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Spatial Patterns of Land Cover Change and Settlement Expansion Around Lake Nakuru National Park, Kenya, Between 2015 and 2026

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Abstract

Protected areas in fast-urbanizing landscapes face pressure from land conversion at their edges. This study quantified land use/land cover (LULC) change in Lake Nakuru National Park (LNNP), Kenya (19,036 ha), and a 5 km buffer around it (38,264 ha) between 2015 and 2026, With a focus on three sub-locations bordering the protected area, Lake Nakuru National Park: Barut, Mwariki and Lake View. Dynamic World near-real-time 10 m LULC predictions derived from Sentinel-2 were reclassified into six classes and compared through post-classification overlays and gross gain/loss (transition) analysis in ArcGIS Pro. Inside the park, open water expanded from 5,702 ha (30.0%) in 2015 to 7,060 ha (37.1%) in 2026, representing a net gain of 1,358 ha (23.8%). In contrast, grassland declined from 4,476 ha to 3,593 ha, representing a 19.7% decrease, while woody vegetation decreased from 8,716 ha to 8,287 ha, a 4.9% decline. Settlements inside the park remained below 0.5% of its total area, increasing from 38 ha to 82 ha. In the buffer, settlements grew from 10,317 ha (27.0%) to 15,885 ha (41.5%), a gross gain of 5,568 ha, while woody vegetation fell by 2,625 ha and grassland by 3,690 ha. The buffer accounted for 99.2% of all conversion to settlements and 99.7% of all conversion to cropland recorded across the park and buffer. At the sub-location level, settlements in Barut rose from 51.5% to 91.2% of its area, mostly at the expense of woody vegetation (107.6 ha) and cropland (58.9 ha); Mwariki rose from 56.4% to 70.7%; and Lake View was already almost fully built up (96.5% to 99.5%). Encroachment around the national park is concentrated outside the park boundary, and the park's northern edge has largely lost its vegetated transition zone. The findings identify Barut as a priority for land-use control and boundary management.

Keywords
buffer; Dynamic World; Lake Nakuru National Park; land cover change; protected area; Sentinel-2; settlement encroachment.

Introduction

Protected areas are established to conserve biodiversity and maintain ecological processes, but their effectiveness can be influenced by land-use changes occurring both within and beyond their boundaries (DeFries et al., 2007). Conversion of natural habitats to agriculture and

settlements can alter the structure, reduce the ecological connectivity and increase interaction between people and wildlife. Such interactions can negatively affect both wildlife and human communities, resulting in threats to wildlife survival, human safety, livelihoods and property. Understanding the spatial distribution of land cover changes is therefore important for informing conservation planning and human-wildlife conflict management.

Protected area networks serve as the base for global biodiversity conservation, safeguarding essential ecosystem services, endangered flora and fauna, and vital hydrological catchments (Hongo & Mulaku, 2021). However, many protected areas are increasingly becoming isolated ecological islands with rapidly modifying human-dominated landscapes (Koskey et al., 2021) Intensive population growth, rapid urban expansion, and the need for more land for agricultural expansion have accelerated land cover change around protected areas affecting wildlife migration corridors, reducing habitat connectivity and placing pressure on wildlife movement corridors and national park boundaries (Mubea & Menz, 2012). Consequently, conservation outcomes depend not only on the legal designation and management of the protected area but also on the nature of surrounding socioeconomic activities. Studies have shown governance and socioeconomic pressures in neighboring communities can influence conservation outcomes just as the designated areas (Hoffmann, 2021; Maxwell et al., 2020). These pressures are pronounced where protected areas are located adjacent to a rapidly expanding urban center. Urban expansion can progressively transform agricultural and natural landscapes into settlements and infrastructure, reducing the ecological buffer between protected area and human populations. Monitoring the spatial pattern and rate of this transformation is essential for identifying emerging pressure points along protected area boundaries and supporting conservation and land use planning.

Lake Nakuru National Park provides an important example of protected area–urban interface. Located adjacent to the expanding Nakuru city, the national park is surrounded by landscape with increasing human population and economic activities. Recent spatiotemporal analysis of Nakuru peri-urban indicates expansion of farmlands built up areas and bare areas between 2003 and 2023, accompanied by progressive decline in grassland cover. However, location specific information on the distribution of these changes along the park boundary remains limited despite the importance for conservation and urban planning. Communities and residential areas, including Barut and Kivumbini wards, as well as Mwariki and Lake View residential areas, are located along the urban–national park interface, where expanding human settlements and land-use activities exert increasing pressure on the park boundary.

Land use change is also evident in the wider landscape. In the Eastern Mau, repeated remote sensing assessments have documented extensive forest clearance and conversion to agricultural land and rural settlements over several years. These changes have altered water catchment including reduction or drying of rivers that historically contributed water to Lake Nakuru (Cherotich et al., 2025; Kassilly et al., 2008). These landscape-scale changes demonstrate the broader environmental pressures within the Lake Nakuru ecosystem.

Land-use pressure around protected areas does not necessarily result in human–wildlife conflict, as such conflicts are influenced by ecological and socioeconomic factors. Community perceptions, the distribution of conservation costs and trust in wildlife authorities also influence the nature and extent of these conflicts (Dickman, 2010). A study comparing communities surrounding the fenced Lake Nakuru National Park and the unfenced Maasai Mara Game Reserve found that fencing reduced the frequency and severity of wildlife incursions. However,

baboons, warthogs and monkeys continued to present challenges to communities around Lake Nakuru, with reported cases of crop damage, property destruction, livestock losses and fear among residents (Kassilly et al., 2008). Reports of baboon incursions in Kivumbini Ward and Lake View estate, alongside documented concerns about fence breaches by carnivores, including spotted hyenas, further indicate potential human–wildlife interaction around the park. However, these reports do not establish the extent or distribution of conflict across Barut, Mwariki, Kivumbini and Lake View. Their inclusion therefore provides geographical context rather than direct evidence of conflict associated with observed land-cover changes.

Research on the Lake Nakuru landscape has addressed land-use and land-cover change at the catchment and peri-urban scales, as well as wildlife incursions and human–wildlife conflict around the national park (Cherotich et al., 2025; Kassilly et al., 2008). However, these studies have examined different geographical areas and research periods, limiting direct comparison of land-cover changes across the protected area and its surrounding landscape. Specifically, there is insufficient spatially consistent evidence comparing land-cover composition and transitions within Lake Nakuru National Park, the surrounding 5 km buffer and the bordering sub-locations of Barut, Mwariki and Lake View over the 2015–2026 period. Existing studies do not provide a unified assessment of settlement expansion, cropland changes and losses of natural vegetation across these three spatial levels. This limits the identification of specific locations experiencing the greatest land-use transformation along the park boundary. The present study addresses this gap by applying a consistent land-cover classification and spatial transition analysis to the national park, its surrounding buffer and the three selected sub-locations. This approach provides comparable measurements of land-cover changes and identifies the locations where settlement expansion and vegetation loss are most pronounced.

