Open Access Research Journal of
Science and Technology
Journals home page: https://oarjst.com/
ISSN: 2782-9960 (Online)

OARJ OPEN ACCESS RESEARCH JOURNALS

(RESEARCH ARTICLE)

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Land use land cover change and its potential implications on conservation of Sitatunga antelope in Saiwa wetland, western Kenya

Millicent Anyango Owiti *, Maurice Ongong'a Ogoma and Grace Wanjiru Kibue

Department of Natural Resources, Egerton University, P.O. Box 536-20115, Egerton, Kenya.

Open Access Research Journal of Science and Technology, 2024, 11(02), 001–012

Publication history: Received on 21 May 2024; revised on 30 June 2024; accepted on 03 July 2024

Article DOI: https://doi.org/10.53022/oarjst.2024.11.2.0084

Abstract

Land use and land cover (LULC) changes are significant drivers of global environmental change, impacting ecosystem processes, biological cycles, and biodiversity. This study aimed to describe the LULC changes in Saiwa Wetland from 1993 to 2023 and discuss their potential impacts on the rare Sitatunga antelope. We utilized remote sensing and GIS technologies, downloading cloud-free Landsat images from the USGS website, including Landsat TM, ETM+, OLI, and Sentinel images. These images underwent supervised and unsupervised classification to identify spectral signatures of various LULC classes. Post-classification refinement and a multi-date post-classification comparison algorithm using QGIS were employed for change detection. The analysis identified five LULC classes: forested areas, reeds/papyrus, grass/shrub areas, bare areas, and water areas. Results indicated a decrease in forested areas from 37% in 1993 to 34% in 2023 and a reduction in grass/shrub areas from 19% to 16%. Conversely, reeds/papyrus increased from 24% to 26%, and bare areas increased from 6% to 8%. Water areas also saw an increase from 13% to 16%. These changes are attributed to human activities such as logging, mining, and agricultural encroachment, along with climatic changes. We envisage that the LULC changes could have effects on the habitats of Sitatunga antelope whose population has declined dramatically from 200 individuals in 2018 to 60 in 2021 in the Saiwa wetland ecosystem. Immediate conservation and restoration measures are essential to preserve the integrity of the Saiwa wetland ecosystem and its associated biodiversity.

Keywords: Land use land cover; Geographic information system; Remote sensing; Saiwa wetland; Sitatunga antelope

1. Introduction

Land use and land cover (LULC) refer to two interconnected but distinct concepts. Land cover describes the physical characteristics of the Earth's surface, such as vegetation, water, soil, and other natural features, while land use pertains to human activities and their economic implications on the land (McConnell, 2015; Rawat & Kumar, 2015; Arsanjani, 2011). Changes in LULC are significant drivers of global and regional environmental change, increasingly recognized in assessments of human environmental impact (Verburg *et al*., 2015; Brovkin *et al*., 2013; Foley *et al*., 2005). Historically shaped by natural forces, the Earth's surface is now predominantly influenced by human activities, such as agriculture, forest management, and energy demand, which significantly affect the soil system (Ellis, 2011). These anthropogenic changes contribute to greenhouse gas emissions, including carbon dioxide and non-carbon dioxide gases (Houghton *et al*., 2012; Le Quéré *et al*., 2015; Smith *et al*., 2015; Tubiello *et al*., 2015).

In Kenya, the expansion of intensive horticulture has significantly impacted LULC in central agricultural production areas (Becht *et al*., 2005; Francis, 2014), and western Kenya due to increasing human population that has led to reduction in arable land sizes. Activities such as the uneven distribution of large farms, extraction of surface water for irrigation, clearing of less productive land, and continuous cultivation to increase year-round crop production have greatly affected environmental resource consumption and management (Aeschbacher *et al*., 2005; Owiti & Oswe, 2007). This growth has attracted high population density and unplanned settlement, putting pressure on environmental

* Corresponding author: Millicent Anyango Owiti

resources and leading to degradation and interspecies competition (Barrow, 2006; Muriuki *et al*., 2011). The primary drivers of LULC change include the increasing demands of a growing population, leading to soil degradation, erosion, and altered watershed properties, potentially causing flooding in nearby areas (Gashaw *et al*., 2018). The consequences of LULC change include desertification, loss of biodiversity, habitat destruction, soil degradation, and reduced capacity of watersheds to sustain natural resources and ecosystem services (Woldeyohannes, 2018).

Besides, inefficient land use can result in declining environmental quality and the loss of valuable agricultural land, which in turn leads to the loss of wildlife habitats (Mangesha, 2014). LULC changes contribute to habitat destruction for various species, including small mammals, birds, and plants. Many plant species that provide habitats for birds and bees, essential pollinators, are at risk of disappearing (Perrings & Halkos, 2015). Agricultural expansion has significantly altered habitats, posing a major threat to biodiversity. Of the 28,000 species assessed as at risk of extinction on the IUCN Red List, agriculture is identified as a threat for 24,000 (IUCN, 2019).

Saiwa Swamp, one of Kenya's crucial wetlands, is located in a watershed experiencing both direct and indirect impacts from a growing human population, particularly due to farming and human settlement. These activities threaten essential ecosystem services such as water quality protection and flood prevention, endangering the survival of the wetland-dependent wildlife species.

