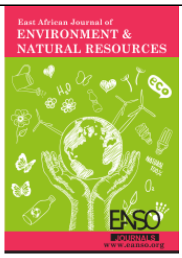

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Original Article

Assessing Land Use and Vegetation Change in Kiborgoch Wetland Conservancy, Kenya: Evidence from 30 Years of Remote Sensing (1994–2024)

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Kiborgoch Conservancy, Land Use Change, Wetland Vegetation, Grassland Degradation, Swamp Expansion, Remote Sensing, Conservation Planning.

ABSTRACT

Wetlands are critical socio-ecological systems that support biodiversity, regulate hydrological cycles, and sustain livelihoods across East Africa. Despite their importance, these ecosystems are increasingly threatened by anthropogenic pressures and climate variability. This study assessed land use and vegetation changes in the Kiborgoch Wildlife and Wetland Conservancy, located in Kenya's Rift Valley, over 30 years (1994–2024). Using Landsat satellite imagery, Normalized Difference Vegetation Index (NDVI) time series, and GIS analysis, land cover was classified into four primary categories: bareland, wetland vegetation, swamp vegetation, and grassland vegetation. The results revealed substantial landscape transformations, including a 51% increase in bareland, a 52% increase in swamp vegetation, and a 36% decline in grassland vegetation. Wetland vegetation exhibited non-linear trends, peaking in 2014 before declining by 2024. NDVI analysis indicated spatially variable trends in vegetation health, with pronounced degradation near settlements and agricultural zones. These changes were largely driven by land encroachment, upstream water abstraction, and the harvesting of vegetation. The findings highlight the urgent need for targeted conservation strategies, enhanced spatial monitoring, and strengthened community-based management to safeguard the ecological integrity of conservancy-managed wetlands in Kenya.

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INTRODUCTION

Wetlands contribute significantly to rural livelihoods and food security across East Africa, fulfilling an estimated 10–40% of annual food needs (Schuyt, 2005). Their fertile soils, perennial moisture, and relatively flat topography make them attractive for agricultural expansion and settlement encroachment (Ballut-Dajud et al., 2022; Maithya et al., 2022; Mañego et al., 2024). In recent decades, climate change, manifested through erratic rainfall patterns and rising temperatures, has further compromised wetland hydrology and functionality (Desta et al., 2012; Ofori et al., 2021). In response to these pressures, several countries, including Kenya, have adopted integrated wildlife and wetland conservancy models that aim to balance ecological protection with community-based resource use (Ogutu et al., 2020; Macharia et al., 2010). Globally, similar approaches include community conservancies in Namibia and Tanzania, Indigenous Protected Areas in Australia, and biosphere reserves in Europe. These models are typically underpinned by participatory governance, benefit-sharing mechanisms, and adaptive management frameworks that ensure community buy-in while safeguarding biodiversity (Hoole, 2008; Kalvelage et al., 2021; Palliwoda et al., 2021; Schuster et al., 2019).

Kenya's conservancy movement has drawn significantly from these global experiences. While formalised frameworks may differ, many conservancies in Kenya operate through collaborative models involving communities, private landowners, NGOs, and government agencies. In wetland-rich regions, conservancies have evolved to integrate seasonal grazing management, water conservation, and biodiversity protection. This localisation of global models has allowed Kenya to pursue a more socially inclusive conservation agenda that is responsive to ASAL contexts. However, many conservancies operate under fragmented legal mandates and face capacity constraints, particularly in ecological monitoring and data management. Despite their importance, conservancy-managed wetland landscapes in Kenya remain under growing pressure from overgrazing, upstream water diversion, vegetation harvesting, and unregulated land conversion (Ballut-Dajud et al., 2022). Effective monitoring of such threats requires consistent spatial data, yet field-based ecological assessments are often limited by logistical, financial, and infrastructural challenges.

In this context, satellite-based technologies offer a viable alternative. Remote sensing tools such as the Normalized Difference Vegetation Index (NDVI) and Landsat imagery have proven effective globally in monitoring vegetation dynamics, detecting degradation, and guiding conservation planning (Kiage & Liu, 2009; Fensholt & Proud, 2012; Mandal et al., 2023; Nguyen et al., 2023). In Kenya's ASALs, where data scarcity is a persistent challenge, these tools provide a cost-effective means to track long-term ecological changes across broad spatial extents. NDVI serves as a reliable proxy for vegetation greenness and biomass, while Landsat's high temporal and spatial resolution enables multi-decadal land cover change analysis. Their integration into GIS platforms further enhances the ability to detect and visualise spatial trends, identify degradation hotspots, and inform adaptive management responses—even in the absence of frequent field validation (Gu & Zeng, 2024).