Despite this existing research, the Lake Nakuru landscape remains fragmented. Previous land cover work around Lake Nakuru has focused on the wider catchment and the Mau complex using Landsat images (Obunga et al.,2025; Were, 2014). However, limited attention has been given to quantifying recent land use changes within Lake Nakuru National Park and its buffer, particularly assessing the extent and spatial variation, encroachment across sub-locations along the parks edge. The availability of open, high-resolution, multi-temporal datasets such as Dynamic World further provides an opportunity to undertake more detailed and spatially consistent land cover assessments than was previously feasible. This gap limits understanding of the localized pressures driving land cover changes in the area adjacent to the park. This study therefore aims at bridging this gap.

The aim of this study was to analyse spatial and temporal LULC change in and around LNNP between 2015 and 2026. The specific objectives were to (1) Quantify the composition of and change in LULC inside LNNP between 2015 and 2026 (2) Assess LULC change in a 5 km buffer around the park and compare encroachment pressure (settlement growth, cropland expansion and natural vegetation loss) between the park and the buffer, and (3) Identify and map the areas of greatest encroachment among three sub-locations bordering the park (Barut, Mwariki and Lake View) by quantifying their LULC change and land cover transitions.

Materials and Methods

A. Study area

This study covered Lake Nakuru National Park and a 5 km buffer around it. Lake Nakuru National Park lies in Nakuru County within the great rift valley. It lies between latitude -0.299°

and -0.344° and longitude 36.03° and 36.08°. It covers an approximate area of 19,036 ha. It encompasses the shallow lake Nakuru together with the surrounding grassland, acacia woodlands, escarpment and the forest. It is surrounded with settlements and agricultural lands. The location of Lake Nakuru National Park, its 5-km buffer and the three bordering sub-locations (Barut, Mwariki and Lake View) presented in Figure 1. The study further analyzed land cover and land cover changes within Barut, Mwariki and Lake view. These areas are geographically located between latitude -0.2990 S and -0.3440 S and Longitude 36.040 E and longitude 36.080 E.

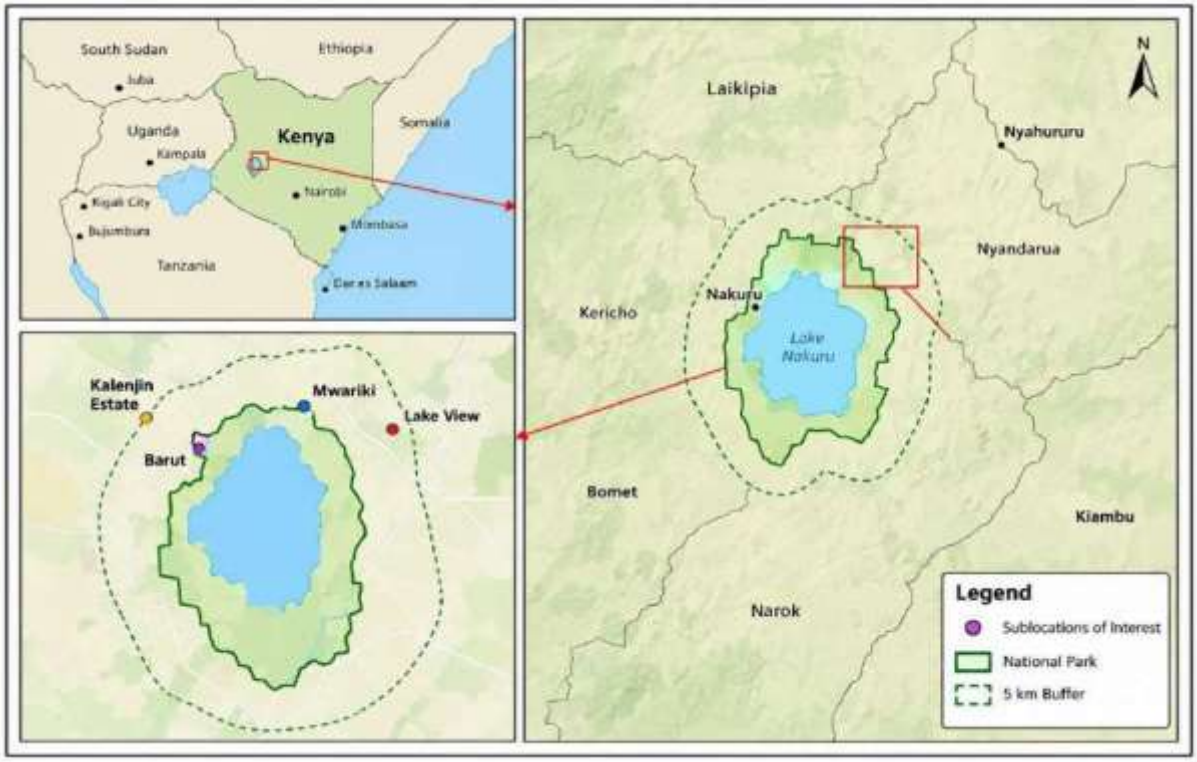

Figure 1: Location of Lake Nakuru National Park and the Three Study Sub-Locations (Barut, Mwariki and Lake View), Nakuru County, Kenya.
Source: Authors' map prepared in ArcGIS Pro. Lake Nakuru National Park boundary data were obtained from the World Database on Protected and Conserved Areas (WDPCA; IUCN and UNEP-WCMC, 2026); the 5-km buffer was generated by the authors.