Sitatunga antelope *Tragelaphus spekii*, the world's only aquatic antelope (Ndawula *et al*., 2011), is a unique swamp-dwelling species that is highly adapted to wetland habitats, thriving in areas with papyrus, phragmites, bulrushes, reeds, and sedges (Flack, 2015; Lindholm, 2013). They prefer the deepest parts of swamps and are proficient swimmers, creating pathways through dense vegetation. As mixed feeders, Sitatungas primarily browse on sedges, bulrushes, and other aquatic grasses, with a particular liking for sweet potatoes and certain herbs (Haines, 2021). The first national census of the Sitatunga antelope in Kenya, conducted in 2021, revealed a dramatic decline in their population within Saiwa National Park, from 200 individuals in 2018 to just 60 by 2021. This decline could be attributed to habitat loss from land use changes, which disrupt the ecological connectivity essential for the species' survival (Foley *et al*., 2005). The growing human population has intensified anthropogenic activities including deforestation and agricultural encroachment around wetland areas (Ahmed *et al*., 2022; Belay & Mengistu, 2019), while climate change poses significant threats by altering the wetland ecosystems (Thirgood *et al*., 2004).

The degradation of the Saiwa Swamp ecosystem threatens critical ecosystem services and the economic benefits of ecotourism. The objectives of this study were to establish the LULC changes in Saiwa Swamp over the past three decades and assess their potential effects on conservation of the Sitatunga antelope.

2. Materials and methods

2.1. Description of study area

The study was conducted in the Saiwa wetland, located in Trans-Nzoia County, western Kenya (Figure 1). A portion of the wetland includes Saiwa Swamp National Park (1°6′N 35°7′E), a small park covering 3 km^2. Established in 1974, the park serves as a habitat for the rare and locally endangered semi-aquatic Sitatunga antelope *Tragelaphus spekei* (Kenya Wildlife Services [KWS], 2024). The park features both swamp and forest vegetation and supports a variety of wildlife, birds, insects, and reptiles. The wetland is nourished by the Sinyerere and Kapenguria rivers and drained by the Saiwa and Sitatunga rivers, which feed into the Nzoia river system, ultimately flowing into Lake Victoria. However, the swamp is under threat from agricultural chemical runoff, encroachment by neighboring farmers, erosion of the riverbanks, and subsequent changes in vegetation. Agriculture is the predominant economic activity in Trans-Nzoia County, contributing significantly to employment, food security, income, and overall socio-economic wellbeing. The major land uses include large-scale maize and wheat farming, with other significant crops being tea, coffee, beans, and potatoes (Mbuni *et al*., 2020). However, small scale horticultural production has gained prominence in the Saiwa wetland and its catchment leading to encroachment on the wetland ecosystem.