While several studies have highlighted the ecological importance of Kenyan wetlands, few have employed detailed spatiotemporal

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approaches to quantify vegetation dynamics or assess anthropogenic drivers over extended periods. The Kiborgoch Wildlife and Wetland Conservancy, located in Kenya's Rift Valley, exemplifies a dual-use conservation landscape that supports both biodiversity and rural livelihoods. However, the area has experienced considerable ecological transformation due to sustained anthropogenic pressures. Understanding the extent, patterns, and underlying causes of these changes is essential for evidence-based land management and ecosystem restoration. This study assessed land use and vegetation changes in the Kiborgoch Wildlife and Wetland Conservancy over a 30-year period (1994–2024) using satellite-derived NDVI time series, Landsat imagery, and GIS-based spatial analysis. Specifically, it aimed to (i) assess long-term land use and vegetation dynamics and (ii) identify the spatial extent and underlying drivers of wetland encroachment.

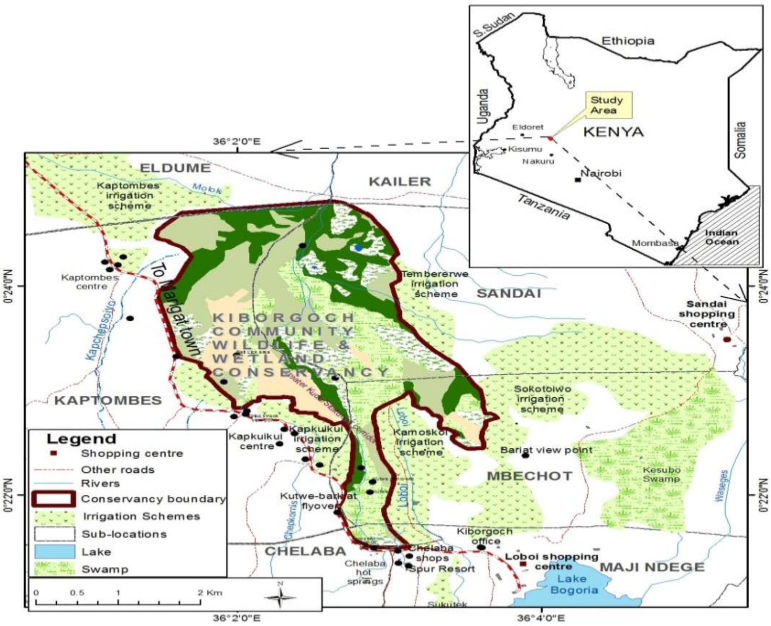
To support this analysis, land cover was categorised into four primary types: Bareland, wetland vegetation, swamp vegetation, and grassland vegetation. Bareland refers to areas with minimal or no vegetative cover, often resulting from erosion, human activity, or natural degradation (FAO, 2000). Wetland vegetation includes herbaceous species adapted to saturated soils, playing a crucial role in water purification and biodiversity support (Mitsch & Gosselink, 2015). Swamp vegetation consists predominantly of hydrophytic woody plants such as shrubs and trees, typically found in seasonally or permanently inundated areas (Ramsar Convention Secretariat, 2016). Grassland vegetation comprises grasses and non-woody plants with sparse tree cover, often used as grazing lands and erosion buffers (White, 1983). These categories formed the analytical basis for mapping and interpreting land cover changes within the conservancy.

MATERIALS AND METHODS

Study Area

The study was conducted in the Kiborgoch Wildlife and Wetland Conservancy, located in Marigat Sub-County, Baringo County, Kenya (0°22'N, 36°03'E).

Figure 1: Location of the Kiborgoch Wildlife and Wetland Conservancy in Marigat Sub-County, Baringo County, Kenya. The Map Illustrates the Wetland's Position Relative to Nearby Villages (Loboi, Sandai, Kapkuikui) and Key Hydrological Features.