B. Land cover data

Land-cover data for the study were obtained from the Dynamic World dataset, a near-real-time (NRT) global land-use/land-cover dataset with a spatial resolution of 10 m. The dataset is derived from European Space Agency (ESA) Sentinel-2 Level-1C imagery and provides land-cover predictions from June 2015 onwards. Sentinel-2 has a temporal resolution of approximately five days (Brown et al., 2022). Dynamic World classifies land cover into nine categories: water, trees, grass, crops, shrub and scrub, flooded vegetation, built area, bare ground, and snow and ice. Each pixel contains probability estimates for all nine classes, together with a label representing the class with the highest predicted probability. The dataset applies a cloud-cover filter of less than or equal to 35%, with additional masking using Sentinel-2 cloud probability to minimise cloud contamination (Brown et al., 2022). The Dynamic World dataset was accessed through Google Earth Engine and processed using ArcGIS Pro. The land-cover data were extracted and analysed separately for three spatial units: Lake Nakuru National Park, its surrounding 5-km buffer, and the three selected bordering sub-locations (Barut, Mwariki and Lake View). This enabled comparison of land-cover patterns

and changes across the protected area, its surrounding landscape and the three sub-locations. The original nine Dynamic World classes were consolidated into six broader categories for analysis. Water was reclassified as open water; trees, shrub and scrub, and flooded vegetation were combined as woody vegetation; grass was reclassified as grassland; crops as cropland; built area as settlements; and bare ground and snow and ice as bare areas (Table 1).

Table 1

Land Cover Classes Domesticated from the Dynamic World Probabilities for Land Cover Change Analysis

Dynamic world class	Reclassified to
Water	Open water
Crops	Cropland
Trees	Woody vegetation
Shrub & scrub	
Flooded vegetation	
Grass	Grassland
Built area	Settlements
Bare ground	Bare
Snow & ice	

Land-cover layers were extracted for three epochs: 2015, 2020, and 2026. Spatial overlays were conducted in ArcGIS Pro to measure changes.

Transition Matrix Analysis

To analyse land cover transitions within the national park and the 5km buffer strip around the lake, the reclassified land cover classes were regrouped to enable identification of changes (gains and losses) in major land cover groups rather than changes among individual classes. The grouping is as shown below (Table 2), (Table 3):

Table 2

Land Cover Change Groups Adopted for Analyzing Land Cover Gains Across Different Land Cover Classes

Change category	Grouped change category
Cropland to Bare	Other land cover types to Bare
Grassland to Bare	
Open water to Bare	
Woody vegetation to Bare	
Bare to Cropland	Other land cover types to Cropland
Grassland to Cropland	
Open water to Cropland	
Woody vegetation to Cropland	
Bare to Grassland	Other land cover types to Grassland
Cropland to Grassland	
Open water to Grassland	
Woody vegetation to Grassland	
Bare to Open water	Other land cover types to Open water
Cropland to Open water	
Grassland to Open water	
Woody vegetation to Open water	

Change category	Grouped change category
Bare to Settlements	Other land cover types to Settlements
Cropland to Settlements	
Grassland to Settlements	
Open water to Settlements	
Woody vegetation to Settlements	
Bare to Woody vegetation	Other land cover types to Woody vegetation
Cropland to Woody vegetation	
Grassland to Woody vegetation	
Open water to Woody vegetation	

Spatial overlays were used to calculate gross gains and losses between 2015 and 2026, both within the national park and within the 5 km buffer.

Table 3

Land Cover Change Groups Adopted for Analyzing Land Cover Losses Across Different Land Cover Classes

Change category	Grouped change category
Bare to Cropland	Bare to other land cover types
Bare to Grassland	
Bare to Open water	
Bare to Settlements	
Bare to Woody vegetation	
Cropland to Bare	Cropland to other land cover types
Cropland to Grassland	
Cropland to Open water	
Cropland to Settlements	
Cropland to Woody vegetation	
Grassland to Bare	Grassland to other land cover types
Grassland to Cropland	
Grassland to Open water	
Grassland to Settlements	
Grassland to Woody vegetation	
Open water to Bare	Open water to other land cover types
Open water to Cropland	
Open water to Grassland	
Open water to Settlements	
Open water to Woody vegetation	
Woody vegetation to Bare	Woody vegetation to other land cover types
Woody vegetation to Cropland	
Woody vegetation to Grassland	
Woody vegetation to Open water	
Woody vegetation to Settlements	

C. Data pre-processing

The boundary of Lake Nakuru national park was obtained from the protected planet's world database on protected and Conserved Areas (WDPCA) (IUCN and UNEP-WCMC (2026), 2026). A 5Km buffer was then created around the national park boundary to facilitate the assessment of land cover changes within the protected area and areas surrounding the protected area. The resulting buffered shape file was overlaid with the land cover datasets to identify and quantify areas of land cover changes within the national park and 5km buffer zone.

Results

A. Land cover classification and spatial distribution

Land cover analysis showed that there were significant changes between 2015 and 2026 within the national park. Open waters and settlements increased while grassland declined across years. Woody vegetation, cropland and bare areas shown year to year variation in direction of changes (Table 4).

Table 4

Land-Cover Areas (ha) Inside Lake Nakuru National Park, 2015-2026

Land cover	2015	2016	2018	2020	2022	2023	2024	2026
Open water	5,702	5,656	5,850	6,333	6,598	6,523	6,733	7,060
Woody vegetation	8,716	7,217	9,229	7,090	8,395	9,310	6,911	8,287
Grassland	4,476	6,075	3,687	5,539	3,681	2,784	5,290	3,593
Cropland	85	17	127	7	241	229	17	13
Settlements	38	50	61	66	71	75	78	82
Bare	18	19	82	0	48	115	7	-
Total	**19,036**	**19,036**	**19,036**	**19,036**	**19,036**	**19,036**	**19,036**	**19,036**

Between 2015 and 2020, open water increased from 5,702 ha (30.0%) to 6,333 ha (33.3%), a gain of 631 ha (11.1%). By 2026, open water had expanded to 7,060 ha (37.1%), representing an overall gain of 1,358 ha (23.8%) relative to 2015. Woody vegetation declined from 8,716 ha (45.8%) in 2015 to 7,090 ha (37.2%) in 2020, a loss of 1,626 ha (18.7%). Although it increased to 8,287 ha (43.5%) by 2026, it remained 429 ha (4.9%) below the 2015 extent. Grassland increased from 4,476 ha (23.5%) in 2015 to 5,539 ha (29.1%) in 2020, a gain of 1,063 ha (23.7%), but declined to 3,593 ha (18.9%) by 2026, an overall loss of 883 ha (19.7%). Cropland decreased from 85 ha (0.4%) in 2015 to 7 ha in 2020 (a loss of 78 ha or 91.8%) and stood at 13 ha in 2026 (84.7% below 2015). Settlements increased from 38 ha in 2015 to 66 ha in 2020 and 82 ha in 2026, equivalent to gains of 28 ha (73.7%) and 44 ha (115.8%) relative to 2015, respectively. Bare areas declined from 18 ha in 2015 to zero in 2020; the 2026 value was not reported (Table 5).

