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Urban Expansion and Land Use/Land Cover Change in the Greater Tamale Area, Ghana, 2000–2025: A Landscape-Metric Analysis with Institutional Perspectives

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Abstract

This study examines urban expansion and land use/land cover (LULC) change in the Greater Tamale Area (GTA), Ghana, between 2000 and 2025, with a projection to 2030. Multi-temporal

Landsat data (Landsat 5 TM, Landsat 7 ETM+, Landsat 8 OLI and Landsat 9 OLI-2) were used to classify six epochs into five LULC classes using Maximum Likelihood Classification, with overall accuracies ranging from 87.0% to 96.0% (Kappa 0.825 0.946) compared to independently sampled reference data for each epoch. Built-up area increased from 7,375 ha in 2000 to 24,737 ha in 2025, a 235% increase, while vegetation cover declined by 74% (26,319 ha to 6,931 ha), bare soil declined by 89%, and agricultural land expanded by 68% (29,896 ha to 50,315 ha). The Urban Expansion Intensity Index rose from 0.68%/year (2000 2005) to 2.56%/year (2020 2025). Landscape-level FRAGSTATS metrics reveal an increase in the Largest Patch Index (17.3% in 2000 to 48.4% in 2025) as agricultural and built-up patches merged and a decrease in Simpson's Evenness Index (0.92 in 2000 to 0.70 in 2025) as there was a greater focus on more dominant patches that were larger in size and less frequent across the landscape. The key proximate drivers of expansion identified by the semi-structured interviews with all the nine planning, parks, and traditional landowners are unregulated release of customary land prior to formal planning approval, conversion of urban-core green space, and peri-urban land value increases. With ongoing trends, the built-up area is projected to be around 25,199 ha by 2030. The proposed study model aims to integrate the three key elements urban consolidation zones, protected agricultural and ecological buffers, and regulated peri-urban corridors to enable compact growth in Greater Tamale and other similar cities in Sub-Saharan Africa.

Keywords: Urban sprawl, land use and land cover change, landscape metrics, urban sustainability and Greater Tamale Area, Ghana.

1. Introduction

Urbanisation is one of the most influential forces affecting the landscape in the twenty-first century (Seto et al., 2012; United Nations, 2019). By 2020, the urbanisation rate had increased to more than 56%, and will continue to grow, with over 90% of all future urban growth occurring in low and middle income countries and largely in Africa and Asia (United Nations, 2019; World Bank, 2019). Rates of urbanization in Sub Saharan Africa are also some of the highest in the world, exceeding 3% per year and expected to more than double urban population between 2020 to 2050 (United Nations, 2019; Hoornweg & Pope, 2017). The process of urbanisation has the potential to benefit economic development, but is often accompanied by urban land use change which is more rapid than the planning process, and the natural vegetation and agricultural land is being converted to built-up area (Hoornweg and Pope, 2017).

Urban sprawl, defined as low-density, outward, loosely coordinated growth (Ewing & Hamidi, 2015), can alter hydrology, fragment habitat and alter ecosystem processes (Haddad et al., 2015). This pattern is perpetuated in the developing world through informal land markets, customary land tenure and poor implementation of spatial plans (Cobbinah & Amoako, 2015), which can impact microclimate management, food security and urban social life (Ament et al., 2023).

Ghana shows these trends: Urbanization rates increased from 43.7% of the population to 56.7% in 2021, and have been growing at a rate of more than 3% per year (GSS, 2021). Secondary cities in the north have received very little empirical attention compared to the southern metropolitan areas (Accra and Kumasi) of the country, which have been the focus of most empirical studies (Abass et al., 2018; Acheampong et al., 2017). Existing research on Tamale has explored issues of land tenure patterns, peri-urban livelihoods, and socio-economic causes of expansion, but few studies have attempted to quantitatively characterize the urban form of the city over a multi-decadal period, particularly in terms of metrics. To address the above gap this study incorporates three

features that had not been integrated together before in previous studies that focused on the Tamale area: a series of classifications spanning six epochs and over a 25-year time frame, with a forward projection to 2030; a full suite of landscape metrics (patch density, edge density, largest patch index, landscape shape index, mean shape index, evenness) rather than a single change statistic; and direct incorporation of institutional interview evidence with the spatial results.

Ecologically, vegetated landscape and agricultural areas converted to built-up reduce habitat connectivity, ecosystem services, and increase the surface heating, groundwater depletions, and flooding potential (Douglas et al., 2008; McGarigal & Marks, 1995; Ament et al., 2023). The costs are particularly strong in cities in Guinea Savannah where livelihoods and food systems are still strongly coupled to the vegetated and agricultural landscape.

This study focuses on the spatio-temporal patterns, intensity and spatial configuration of LULC change in the Greater Tamale Area (GTRA) from 2000 to 2025 with an extension to 2030 based on multi-temporal Landsat imagery, the Urban Expansion Intensity Index (UEII), landscape metrics (FRAGSTATS) and stakeholder interviews for institutional context. To this end the study aims to:

1. Examine land use and land cover change in the Greater Tamale Area from 2000 to 2025 and predict the land use by 2030.

2. Measure and quantify the intensity, spatial configuration and structural reorganisation of urban growth using the Urban Expansion Intensity Index and FRAGSTATS landscape metrics, and correlate these patterns to institutional and land-governance drivers identified from stakeholder interviews. The findings will be used to guide the monitoring of SDG 11 (Sustainable Cities and Communities); inform the Land Use and Spatial Planning Act, 2016 (Act 925); and to assist

operational planning by the Tamale Metropolitan Assembly and the Land Use and Spatial Planning Authority (LUSPA).

2. Theoretical Framework: Urban Sprawl and Landscape Pattern in Sub-Saharan African Cities

Low-density, outward, discontinuous growth that extends beyond the traditional urban core is the usual definition of urban sprawl (Ewing, 1997; Angel et al., 2011), and refers to the development of clusters of settlements around the edge of the city, along transport corridors, or in a leapfrog pattern. In Sub-Saharan African cities, this is fuelled by land-market dynamics, transport infrastructure and weak institutional enforcement of spatial plans (Angel et al., 2011) that combine with customary land tenure and informal land transactions to reinforce the process of outward, fragmented extension of cities.

The other structural lens employed in this study is a landscape ecological lens, as ecological processes and ecosystem functioning are dependent on landscape structure, which is defined as the composition, arrangement, and connectivity of land-use patches (Forman & Godron, 1986; McGarigal & Marks, 1995). Urbanisation is therefore an event that alters the landscape, changing the relatively homogeneous natural, or agricultural, matrix into a relatively heterogeneous mosaic of built, vegetated and cultivated patches. This structural change is translated into metrics like patch density, edge density, largest patch index, landscape shape index and mean shape index (Herold et al., 2003; McGarigal et al., 2012) and this is what this study uses for the Greater Tamale landscape from 2000 to 2025.

2.1 Empirical Review

The expansion of urban land is generally greater than urban population, especially in developing countries, which exacerbates the pressure on the surrounding land (Seto et al., 2012). Other metric studies have revealed a wide range of trends towards less compact and more fragmented urban development, in addition to horizontal sprawl (Angel et al. 2011). Informal land markets and customary tenure are also consistently cited as contributing to a reduction in parcel density and fragmentation of green space in cities in Sub-Saharan Africa, including Lagos, Addis Ababa and Nairobi (Cobbinah et al., 2015; Ament et al., 2023), and making infrastructure provision more challenging with the development of leapfrogs and corridors.

Savannah cities have a different path from coastal and forest-zone cities within West Africa due to their greater ecological reliance on the agriculture found around these cities. Previous studies in both Accra and Kumasi, Ghana, report significant built-up expansion and loss of green space resulting from population pressure and land-market dynamics (Abass et al., 2018; Owusu et al., 2021; Acheampong et al., 2017). To date, literature on the Tamale area has been mostly concerned with land tenure and socio-economic causes and has been relatively limited in the application of structural metrics from FRAGSTATS. The empirical space addressed by this study is this gap, in terms of fragmentation and dispersion quantified and characterised by a metric for Greater Tamale over a multi-decadal time span.

3. Materials and Methods

3.1 Study Area

The Greater Tamale Area (GTA) represents the commercial and administrative centre of northern Ghana (Figure 1) with an area of approximately 849 km (84,865-84,915 ha across the epochs classified). The 2021 census (GSS, 2021) counted 374,744 people in Tamale. The city is a strategic hub between northern Ghana, Burkina Faso, Togo and Côte d'Ivoire. Climate: Guinea Savannah,

one rainy season (May-October), mean rainfall of about 1,100 mm; mean temperature range is 25-35 degreesC. Indigenous flora consists mainly of open woodland (Vitellaria paradoxa, Parkia biglobosa) with grassland in between.

