Assessing Urban Growth, Land Consumption, and Natural Landscape Transformation in Kakamega Central Region, Kenya

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Absztrakt

A földhasználat és a földborítás (LULC) változásai továbbra is kritikus kihívást jelentenek a fenntartható városfejlesztés szempontjából, különösen a gyorsan növekvő közbenső városokban és környezetükben. Ez a tanulmány a következő célokat tűzte ki maga elé: (i) a LULC-átalakulásokban megfigyelhető mintázatok felmérése Kakamega városában és közvetlen almegyéiben, (ii) a földfelhasználási ráta (LCR) és a földfelhasználási együttható (LAC) trendjének vizsgálata, és (iii) a városi növekedés természeti tájra gyakorolt hatásának értékelése LCR és LAC mérőszámok segítségével 2003 és 2023 között. A 2003-as, 2013-as és 2023-as Landsat felvételeket használtuk a vizsgálati területen öt fő földborítási típus, nevezetesen a beépített területek, a szántóföldek, a gyepek, az erdők és a víztestek térbeli és időbeli változásainak elemzésére. Az Orfeo Toolbox (OTB) gépi tanuláson alapuló Random Forest algoritmusát használó felügyelt osztályozási módszert alkalmaztuk. Az összes földborítási osztály teljes pontossága meghaladta a 85%-ot az összes elemzett évben. Az osztályozás utáni változáselemzés változó mintázatokat tárt fel a földborítás átmeneteiben. A tanulmány kimutatta, hogy a beépített terület gyorsan, 451,4%-kal bővült 2003 és 2013 között, illetve 130,9%-kal 2013 és 2023 között, aminek fő oka a gyepek és a szántóföldek voltak. A teljes vizsgálati időszak alatt a szántóföldek területe 148%-kal nőtt, míg a gyepek és a víztestek területe 73,8%-kal, illetve 30%-kal csökkent. Mind a beépített terület (LCR), mind a LAC jelentős növekedési pályát mutatott a vizsgálat időtartama alatt, ami a nem hatékony földhasználatra utal, ami hatással van a természeti tájra. Ezek az eredmények alapvető betekintést nyújtanak a városi növekedés fenntarthatósági állapotába, empirikus bizonyítékokkal felvértezve a döntéshozókat a megalapozott politikaalkotáshoz és a régió természeti tájának megőrzéséhez.

Abstract

Changes in Land Use and Land Cover (LULC) remain a critical challenge for sustainable urban development, especially in rapidly growing intermediate towns and their surroundings. This study aims to: (i) assess the patterns in LULC conversions in Kakamega town and immediate sub-counties, (ii) examine the trend in Land Consumption Rate (LCR) and Land Absorption Coefficient (LAC), and (iii) evaluate the implications of urban growth on natural landscape using LCR and LAC metrics between 2003 and 2023. Landsat images of 2003, 2013, and 2023 were used to analyze spatiotemporal changes in five major land cover types in the study area namely: built-up, cropland, grassland, forest, and water bodies. A supervised classification method using the machine learning Random Forest algorithm in Orfeo Toolbox (OTB) was employed. The overall accuracy for all land cover classes exceeded 85% across all the years analyzed. Post-classification change analysis revealed varying patterns in land cover transitions. The study noted that the built-up area expanded rapidly by 451.4% between 2003 and 2013 and by 130.9% between 2013 and 2023, with grassland and cropland as the principal contributors. Throughout the entire study period, cropland increased by 148%, while grassland and water bodies declined by 73.8% and 30%, respectively. Both LCR and LAC exhibited a notable upward trajectory throughout the study duration, indicating inefficient land use with implications for the natural landscape. These findings offer foundational insights into the sustainability status of urban growth, equipping decision-makers with empirical evidence to drive informed policy development and conserve the region's natural landscape.

1. Introduction

Population growth and urbanization stand out as mutually interacting factors accelerating LULC transformation worldwide (Rimal et al., 2025). Specifically, population growth exerts pressure on land for settlement and infrastructure development, resulting in built-up landscapes (Eludoyin et al., 2025; Kipkulei et al., 2022). Similarly, urbanization promotes rural-urban migration, enabling settlement concentration in cities (Amal & Sabyasachi, 2025). Ultimately, both population growth and urbanization increase impervious surfaces, which consume areas previously covered by farmlands and natural ecosystems (Albalawi, 2025; Peng et al., 2024). The anticipated growth of the world population to nearly 10 billion by 2050 underscores the inevitable intensification of terrestrial modification, especially in the global south (UNDESA, 2022). Therefore, accurate data on land consumption commensurate with demographic expansion is pivotal for achieving Sustainable Development Goal (SDG) 11 (sustainable cities for human settlement) (UN-Habitat, 2018).