Table 5
Land-Cover Areas and Changes Inside Lake Nakuru National Park, 2015–2026*

Land cover	2015 (ha)	2020 (ha)	2026 (ha)	Change 2015–2020 (ha)	Change (%)	Change 2015–2026 (ha)	Change (%)
Open water	5702	6333	7060	+631	+11.1	+1,358	+23.8
Woody vegetation	8716	7090	8287	−1,626	−18.7	−429	−4.9
Grassland	4476	5539	3593	+1,063	+23.7	−883	−19.7
Cropland	85	7	13	−78	−91.8	−72	−84.7
Settlements	38	66	82	+28	+73.7	+44	+115.8
Bare	18	0	—	−18	−100.0	—	—
Total	**19,036**	**19,036**	**19,036**				

**Values represent land-cover area in hectares (ha). Percentage change was calculated relative to the 2015 baseline. Positive values indicate gains, while negative values indicate losses. A dash (—) indicates missing or unreported data.*

B. Land Cover Dynamics and Buffer Zones

Within the 5-km buffer, settlement area increased from 10,317 ha (27.0%) in 2015 to 13,640 ha (35.6%) in 2020, a gain of 3,323 ha (32.2%). By 2026, settlement area had reached 15,885 ha (41.5%), an overall gain of 5,568 ha (54.0%) relative to 2015. Woody vegetation declined from 10,504 ha (27.5%) in 2015 to 7,120 ha (18.6%) in 2020, a loss of 3,384 ha (32.2%). It increased to 7,879 ha (20.6%) in 2026 but remained 2,625 ha (25.0%) below the 2015 extent. Grassland increased from 9,899 ha (25.9%) in 2015 to 10,990 ha (28.7%) in 2020, a gain of 1,091 ha (11.0%), before declining to 6,209 ha (16.2%) in 2026, an overall loss of 3,690 ha (37.3%). Cropland decreased from 7,395 ha to 6,397 ha between 2015 and 2020 (−998 ha; −13.5%), then increased to 8,123 ha in 2026, an overall gain of 728 ha (9.8%). Open water increased from 39 ha in 2015 to 49 ha in 2026 (+10 ha; +25.6%), while bare areas increased from 111 ha to 120 ha (+9 ha; +8.1%) over the same period (Table 6).

Table 6
Land-Cover Areas and Changes in the 5-km Buffer Zone around Lake Nakuru National Park, 2015–2026

Land cover	2015 (ha)	2020 (ha)	2026 (ha)	Change 2015–2020 (ha)	Change (%)	Change 2015–2026 (ha)	Change (%)
Open water	39	38	49	−1	−2.6	+10	+25.6
Woody vegetation	10504	7120	7879	−3,384	−32.2	−2,625	−25.0
Grassland	9899	10990	6209	+1,091	+11.0	−3,690	−37.3
Cropland	7395	6397	8123	−998	−13.5	+728	+9.8
Settlements	10317	13640	15885	+3,323	+32.2	+5,568	+54.0
Bare	111	81	120	−30	−27.0	+9	+8.1
Total	**38,264**	**38,264**	**38,264**				

C. Land cover status in Barut, Mwariki and Lake View Regions

In Barut sub location, land cover shifted from being dominated by settlements (51.5%), woody vegetation (30.9%) and cropland (15.4%) in 2015 to being dominated by settlements covering (91.2%) in 2026. Settlements area increased from 224 ha (51.5%) in 2015 to 398 ha (91.2%) in 2026. Woody vegetation declined sharply from 135 ha (30.9%) to 19 ha (4.3%). Cropland decreased from 67 ha (15.4%) in 2015 to 18 ha (4.2%). Grassland declined from 7 ha (1.6%) in 2015 to 0.4 ha (0.1%) in 2026.Bare areas remained negligible at 3 ha in 2015 and 0.2 ha in 2026. (Table 7)

Table 7
Land-Cover Status in Barut Sub-Location, 2015–2026

Land cover	2015		2020		2026	
	Area (ha)	% Cover	Area (ha)	% Cover	Area (ha)	% Cover
Open water	0	0	0	0	0.4	0.1
Woody vegetation	135	30.9	46	10.5	19	4.3
Grassland	7	1.6	3	0.6	0.4	0.1
Cropland	67	15.4	66	15.1	18	4.2
Settlements	224	51.5	321	73.7	398	91.2
Bare	3	0.6	0.4	0.1	0.2	0.1
Total	**436**		**436**	**100**	**436**	**100**

Between 2015 and 2026, land cover in composition in Mwariki underwent substantial changes characterized by expansion of settlements and decline in woody vegetation and cropland. Settlements increased from 213 ha (56.4%) in 2015 to 266.6 ha (70.7%) in 2026. Open water increased from 30 ha (8.1%) in 2015 to 42.9 ha (11.4%) in 2026. Woody vegetation experienced a sharp decline from 58 ha (15.4%) in 2015 to 16.3 ha (4.3%) in 2026. Cropland similarly decreased from 26 ha (7%) in 2015 to 4.1 ha (1.1%) in 2026. Grassland experienced some temporary fluctuation increasing from 50 ha in 2015 to 62 ha in 2020 then 47.3 ha in 2026 registering a net decline. Bare areas remained negligible in all years (Table 8).

Table 8
Land-Cover Status in Mwariki, 2015–2026

Land cover	2015		2020		2026	
	Area (ha)	% Cover	Area (ha)	% Cover	Area (ha)	% Cover
Open water	30	8.1	27	7.2	42.9	11.4
Woody vegetation	58	15.4	17	4.5	16.3	4.3
Grassland	50	13.1	62	16.5	47.3	12.5
Cropland	26	7.0	11	3.0	4.1	1.1
Settlements	213	56.4	259	68.8	266.6	70.7
Bare	0.1	0.03	-	-	-	-
Total	**377**	**100**	**377**	**100**	**377**	**100**

In Lake View all the years were dominated by settlements, 15 ha (96.5%) in 2015, 164 ha (99.2%) in 2020 and 164.1 ha (99.5% in 2026. Woody vegetation decreased from 3 ha (2%) in 2015 to 0.6 ha (0.4%) in 2026. Grassland declined from 2 ha (1.2%) in 2015 to 0.1 ha (0.1%) in 2026. While cropland decreased from 1 ha (0.3%) in 2015 to 0.1 ha (0.1%) in 20026. Open water and bare areas were not recorded in the area (Table 9).