Source: *Author, adapted from Kenya National Survey Maps (2024)*

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Research Design

To address the objectives of this study, a longitudinal mixed-method research design was employed. This approach was selected to enable robust analysis of both quantitative changes in land cover and qualitative observations on ecosystem structure, consistent with the study's goal of informing sustainable wetland-conservancy management. The design integrated remote sensing, GIS analysis, and field-based verification to track spatiotemporal trends in land use and vegetation. Specifically, the study used a time-series framework to capture land cover changes at four decadal time points (1994, 2004, 2014, and 2024), supported by both satellite imagery and ground-truth data. This framework allowed for the measurement of gradual and abrupt changes in land cover types such as bare land, swamp vegetation, wetlands, and grasslands within the conservancy. The study employed three core methodological components. First, a multi-temporal satellite image analysis was conducted using Landsat and MODIS NDVI datasets to detect long-term changes in vegetation and land use patterns. Second, GIS-based classification and mapping techniques were applied, combining both unsupervised and supervised approaches to generate land cover maps and quantify transitions over time. Lastly, ground validation and ancillary data collection were carried out through GPS-referenced field observations and the use of high-resolution imagery from Google Earth, which helped confirm the accuracy of classifications and provided contextual insights into the observed landscape changes.

The mixed-method design ensured a holistic understanding of landscape transformation within the conservancy, bridging quantitative geospatial data with on-the-ground ecological realities. By aligning the analytical process with the study's objectives, the research design not only measured land cover change but also provided evidence for the ecological impacts of anthropogenic activities on the wetland ecosystem. This design was essential in producing findings that can inform evidence-based conservation planning and policy interventions within Kiborgoch and similar conservancy-managed wetlands.

Sampling Framework

A purposive spatial sampling framework was adopted to ensure comprehensive spatial coverage and alignment with field verification activities.

- Temporal Sampling: The study selected four decadal time points based on the availability of high-quality, cloud-free satellite imagery corresponding to the dry season (typically December). This seasonal window minimised spectral variability due to vegetation phenology and atmospheric interference.
- Land Cover Sampling: Four major land cover categories were identified: bare land, wetland, swamp vegetation, and grassland. For each category, 5–10 GPS-referenced field points were collected based on visual interpretation, expert knowledge, and Google Earth imagery. These were used to validate classification outputs and refine training samples.
- Sampling Unit: Analysis was conducted using a 30m × 30m grid resolution, consistent with the Landsat satellite spatial resolution. The classification was guided by this unit scale, allowing for accurate pixel-based change detection.

Data Sources and Collection

Satellite Imagery

This study employed both Landsat and MODIS satellite datasets to assess long-term land use and vegetation dynamics. Landsat imagery was preferred for its medium spatial resolution (30 m), allowing for detailed land cover classification. However, its 16-day revisit cycle limited temporal granularity. To supplement this, MODIS NDVI 16-day composite data (250 m resolution) were used to capture vegetation health trends and seasonal variation. MODIS imagery provided broader temporal coverage, while Landsat captured finer spatial detail. The four decadal images Landsat 5 (1994), Landsat 7 (2004), Landsat 8 (2014, 2024) were acquired from the

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USGS Earth Explorer, all taken during December, when cloud cover is minimal and vegetation variability is low. December was selected for its clear-sky conditions and alignment with the dry season, improving comparability (Kiage & Liu, 2009). For MODIS NDVI, monthly data were obtained for 2004, 2014, and 2024. NDVI was calculated using red (620–670 nm) and near-infrared (841–876 nm) bands, providing a proxy for chlorophyll activity and vegetation productivity (Fensholt & Proud, 2012). The fusion of these datasets improved spatial and temporal assessment beyond the capabilities of a single sensor.

Ground-Truthing and Ancillary Data

Reference data were critical for training and validating the classification. High-resolution Google Earth imagery was used to preliminarily identify land cover classes and select representative sampling locations. Fieldwork involved multiple visits during which GPS-referenced photographs were taken across identified land cover types. Additional contextual information was obtained from 1:50,000 UTM topographic maps and local informants familiar with past land use dynamics. This multi-source verification ensured that the satellite classifications reflected actual ground conditions and improved classification reliability.

Data Processing and Analysis

Image Preprocessing and Classification

All satellite images underwent radiometric and geometric correction, atmospheric normalisation, and projection to UTM Zone 36S. False-colour composites were generated for visual assessment.

A two-step classification approach was used:

- Unsupervised classification (ISODATA clustering) to explore spectral groupings.
- Supervised classification using the Maximum Likelihood Algorithm (MLA) within ArcGIS, with training samples derived from validated ground-truth points.