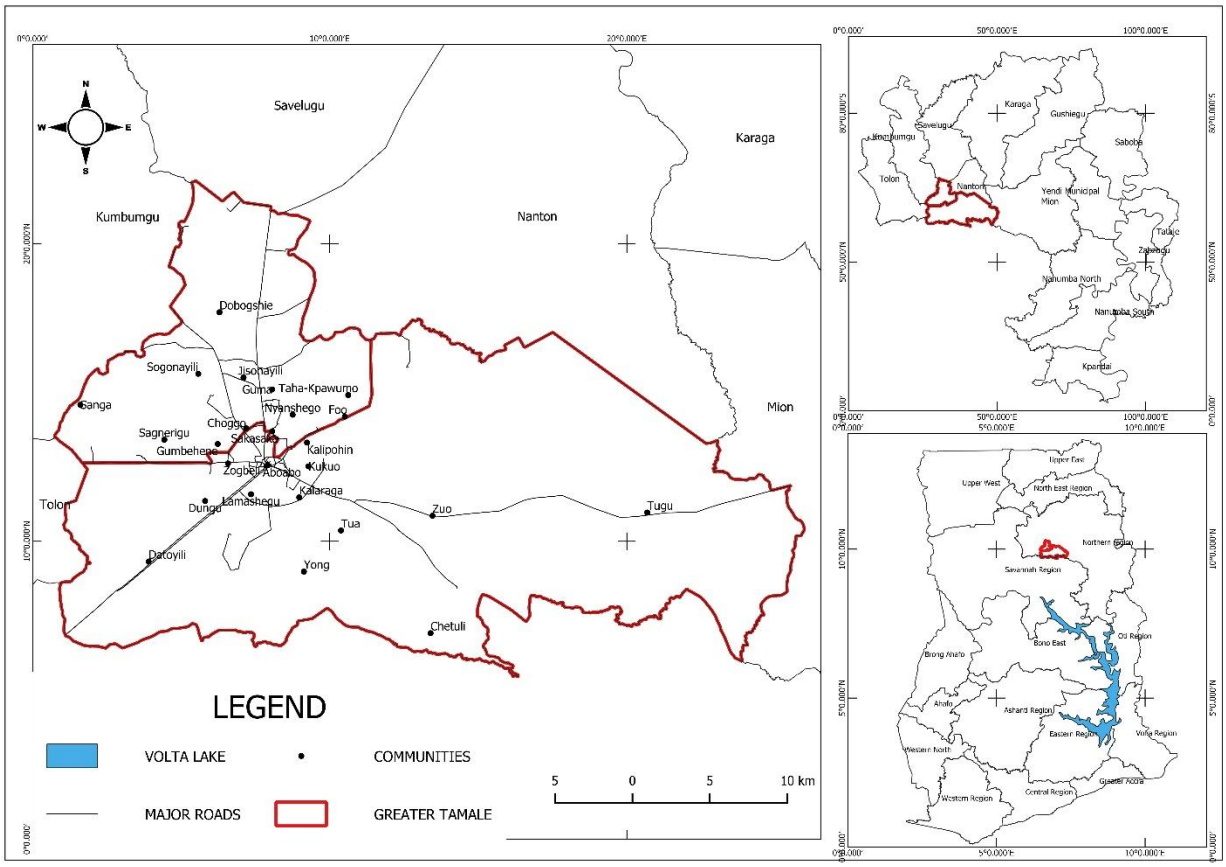


Figure 1 Map of Greater Tamale Area in Context of Northern Region and Ghana

3.2 Data Collection

Multi-temporal Landsat imagery was acquired for six epochs 2000, 2005, 2010, 2015, 2020, and 2025 at 30 m spatial resolution, dry-season (January March) acquisition, using Landsat 5 TM (2000, 2010), Landsat 7 ETM+ (2005), Landsat 8 OLI/TIRS (2015, 2020), and Landsat 9 OLI-2 (2025) (Table 1). Imagery for the dry season was favored because cloud cover was minimized and phenological conditions (post-harvest, senescent cropland) were normalized throughout epochs.

The supporting datasets used were 1:50,000 topographic maps (Ghana Survey and Mapping Department) and administrative boundary shapefiles (Ghana Survey and Mapping Department, 2021). There was a separate sample from the reference data, which was independently sized for each epoch, and interpreted from high-resolution historical and contemporary imagery. There were 100 points each for 2000, 2005, 2015, 2020 and 2025, with 119 points in 2010 (Table 4) distributed across the five LULC classes.

Table 1. Satellite Datasets Used

Year	Sensor	Path/Row	Resolution (m)	Season	Date Acquired	Cloud cover	Image quality
2000	Landsat 7 ETM+	194/053	30	Dry season (Jan–Mar)	1/26/2000	0.00	9
2005	Landsat 7 ETM+	194/053	30	Dry season (Jan–Mar)	1/23/2005	2.00	9
2010	Landsat 7 ETM+	194/053	30	Dry season (Jan–Mar)	1/6/2010	0.00	9
2015	Landsat 8-9 OLI/TIRS	194/053	30	Dry season (Jan–Mar)	1/27/2015	0.00	9
2020	Landsat 8-9 OLI/TIRS	194/053	30	Dry season (Jan–Mar)	2/26/2020	0.12	9
2025	Landsat 8-9 OLI/TIRS	194/053	30	Dry season (Jan–Mar)	2/7/2025	0.06	9

3.3 Image Pre-processing and Classification

Images were radiometrically calibrated to the USGS Collection 2 Level-2 surface reflectance, geometrically referenced to UTM Zone 30N (WGS 1984) and clipped to the study area. The data underwent atmospheric correction using the USGS processing for data from the sensors (LEDAPS for Landsat 5/7; LaSRC for Landsat 8/9). Training samples were assigned to each LULC class based on reference imagery and field knowledge of the study areas and per epoch supervised Maximum Likelihood Classification (MLC) was performed to classify the data into five LULC

classes: built-up area, agricultural land, vegetation, bare soil and water bodies. The spectral overlap between bare soil and senescent dry season cropland in a Guinea Savannah environment is recognised as a source of classification uncertainty (Section 6), and is a potential explanation for the reduced accuracy found for the built-up class in certain epochs (Section 4.1).

Confusion matrix was calculated for each epoch and overall accuracy and Kappa coefficient were computed:

Overall Accuracy = (Total Correctly Classified Pixels / Total Reference Pixels) × 100 (1)

$\kappa = (p_o - p_e) / (1 - p_e)$ (2)

Where p_o is observed agreement and p_e is expected agreement by chance.

3.4 Change Detection and Landscape Analysis

Post-classification comparison was used to detect change between consecutive epochs (Rwanga & Ndambuki, 2017), with the class-level change rate computed as:

$R = [(A_t2 - A_t1) / A_t1] \times 100$ (3)

Where A_t1 and A_t2 are the area of a class at the first and final time points.

The Urban Expansion Intensity Index (UEII) (Yeh & Li, 2001) was computed as:

$UEII_ij = [(U_j - U_i) / (A \times (T_j - T_i))] \times 100$ (4)

Where U_j and U_i are built-up area at times j and i, A is the mean total study area across epochs (84,874 ha), and $T_j - T_i$ is the time interval in years.

Landscape metrics (Table 2) were computed in FRAGSTATS (McGarigal et al., 2012) at the landscape level, jointly across all five LULC classes, and separately for an NDVI-derived binary vegetation/non-vegetation classification to characterise vegetation-specific structural change.

Table 2. Landscape Metrics Used

Metric	Abbreviation	Description	Interpretation

Patch Density	PD	Number of patches per 100 ha, landscape-level	Higher = more fragmented
Largest Patch Index	LPI	% of total landscape occupied by the single largest patch	Higher = greater dominance of one contiguous patch
Edge Density	ED	Edge length per hectare, landscape-level	Higher = more complex boundaries
Landscape Shape Index	LSI	Perimeter-to-area ratio, standardised by landscape size	Higher = more irregular boundaries
Mean Shape Index	MSI	Average patch shape complexity (theoretical minimum = 1.0)	Higher = more irregular patch shapes
Simpson's Evenness Index	SIEI	Evenness of area distribution among classes (0–1)	Lower = landscape dominated by fewer classes

The 2030 projections for class areas and landscape metrics have been extrapolated from the trend from 2000 to 2025 (Tables 5, 7, and 7a).

At the same time, nine stakeholders who are planning officials, Parks and Gardens Department staff and traditional landowners (Table 3) were interviewed, purposefully sampled to thematic saturation, informed consent and pseudonymised, using a semi-structured protocol. A sample of nine is sufficient for the use of a supporting qualitative component that has achieved thematic saturation for a bounded institutional perspective sample, but not statistically representative (Section 6).

Table 3. Study Participants

Participant Category	Gender	Number	Pseudonym
Land Use and Spatial Planning Authority (LUSPA)	Male	1	Planner A
Land Use and Spatial Planning Authority (LUSPA)	Female	1	Planner B
Land Use and Spatial Planning Authority (LUSPA)	Male	1	Planner C
Parks and Gardens Department	Male	1	Officer A
Parks and Gardens Department	Female	1	Officer B
Parks and Gardens Department	Male	1	Officer C
Traditional Landowners	Male	1	Landowner A
Traditional Landowners	Male	1	Landowner B
Traditional Landowners	Female	1	Landowner C

3.5 Data Analysis

The image classification and change detection were conducted using ArcGIS Pro and landscape metrics were calculated using FRAGSTATS. Qualitative interview data were analysed thematically, coding for common institutional and land-governance themes, and presenting the results by direct quotation.

4. Results

4.1 Classification Accuracy

Table 4 shows that the supervised Maximum Likelihood Classification had high accuracy ratings for all six epochs. Overall classification accuracy was between 87.0% and 96.0% and the kappa values were in the range of 0.825 to 0.946, which represented excellent agreement between the classified images and the independently interpreted reference samples. The overall accuracy of all epochs was well below the minimum 85% recommended for confident land use/land cover (LULC) change detection (Anderson et al., 1976) and all Kappa coefficients showed near perfect agreement as per Landis and Koch classification of 1977.

Table 4. Accuracy assessment summary for the Greater Tamale Area (2000–2025).

Year	Overall Accuracy (%)	Kappa Coefficient	Remarks
2000	90	0.862	Excellent
2005	85	0.813	Very Good
2010	92.4	0.873	Excellent
2015	94	0.908	Excellent
2020	87	0.825	Very Good
2025	92	0.849	Excellent

For most LULC classes, producer's and user's accuracies were high throughout the study period (Table 4a). Generally, the producer's accuracies for vegetation, water bodies and bare soil were over 90%, and for agricultural land, the producer's accuracies ranged from 88.5% to 100%. The

built-up class had relatively low producer's accuracy in 2000 (40.0%) and 2020 (70.6%) due to the classification of some built-up pixels in the classification process that were most likely confused with exposed dry-season soils due to their spectral similarity.

Post-classification quality assessment also revealed that the structure used by the internal classes of the 2015 classified raster differed from the one used for the other classified rasters after they had been harmonised to the common classification scheme which was used across the study. The harmonised classification was able to reach an acceptable overall accuracy of 94.0%, however there was some inconsistency as the bare-soil estimate was anomalously small. Because of this, the land cover estimates for the 2015 epoch should be taken with a grain of salt relative to the other years.

Table 4a. Producer's and User's Accuracy by Land Use/Land Cover Class (%).

Class	2000	2005	2010	2015	2020	2025
Vegetation (User/Producer)	82.8/96.0	100.0/95.0	100.0/93.3	97.9/95.8	100.0/90.9	100.0/88.9
Water Body (User/Producer)	100.0/75.0	100.0/100.0	90.0/75.0	100.0/100.0	100.0/66.7	100.0/100.0
Bare Soil (User/Producer)	100.0/92.6	93.8/96.8	90.7/98.6	100.0/100.0	85.7/93.8	100.0/100.0
Built-up Area (User/Producer)	80.0/40.0	88.2/88.2	100.0/71.4	96.0/96.0	100.0/70.6	83.3/83.3
Agricultural Land (User/Producer)	89.5/100.0	100.0/100.0	90.0/100.0	84.0/91.3	74.2/88.5	93.8/95.2

4.2 Land Use and Land Cover Dynamics

There was significant land cover change in the Greater Tamale Area between 2000 and 2025 (Table 5). Built-up area increased from 7,374.51 ha in 2000 to 24,736.59 ha in 2025, representing a net increase of 17,362.08 ha (235.4%). Agricultural land expanded from 29,895.75 ha to 50,314.95 ha, an increase of 20,419.20 ha (68.3%), while vegetation declined by 19,387.80 ha

(73.7%) during the same period. Water bodies were relatively constant and showed only small changes during the 25 year period.