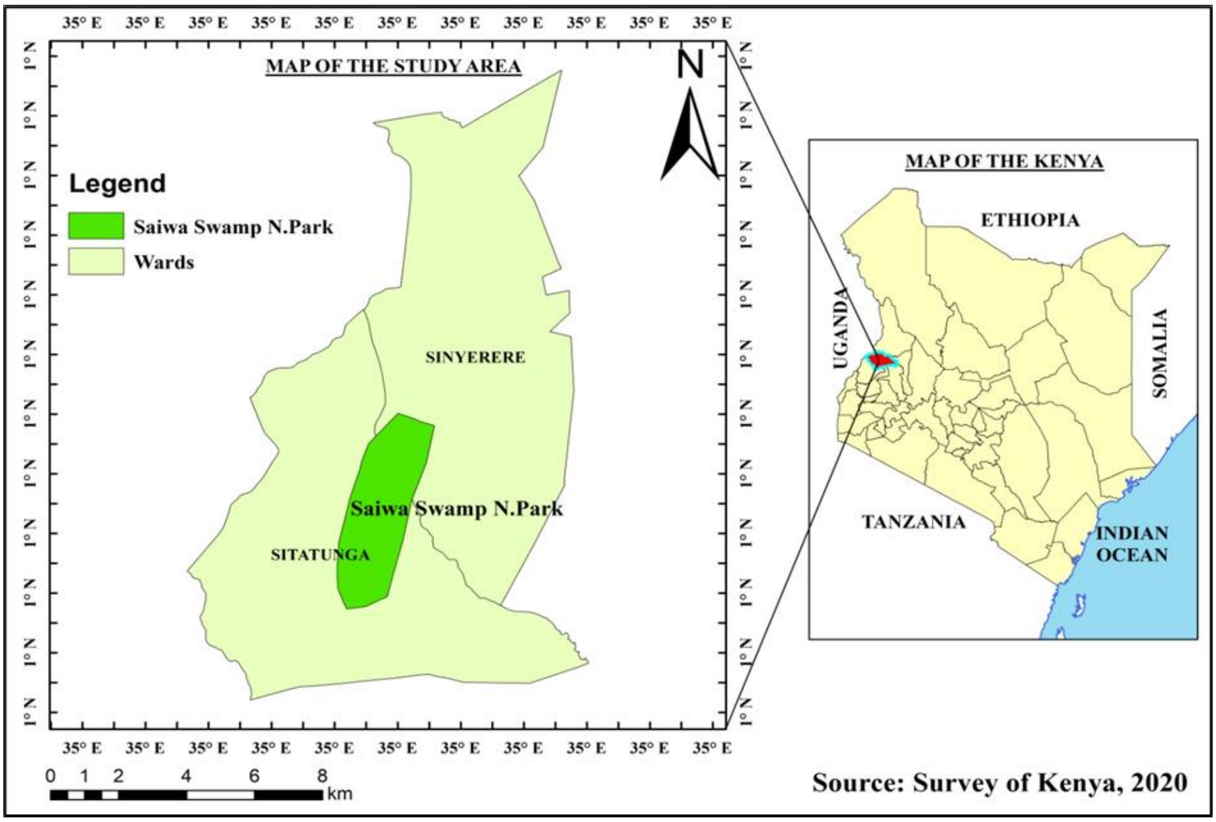


Figure 1 Map of study site

2.2. Data sources and acquisition

For this study, we obtained satellite imagery spanning from 1993 to 2023 for the Saiwa wetland from the USGS Earth Explorer website (https://earthexplorer.usgs.gov/). This dataset included 30 years of multi-temporal satellite images at 5-year intervals, featuring Landsat 5 Thematic Mapper (TM) at 30 m resolution, Landsat 7 Enhanced Thematic Mapper Plus (ETM+) at 30 m with a 15 m panchromatic band, Landsat 8 Operational Land Imager (OLI) at 15 m resolution, and Sentinel images at 10 m resolution. Before downloading, we performed an image quality assessment to ensure the selection of the highest quality images for the study area (Roy *et al*., 2022). These images were chosen for their cost-effectiveness, easy accessibility, and appropriate spectral and spatial resolutions (Zhang *et al*., 2020).

In addition to satellite imagery, we utilized a global positioning system (GPS) to gather data for verification during ground truthing surveys, which included confirming the accuracy of the classified land use and land cover (LULC) map (Chen *et al*., 2021). We also obtained supplemental datasets, including Kenya's country and Trans Nzoia County shapefiles, from Google Earth to support our analysis. For vegetation type characterization, we placed belt transects and conducted sampling within 1m x 1m quadrants placed at intervals of 10 meters, where we identified and recorded all species within each quadrant (Mbow *et al*., 2020).

Table 1 Description of satellite images used in this study for LULC analysis

Satellite Sensor	Acquisition Dates	Resolution (meters)	Website search ID
TM	Jun 1993	30m	LT05_L1TP_170059_19940922_20200912_
ETM+	Feb 2003	30m	LE07_L1TP_170059_20030518_20200916
OLi	Jan 2013	15m	LC08_L1TP_170059_20130724_20200912
Sentinel	Mar 2023	10m	T36NYG_20230903T074619

TM = Thematic Mapper sensor; ETM+ = Enhanced Thematic Mapper plus sensor, OLi= Operation Land Imager and Sentinel.

2.3. Image processing

We conducted pre-processing of the data using IDRISI Image Processing in TerrSet 2020, which involved geo-referencing, mosaicking, and sub-setting the images based on the Area of Interest (AOI) (Ahmed & Ahmed, 2018) and concatenation. The purpose of pre-processing was to enhance image data by minimizing unwanted distortions or by improving specific visual qualities that are beneficial for further analysis (Kaur & Rani, 2020). To improve image quality, all acquired satellite images underwent geometric correction using ground control points and radiometric corrections through the empirical line calibration method before analysis (Li *et al*., 2019). For image processing and supervised classification, we combined the bands into a single layer using the layer stacking technique in ERDAS software. We assigned each image a consistent false-colour composite (FCC) for mapping purposes (Gupta *et al*., 2021) since FCCs are effective in generating the best training samples for classification and analysis (Zhang *et al*., 2020). We then used these training samples to perform supervised classifications. We utilized the GPS data to assess the accuracy of the classification (Gupta *et al*., 2021).

2.4. LULC image classification

Following established methodologies (see e.g. Yasin *et al*., 2024; Yan *et al*., 2020), we conducted image classification to delineate distinct spectral signatures corresponding to various Land Use and Land Cover (LULC) categories from the Landsat datasets. We utilized the designated AOI tools to extract digital polygons of each sampled pixel, and employed a signature editor for further refinement of the classification process (Rajasekaran *et al*., 2019). We classified the study area into five primary LULC classes: forests area, grass/shrub, grass/bare, reeds/papyrus, and water areas **(Table 2)**. To facilitate the classification process, we employed the supervised maximum likelihood classifier algorithm to enhance consistency with the established practices (Moussa *et al*., 2018).

Table 2 Land cover classification scheme used in the study

Cover class	Description
Forests Area(FA)	The continuous stand of trees, many of which may attain a height of 50 m including natural forest, mangrove and plantation forest.
Grass/Shrub (G/S)	Areas of land covered with scattered grasses, shrubs
Grass/Bare (G/B)	Areas with exposed soil and rock outcrops with pits of scattered grass.
Reeds/Papyrus(R/P) Water areas (WA)	Areas covered by reeds and papyrus vegetation Areas naturally or artificially covered by water shallow deep.