Table 9
Land-Cover Status in Lake View, 2015–2026

Land cover	2015		2020		2026	
	Area (ha)	% Cover	Area (ha)	% Cover	Area (ha)	% Cover
Woody vegetation	3	2.0	-	-	0.6	0.4
Grassland	2	1.2	1	0.8	0.1	0.1
Cropland	1	0.3	-	-	0.1	0.1
Settlements	159	96.5	164	99.2	164.1	99.5
Total	**165**	**100**	**165**	**100**	**165**	**100**

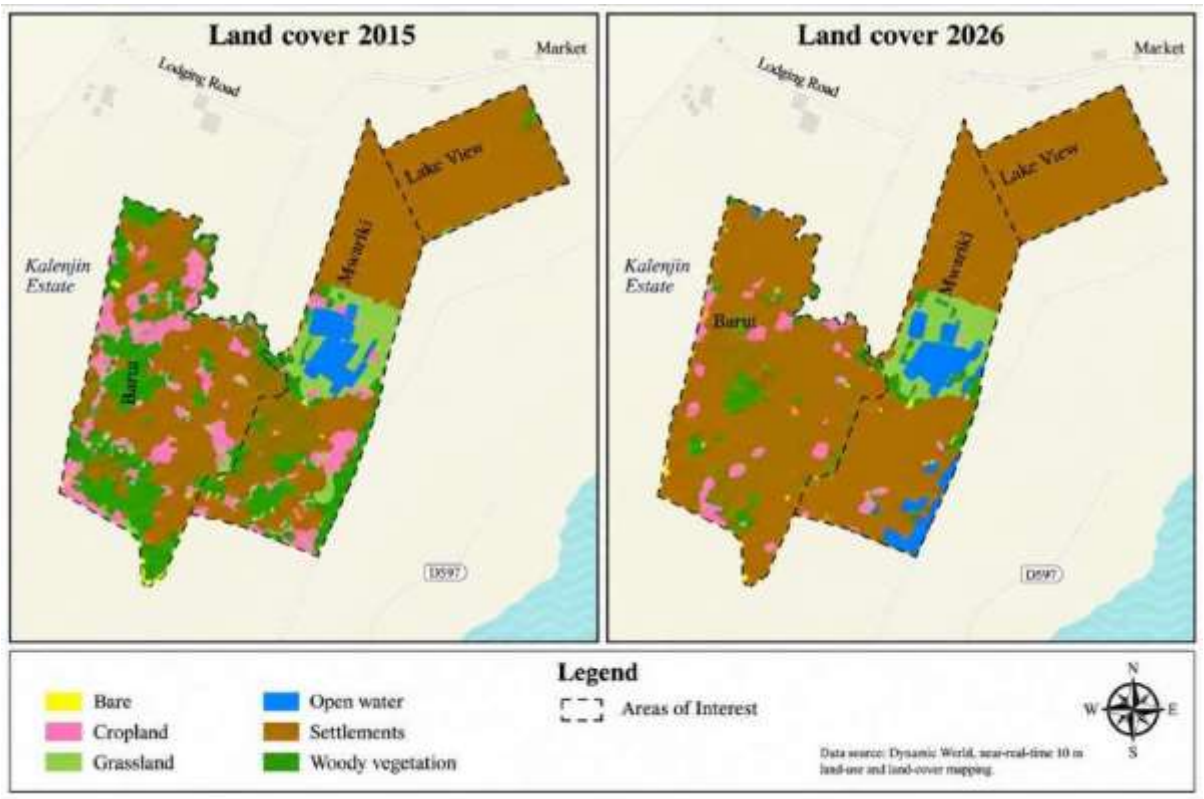

Figure 2: Land Cover Map for Barut, Mwariki and Lake View (2015 - 2026)

Land Cover Transitions Between 2015 and 2026 in the National Park and Buffer

Land cover changes revealed gains in major land cover types within the national park. 42 ha of other land cover types were converted to settlements, 11 ha were converted to cropland, 1,456 ha converted to water while 1,038 ha converted to woody vegetation (Table 10). Within the buffer strip 5,568 ha were converted to settlements, 4,167 ha to cropland, 20 ha to water and 2,597 ha to woody vegetation (Table10).

Table 10

Positive Land Cover Transition for Major Land Cover Types in ha

Land cover Change Type	National Park	Buffer strip	Total
Other land cover types to Bare	0	95	95
Other land cover types to Cropland	11	4,167	4,178
Other land cover types to Grassland	503	1,131	1,634
Other land cover types to Open water	1,456	20	1,476
Other land cover types to Settlements	42	5,568	5,611
Other land cover types to Woody vegetation	1,038	2,597	3,635
Total	**3,051**	**13,578**	**16,629**

Major land cover was lost to other land cover classes within the national park. 98 ha of water areas were lost to other land cover types. A total of 83 ha of cropland transitioned to other land cover classes, 1,467 ha of woody vegetation cover transitioned to other land cover classes while 1,386 ha of grassland transitioned to other land cover classes (Table 11).

Within the buffer strip 11 ha of water transitioned to other land cover classes, 3,439 ha transitioned from croplands to other land cover types; 5,222 ha of vegetated areas also transitioned to other land cover types, 4,821 ha of grassland transitioned to other land cover classes, while 86 ha of other lands transitioned to other classes (Table 11).

Table 11

Negative Land Cover Transitions for Major Land Cover Types in ha

Land cover Change Type	National Park	Buffer strip	Total
Bare to other land cover types	18	86	104
Cropland to other land cover types	83	3,439	3,522
Grassland to other land cover types	1,386	4,821	6,207
Open water to other land cover types	98	11	109
Settlements to other land cover types	0	1	2
Woody vegetation to other land cover types	1,467	5,222	6,689
Total	**3,052**	**13,579**	**16,632**

Conversion to settlements was greater in the buffer than inside the national park. A total of 42 ha in the national park while 5,568 ha in the buffer zone were converted to settlements. Similarly, conversion to cropland/agricultural area was greater in buffer strip (4,167 ha) than within the national park (42 ha). The results therefore indicate that the buffer strip accounted for the largest share of land cover transitions associated with human land use expansion.