Multiple training signatures were created per land cover class. The classification outputs were refined using the ArcGIS merge and reclassify tools, and a minimum distance to means (MINDST) classifier was applied to finalise the classification into four land cover categories: bare land, wetland, swamp vegetation, and grassland (Lillesand & Kiefer, 2004; Nagi, 2011).

The choice of anniversary dates (December 31st of each respective year) minimised seasonal reflectance differences due to solar angle or vegetation phenology, enhancing inter-year comparability (Oehmcke et al., 2020).

Change Detection Analysis

Land cover changes were quantified using a post-classification comparison method, which involved overlaying classified maps from different periods to detect spatial transitions. This method produced change matrices, showing net gains and losses in each land cover type, and allowed for temporal analysis of transformation patterns.

NDVI Analysis

NDVI values were computed from MODIS data using the formula:

$$NDVI = (NIR - Red) / (NIR + Red)$$

NDVI trends were analysed to assess vegetation productivity and degradation. High NDVI values indicated dense, healthy vegetation, while lower values signalled stress or sparse cover. Monthly NDVI composites were used to account for seasonal variability, and trends were visualised using line graphs and spatial heatmaps. All spatial and statistical analyses were performed using ArcGIS 10.x and Microsoft Excel.

RESULTS AND DISCUSSION

The spatial distribution of land cover types in 1994 is illustrated in Figure 2, where grassland dominated the landscape, particularly in central and northern zones. Figure 3 shows the 2004 distribution, indicating minor increases in wetland and swamp vegetation. By 2014, as depicted in

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Figure 4, a dramatic expansion in wetland area occurred, coinciding with a steep decline in grassland. Figure 5 presents the 2024 scenario, revealing significant increases in bare land and swamp vegetation, while wetland areas had receded from their 2014 peak.

Figure 2: Land Use/Land Cover (LULC) Map of Kiborgoch Conservancy in 1994, Showing Extensive Grassland Cover Dominating the Central and Northern Zones, with Minimal Bare Land Presence

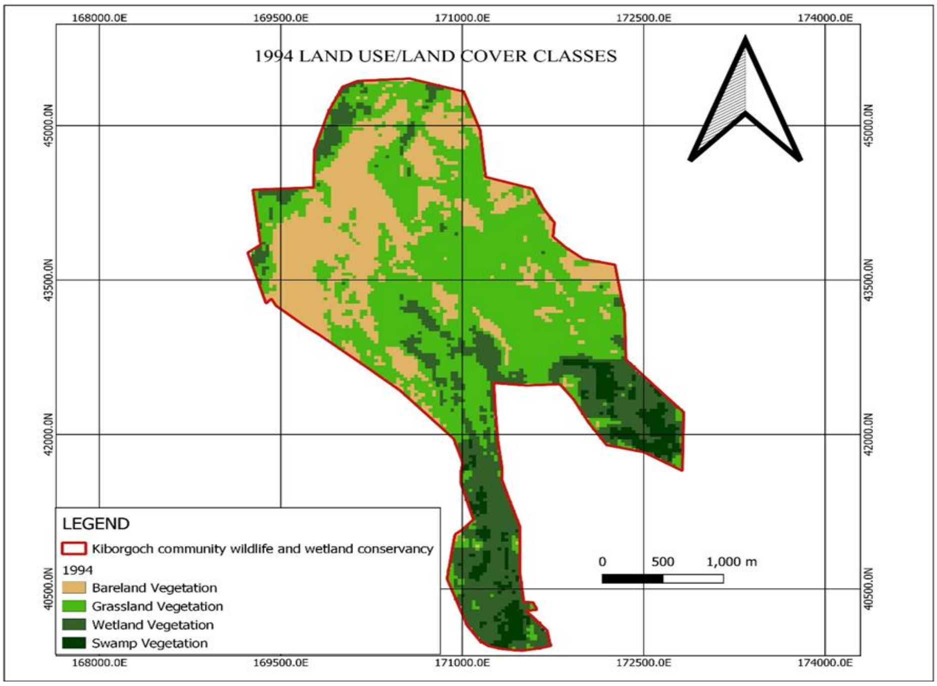

Figure 3: LULC Classification for 2004 Reveals Early Signs of Wetland and Swamp Vegetation Expansion, Particularly in the Southern and Eastern Parts of the Conservancy.