Table 5. Land use and land cover distribution in the Greater Tamale Area (2000–2025) with projected values for 2030.

Lulc class	2000	2005	2010	2015	2020	2025	2030	NET CHANGE	% CHANGE
Buit-up	3,596.32	3,535.85	7,695.19	9,268.65	14,416.02	23,207.81	24,994.24	21,397.92	595.00
Vegetation	25,702.21	31,605.71	11,336.06	41,762.80	34,155.29	30,199.00	30,406.96	4,704.75	18.30
Water	876.69	1,143.19	259.21	340.34	161.53	159.81	148.66	-728.03	-83.04
Bare land	19,130.00	27,491.52	36,441.72	20,026.72	26,450.93	21,212.45	19,719.74	589.74	3.08
Agriculture	35,465.94	20,995.73	29,039.79	13,372.95	9,587.70	9,992.40	9,502.39	-25,963.55	-73.21
Total	**84,771.16**	**84,771.99**	**84,771.97**	**84,771.47**	**84,771.46**	**84,771.47**	**84,771.99**		

Urban expansion was ongoing from 2000 to 2015, and although there was some decrease in built-up area in 2015-2020, urban expansion increased sharply in 2020-2025. The rescaled class-coding structure before harmonisation found in the 2015 raster was clearly different from all other examined epochs, as was also the case with the bare-soil estimate (606.87 ha) which was significantly lower than the bare-soil estimates of 20,540–29,175 ha in all years before and after. This anomaly is therefore not taken to indicate a true landscape-level shift in bare soil or a reversal in urbanisation. Therefore, the interval specific estimates, based on the 2015 epoch, are thought to be less reliable than the overall long-term trends from 2000 to 2025.

4.3 Urban Expansion Intensity

According to the Urban Expansion Intensity Index (UEII) urban expansion increased during the study period (Table 5a). Annual expansion intensity increased from 0.677% during 2000–2005 to 0.919% during 2005–2010, before rising further to 1.631% during 2010–2015.

Table 5a. Urban Expansion Intensity Index (UEII).

INTERVAL	BUILT-UP CHANGE	YEAR	%/UEII
2000-2005	-60.47	5	-0.014
2005-2010	4,159.34	5	0.981
2010-2015	1,573.46	5	0.371
2015-2020	5,147.37	5	1.214
2020-2025	8,791.80	5	2.074

The most recent period (2020-2025) had the highest expansion intensity (2.564% $year^{-1}$), suggesting rapid urbanization during this time. The negative UEII value for the 2015-2020 period is a classification uncertainty problem for the 2015 period and not a reflection of actual urban contraction. The overall urban growth intensity of the Greater Tamale Area was 0.818% per year which is average, indicating a steady outward growth of the area over the last 25 years.

4.4 Landscape Metrics

Prospective structural reorganisation of the Greater Tamale landscape, measured at a landscape level, indicates progressive structural reorganisation from 2000 to 2025 (Table 7). Patch Density has risen from 54.23 patches per 100 ha in 2000 to 80.41 patches per 100 ha in 2010 before decreasing to 52.51 patches per 100 ha in 2025, indicating initial fragmentation of the landscape, followed by consolidation. Edge Density exhibited a similar pattern, increasing from 177.33 m ha^{-1} in 2000 to more than 213 m ha^{-1} during 2005–2010 before declining to 138.71 m ha^{-1} in 2025.

The progressive increase in the Largest Patch Index from 32.81% in 2015 to 48.41% in 2025 and 52.33% in 2030, suggested larger contiguous areas of land cover. The Mean Shape Index, which is closer to the theoretical minimum, remained fairly stable during the study period and indicated relatively stable patch geometry despite the changing landscape composition. By 2025, however, Simpson's Evenness Index had dropped from 0.943 in 2010 to 0.696, and is expected to fall further to 0.665 by 2030, which shows a growing trend of fewer land-cover classes taking over dominance.

4.5 Vegetation Structure (NDVI-Based Landscape Metrics)

The changes in vegetation derived from the NDVI values were also validated independently (Table 7a) with the vegetation changes derived from the classified LULC maps. The Largest Patch Index was also above 99% for the whole time of observation but the amount of fragmentation of the remaining vegetation (Patch Density and Edge Density) increased from 0.001 in 2000 to 2.345 in 2025 and 0.000 to 5.372, respectively. In the projected 2030 scenario, the fragmentation of vegetation will be seen to have increased significantly in terms ofPatch Density (25.311 patches/ha) and Edge Density (151.453 edges/ha), while the value of Largest Patch Index (LPI) is decreased (28.70%). These trends are independent evidence that even though there are still some relatively large patches of vegetation, they are increasingly becoming fragmented in the Greater Tamale Area.

4.6 Institutional Perspectives on Urban Expansion and Green Space

Interviews with planning officials, Parks and Gardens Department staff, and traditional landowners identify three convergent proximate drivers of outward growth: unregulated customary land release ahead of formal planning approval, conversion of formerly recreational or green spaces to residential and commercial use under population pressure, and rising peri-urban land values that incentivise landowners to sell rather than retain land for farming.

A physical planner (Planner A, Tamale Metropolitan Assembly) described the sequencing problem directly:

> "The development process that has been taking place in the peri-urban communities is not strictly guided by the approved planning schemes. Chiefs and family heads normally release land directly to developers, and planning approval usually occurs when construction has already commenced."

A Parks and Gardens Department official (Officer B) linked this to green-space loss specifically:

> "Tamale used to have a number of uncovered green spaces and tree-filled spaces in the city. Nevertheless, as the population has grown fast and houses have been built in large numbers, most of these areas have either been encroached upon or redesignated for development."

A traditional landowner described the economic logic driving land release:

> "When the city sprawls down to our communities, individuals have started demanding land to build houses. Land values have risen, and families would rather sell land to be developed than use it for farming or leave it as natural forest cover."

The sequencing problem described by Planner A approval lagging construction is a plausible institutional mechanism behind the fragmentation pattern in Table 7: informal, unplanned parcels are typically smaller and less contiguous than planned subdivisions, consistent with the rise in Patch Density and Edge Density between 2000 and 2010. Officer B's account of green-space conversion in the urban core is the institutional counterpart to the sharp vegetation decline in Table 5 (−73.7% over 2000–2025). The traditional landowner's account of land-value-driven sales explains why peri-urban land conversion in this study is landowner-initiated and largely outside

formal planning control, rather than developer-led a distinction with direct implications for which planning instruments (Section 7) are likely to be effective.

4.7 Population Growth and Future Land Pressure

Tamale's population increased from 223,252 in 2010 to 374,744 in 2021. Population estimates have been made that will determine between 767,000 and 1,016,000 people living in the city by 2050, depending on the annual growth rates in the future.

Table 6. Population projection scenarios for Tamale to 2050.

Scenario	Annual Growth Rate	Projected Population (2050)
Low	2.5%	767,000
Medium-low	2.8%	835,000
Medium	3.1%	908,000
High	3.5%	1,016,000

Current projections are for the city population to double by 2050 even with the most conservative growth rate, which will continue to put strain on land, housing, infrastructure and urban services. Without effective development control, the growth of the future is expected to continue to be integrated in the outside peri-urban areas, causing tensions on the remaining agricultural areas and spaces for the city.

5. Discussion

5.1 Classification Accuracy

The results of the classifications indicate that the maps of land use and land cover (LULC) produced for the Greater Tamale Area are reliable enough for long-term change detection analysis.

The overall classification results were between 87.0% and 96.0%, and the Kappa values were 0.825 to 0.946, which is a good degree of agreement between the classified images and the independently interpreted reference samples. They are higher than Anderson et al. (1976) recommended for minimum accuracy for LULC studies of 85% and within the "almost perfect" agreement category suggested by Landis and Koch (1977). Together, these findings give confidence that the mapped changes are not generally the result of classification error but are indeed representative of landscape changes.

The results obtained are similar to other studies that used Landsat data in Sub-Saharan Africa, including Ghana. Overall classification accuracy of more than 85% was also reported by Abass et al. (2018) and Owusu et al. (2021) when supervised classification techniques were applied showing that medium resolution satellite imagery is suitable to monitor urbanization. Similarly, Rwanga and Ndambuki (2017) stated that post classification comparison is still one of the most reliable methods for LULC analysis due to the possibility of assessing the uncertainty of classification prior to the temporal comparisons.

The producer's accuracy for built-up class was relatively low in 2000 (40.0%) and 2020 (70.6%), indicating omission errors related to the similarity of the impervious surface and exposed dry-season soils and harvested cropland in the spectral ranges. In such spectral confusion situations, which often occur in Guinea Savannah environments because of the overlap in spectral response for multiple land-cover classes during the dry season, the land cover classification results may be confounded. (McGarigal et al., 2012) Further, the post-classification verification showed that the classified raster from 2015 had a different internal coding structure of classes before being harmonised with the common five-class landscape use classification (LULC) structure. The harmonised classification resulted in an overall satisfactory accuracy of 94.0% but this coding

variation was also associated with an unusually low estimate for bare soil, which suggests that the proportions of the classes in 2015 should be taken with some caution. Importantly, this uncertainty only applies to the size of land-cover estimates for the 2015 epoch, and does not undermine the longer-term trajectory of urban expansion, given the long-term consistency of classification accuracy, NDVI-derived landscape metrics and qualitative institutional evidence.

5.2 Land Use and Land Cover Dynamics

The results showed that there had been a significant landscape change in Greater Tamale over the 25 year study period. Vegetation decreased by about 73.7%, farmland grew by 68.3% and built-up land grew by about 235.4%. The changes in the landscape imply that urbanisation has transformed the landscape composition, and that natural vegetation has been replaced by land uses associated with humans. The concurrent growth of urban and rural areas also indicates that urban expansion has not been solely in the form of direct reclamation of agriculture land, but also in the form of conversion from natural vegetation to agriculture land along the peri-urban fringe.