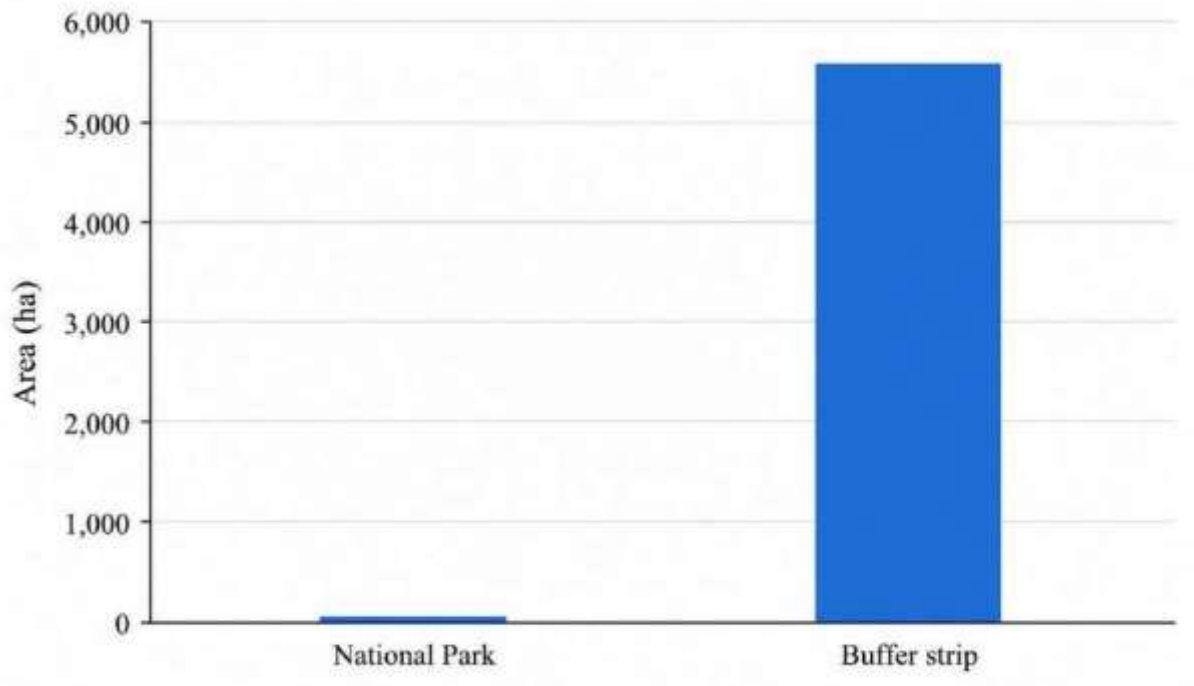

Figure 3: Comparison of Settlement Expansion between the Buffer Zone and the National Park

Land Cover Transitions in Barut, Mwariki, and Lake View

In Barut settlements expansion constituted the dominant change with a total of 173.1 ha increase between 2015 and 2026. This constitutes of conversion from woody vegetation (107.6 ha), cropland 5809 ha, grassland 4.5 ha and bare areas 2.1 ha. Conversion among other land cover classes was limited with 8.5 ha of woody vegetation converted to cropland and 2.2 ha of grassland converted to cropland. 0.5 ha of cropland and 0.5 ha bare areas were converted to woody vegetation (Table 12).

Table 12

Land Cover Change 2015 - 2026 for Barut Area

Sn	Land cover change	Area (ha)	Sn	Land cover change	Area (ha)
1	Bare to Cropland	0.1	8	Grassland to Settlements	4.5
2	Bare to Settlements	2.1	9	Grassland to Woody vegetation	0.02
3	Bare to Woody vegetation	0.5	10	Woody vegetation to Bare	0.2
4	Cropland to Grassland	0.02	11	Woody vegetation to Cropland	8.5
5	Cropland to Settlements	58.9	12	Woody vegetation to Grassland	0.2
6	Cropland to Woody vegetation	0.5	13	Woody vegetation to Open water	0.4
7	Grassland to Cropland	2.2	14	Woody vegetation to Settlements	107.6

In Mwariki, the largest transition was from cropland to settlements accounting for 14.1 ha followed by grassland to open water 7.1 ha and open water 6.3 ha. Cropland exhibited the larges total area transition 25.2 ha trough conversion to settlements. Open water 4.7 ha, grassland 4.2 ha and woody vegetation 2.2 ha (Table 13).

Table 13

Land Cover Change 2015 - 2026 for Mwariki Area

Sn	Land cover change	Area (ha)	Sn	Land cover change	Area (ha)
1	Bare to Settlements	0.1	9	Grassland to Settlements	4.3
2	Cropland to Grassland	4.2	10	Grassland to Woody vegetation	3.0
3	Cropland to Open water	4.7	11	Open water to Grassland	6.3
4	Cropland to Settlements	14.1	12	Open water to Woody vegetation	1.2
5	Cropland to Woody vegetation	2.2	13	Woody vegetation to Cropland	212.7
6	Grassland to Cropland	0.1	14	Woody vegetation to Grassland	2.7
7	Grassland to Open water	7.1	15	Woody vegetation to Open water	1.6

In Lake view, woody vegetation to settlement accounted for 3.3 ha, grassland to settlements 1.5 ha, cropland to settlements 0.2 ha while 0.3 ha of cropland were converted to woody vegetation. Grassland to cropland accounted to 0.1 ha (Table 14).

Table 14

Land Cover Change 2015 - 2026 for Lake View Area

Sn	Land cover change	Area (ha)
1	Cropland to Settlements	0.2
2	Cropland to Woody vegetation	0.3
3	Grassland to Cropland	0.1
4	Grassland to Settlements	1.5
5	Grassland to Woody vegetation	0.3
6	Woody vegetation to Settlements	3.3

Settlements expansion was highest in Barut followed by Mwariki and lastly Lake view (Figure 4)