Like other African countries, Kenya's rapid population growth, particularly in urban areas, in recent decades has driven changes in LULC (Chepkorir et al., 2025). This period coincides with the implementation phase of the 2010 constitution, which decentralized functions to county governments (Muwonge et al., 2022). As anticipated, county governments have reported significant achievements, including the establishment and expansion of municipal infrastructure such as roads, hospitals, and markets (Anami, 2023; Oyugi & Onwonga, 2024). The viability of vulnerable habitats is progressively compromised by a bilateral expansion: private sector and government initiatives are competing for high-value ecosystems, while the swift proliferation of emerging small towns precipitates a demographic influx, catalyzing the transition of formerly pristine areas into impervious residential and commercial landscapes (Muriithi, 2024; Splinter & Van Leynseele, 2019).

The management of expanding built-up areas is intrinsically complex and context-dependent, demanding positioned benchmarks to evaluate spatial footprints relative to demographic shifts (Laituri et al., 2025; Oseni et al., 2020). With the gradual and sometimes unnoticeable increase in built-up extension, developing regions are challenged by the scarcity of data that can aid urban planning (Solarin et al., 2021). Luckily, the recent advancement in remote sensing and Geographic Information Systems (GIS) presents an alternative source of data (Phan et al., 2021). More importantly, the Landsat satellite sensor products have enhanced long-term monitoring of urbanization and LULC dynamics. The Landsat series provides multispectral data at regular intervals, allowing the detection of changes in different LULC types over time (Chowdhury, 2024; Hemati et al., 2021). Beyond data provision, geospatial technology has enabled faster and near real-time detection of LULC changes at reduced cost (Brown et al., 2022).

Even so, integrating LULC change detection with quantitative models in evaluating urbanization dynamics offers valuable insights for urban planning (Kipkulei et al., 2022; Ologunde et al., 2025). Specifically, LCR and LAC are widely recognized metrics for sustainability in urban expansion, especially in monitoring SDG 11 (UN-Habitat, 2018). LCR measures the expansion of built-up areas into previously non-urban ecosystems such as wetlands, grasslands, or forests, over time (Aduloju et al., 2026). On the other hand, LAC evaluates the change in consumption of recently built-up area per unit increase in population (Olagunju et al., 2023). While they generate important information, the application of these metrics in studies conducted in Kenya consistently shows that built-up areas are increasing at the expense of natural ecosystems (Mwathi, 2016; Omollo et al., 2018; Oyugi et al., 2017). For example, Oyugi et al. (2017) combined land cover change analysis and land consumption metrics to examine the implications of urban growth on the quality of the environment in Nairobi city between 1988 and 2015. The study reported a steady increase in forest, built-up, and transitional areas, and a decline in grassland, wetland, and agricultural lands. The trends in LCR and LAC revealed that in about half of the study duration, the built-up area grew through internal densification. The latter period recorded a simultaneous rise in LCR and LAC, indicating the extension of the urban area to the eastward peripheries of Nairobi city, thereby reflecting urban sprawl. Comparable trends in built-up expansion with characteristics of haphazard distribution were also observed in other areas (Babu et al., 2014; Hind et al., 2022; Orire et al., 2022; Salghuna et al., 2018).

The previous studies above have quantified population and commercially driven urbanization; however, they have primarily focused on the spatial context within major town boundaries. Additionally, these urban environments are mostly covered by savanna grasslands, cultivated trees, or dry forests (Omollo et al., 2018; Oyugi et al., 2017; Salghuna et al., 2018). Despite extensive research on the sustainability of urban expansion in Kenya's biodiversity-rich landscape, the peripheries of vestige tropical forests like Kakamega remain understudied. As a result, policymakers are left with generalized evidence that often fails to adequately inform sustainable intervention strategies, delaying the realization of SDG 11. Against this backdrop, this study leverages open-source Landsat imagery and land consumption metrics to assess the sustainability of urbanization in the vicinity of Kakamega town, thereby addressing this research gap.