2.5. LULC Change detection

We performed change detection through post-classification refinement to enhance the accuracy of the classification process. We employed a multi-date post-classification comparison change detection algorithm to detect changes over time (Tiede *et al*., 2019; Zhang *et al*., 2020). The land cover map generated in 1993 was compared with maps from subsequent years up to 2023 using QGIS software (Smith *et al*., 2018).

2.6. Literature review on potential impact of LULC change on Sitatunga antelope

We used the results of land use and land cover (LULC) change analysis in projecting the potential impact of these changes on the Sitatunga antelope habitats and population. Utilizing available literature on the species, particularly studies focusing on habitat preferences, distribution patterns, and ecological requirements, we discussed how alterations in LULC may affect the suitability and availability of habitats for Sitatunga antelopes. By integrating LULC change results with knowledge from published literature (see e.g. Tekalign *et al*., 2021; Bekele *et al*., 2020; Mutebi *et al*., 2019; Alemu *et al*., 2018; Yoseph *et al*., 2017; Obiero *et al*., 2012;). on Sitatunga antelopes, we were able to anticipate and assess the potential ecological consequences of these changes thereby informing conservation strategies and management interventions aimed at mitigating adverse impacts and promoting the long-term viability of Sitatunga antelope populations within Saiwa wetland.

3. Results and discussion

3.1. Vegetation characterization

During the study period, the satellite images revealed three primary classes of vegetation within Saiwa wetland: forests, papyrus reeds, and grass/shrub areas (Figure 2). Ground surveys were conducted to confirm the specific types of vegetation, as the satellite resolution alone was insufficient for precise identification.

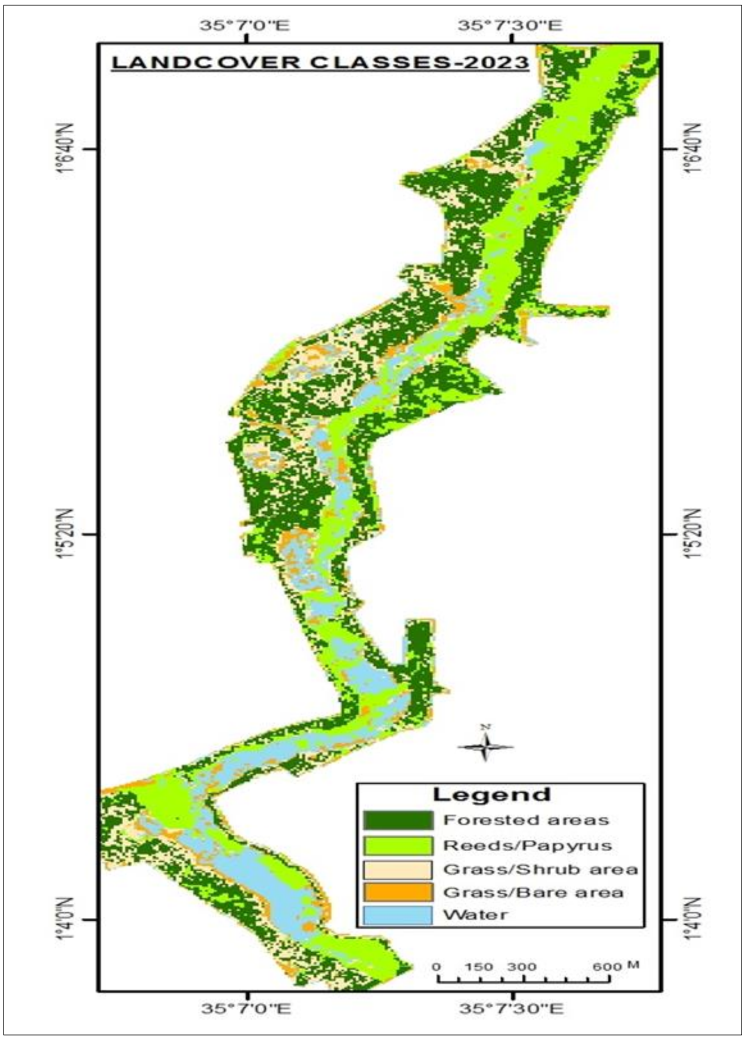


Figure 2 Saiwa Wetland Land Cover Classes

Table 3 shows the vegetation types in Saiwa wetland. The forested areas were rich in a variety of tree species, including fig trees, exotic banana trees, *Acacia* trees, *Afzelia africana*, and *Syzygium* trees. This mixture of indigenous and exotic species contributes to the canopy cover in different regions of the wetland. The forests provide vital habitat and resources for numerous wildlife species, such as the rare sitatunga antelope, as well as primates like the black-and-white colobus monkeys and the rare De Brazza's monkey (KWS, 2021). The reeds in Saiwa wetland papyrus reeds, *Scirpoides holoschoenus*, *Typha latifolia*, *Typha domingensis*, and *Echinochloa pyramidalis*. These reeds are fundamental components of the wetland ecosystem, aiding in water purification, sediment stabilization, and providing habitat for aquatic organisms.