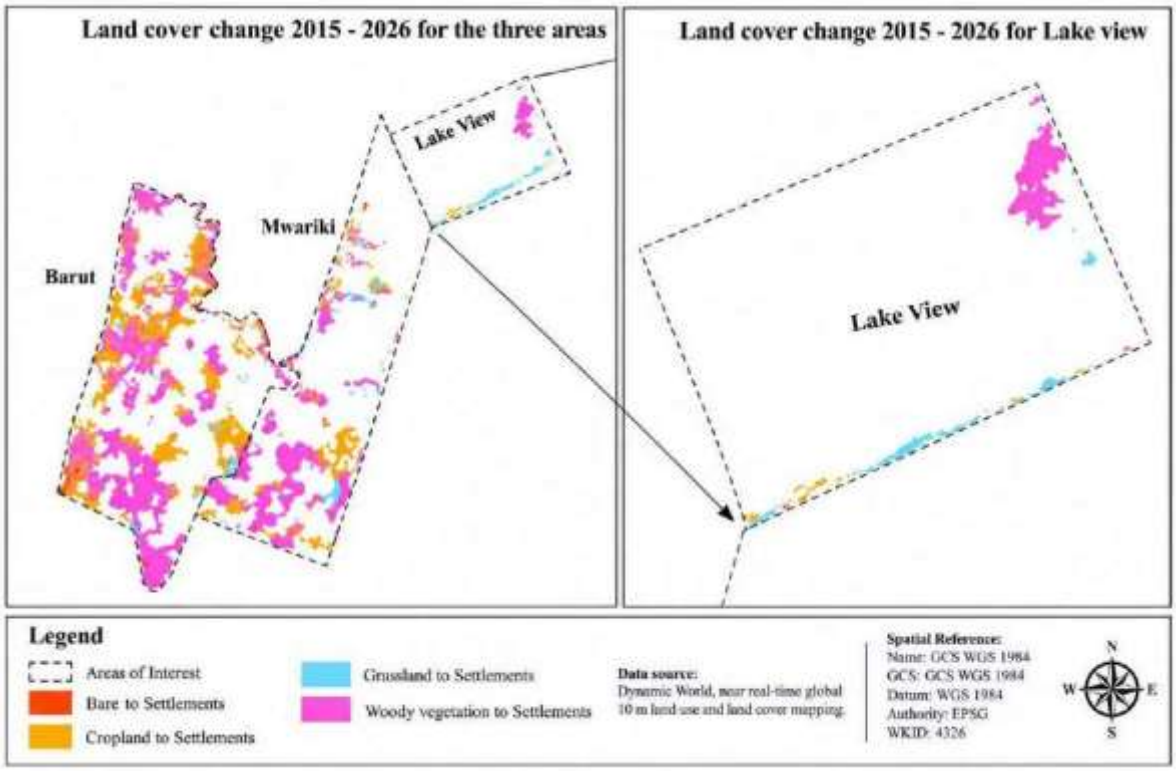

Figure 4: Expansion of Settlements in Barut, Mwariki and Lake View

Cropland expansion was highest in Barut followed by Mwariki and lastly Lake view (Figure 5)

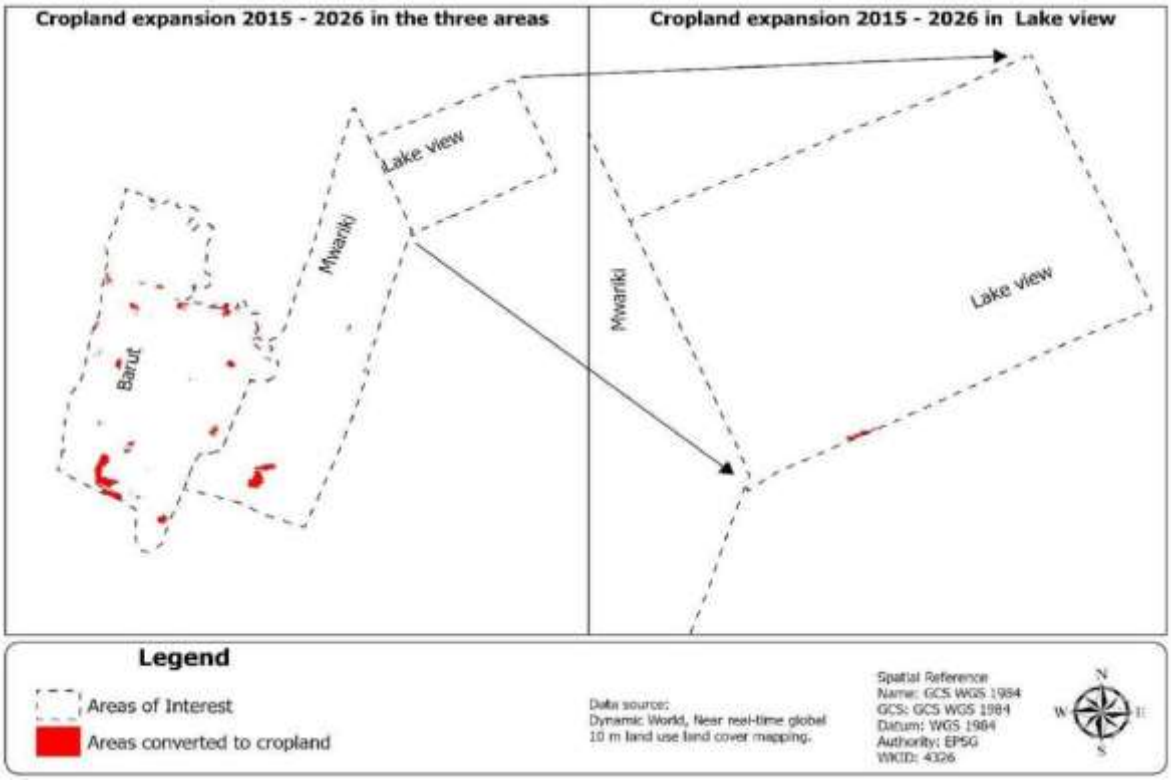

Figure 5: Expansion of Croplands in Barut, Mwariki and Lake View

Discussion

The findings demonstrate contrasting spatial and temporal patterns of land-use/land-cover (LULC) change within Lake Nakuru National Park (LNNP) and its surrounding 5-km buffer between 2015 and 2026. Within the park, open water increased from 5,702 ha (30.0%) in 2015 to 6,333 ha (33.3%) in 2020, representing a gain of 631 ha (11.1%) relative to 2015. By 2026, open water had increased to 7,060 ha (37.1%), a net gain of 1,358 ha (23.8%) relative to the 2015 baseline. The increase in mapped open-water extent is consistent with reports of rising water levels in Lake Nakuru and other Rift Valley lakes, although the present land-cover analysis does not establish the hydrological causes of this change (Ampting et al., 2025; Obunga et al., 2025). Grassland increased by 1,063 ha (23.7%) between 2015 and 2020, but by 2026 it had declined to 3,593 ha, representing a net loss of 883 ha (19.7%) relative to 2015. Woody vegetation declined by 1,626 ha (18.7%) by 2020, followed by partial recovery; its 2026 extent remained 429 ha (4.9%) below the 2015 level. These results show that endpoint comparisons alone can obscure intervening fluctuations in land-cover extent. Grassland provides forage and habitat for herbivores in the park. Its net reduction of 883 ha (19.7%) between 2015 and 2026 may reduce the area of available forage and habitat, with potential consequences for herbivore distribution and the likelihood of wildlife moving into adjoining human-used areas in search of resources. Such effects are plausible ecological implications rather than outcomes measured by this study: wildlife abundance, animal movement, forage quality and human–wildlife incidents were not assessed. The mapped increase in open water may also alter the spatial distribution of terrestrial habitat, but its ecological consequences require field-based investigation.