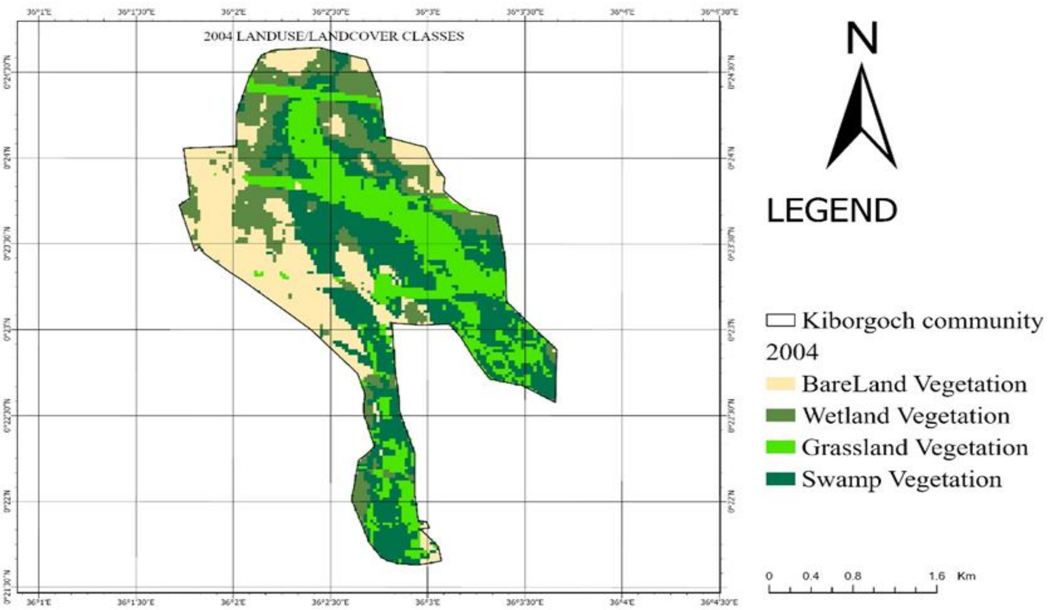

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Figure 4: The 2014 Map Illustrates a Peak in Wetland Coverage and a Marked Reduction in Grassland, Indicating Major Ecological Transitions during This Period.

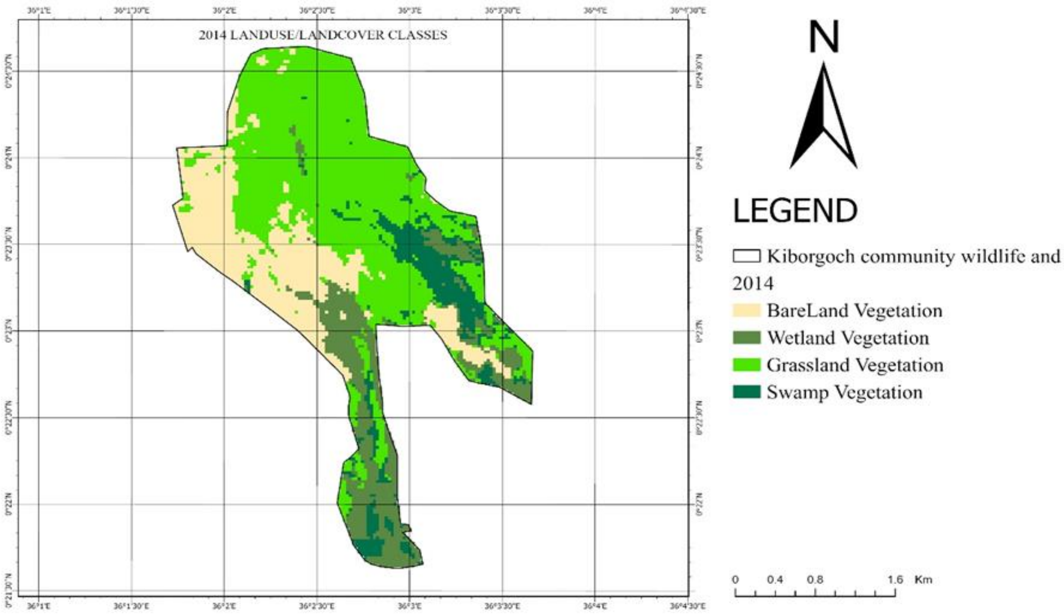

Figure 5: By 2024, LULC Changes Reflect Significant Bare Land Expansion and Swamp Proliferation, Coupled with a Notable Decline in Overall Wetland Area.