The grass/shrub vegetation in Saiwa wetland encompasses a diverse array of plant species, such as *Prunus africana*, *Maesa lanceolata*, and *Acacia hockii*. This diversity indicates a robust habitat capable of supporting various wildlife species. The presence of grasses like *Melinis minutiflora* and *Setaria sphacelata* contributes significantly to the park's ecosystem. Shrubs, in particular, provide essential food and habitat for numerous species, including insects, birds, and small mammals, thus enhancing the park's biodiversity and ecological structure (Palapala *et al*., 2020). These shrubs play a crucial role in maintaining the ecological balance and resilience of the Saiwa Swamp ecosystem (Wang *et al*., 2019).

Table 3 Vegetation types in Saiwa wetland

Grass/Shrub Vegetation	Forested Area	Reeds
Prunus africana	*Ficus sycomorus*	Papyrus reeds
Maesa lanceolata	*Ficus cyathistipula*	*Scirpoides holoschoenus*
Acacia hockii	Cavendish banana	*Typha latifolia*
Maytenus heterophylla	*Musa sikkimensis*	*Typha domingensis*
Periploca linearifolia	*Afzelia africana*	*Echinocloa pyramidalis*
	Syzygium trees	

This diverse vegetation composition underlines the ecological richness of Saiwa wetland, supporting a wide range of species and contributing to the overall health and functionality of the ecosystem.

3.2. Land Use Land Cover Changes

The land use and land cover (LULC) changes in Saiwa wetland over the 30-year period from 1993 to 2023 reveal significant transformations, which are illustrated in GIS maps (Figures 3 and 4) and summarized in Table 4. The trends observed in LULC changes are further illustrated in Figure 5 that provides a visual representation of these shifts over the years. These trends reflect the impact of various anthropogenic activities and natural processes on the land cover, which consequently affect the habitat and population dynamics of the Sitatunga antelope in the Saiwa wetland.

The forested areas in Saiwa wetland have shown a consistent decline over the study period. In 1993, forested regions accounted for 107 hectares, making up 37% of the total area. By 2023, this had decreased to 100 hectares, representing 34% of the area. This decline in forest cover is primarily due to human activities such as logging, mining, and agricultural encroachment, as well as changing climatic conditions (CIFOR, 2018). These factors contribute to vegetation clearance, which adversely affects the Sitatunga antelope by reducing their habitat and shelter, crucial for their survival and reproduction. The conversion of wetland vegetation to cropland and settlements, driven by population growth, further exacerbates habitat loss for the Sitatunga. These activities not only reduce the available habitat but also fragment the remaining forest patches, making it difficult for Sitatunga to move between them, thus limiting their access to resources and increasing their vulnerability to predators (Palapala *et al.,* 2020; Wang *et al*., 2019).

The area covered by papyrus reeds and other aquatic vegetation has experienced slight fluctuations but an overall increase. In 1993, reeds occupied 70 hectares (24%), which dropped to 57 hectares (20%) in 2003. However, by 2023, the coverage had increased to 75 hectares, accounting for 26% of the wetland. The increase in area covered by papyrus reeds could be attributed to the deposition of agricultural chemicals, which promote the growth of papyrus reeds by supplying essential nutrients in diluted forms (Johnson, 2022). However, the increase in reeds is partly due to the runoff of agricultural chemicals, which might have long-term negative effects on water quality and wetland health. While the short-term increase in cover might offer some refuge, the overall degradation of wetland quality could undermine these benefits (Chen *et al*., 2019).

Grass and shrub areas have declined from 19% in 2003 to 16% in 2023. These areas covered 56 hectares in 1993, slightly increased to 58 hectares in 2003, but then decreased to 47 hectares by 2023. The decrease in grass/shrub areas from 19% in 2003 to 16% in 2023 adversely affects the Sitatunga's foraging grounds. These areas are important for their diet, which includes a variety of grasses and shrubs. The reduction in these areas, driven by agricultural encroachment and settlement expansion, leads to a scarcity of food resources, forcing Sitatunga to venture into less suitable areas where they are more exposed to predation and human-wildlife conflicts (Foley *et al*., 2005). This situation exacerbates their declining population trend, as observed between 2018 and 2021.

Bare areas within the wetland have shown a slight increase. From covering 6% (18 hectares) in 1993, these areas expanded to 7% (21 hectares) in 2003 and 2013, and further to 8% (23 hectares) in 2023. The increase in bare areas is likely due to land cover changes and anthropogenic activities that degrade the wetland ecosystem (Chen *et al*., 2019). Bare areas, often a result of soil erosion and overgrazing, do not provide suitable habitat for Sitatunga, contributing to the overall decline in habitat quality. This degradation disrupts the ecological balance, reducing the availability of suitable and contiguous habitats necessary for the Sitatunga's survival (Zhao, Peng, & Jiang, 2018).

Water areas have increased from 13% in 1993 to 16% in 2023. This rise from 39 hectares to 45 hectares in water area suggests changes in the hydrological dynamics of the wetland's rise can be attributed to factors such as poor drainage, increased water supply, and slow water flow (Smith, 2021). While an increase in water in water bodies can initially seem beneficial, it may indicate poor drainage and altered water flow patterns that could disrupt the natural habitat structure. For a semi-aquatic species like the Sitatunga, stable and predictable water levels are crucial. Water fluctuations can affect their breeding and feeding grounds, further stressing the population (Smith, 2021).