This study aims to achieve the following objectives: (i) to assess the patterns in LULC conversions in Kakamega town and its immediate sub-counties, (ii) to examine the trend in LCR and LAC, and (iii) to evaluate the implications of urban growth on natural landscape between 2003 and 2023 using LCR and LAC metrics. The findings of this study provide a framework for analyzing the ramifications of sprawl on sustainability and generate practical recommendations for strengthening compact urban development policies in developing regions.

2. Materials and methods

2.1. Study Area

The Kakamega town is located in Kakamega County, western Kenya. Its area combined with the surrounding sub-counties included in this study is 1,394.2 km^2, extending from latitudes 0° 08' and 0° 36' north and longitudes 34° 05' and 34° 58' east. According to urban plan records of the County Government of Kakamega (CGK), the area initially formed Kakamega district, with Kakamega municipality as its headquarters (CGK, 2013). Currently, it is divided into five sub-counties: Lurambi, Shinyalu, Malava, Navakholo, and Ikolomani, forming Kakamega Central Region (Figure 1). The municipality now serves as the county and western region headquarters. The eastern part of the study area is covered by Kakamega Forest, considered the only remaining natural tropical forest in Kenya. The forest is a habitat for numerous endemic wildlife species, including birds, primates, and reptiles (Osewe et al., 2022). Besides the forest, the area has extensive agricultural land, grassland, and permanent rivers Nzoia, Isikhu, and Yala. The area has high population density, with the 2019 census reporting a population of 0.77 million, which is approximately half the county's total. Urbanization is a trend in this region, particularly in the extended municipality and its satellite towns. The new municipality alone hosts about 285,882 inhabitants (Shikoli et al., 2024), with projections indicating that the figure will rise to 353,989 by 2029 (Kenya National Bureau of Statistics, 2019). The high urban population density is attributed to the presence of universities and the impact of devolved governance (Anami, 2023; CGK, 2023). Figure 1 shows the map of the study area.

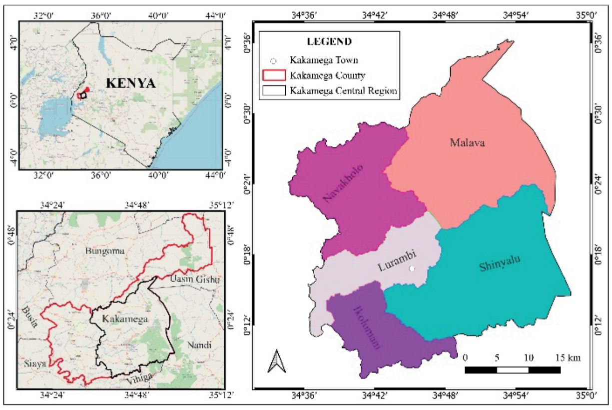

Figure 1. Map of the study area

2.2. Data collection

In studies involving historical analysis of LULC dynamics, Landsat satellite imagery sourced from the United States Geological Survey (USGS) Earth Explorer website (https://earthexplorer.usgs.gov/) is the preferred data source. This preference is guided by the advantageous qualities of Landsat data, including their spatiotemporal availability and near-zero cost (Hemati et al., 2021). In this study, Landsat satellite imagery products and demographic data of 2003, 2013, and 2023 were used to assess the LULC dynamics and land consumption patterns in Kakamega town and its outskirts. The 2003-2023 time frame is essential for this study as it captured accelerated transformations in LULC driven by regime changes and Kenya's 2010 constitutional shift. The latter reform devolved key urban growth and planning functions to Kenyan County, significantly reshaping the region's spatial development (Muwonge et al., 2022). The study utilized LULC datasets developed in our previous study (Ominde et al., 2026), which entails a full description of data collection, pre-processing, and classification procedures applied.

In summary, the Landsat images covering the study area and captured during the dry season (January and February) were downloaded from the USGS archive. These conditions were maintained throughout the study period to ensure consistency, minimal cloud effects, and comparability of classification outputs. Population data for the study area were extracted from the County Government of Kakamega's integrated development plans and national census reports (CGK, 2023; Kenya National Bureau of Statistics, 2019). These data sources provide the exact population for each census from which projections for the presented years were calculated using the consecutive county annual population growth rates of 2.12%, 2.5%, and 1.2%. The population projections were used to calculate LCR and LAC.