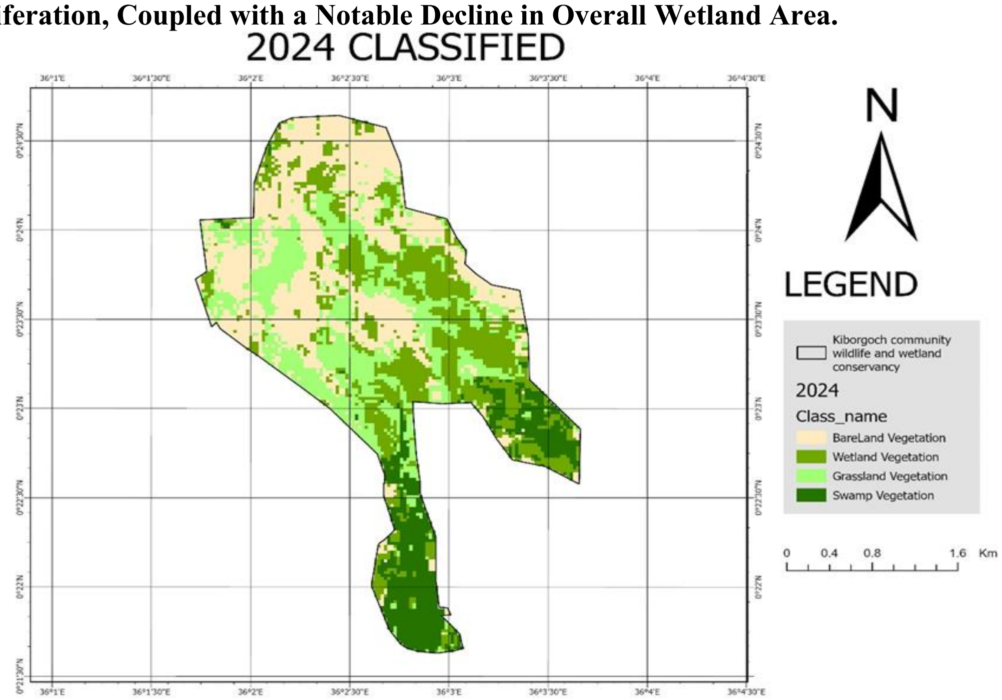

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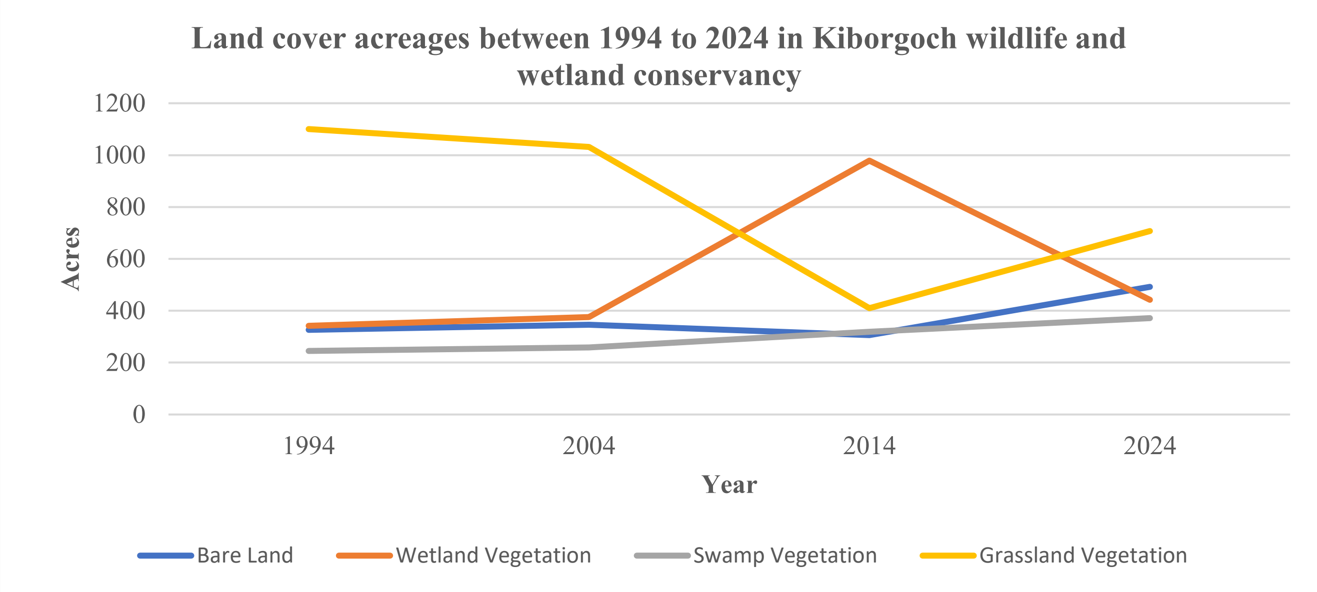
Figure 6: Land Use and Cover Change Transitions between 1994 and 2024 in the Kiborgoch Conservancy.