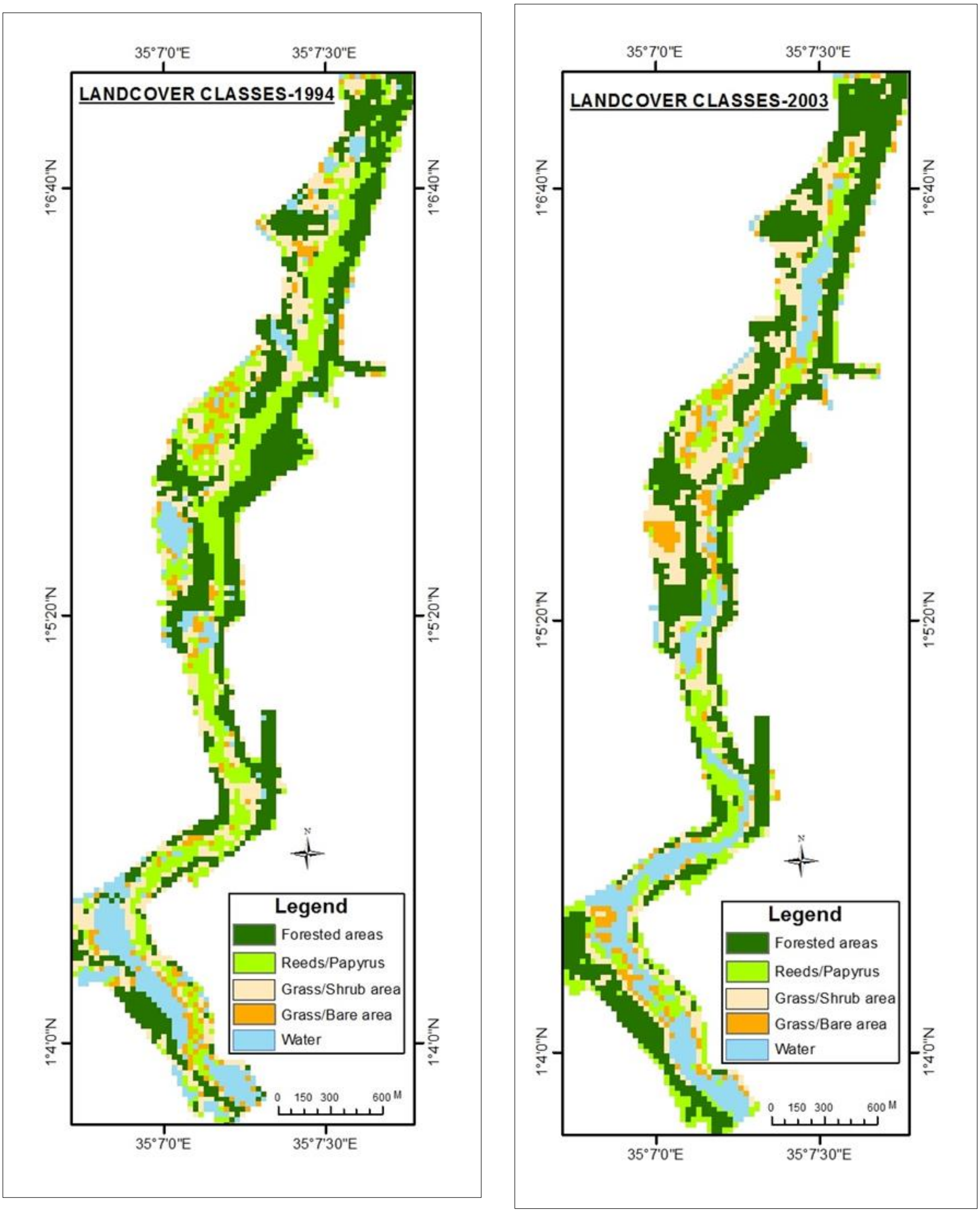
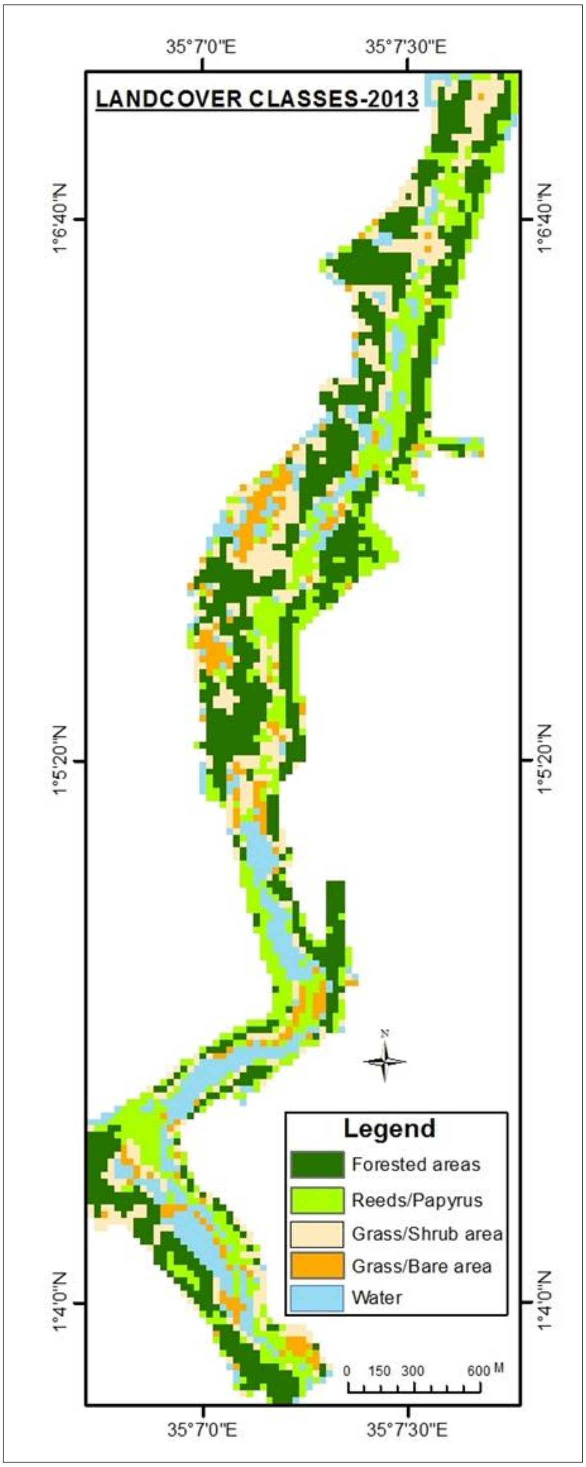


