies remained stable with minimal encroachment.

5 Conclusion

The findings of this study reveal the substantial influence of LULC changes on ecosystem services in Kaduna Millennium City. The observed increase in built-up areas and bare fields, along with the loss of vegetation and grasslands, reflects rapid urban expansion and environmental transformation. The growing ecosystem fragmentation, indicated by higher patch and edge densities and lower contagion and aggregation indices, suggests that natural ecosystems are becoming more fragmented and isolated. This structural shift disrupts ecological equilibrium, potentially harming biodiversity and the provision of key ecosystem services, including carbon sequestration, air purification, and water management.

Furthermore, the habitat quality evaluation highlights the environmental repercussions of urbanization, with a significant decline in regions of outstanding habitat quality and a commensurate increase in degraded areas. This trend underscores the critical need for sustainable urban development and conservation efforts to reduce habitat loss and increase ecological resilience. Future studies should explore the socio-economic drivers of these shifts and evaluate the effectiveness of green infrastructure and reforestation projects in restoring ecosystem functioning. Policymakers and urban planners must integrate ecological considerations into development initiatives to balance urban expansion with environmental sustainability in Kaduna Millennium City.

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