Land-cover transformation was more pronounced in the 5-km buffer than within the park. Settlement area increased from 10,317 ha (27.0%) in 2015 to 13,640 ha (35.6%) in 2020, a gain of 3,323 ha (32.2%) relative to 2015. By 2026, settlements occupied 15,885 ha (41.5%), representing a net increase of 5,568 ha (54.0%) relative to the 2015 baseline. Over the same periods, woody vegetation declined by 3,384 ha (32.2%) by 2020 and by 2,625 ha (25.0%) by 2026, while grassland first increased by 1,091 ha (11.0%) by 2020 and then declined to a net loss of 3,690 ha (37.3%) by 2026. Cropland declined by 998 ha (13.5%) by 2020 but increased to 8,123 ha in 2026, a net gain of 728 ha (9.8%) relative to 2015. The transition analysis further indicates that 5,568 ha were converted to settlements in the buffer compared with 42 ha inside the park, while conversion to cropland was 4,167 ha in the buffer compared with 11 ha inside the park. The magnitude and direction of these changes indicate that settlement and agricultural transformation were concentrated outside the park boundary.

The concentration of settlement expansion and vegetation loss in the buffer is consistent with previous studies of land-cover change in the Nakuru peri-urban landscape and the wider Lake Nakuru–Eastern Mau system. Cherotich et al. (2025) documented expansion of built-up and agricultural areas in peri-urban Nakuru, while studies of the Mau catchment and Lake Nakuru drainage basin have described land conversion and catchment modification associated with agricultural activity and settlement development (Boitt, 2016; Were, 2014; Obunga et al., 2025). Mubea and Menz (2012) also used multi-sensor satellite data to examine land-use change in Nakuru. The present analysis adds a spatially focused comparison of the park, its immediate 5-km buffer and three bordering sub-locations, showing that the greatest mapped settlement gains occurred in the surrounding landscape. The pattern is also consistent with broader evidence that population growth and land conversion at protected-area edges can intensify pressures on the landscapes surrounding conservation areas (Wittemyer et al., 2008;

Maxwell et al., 2020). These comparisons support the interpretation that the park boundary separates areas with markedly different land-cover trajectories, although the study did not test the effectiveness of enforcement or establish the causes of individual conversions.

The three bordering sub-locations show that settlement expansion was spatially uneven. Barut experienced the largest increase in settlement area, from 224 ha in 2015 to 398 ha in 2026, while woody vegetation declined from 135 ha to 19 ha. The transition analysis indicates that settlement expansion in Barut involved conversion of 107.6 ha of woody vegetation, 58.9 ha of cropland, 4.5 ha of grassland and 2.1 ha of bare land. Mwariki recorded an increase in settlement area from 213 ha to 266.6 ha, accompanied by a decline in woody vegetation from 58 ha to 16.3 ha and cropland from 26 ha to 4.1 ha. Lake View was already highly developed in 2015, when settlements occupied 159 ha (96.5%) of the sub-location; this increased to 164.1 ha (99.5%) in 2026. The smaller absolute settlement increase in Lake View should therefore be interpreted in the context of its already high level of built-up cover at the beginning of the study period.

These differences have practical implications for land-use planning around LNNP. In Lake View, where settlement cover was already dominant in 2015, management is likely to require attention to the existing urbanised interface, including management of drainage, waste, access and interactions between residents and wildlife. In Barut, the large increase in settlement area and the substantial conversion of woody vegetation and cropland to settlements identify a priority area for monitoring and development control. Mwariki represents an intermediate pattern, with continued settlement growth alongside remaining grassland and woody vegetation. The findings therefore support spatially differentiated planning rather than a uniform intervention across the entire park boundary. Protection or restoration of remaining semi-natural vegetation should be considered alongside county spatial plans and park management measures. These recommendations concern land-cover conditions and planning priorities; the study did not directly measure ecological connectivity, wildlife movement or human–wildlife conflict.

Conclusion and Management Implications

Between 2015 and 2026, land-cover change around Lake Nakuru National Park followed contrasting patterns. Within the park, mapped open-water extent increased by 1,358 ha (23.8%), while grassland and woody vegetation declined by 883 ha (19.7%) and 429 ha (4.9%), respectively. Settlement cover remained below 0.5% of the park but increased from 38 to 82 ha. In the surrounding 5-km buffer, settlements expanded by 5,568 ha (54.0%), accompanied by declines in woody vegetation and grassland of 2,625 ha (25.0%) and 3,690 ha (37.3%), respectively. Among the three sub-locations, Barut experienced the greatest settlement expansion, increasing by 174 ha (77.7%) between 2015 and 2026, while woody vegetation declined by 116 ha (85.9%). Mwariki recorded a settlement increase of 53.6 ha (25.2%), while Lake View, already almost completely built up in 2015, recorded a smaller increase of 5.1 ha (3.2%). These findings support targeted rather than uniform intervention along the park boundary. For management, three priorities follow from the spatial evidence (1) strengthen integrated county–park land-use planning within the immediate park interface; (2) retain and restore remaining woody and grassland corridors, particularly where they separate settlement from the park; and (3) establish a repeatable remote-sensing monitoring framework with independently validated classifications and explicit change-detection uncertainty. The results do not demonstrate that settlement expansion has caused human–wildlife conflict or that the

park boundary is breached; rather, they identify land-cover conditions that may increase future ecological and management pressure.

Declarations

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Authorship Statement
Sharon Jerop Kemboi is the corresponding author and performed data collection and wrote the first draft of the manuscript. Dr. Eliud Michura and Dr. Rose Nyakemiso Sagwe designed the study and supervised the work. All co-authors reviewed and approved the final version of the manuscript for publication and agree to be accountable for all aspects of the work.

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Declaration of Competing Interests
The authors declare no competing interests.

Research Approval
Ethical approval was obtained from the Kabarak University Scientific and Ethics Review Committee, while a research permit was granted by the National Commission for Science, Technology and Innovation (NACOSTI) under Licence No. **NACOSTI/P/26/4187408**, as part of the broader parent research project. Permission to conduct the study in Lake Nakuru National Park was granted by the Kenya Wildlife Service (KWS). Relevant local authorities were notified before data collection. All respondents provided voluntary informed consent. Participant anonymity, confidentiality of information and ethical research conduct were maintained throughout the study.

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