Figure 3 Saiwa wetland land cover classification for 1993 and 2003



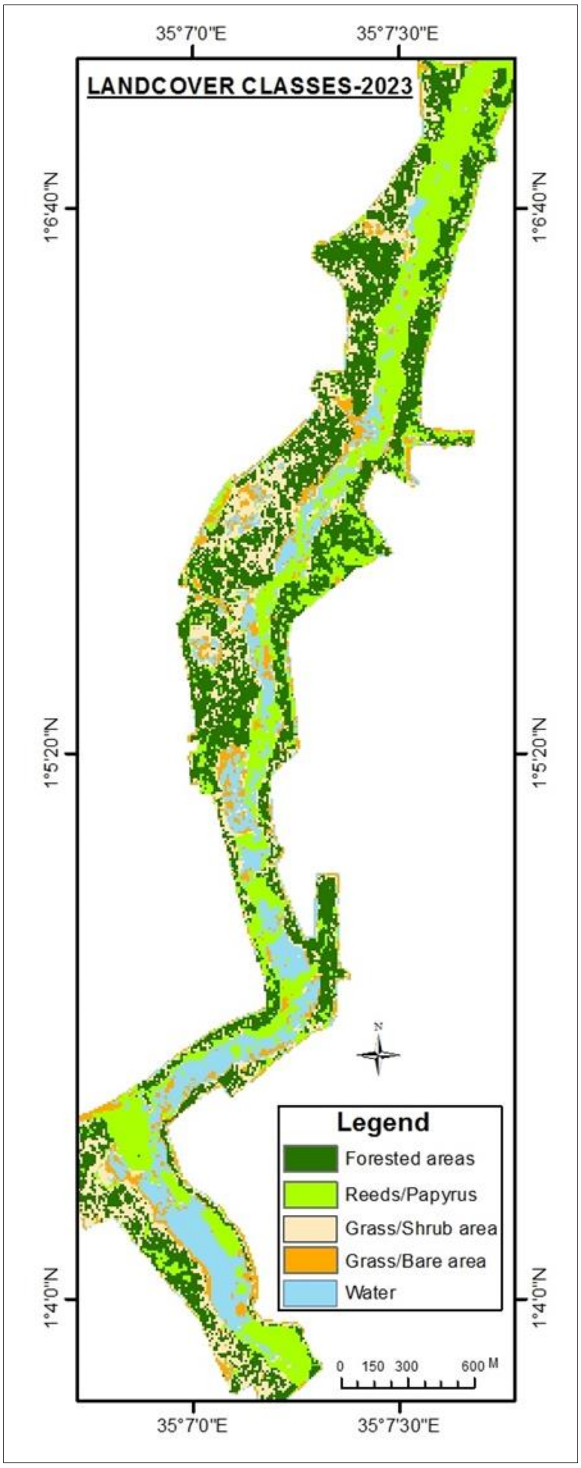


Figure 4 Saiwa wetland land cover classification for 2013 and 2023

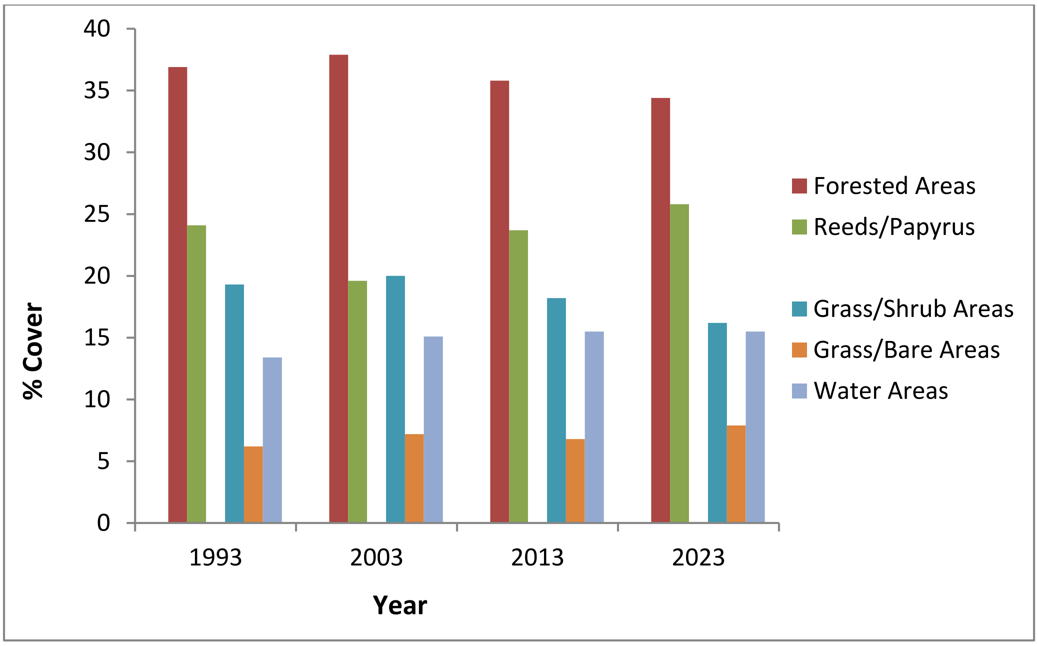


Figure 5 Trend analysis of the land use land cover change

Table 4 Land Use Land Cover Distribution

Class Type	1993 (Area Ha)	% Cover	2003 (Area Ha)	% Cover	2013 (Area Ha)	% Cover	2023 (Area Ha)	% Cover
Forested Areas	107	37	110	38	104	36	100	34
Reeds/Papyrus	70	24	57	20	69	24	75	26
Grass/Shrub Areas	56	19	58	20	53	18	47	16
Grass/Bare Areas	18	6	21	7	20	7	23	8
Water Areas	39	13	44	15	45	16	45	16
Total	290	100	290	100	290	100	290	100

3.3. Implications for conservation

The observed LULC changes underscore the urgent need for targeted conservation strategies. The decline in the population of Sitatunga antelopes from 200 individuals in 2018 to 60 in 2021 correlates with the observed LULC changes. The reduction in forested and grass/shrub areas directly impacts their habitat, making it harder for these antelopes to find adequate shelter and food. The increase in bare areas and water bodies further complicates the habitat dynamics, potentially increasing the vulnerability of Sitatunga to predators and human-wildlife conflicts (Mutebi *et al.*, 2019; Alemu *et al.*, 2018). Protecting and restoring forested and grass/shrub areas is critical to providing the necessary habitat for the Sitatunga. Conservation efforts should focus on mitigating the impact of human activities such as deforestation and agricultural expansion by promoting sustainable land-use practices and enhancing community awareness and involvement in wetland conservation (Obiero *et al.*, 2012). Additionally, maintaining the health of papyrus reeds and improving water management practices to ensure stable hydrological conditions will be vital. These measures, combined with continuous monitoring and research, can help in formulating effective management interventions aimed at halting and reversing the decline of the Sitatunga population (Bekele *et al.*, 2020; Tekalign *et al.*, 2021).

4. Conclusion