Source: *Analysis 2024*

Land Use and Land Cover Change (1994–2024)

The analysis showed a significant transformation in land use and land cover (LULC) across the four reference years 1994, 2004, 2014, and 2024 within the Kiborgoch Wildlife and Wetland Conservancy. The 30 years was marked by a continuous increase in bare land and swamp vegetation, fluctuating trends in wetland extent, and a pronounced net decline in grassland (Table 1). Bare land expanded from 325.78 acres in 1994 to 492.13 acres in 2024, indicating progressive land degradation likely driven by deforestation, overgrazing, and unregulated cultivation. This mirrors findings from other semi-arid regions such as the River Loboi watershed, where similar degradation patterns were associated with vegetation loss and topsoil exposure (Bitengo et al., 2015; Kundu et al., 2024). These transformations often result in reduced land productivity, heightened erosion, and compromised ecological resilience in conservancy-managed landscapes (Chakraborty et al., 2023; Davidson, 2014).

Wetland extent showed non-linear dynamics. From 341.90 acres in 1994, wetlands expanded significantly to a peak of 978.81 acres in 2014, before declining sharply to 442.65 acres in 2024. The temporary surge could be attributed to episodes of high rainfall and surface water accumulation, while the subsequent decline likely reflects a combination of upstream water abstraction, sedimentation, and deforestation. Similar fluctuations have been observed in East African wetlands such as Lake Sare, where climatic pulses temporarily mask longer-term degradation trends (Okumu, 2012; Ballut-Dajud et al., 2022).

In contrast, swamp vegetation exhibited a steady upward trend, increasing from 245.07 acres in 1994 to 371.57 acres in 2024. This pattern may reflect vegetation succession under persistent soil moisture or disrupted drainage. According to Muasya et al. (2004), such conditions promote colonisation by macrophytes and semi-aquatic plants, especially following disturbance or land abandonment. While this may indicate a degree of ecological recovery, it may also lead to reduced species diversity and trophic simplification, especially if dominated by invasive or opportunistic species (Gardner & Finlayson, 2018).

Grassland, the dominant land cover in 1994, experienced the most significant net loss,

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shrinking from 1,100.40 acres to 706.80 acres over the study period. The steepest decline occurred between 2004 and 2014, when over 600 acres of grassland were lost—likely converted to swamp or bare land. As critical habitats for wildlife, erosion control zones, and forage sources, the reduction of grassland cover raises serious conservation concerns. The modest recovery by 2024 may be attributed to passive regeneration or localised restoration efforts. Comparable trends have been observed by Liu et al. (2023) and Marambanyika & Beckedahl (2016), who documented grassland-to-swamp conversions in response to prolonged saturation and shifts in grazing intensity.

Collectively, these LULC dynamics reflect the interplay of anthropogenic activities and environmental processes in shaping the structure and function of the conservancy's ecosystems. The directional shifts suggest a broader ecological trajectory toward degradation and altered land productivity, warranting urgent intervention through land use planning, wetland restoration, and community-based conservation strategies.

Table 1: Land Use and Land Cover Changes in the Kiborgoch Wildlife and Wetland Conservancy between 1994 and 2024.

Land Cover Type	1994 (acres)	2004 (acres)	2014 (acres)	2024 (acres)	Change (1994–2004)	Change (2004–2014)	Change (2014–2024)	Total Change (1994–2024)	% Change (1994–2024)
Bare Land	325.78	346.57	306.08	492.13	+20.79 (↑)	-40.49 (↓)	+186.05 (↑)	+166.35 (↑)	+51.03%
Wetland Vegetation	341.9	376.15	978.81	442.65	+34.25 (↑)	+602.66 (↑)	-536.16 (↓)	+100.75 (↑)	+29.47%
Swamp Vegetation	245.07	258.65	318.32	371.57	+13.58 (↑)	+59.67 (↑)	+53.25 (↑)	+126.50 (↑)	+51.62%
Grassland Vegetation	1100.4	1031.78	409.94	706.8	-68.62 (↓)	-621.84 (↓)	+296.86 (↑)	-393.60 (↓)	−35.77%