Global evidence shows that urban areas are growing at a higher rate than population, especially in developing countries (Seto et al., 2012), and this is reflected in the rapid growth of built-up land. Likewise, Angel et al. (2011) found that cities grow faster than population growth alone, and that the growth is typically low-density, outward, and more typical of urban sprawl. The Greater Tamale Area shows this development pattern well, showing that built-up area has more than tripled in the last 25 years, from 2000 to 2025.

The trends observed are also consistent with other cities in Ghana. Abass et al. (2018) noted that built-up surfaces around Kumasi have been increasing continuously and vegetation cover had been reducing, while Acheampong et al. (2017) observed a rapid urban encroachment of agricultural and green spaces to urbanization in Accra. The proportionate gain in built-up area for Greater

Tamale is however greater than for these larger metropolitan areas. This difference may be due to the fact that Tamale is a fast-growing secondary city with small absolute gain representing a significant proportional gain as the city development started from a comparatively small base.

This growth in agriculture land is in contrast to several other metros where urbanization typically leads to a decrease in agricultural land (Owusu et al., 2021). Agricultural growth within the Greater Tamale Area seems to have been in the form of natural vegetation clearance as well as not saving existing farmland. This pattern is typical of the dynamism of Guinea Savannah landscapes where the first use of the land is agriculture followed by urban development.

The overall decrease in built-up area between 2015 and 2020 does not necessarily indicate temporary urban contraction. After examining the classification outputs it was found that the classification of the 2015 raster was unique, in that it had a different internal class-coding structure prior to harmonisation than the other years, leading to a significantly lower bare soil estimate than the other years. Therefore, there is more uncertainty in the interval-specific changes using the 2015 epoch, as compared to the rest of the time series.

5.3 Urban Expansion Intensity

The Urban Expansion Intensity Index (UEII) shows that urban growth has been increasing over time during the study period with the highest annual growth between 2020 and 2025. This trend indicates that the rate of urbanization in the Greater Tamale area has been growing at a higher rate over time, not a steady pace. The cities are increasingly becoming more urbanised and rapidly encroaching on the peri-urban areas, which is consistent with the urban sprawl theory which suggests that as city populations, infrastructure and economic activities grow, the surrounding peri-urban areas are gradually appropriated by the cities (Ewing, 1997; Angel et al., 2011).

The observed acceleration is very similar to the findings of Seto et al (2012) on the global scale, who showed that urban land expansion is accelerating fastest in the context of developing countries. The same can be seen across Sub Saharan Africa, where low-level planning systems and informal land markets and high rates of demographic growth drive outward urban sprawl (Cobbinah et al., 2020; Ament et al., 2023).

The calculated UEII value for 2015-2020 indicates a temporary decrease in urban expansion, but this should be taken with a grain of salt since it is strongly affected by the 2015 epoch classification uncertainty. The interval-specific estimate is therefore less reliable in showing development trends than is the long-term acceleration of urban growth between 2000 and 2025. Interview evidence also revealed that customary transfers of land often take place before statutory planning approval is granted, and that this favours peri-urban growth over urban renewal.

5.4 Landscape Structure and Fragmentation

From the landscape data, there are indications of significant reorganisation of the greater Tamale landscape over the study period. Patch Density and Edge Density were higher in early stages of urbanization suggesting more fragmentation as continuous vegetation was broken up into smaller patches. There are general patterns of fragmentation that have been reported throughout rapidly urbanising areas where roads, housing and infrastructure are increasingly dividing natural landscapes over time (Herold et al., 2003; McGarigal et al., 2012).

After this initial fragmentation, the Largest Patch Index rose significantly after 2015 whereas Simpson's Evenness Index fell significantly. In this context, these trends suggest that the extent of relatively few classes of land cover is increasing, such as agricultural land and built-up areas. This observation is consistent with that of Forman and Godron (1986) who suggested that the process of urbanisation eventually leads to an increase in the size and homogeneity of patches of

anthropogenic land-cover. This trend is thus a measure of consolidation of human modified landscapes, not ecological recovery, as indicated by the rising Largest Patch Index.

The declining Simpson's Evenness Index further shows that the diversity of the landscape has been decreasing year after year, with the replacement of natural vegetation by agricultural and built-up areas. Landscape heterogeneity has also decreased in other rapidly urbanising cities where anthropogenic land uses have taken the place of ecosystem structure, including in Haddad et al. (2015) and Ament et al. (2023).

5.5 Vegetation Fragmentation

The independent assessment of vegetation degradation by the NDVI derived landscape metrics also supports the vegetation degradation detected from supervised LULC classification. There was a general trend of increased fragmentation of the remaining vegetation as Patch Density and Edge Density increased over the length of the study, though this trend was not always as apparent as that of the larger areas of vegetation. It shows that the degradation of the vegetation area was not only decreasing the area, but also reducing the size and isolation of the remaining vegetation areas.

The results contribute to the ecological research that shows that loss of habitat often occurs before total vegetation loss (Haddad et al., 2015). A smaller patch of habitat decreases the available habitat connectivity, triggers edge effects and diminishes the resilience of the habitat before substantial loss in vegetation cover occurs. Therefore, ecological impacts of urban development go beyond just vegetation area loss to ecosystem degradations and dysfunction.

The findings are also corroborated by the study of Douglas et al. (2008) that found higher temperatures on the land surface to be correlated with the loss of urban vegetation, rise in flood risk, and loss of ecosystem services. In the Guinea Savannah environment of northern Ghana the

ecological impacts are more important as vegetation plays a role in the regulation of microclimate, soil conservation, biodiversity conservation and rural livelihoods. Thus, ongoing deforestation could be significant for the environmental sustainability and climate resilience in the Greater Tamale Area.

5.6 Institutional Drivers of Urban Expansion

The qualitative results help to explain the spatial patterns revealed by the remote sensing analysis, in terms of institutional explanations. The use of customary land allocation prior to statutory planning approval was always cited as one of the main factors leading to uncontrolled peri-urban development by planning officials. These results corroborate Cobbinah and Amoako (2018) who contended that customary land tenure systems often cause formal planning control in the rapidly urbanizing African cities to suffer.

The participants also recognised the rapid urbanisation and the pressure of housing demand are leading to the loss of green urban spaces to urban development. This is consistent with the findings of Ament et al. (2023) who found that the encroachment of urban development in Sub-Saharan Africa has become more and more at the expense of green infrastructure and natural ecosystems.

Traditional landowners also cited the value of their land as an important reason for turning their agricultural and natural lands into residential areas. This result corroborates the work by Angel et al. (2011) who highlighted the role of land-market processes in explaining urban sprawl. In many urban studies, however, the private actors are the most important in influencing the spatial development of the urban fringe with the former private developers controlling the land use, the study shows that the land use that was seen in the Greater Tamale Area was largely influenced by the role of the customary landowners. Planning measures which address only developers are

therefore unlikely to ensure sustainable urban development without engaging customary authorities in land administration and in development control processes. The qualitative evidence thus adds to the quantitative results and shows that in addition to population growth, the dynamics of customary land governance, land value growth, lack of planning law enforcement and the demands for residential land use drive rapid urban expansion.

5.7 Population Growth and Future Land Pressure

Population estimates in the Greater Tamale Area suggest that in the high growth scenario, the population may reach 1,000,000 inhabitants by 2050 and even the most conservative estimates show that the population is more than doubling compared to 2021. Such predictions will mean continued requirement for housing and infrastructure, as well as public services, which will drive pressure on neighbouring agricultural land, natural habitat, and urban green space.

These estimates are in line with the United Nations (2019) projections of Sub-Saharan Africa having the highest rate of urban population growth in the next decades. Likewise, as economic opportunities continue to grow away from the nation's capitals, the World Bank (2019) estimates that secondary cities will host a significant share of new urban growth in the future.

However, the results also suggest that demographic growth is by no means the only factor influencing future land conversion. Uncontrolled outward expansion was repeatedly pointed to as a direct consequence of a lack of governance at a spatial level, the lack of a tenure system in the land market and a weak planning governance framework. This is in contrast to deterministic perspectives on urbanisation which focus land conversion on population growth. Rather, the present study shows that the institutional capacity and land governance also are important drivers of the transformation of landscapes as a result of population growth. Enforcement of the planning regulations and incorporation of customary authorities in formal land-use planning and

safeguarding strategic green infrastructure could therefore have a significant effect on reducing urban sprawl in the future and still allow for urban population growth.

6. Limitations

Although the analytical approach was strong and classification accuracy was high, there were some limitations in the findings of this study. Medium-resolution Landsat data (30 m spatial resolution) does not allow the identification of fine-scale features of the landscape like individual buildings, narrow roads and small urban green areas. Furthermore, the environment of Guinea Savannah is a mixed one, especially at the boundaries of built-up areas, bare soil and agriculture, leading to some level of confusion between the land-cover classes.

Post-classification assessment revealed there was a difference in internal class-coding structure of the 2015 classified raster, which was used and had to be harmonised into the common five-class LULC classification scheme. This coding disagreement was correlated with an unusually low estimation of bare soil compared to the other study years, adding to the uncertainty in the estimation of land cover for the 2015 epoch. The 2015-2020 interval therefore should be interpreted with caution as compared to the other intervals. However, the overall trends of built-up increase, vegetation decrease and agriculture expansion are still strong, consistently backed by classification accuracy assessment, NDVI-derived landscape metrics and qualitative institutional evidence.

The multi-sensor, multi-decadal integration of imagery from four Landsat generations (TM, ETM+, OLI and OLI-2) also has inherent cross-sensor radiometric differences that are typically found in multi-decadal remote sensing studies. These differences were minimized in the standard image pre-processing and classification process but cannot be completely removed because of variations inherent in the different sensors. Moreover, the algorithm used, Maximum Likelihood

Classification, was chosen for consistency across all six temporal epochs. More recent machine-learning algorithms like Random Forest or Support Vector Machines could be used to improve class discrimination in a heterogeneous landscape, however using a single classification approach across the study provided consistency and comparability in the long term LULC estimates.