2.3. Pre-processing and image classification

This stage involved radiometric calibration, which enabled conversion of Landsat Level-1 datasets to Top of Atmosphere reflectance. Atmospheric correction was also applied to minimize absorption and scattering effects. Other pre-processing steps included layer stacking and sub-setting the imagery to the extent of the study area boundary. Layer stacking was performed by ordering spectral bands in accordance to their wavelengths thereby generating multispectral composites. This process generates color composites that increase accuracy in multi-temporal land cover analysis (Bui & Mucsi, 2022). The stacked raster datasets were clipped to the study area to enable consistent spatial comparison across the study period.

The pre-processed images were further classified into cropland, built-up, forest, grassland, and waterbody categories. This was achieved by employing a supervised classification technique using a random forest algorithm. The classified maps were further used to compute transitions in land cover and land consumption indicators.

2.4. Training data and validation

Reference samples for each land cover type were manually extracted from representative false color composites of the stacked images (Oseni et al., 2020). The sample pixels were authenticated by comparing them against high-resolution Google Earth imagery and corroborating with the researchers' expert knowledge of the study area. We used a stratified random sampling approach to select ninety samples of each land cover category. The selection of sample points was confined to areas where each land cover type was distinctly prominent and remained spatially consistent throughout the observation periods. In situations where high-resolution data were unavailable for the initial years, samples were collected across consecutive years demonstrating stable land cover transitions. The collected samples were then divided into two subsets for independent training the classifier (70%) and validating classified maps (30%). The LULC classification output was evaluated using a confusion matrix (Seyam et al., 2023) in the OTB infrastructure.

2.5. Accuracy assessment

The classification of LULC from satellite images is always confronted with inaccuracies arising from the classification of thematically related pixels (Mahamba et al., 2022). The classification performance was evaluated by comparing classified maps with independent validation samples. This process generated a confusion matrix that is widely used in assessing the reliability of classification in LULC change research (Seyam et al., 2023). The overall accuracy and kappa coefficients computed from the confusion matrix were used to evaluate the overall performance of the classification process. Our reliability evaluation yielded precise results that conform to the accuracy thresholds set by Anderson et al. (1976). Table 1 displays a summary of the LULC change accuracy assessment.

Table 1. Summary of LULC change accuracy assessment.

LULC Category	2003	2013	2023
Kappa	83.0	84.0	82.0
Overall Accuracy	86.7	87.3	85.3

2.6. LULC change detection and consumption analysis

At this point, temporal changes in LULC in the study area were assessed by comparing classified maps in successive time frames. Change detection on classified maps was performed in QGIS using the Semi-automatic Classification Plugin (SCP) (Ahmad et al., 2023). The plugin enables post-processing of classified LULC images, including change detection and land cover conversions (Ahmad et al., 2023). The process yielded quantitative data containing gains and losses in each LULC type and transition matrices, indicating how each land cover changed across the study period. Finally, the land area under built-up for each year and the corresponding populations were used to calculate LCR and LAC.

The calculation of LCR and LAC utilized the formula:

$$LCR = A/P \qquad (1)$$

where

LCR Land Consumption Rate,

A Areal extent of the city under a given LULC [ha],

P Population of the city at a particular date.

$$LAC = (A_2 - A_1) \,/\, (P_2 - P_1) \qquad (2)$$

where

LAC Land Absorption Coefficient,

A_1, A_2 are the areal extents of the city under a given LULC in hectares for the early and later years,

P_1, P_2 are population figures of the city for the early and later years (Yeates & Garner, 1976).

LCR is a measure of the growth of built-up areas over time, often linked to population growth or urbanization. It is widely used to assess the sustainability of land-use activities in cities and emerging towns, including adjacent areas that were previously non-urban such as forests, grasslands, or croplands (Ipadeola & Babalola, 2025). According to Olagunju et al. (2023), a high LCR indicates greater land consumption per person, suggesting urban sprawl or unsustainable land use, whereas a low LCR indicates compact growth of the built-up area or sustainable development. On the other hand, LAC is a measure of how newly built-up land is consumed per unit increase in population (Yeates & Garner, 1976). A low LAC suggests compactness or concentration of growth of population within city or town limits, while a high LAC implies expansion of built-up area beyond the limits of a city or town (Orire et al., 2022; Salghuna et al., 2018). While population density merely reflects spatial crowding, land consumption metrics gauge land use intensity, making them crucial tools for assessing sustainability in urban growth (Sharma & Kumar, 2023). The analysis workflow is outlined in Figure 2.