(↑) Increase in area, (↓) Decrease in area

The NDVI analysis reinforces the spatial evidence of degradation, with declining vegetation vigour concentrated in southern and upstream margins. These findings align with Fensholt and Proud (2012), who identified NDVI as a reliable proxy for land health and degradation assessment. In the Kiborgoch context, low NDVI zones correlated strongly with areas undergoing bare land expansion and grassland loss, suggesting feedback loops where vegetation decline exacerbates exposure and subsequent erosion (Nguyen et al., 2023).

Altogether, these patterns reflect spatially uneven but ecologically significant change. The spatial concentration of degradation presents a strategic entry point for focused ecological restoration, including actions like reforestation, rotational grazing, and hydrological repair. These results underscore the importance of participatory land use planning and locally led conservation models in sustaining ecosystem functionality, particularly in complex, multi-use landscapes such as Kiborgoch (Hoole, 2008; Ogutu et al., 2020; Kalvelage et al., 2021).

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The observed reduction in dense vegetation zones signifies wetland degradation and compromises essential ecological functions such as water purification, carbon sequestration, and wildlife habitat provision (Kundu et al., 2024; Liu et al., 2023). Muasya et al. (2004) further emphasised the need to monitor swamp use, especially where seasonal grazing and harvesting of macrophytes occur, as such activities can disrupt wetland resilience. The 30-year analysis highlights the cumulative impact of human pressures on the conservancy's ecological structure. The concurrent decline in wetland acreage and increase in bare land and swamp vegetation serve as a proxy for intensified anthropogenic stress. Similar trends have been documented in adjacent ecosystems, including the River Loboi watershed, which transitioned from a savannah to a shrub-dominated, highly degraded landscape, an estimated 87.5% of which now exhibits signs of severe degradation (Bitengo et al., 2015).

CONCLUSION AND RECOMMENDATION

This study provides a comprehensive spatiotemporal assessment of land use and vegetation changes within the Kiborgoch Wildlife and Wetland Conservancy over 30 years. The findings highlight a clear trajectory of ecological degradation marked by the expansion of bare land and swamp vegetation, the decline of grasslands, and fluctuating wetland extents. These shifts reflect the compounded impacts of human activity and climatic variability on wetland systems.

The decline in vegetation health, as evidenced by NDVI trends, and the spatial concentration of degradation zones underscore the need for spatially targeted and community-informed conservation strategies. Grassland reduction and wetland shrinkage signal losses in biodiversity, ecosystem services, and overall landscape resilience. Addressing these trends requires a shift toward sustainable land use practices, restoration of natural hydrological systems, and active participation of local communities. Integrating remote sensing and long-term ecological monitoring into policy and management frameworks is essential to ensure timely identification and response to emerging environmental threats. The insights from this study contribute valuable evidence for guiding adaptive wetland management, particularly in conservancy-managed systems across East Africa.

To mitigate further degradation and restore ecological balance within the Kiborgoch Conservancy, several strategic actions are recommended. First, the development of participatory land use planning frameworks involving local communities and conservation stakeholders is essential to manage resource use and reduce pressure on vulnerable zones. The establishment of vegetative buffer zones, coupled with active reforestation, will help stabilise soils and enhance wetland functions. Protecting upstream catchments and ensuring sustainable hydrological flows should also be prioritised to safeguard wetland hydrodynamics.

Furthermore, promoting alternative livelihood options such as climate-smart agriculture, ecotourism, and non-timber forest products can reduce dependency on extractive land uses. Embedding long-term ecological monitoring systems combining satellite imagery with field-based observations will enable the timely detection of environmental changes and support adaptive management. Finally, conservation goals must be aligned with existing county and national policy frameworks, and capacity-building efforts must be expanded to strengthen community stewardship, raise environmental consciousness, and embed sustainable practices into local decision-making processes. While this study offers a robust assessment of land use and vegetation dynamics over 30 years, it also reveals areas that warrant deeper investigation. Future research should prioritise high-resolution spatial analyses to better capture micro-scale land cover changes, especially in transition zones between swamp vegetation and degraded grasslands. Integrating socio-economic data with remote sensing outputs would provide critical insights into how livelihood strategies, land tenure systems, and community perceptions influence land use patterns.

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