The qualitative portion was aimed not so much as producing statistically representative findings as to supplement the quantitative results with institutional perspective on the drivers of urban expansion. As such their views from purposively selected planning officials, Parks and Gardens and traditional landowners should be read within their institutional setting. The projections of population shown for 2050 are also based on scenarios and projected population growth rates, and are intended to illustrate future pressures on the population, not to make an accurate prediction. These limitations notwithstanding, the alignment between the remote sensing analysis, landscape metrics, NDVI assessment and institutional evidence offer a basis of confidence in the main findings of the study. For future research, it will be useful to combine high resolution satellite data, sophisticated machine-learning classification methods, longer-term ground-truthing and a more extensive stakeholder engagement to advance the spatial validation and institutional analysis of urban dynamics in the Greater Tamale Area.

7. Conclusion and Practical Implications

The Greater Tamale Area in Ghana was comprehensively analyzed in this study to assess urban expansion and land use/land cover (LULC) changes in the area from 2000 to 2025 using multi-temporal Landsat images, landscape metrics, and perspectives from institutions. The results reveal that the Greater Tamale Area is currently experiencing a rapid rate of landscape change, with continuous urban growth, significant vegetation clearance, loss of bare ground, and growth of agricultural areas. The built-up land cover grew by 235% during the study period, while the

vegetation cover decreased by almost three-quarters, showing that urban development is gradually replacing the natural vegetation cover and altering the spatial pattern of the landscape. At the same time, the Urban Expansion Intensity Index showed that the growth in cities and towns has picked up significantly since 2010, placing greater pressure on peri-urban land. The landscape has also become more dominated by large agricultural and built-up patches and increasingly less diverse, as they were observed by landscape metrics, with fragmentation of the remaining vegetation. The results all point to reorganisation of landscape structure and ecological processes in addition to changes in land-cover composition that occurs when urbanisation is underway in Greater Tamale.

The qualitative results corroborate the spatial results and reveal that institutional and governance aspects play a strong role in these changes. Interviews with planning authorities, Parks and Gardens officers and traditional landowners suggest that customary release of land before formal planning approval, urban green space losses, and rising land values in peri-urban areas are important factors in the process of urbanisation. This indicates that the observed landscape change is not only due to the population growth but also the combination of customary land tenure systems, market incentives, and the lack of spatial planning and development control. The combination of geospatial evidence and institutional perspectives is thus a more holistic view of urban expansion than each approach could offer alone.

The study adds to urban sustainability research by providing an example of the use of remote sensing, landscape ecology, and qualitative institutional analysis to study urban growth in rapidly growing secondary cities. Apart from a few exceptions in the literature that have been conducted in Accra and Kumasi, this research aimed to fill a gap in the literature regarding landscape transformation in Greater Tamale and offers valuable long-term quantitative evidence. The use of these FRAGSTATS landscape metrics, combined with the Urban Expansion Intensity Index,

provides a landscape-level expansion of the traditional approach of analysing LULC change, by also capturing the spatial dynamics and composition of landscapes.

The results highlight from a policy point of view the need for the improvement of the two fundamental pillars of land governance and space planning in the context of rapid urbanisation in secondary cities. There is a need to direct development away from such inappropriate uses of customary land prior to the start of construction, through a proactive approach to development control, and to ensure that urban growth boundaries, protected green infrastructure, ecological buffer zones and designated agricultural protection areas are incorporated into metropolitan planning to limit unplanned peri-urban development. Greater partnership between the Land Use and Spatial Planning Authority (LUSPA) and the Tamale Metropolitan Assembly with customary authorities will lead to better adherence to planning laws and foster more sustainable urban development. Satellite remote sensing and GIS based monitoring should also be routine, to sustain evidence based action planning and to allow early detection of land-use change.

Figures

Figure 1. Classified land use/land cover maps of the Greater Tamale Area, 2000, 2005, 2010, 2015, 2020, and 2025.

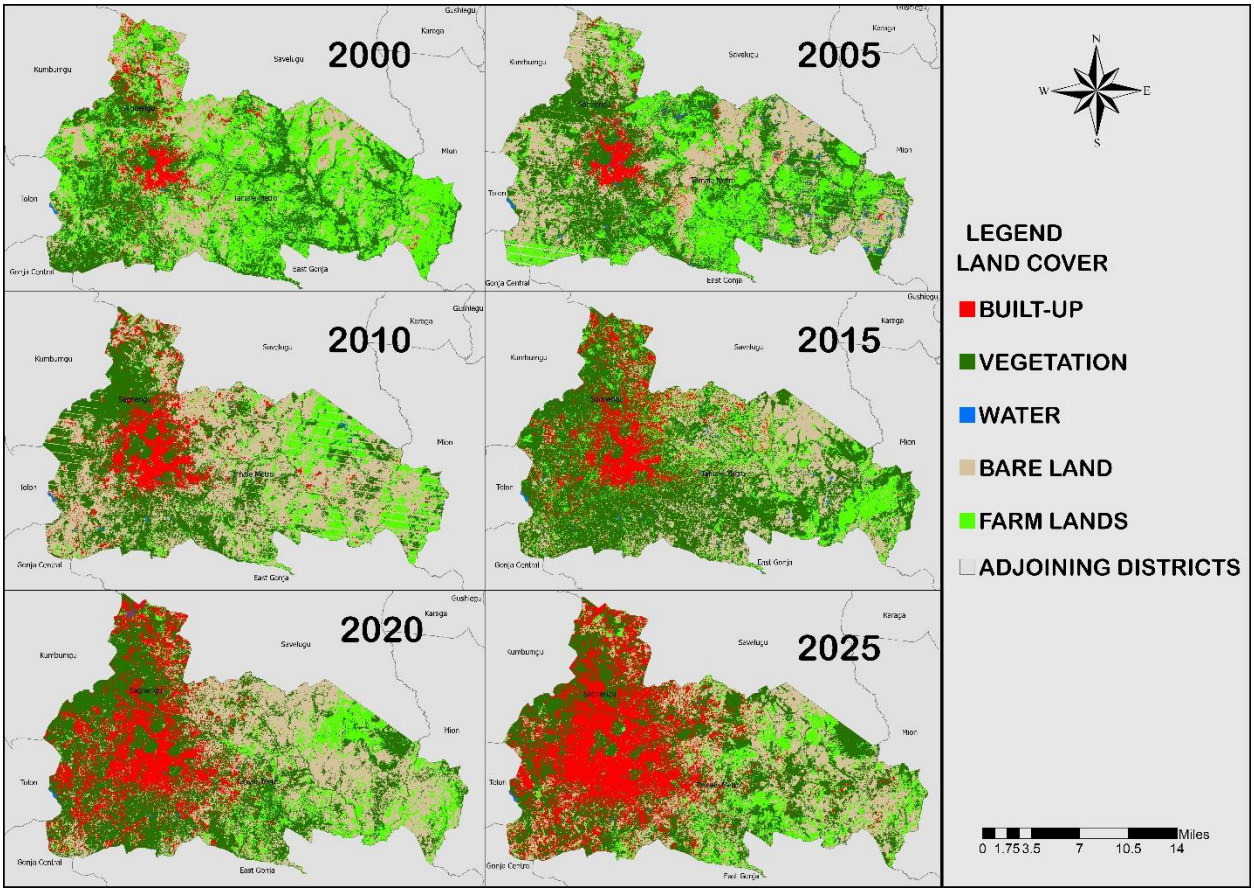

2000
2005
2010
2015
2020
2025
Gushiegu
Karaga
Saveligu
Kumbungu
Nanton
Mion
Tolon
Tamale Metro
Gonja Central
East Gonja
N
W
E
S
LEGEND
LAND COVER
BUILT-UP
VEGETATION
WATER
BARE LAND
FARM LANDS
ADJOINING DISTRICTS
0 1.753.5 7 10.5 14
Miles

Figure 2. NDVI classification maps of the Greater Tamale Area, 2000–2025.

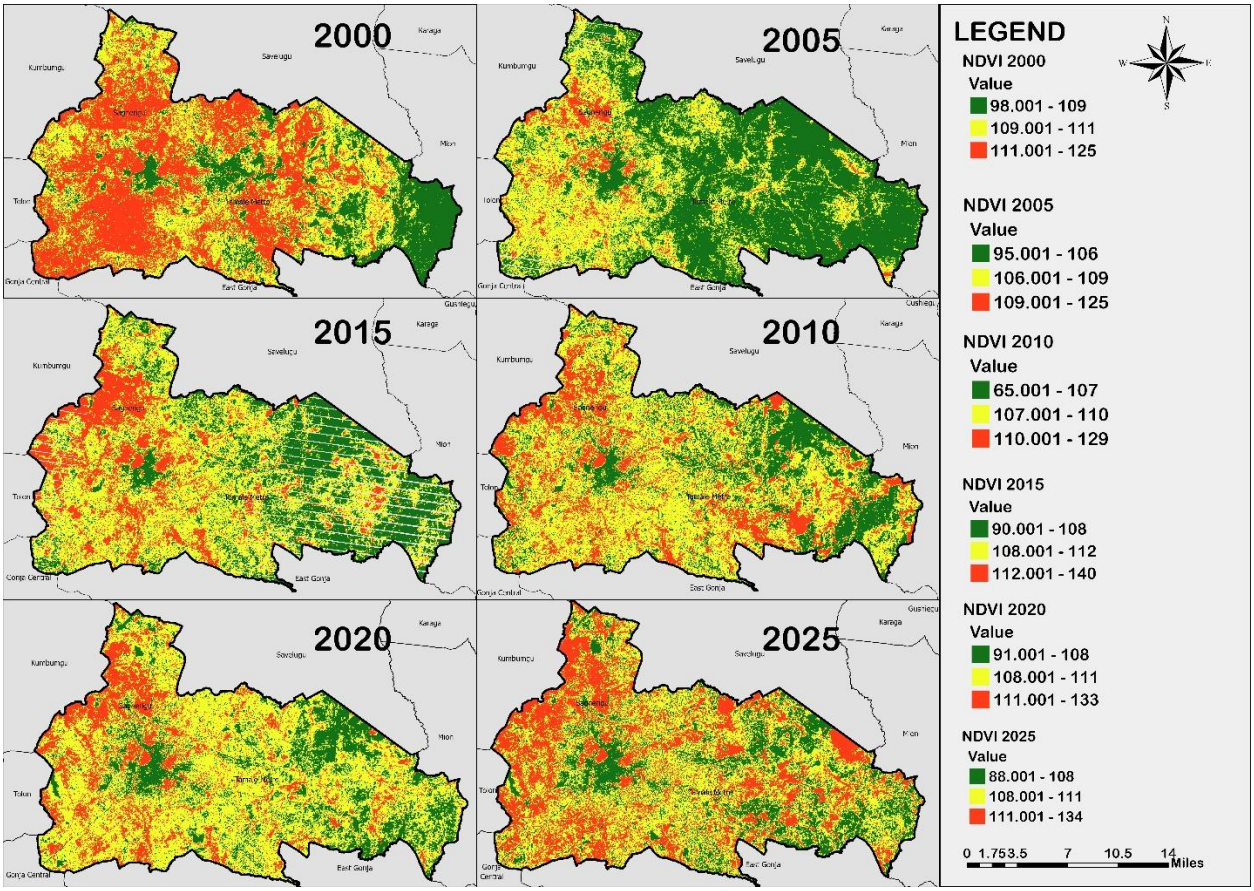


Figure 3. Urban growth boundary expansion, Greater Tamale Area, 2000–2025.