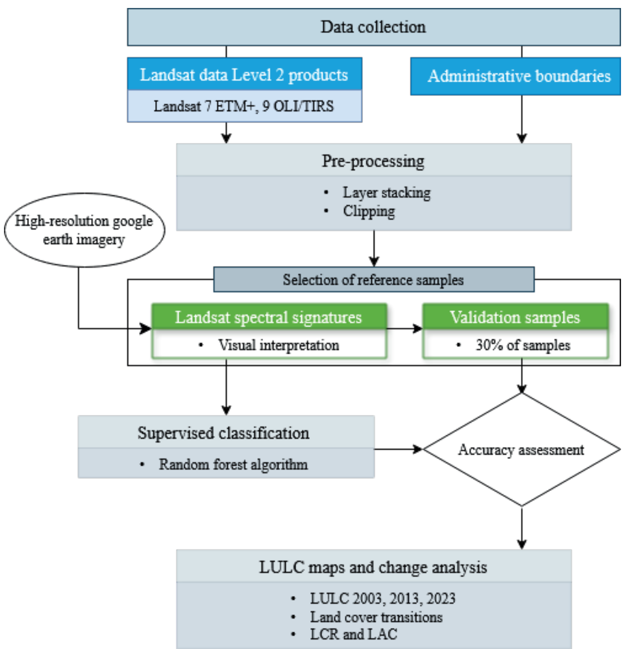

Figure 2. Study workflow

3. Results

3.1. LULC classification and transitions

The classification output revealed the five main LULC types in Kakamega town and the immediate hinterland, which are Cropland, Grassland, Forest, Built-up, and Water body (Figure 3). Analysis of the classified maps revealed a significant conversion in LULC across the study period (Table 2).

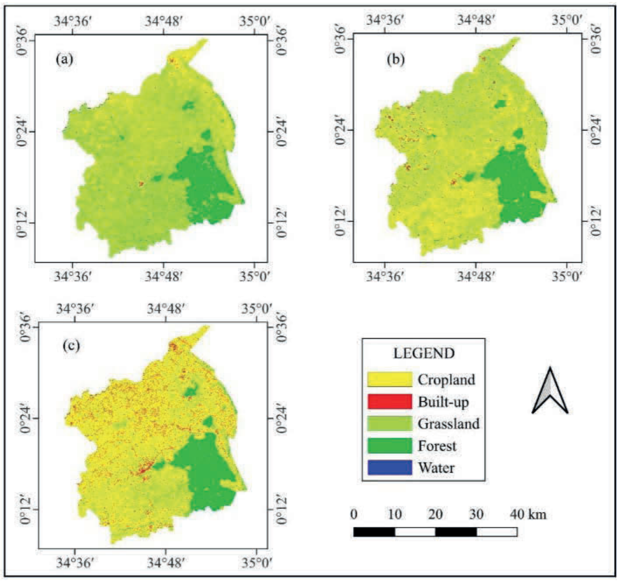

Figure 3. LULC maps of the study area: (a) 2003, (b) 2013, and (c) 2023

The grassland coverage in the study area declined substantially, falling by 611.16 km^2 between 2003 and 2023 (Figure 4). The transition matrix indicates that cropland was the principal beneficiary of grassland conversion, receiving 483.25 km^2 (58.39%) and 436.63 km^2 (82.28%) of 2003 and 2013 grassland, respectively, as shown in Table 2. In total, cropland recorded a consistent upward trend, increasing by about 148.4% (542.9 km^2) over the study period. The built-up area grew by 451.4% (24.8 km^2) between 2003 and 2013 and by 130.9% (39.7 km^2) between 2013 and 2023. The growth shows an upward trend, recording an increase of 1172.8% between 2003 and 2023. A larger area of conversion from non-built-up to built-up cover occurred in the second decade of the study (Table 2b). Conversions were mostly from cropland and grassland, suggesting extensive urban growth into non-built areas and forest buffers.

Forest areas experienced minor disruptions during the study period, but huge losses of grass cover that buffers them signalled increasing threats. In the pre-2013 period, a slight gain in forest cover was noted, partly from Cropland (0.75 km^2) and Grassland (27.36 km^2) conversions (Table 2a). However, stability was slightly shaken between 2013 and 2023 due to the transition of some forest areas into grassland, built-up areas, and cropland (Table 2b). Surface water area declined by 68.5% compared to 2003 levels during the first decade. However, the second decade saw some restoration with 121.9% of its 2013 cover, driven by the conversion of grassland and cropland to water areas (Table 2b). This recovery, however, did not match the initially recorded coverage of 1.58 km^2 in 2003. In total, the water area declined by 30% during the 2003-2023 study period. Figure 4 shows the

Table 2. Transition matrix for: (a) 2003-2013, and (b) 2013-2023

(a)		2003										
	LULC	**Forest**		**Grassland**		**Cropland**		**Built-up**		**Water**		**Total 2003**
		Area	%Area	**Area**	%Area	**Area**	%Area	**Area**	%Area	**Area**	%Area	**Area**
2013	**Forest**	**170.91**	88.81	27.36	3.31	0.75	0.21	0.02	0.38	0.00	0.00	199.04
	Grassland	2.90	1.51	**303.48**	36.67	221.32	60.52	2.74	49.73	0.25	16.01	530.68
	Cropland	18.43	9.58	483.25	58.39	**128.59**	35.16	1.20	21.86	0.82	52.01	632.30
	Built-up	0.19	0.10	13.54	1.64	15.03	4.11	**1.54**	28.00	0.01	0.34	30.31
	Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.50**	31.33	0.50
Total		**192.43**	**100**	**827.62**	**100**	**365.70**	**100**	**5.50**	**100**	**1.575**	**100**	

(b)		2013										
	LULC	**Forest**		**Grassland**		**Cropland**		**Built-up**		**Water**		**Total 2013**
		Area	%Area	**Area**	%Area	**Area**	%Area	**Area**	%Area	**Area**	%Area	**Area**
2013	**Forest**	**179.17**	90.66	3.24	0.61	14.13	2.23	0.05	0.15	0.00	0.00	196.58
	Grassland	15.04	7.61	**46.78**	8.81	153.84	24.33	0.80	2.63	0.00	0.00	216.46
	Cropland	3.32	1.68	436.63	82.28	**446.56**	70.62	20.88	68.89	0.03	5.07	907.42
	Built-up	0.08	0.04	43.95	8.28	17.25	2.73	**8.59**	28.32	0.00	0.00	69.87
	Water	0.00	0.00	0.08	0.01	0.52	0.08	0.00	0.01	**0.47**	94.93	1.08
Total		**197.62**	**100**	**530.68**	**100**	**632.30**	**100**	**30.31**	**100**	**0.50**	**100**	

overall proportions of lost and gained LULC in the study area, while Table 2. presents the transition matrices for 2003-2013 and 2013-2023.

3.2. LCR and LAC

The LCR increased from 0.0008 in 2003 to 0.0078 in 2023. Likewise, LAC rose from 0.0131 between 2003 and 2013 to 0.0710 between 2013 and 2023 (Table 3). Rising LCR and LAC values indicate inefficient land use and unregulated urban expansion in Kakamega town and its peri-urban area. These observations delineate a path of unsustainable territorial growth that contributes to sprawl and exerts excessive strain on local natural ecosystems such as forests, grasslands, and water resources. The trend threatens the safety and resilience of the region, thereby limiting its capacity to provide a secure environment for its expanding urban population. Table 3. displays land consumption and absorption statistics.

Table 3. Land consumption and absorption statistics in the study area.

Year	Gain/ Loss (km^2)	Built-up area (ha)	Popu-lation	LCR	LAC	
2003	5.5	550	656243	0.0008	**2003 - 2013**	0.0131
2013	30.31	3031	846298	0.0036	**2013 - 2023**	0.0708
2023	69.87	6987	902162	0.0077		

4. Discussion

4.1. Land cover conversions and consumption indicators

Analysis reveals that the natural landscape of Kakamega town and its fringes in Kakamega County has undergone radical restructuring, driven by substantial LULC changes between 2003 and 2023. The most overt transformations were the acute diminution of grassland, the substantial escalation in built-up area, and the agricultural extensification over the study duration. An inter-year comparison between 2003-2013 and 2013-2023 revealed profound trends in LULC changes. Grassland experienced consistent loss, while cropland and built-up areas showed persistent gains over the two decades. However, major declines for grassland, and gains for cropland and built-up cover were higher in the second decade in comparison to the first one. Water bodies showed an irregular trend, characterized by a marked contraction in the first decade, followed by a marginal recovery in the second. The substantial decline in natural ecosystems, compounded with cropland expansion in this rapidly urbanizing rural region, exemplifies LULC changes reported in other parts of the world (Peng et al., 2024; Yasin et al., 2025; Zhang et al., 2025).