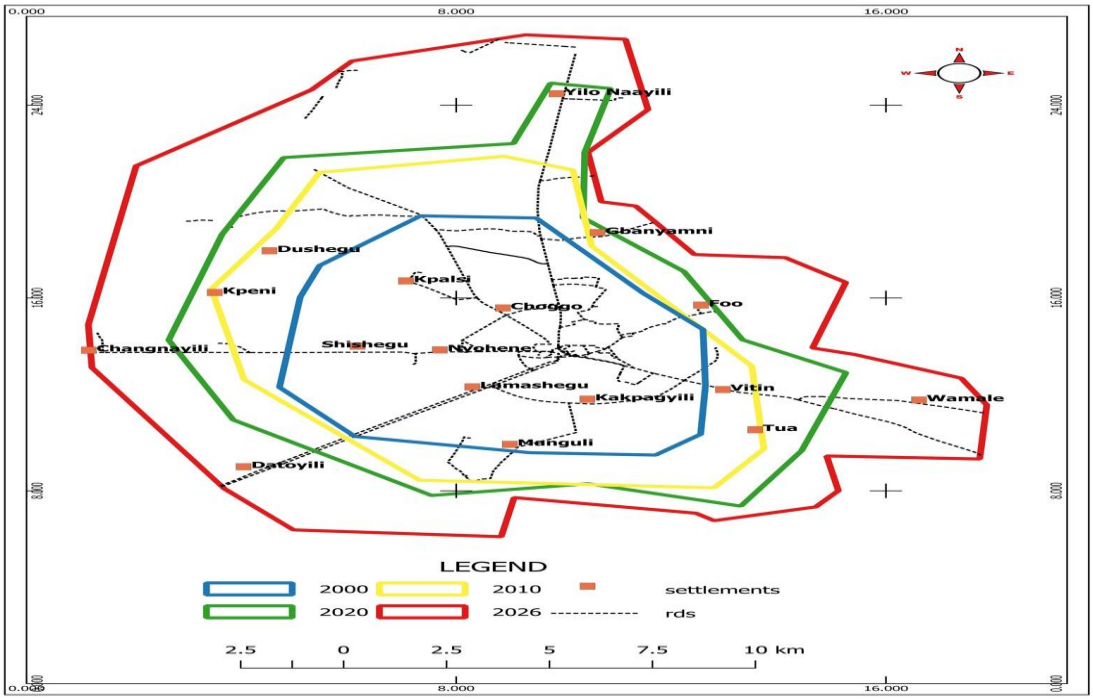


Figure 4 ***LULC Trends (2000–2030)***

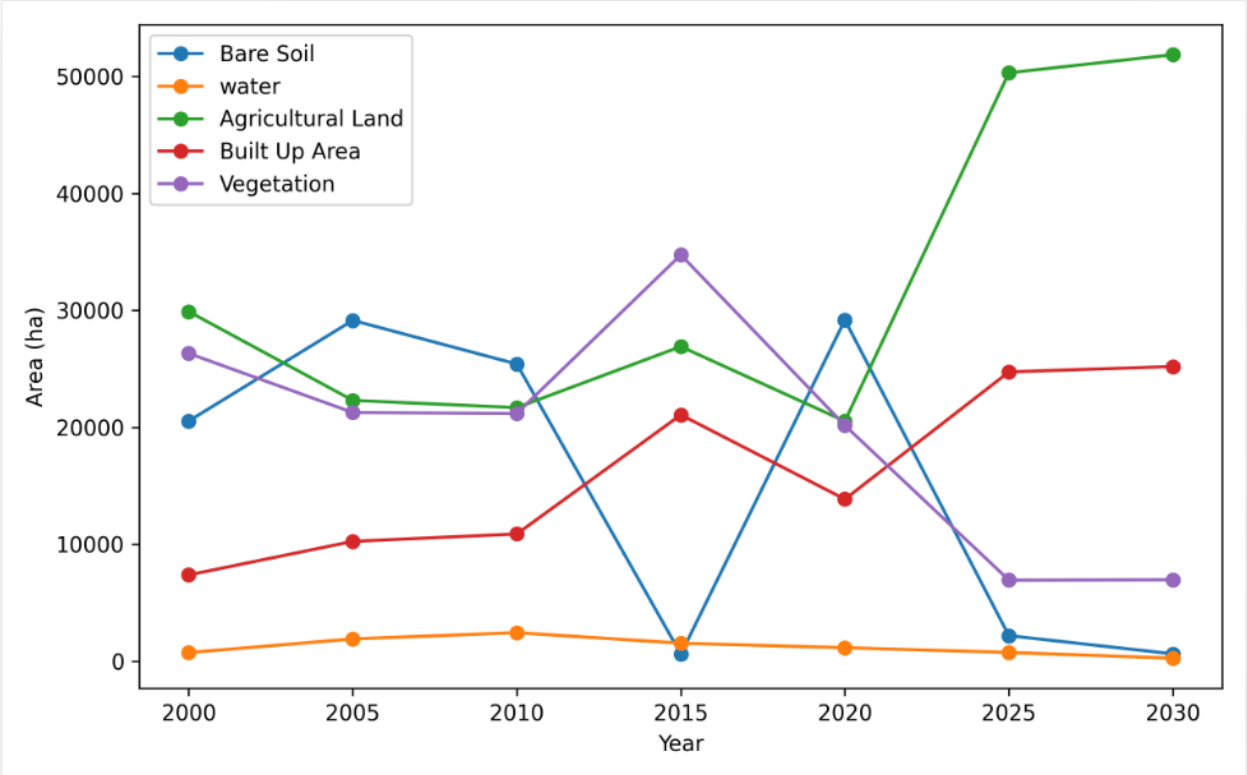


Figure 5 Built-up Area Trend (2000–2030)

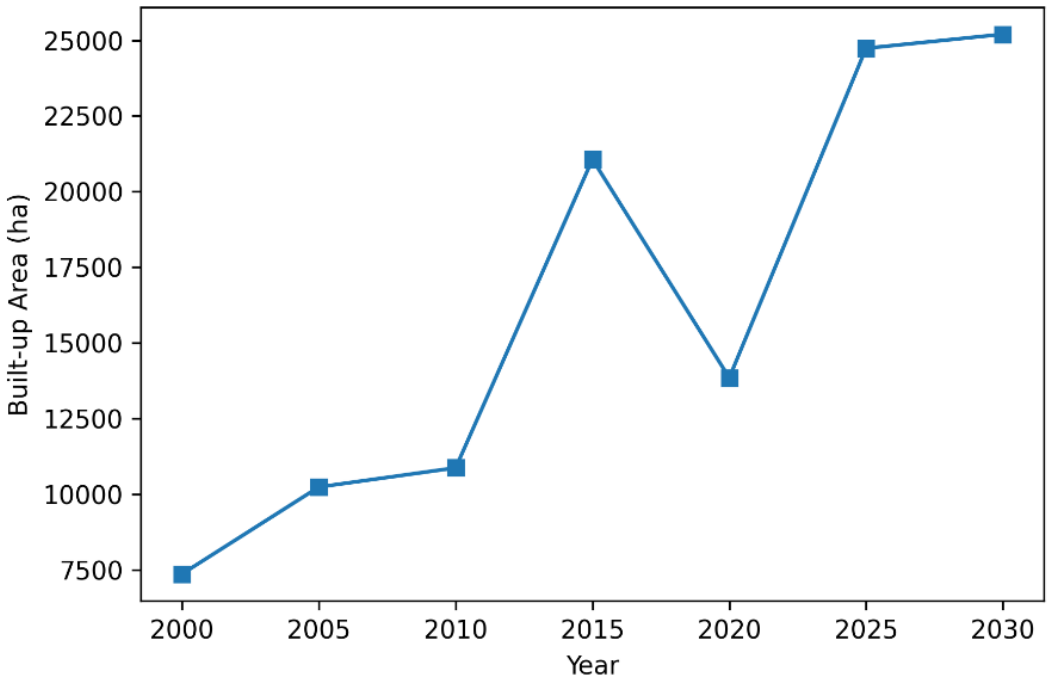


Figure 6. Net LULC Change (2000–2025)

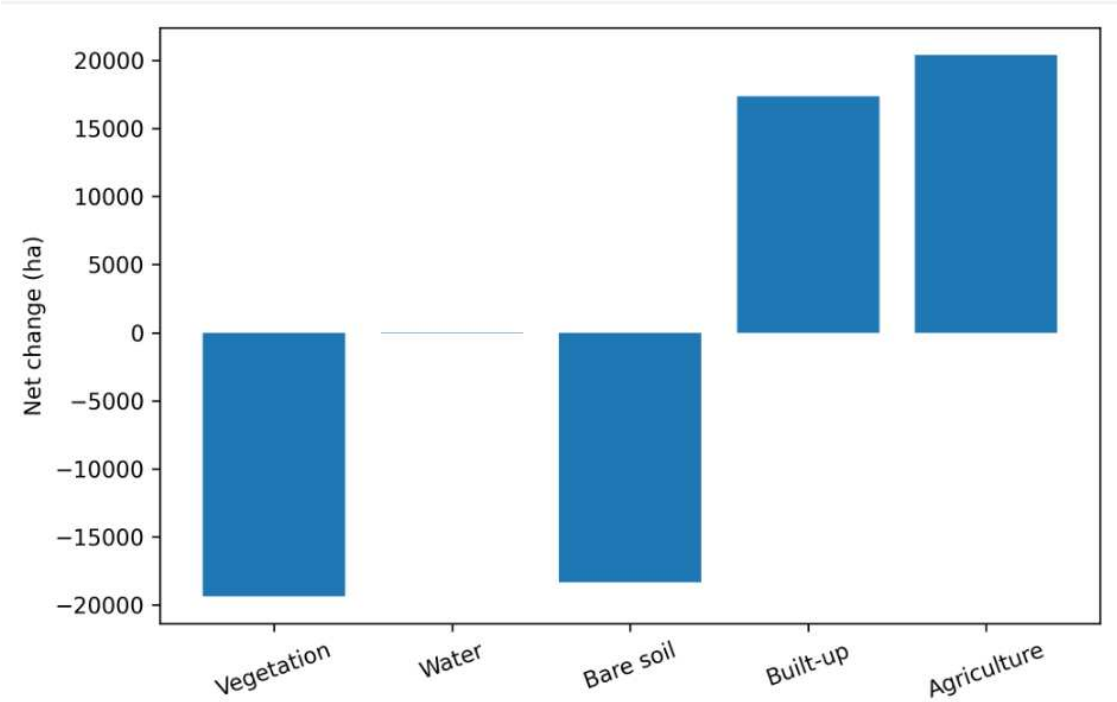


Figure 7. Urban Expansion Intensity Index (UEII)