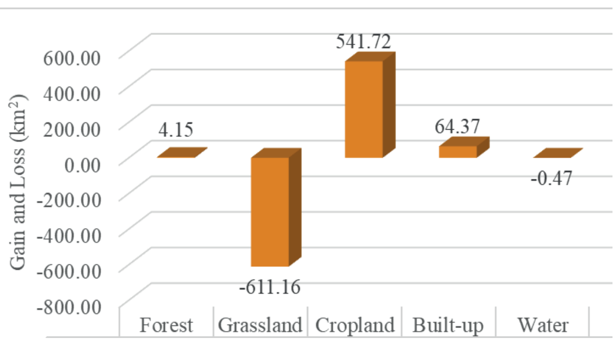

Figure 4. Proportions of gains and losses in LULC between 2003 and 2023

Particular attention should be paid to the extensive loss of grassland and gains in agricultural areas, which can be linked to both land-cover conversions and spectral mixing effects. Analysis of the transition matrix reveals that grassland was extensively converted to agricultural land, coupled with a drastic decline in water areas. This aligns with the region's demographic growth and urban sprawl which heighten the pressure for both housing and agricultural productivity in Kakamega's landscape (Shikoli et al., 2024; Shilibwa et al., 2022). This finding however, should be interpreted cautiously for the following reason. The medium-resolution Landsat images captured at the beginning of the year coincide with the dry season when land in the region is under primary tillage (CGK, 2023; Evans et al., 2020). In such circumstances, tilled lands often appear as dry grassland, leading to spectral mixtures between the two classes (Muthoka et al., 2025; Zhang et al., 2025). Thus, the substantial disparities in cropland and grassland may be attributed to a convergence of land-cover transformation and inherent seasonal spectral classification. However, the high overall accuracy and kappa coefficients validate the classification output, reinforcing the credibility of the derived inferences.

Cropland and developed area expansion in Kakamega illustrate the interplay between the two land cover categories in developing regions. Urban growth tends to exert pressure on land for food and space, leading to the extension of cropland into adjacent uncultivated areas (Ben-Said et al., 2025; Gabisa et al., 2025). At the same time, high urban density, land costs, development triggers, and land-use policies influence the growth of built-up areas (Aduloju et al., 2026; Ndung'u & Zentai, 2025). In the present study, extensive growth in cropland and built-up areas, with grassland as the main contributor, is consistent with several studies in western Kenya (Kogo et al., 2021; Mutenyi et al., 2024; Shilibwa et al., 2022). For instance, a recent study in the adjacent Khwisero sub-county by Mutenyi et al. (2024) highlights a significant trend of converting non-built-up land to urban use. These conversions are largely driven by socioeconomic and governance factors, including increasing settlement, agricultural extension, urban policies, and institutional challenges (Shikoli et al., 2024; Shumila et al., 2024).

While the aforementioned studies in this section support the observed dynamics of land cover, we note a higher rate of built-up area growth resulting from natural landscape conversions over the study period (Table 2). Such developments continue notwithstanding the study area's historical status as a regional headquarters and a strategic command centre for western Kenya (Anami, 2023). It is anticipated that such areas would have benefited from proactive land use regulatory frameworks and controlled growth (Splinter & Van Leynseele, 2019; Van Oostrum, 2024). Building on this anticipation, we further evaluated the sustainability of land utilization using LCR and LAC. This multifaceted analysis provides quantitative evidence of a rapid urbanization trend within Kakamega town and surrounding sub-counties. In particular, the rise in LCR and LAC between 2003 and 2023, as illustrated in Table 3, indicates that the expansion of the urban area outpaced population growth in the study area. According to Salghuna et al. (2018), an increase in LCR and LAC suggests intensified conversion of non-urban land into built-up areas and subsequently, urban sprawl. This pattern of development, characterized by low density and sparse development, is often associated with the degradation of forest, grassland, and water resources (Aduloju et al., 2026). Subsequently, the steady encroachment of unplanned development in the study area renders the tropical Kakamega forest's biodiversity increasingly precarious.

4.2. Emerging trends and implications on the natural landscape and policy

The observed increasing trend in LCR and LAC typically indicates rapid urban development relative to population growth in the Kakamega landscape. This finding corroborates the proliferating urban sprawl and the resultant pressure on land resources for residential, commercial, and agricultural development as documented in Kakamega County development reports (CGK, 2013, 2023). Contrary to similar studies that report standard increases in LCR and LAC (Mwathi, 2016; Omollo et al., 2018), our findings reveal a notable deviation. We note a persistent and aggressive rise in both LCR and LAC throughout the study duration. This trend illustrates a fragmented urbanization pattern with growth tethered to major transit networks, reflecting a corridor-driven expansion. The simultaneous increase in land consumption indicators shows that in the Kakamega and its fringes, urban land is expanding faster than population growth, and land use is becoming less efficient.

In contrast, the upward trend in LCR and LAC underscores the complex urban-rural nexus. The terrain encompasses essential agrarian tracts alongside critical biodiversity corridors, particularly the unique grasslands and the last eastern vestiges of the Guineo-Congolian rainforest (CGK, 2023; Osewe et al., 2022). Whereas Nairobi and Kisii exhibit sprawl driven by densification and accelerating economic transitions in the rural-urban fringe (Omollo et al., 2018; Oyugi et al., 2017), the Kakamega area follows a different trajectory. The scattered nature of its growth has fuelled a proliferation of farming activities, exerting substantial pressure on sensitive systems. These divergent findings stress the urgency of context-specific policy interventions to regulate the accelerating informal growth of peri-urban areas. The occurrence of scattered urban development potentially exposes natural landscapes to higher degradation risks and consequent livelihood vulnerability, especially in economically challenged rural areas. Therefore, sustainable development plans should prioritize the existing pattern of urban growth and the unique challenges it poses to the local natural landscape.

The natural landscape comprising forests, grasslands, and water bodies in this study offers significant benefits not only to the Kakamega residents but also to the global community through climate regulations (Osewe et al., 2022). The observed non-linear LCR and surging LAC, with associated inefficiencies, in Kakamega can be managed by transforming urban land-use planning through strong policy interventions that promote sustainable agriculture, including agroforestry and conservation farming (Olagunju et al., 2023). While policy implementation has been a challenge in Kakamega (Shikoli et al., 2024), strict enforcement of land-use regulations should be revisited to conserve the natural landscape from destruction and loss. To address accelerating urban growth, it is pivotal to embrace compact growth models that set minimum floors for new buildings, target interventions in zones with LAC bursts, and continuously monitor population-related LULC dynamics. The urgent implementation of the proposed policy interventions can reverse ecological losses and guarantee a safe and resilient lifestyle for residents in the rapidly urbanizing Kakamega Central Region.

4.3. Study limitations

Due to its reliance on satellite-based observations, this study is limited in its ability to capture the socio-economic dimensions driving land use and LULC changes in Kakamega County. Consequently, a comprehensive understanding of human-environment interactions remains constrained without the integration of remote sensing data with complementary socioeconomic datasets. The dependence on medium-resolution Landsat imagery in conjunction with a lack of high-resolution validation data such as Google Earth datasets for earlier periods may introduce increased classification uncertainties. Nonetheless, the study provides a valuable framework based on satellite observations and demographic data, offering a robust foundation for policymakers to support evidence-based sustainable land-use planning.

5. Conclusion

This study investigated LULC shifts and urbanization trends in the Kakamega Central Region of Kenya between 2003 and 2023 with a focus on land consumption patterns providing critical insights into the resulting fragmentation of natural ecosystems. Additionally, it demonstrates how merging geospatial technologies with land consumption metrics provides a comprehensive analytical structure for assessing urbanization transformation intensity and the consequent ecological degradation. The findings further reveal significant transformations in the built-up area which experienced a consistent increase during the study duration. Simultaneously, agricultural expansion intensified, largely facilitated by the transition of grassland habitats. Substantial decline in water bodies and slight fluctuations in forest area were also observed. The trend in land consumption metrics indicated scattered urban sprawl with profound implications for the natural landscape. If left uncontrolled, the rapid proliferation of built-up and cropland will likely precipitate in further irreversible ecological degradation of the natural landscape in Kakamega, thereby derailing efforts to achieve SDG 11. These findings provide essential perspectives for policymakers charged with formulating ecosystem restoration frameworks and cultivating sustainable urban development within peri-urban landscapes. To augment these findings, further empirical research is essential in determining fundamental socioeconomic drivers that dictate the rate and trajectory of fragmented urban development in Kakamega Central Region.

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