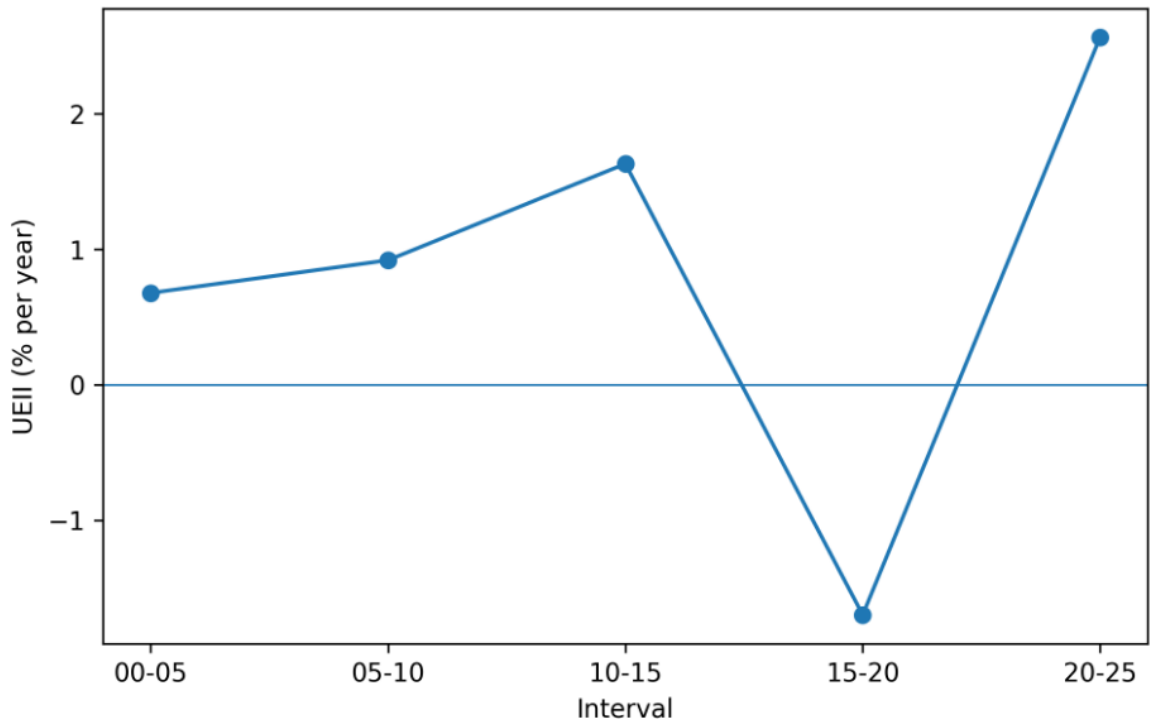


Figure 8. Patch Density

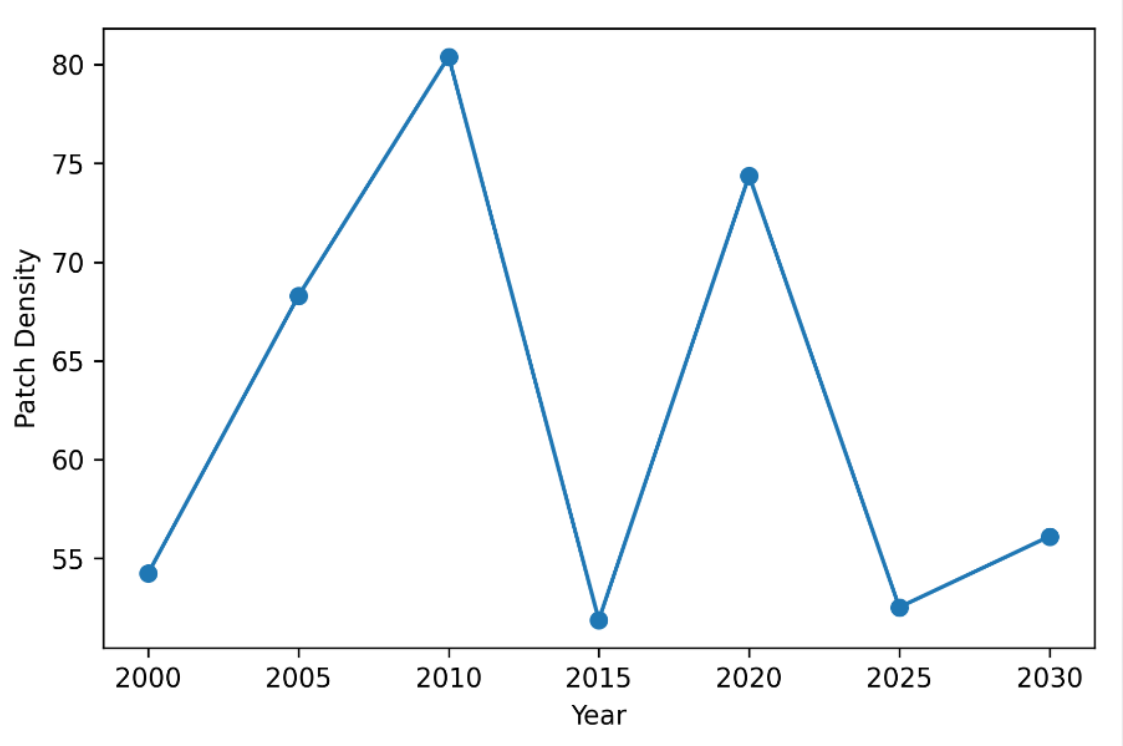


Figure 9. Largest Patch Index

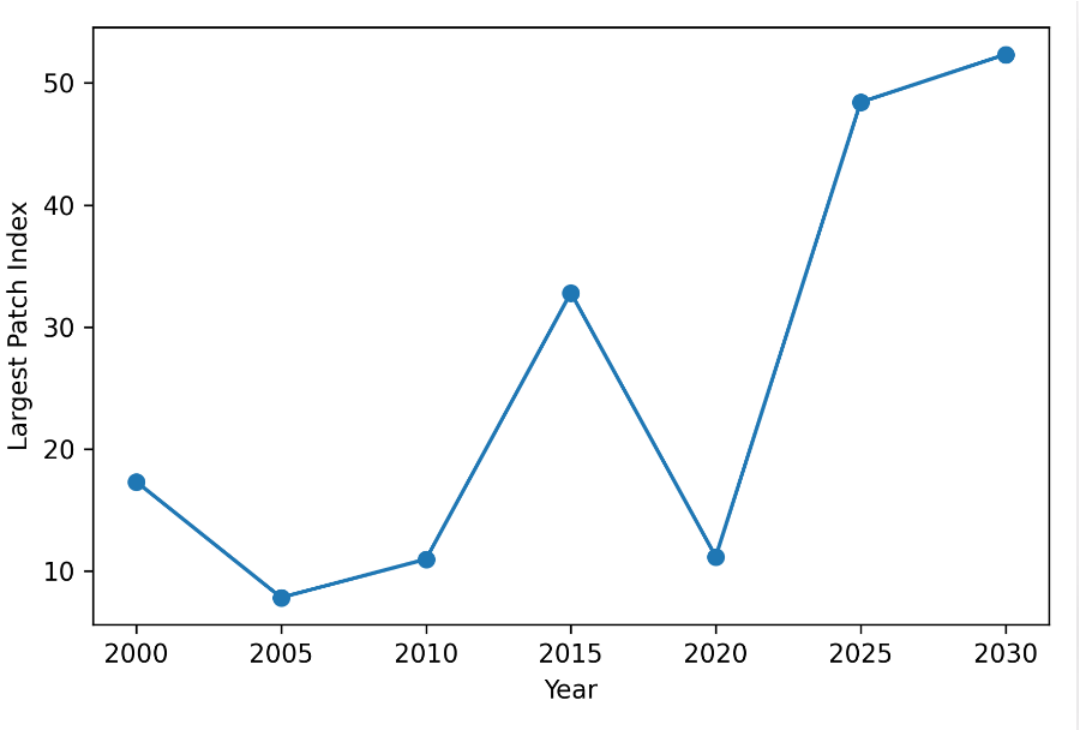


Figure 10. Edge Density

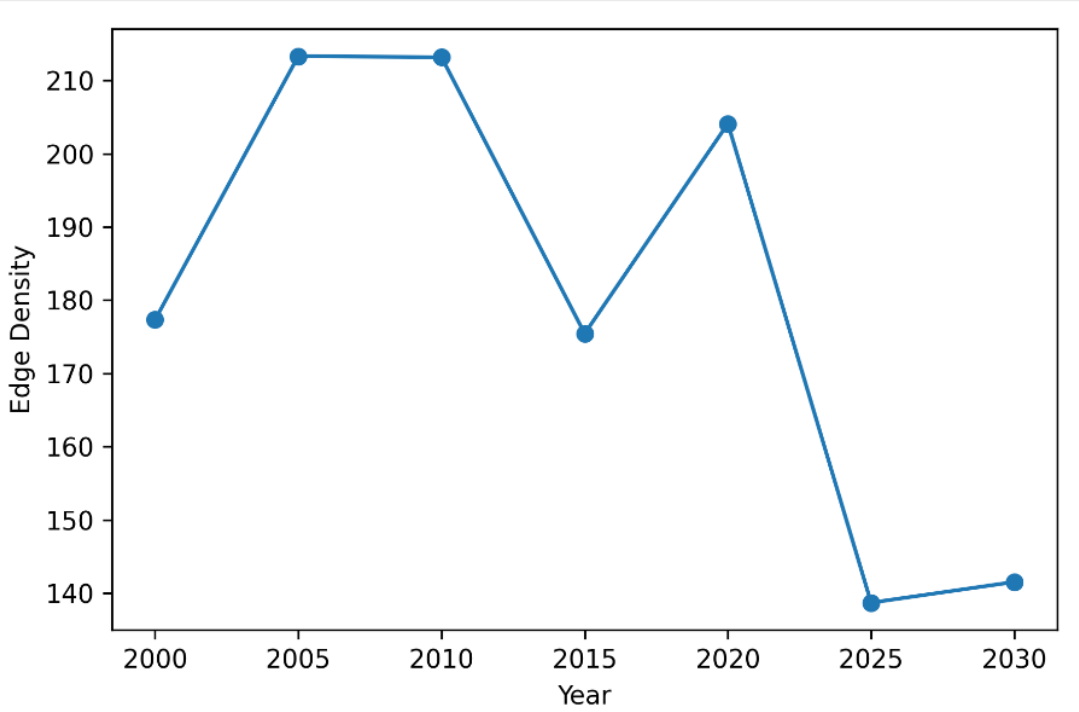


Figure 11. Landscape Shape Index

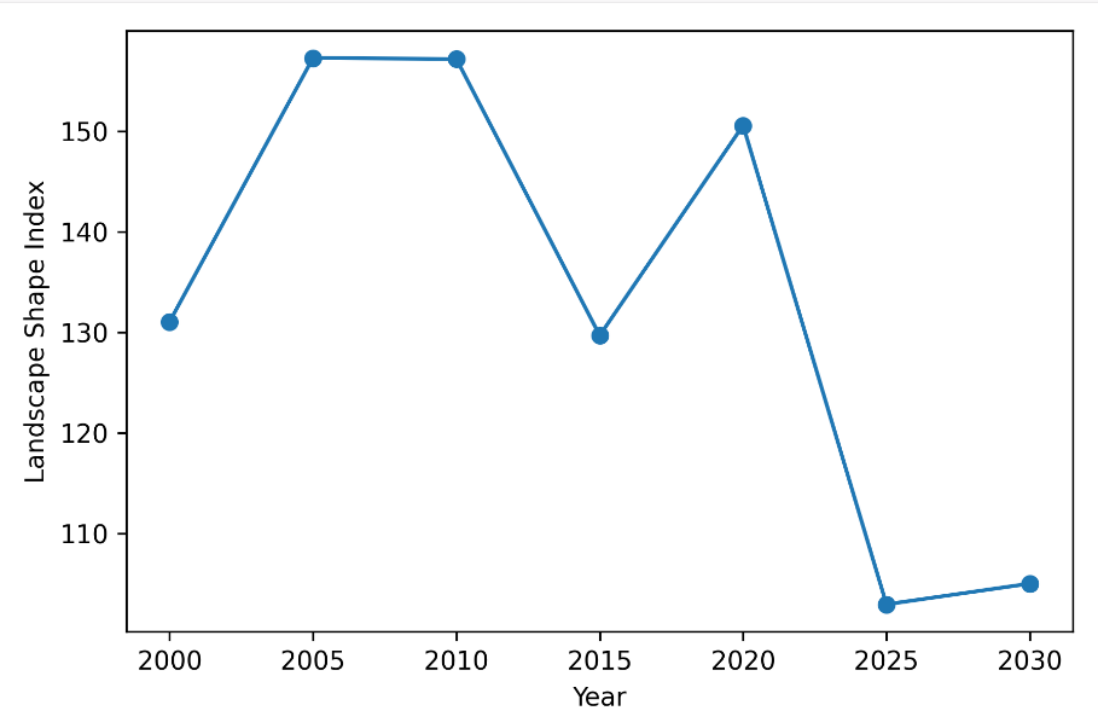


Figure 12. Mean Shape Index

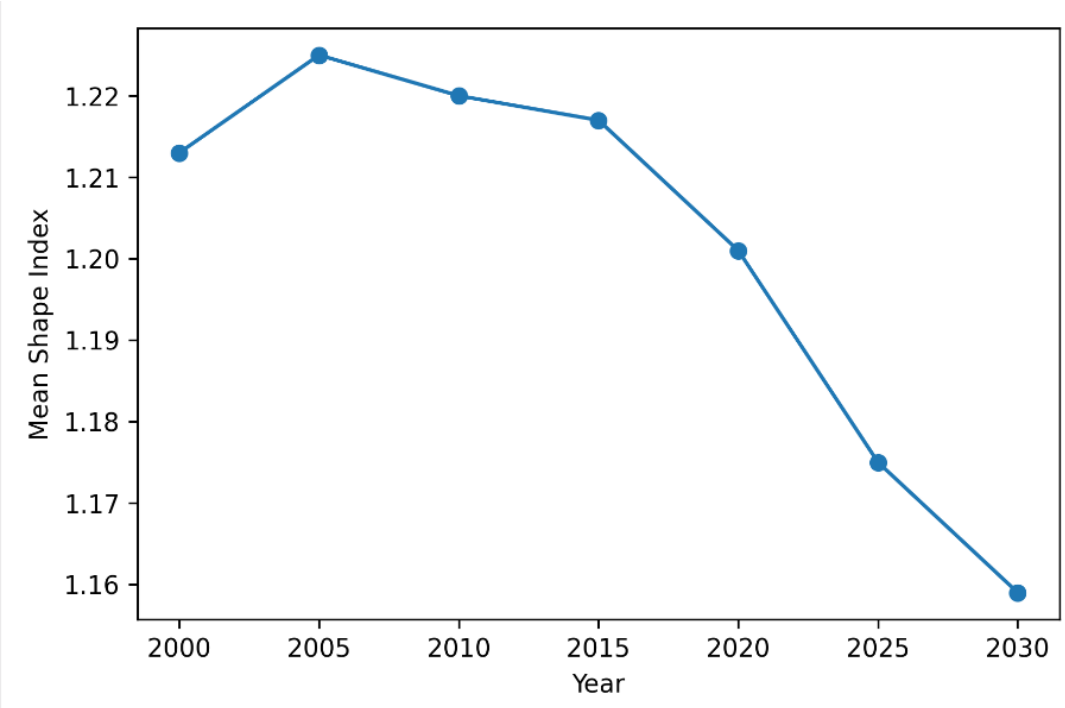
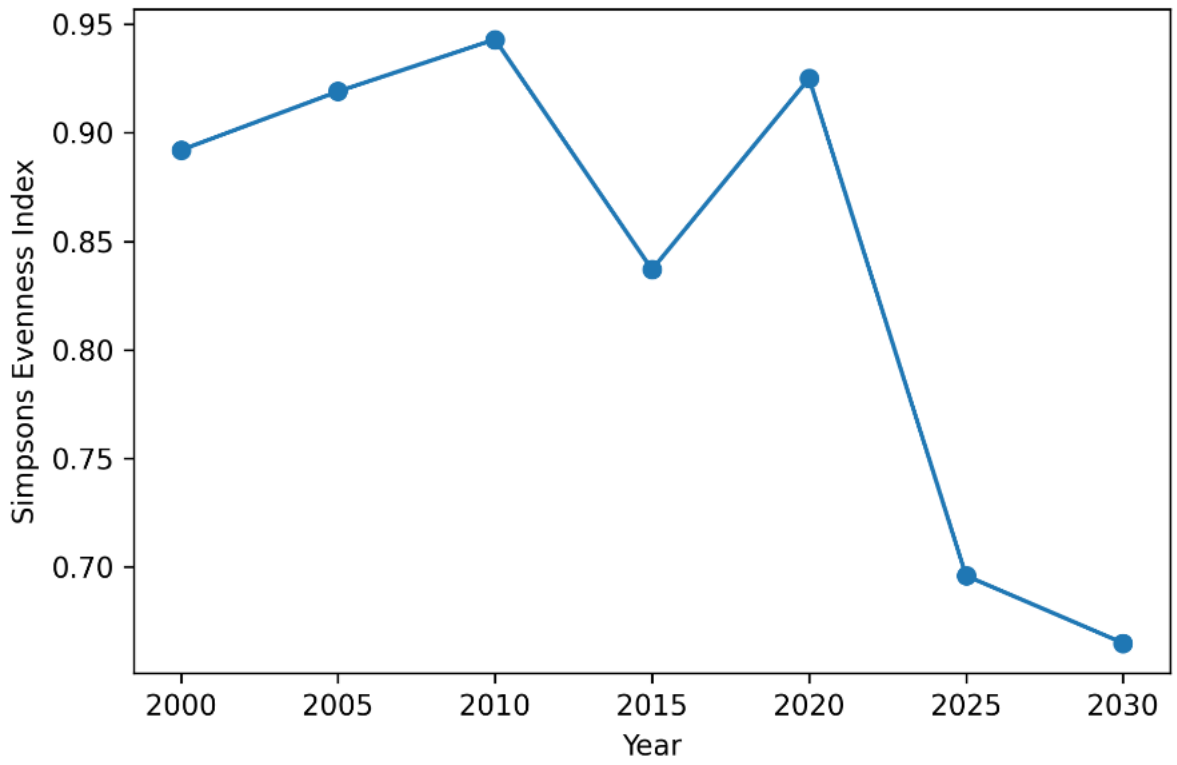


Figure 13. Simpson's Evenness Index



Statements and Declarations

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Competing Interests: The authors have no relevant financial or non-financial interests to disclose.

Data Availability: Data sets generated during this study are available from the corresponding author on reasonable request.

Ethics Approval and Consent to Participate: Ethical approval for this study was granted by the Institutional Review Board, University for Development Studies, Ghana. All methods involving human participants were performed in accordance with the ethical standards of that Board and the principles of the Declaration of Helsinki. The study involved semi-structured interviews with technical officers, residents, and experts from planning institutions in the Greater Tamale Area; it

did not involve invasive procedures. Participation was voluntary and informed consent was obtained from all participants; information was used strictly for academic purposes and confidentiality was maintained.

Consent to Publish: Participants were informed that their contributions would be used for academic publication, and consent to publish was obtained from all relevant participants prior to manuscript preparation and submission.

Clinical trial number: Not applicable.

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