This study highlights significant land use and land cover (LULC) changes in Saiwa wetland over the period from 1993 to 2023. The analysis reveals a decline in forested areas from 37% in 1993 to 34% in 2023, primarily driven by deforestation resulting from logging, agricultural expansion, and human settlement. This loss of forest cover negatively impacts the Sitatunga antelope by reducing their essential habitat and shelter. Similarly, grass and shrub lands have decreased from 19% in 2003 to 16% in 2023, diminishing foraging grounds and increasing the vulnerability of the Sitatunga to predators. Conversely, the area covered by papyrus reeds has increased from 24% in 1993 to 26% in 2023, likely due to nutrient enrichment from agricultural runoff. While this can provide additional cover for some species, it may also indicate changes in water quality and ecosystem balance. The study also observes an expansion of bare land areas from 6% in 1993 to 8% in 2023, indicating land degradation from overgrazing and human encroachment, impacting the wetland's biodiversity and the availability of suitable habitats for the Sitatunga. Additionally, water bodies expanded from 13% in 1993 to 16% in 2023, suggesting changes in hydrological dynamics that could affect habitat structure for the Sitatunga. The observed LULC changes have critical implications for the Sitatunga antelope, whose population declined from 200 individuals in 2018 to 60 in 2021. The loss of forested and grass/shrub areas directly impacts their habitat, increasing their exposure to threats.

Recommendations

To address the challenges posed by LULC changes in the Saiwa wetland and to support the conservation of the Sitatunga antelope, a number of strategic actions are recommended. Firstly, establishing buffer zones around the wetland is imperative. These zones will help minimize human encroachment and protect the delicate wetland ecosystem from further degradation. Secondly, promoting sustainable agricultural and land-use practices is necessary to prevent ongoing environmental degradation. Such practices will ensure that the land remains productive while safeguarding the wetland's integrity. Lastly, engaging local communities in conservation efforts is vital for the long-term stewardship of the Saiwa wetland and its biodiversity. By involving community members, conservation initiatives can benefit from local knowledge and support, fostering a collaborative approach to environmental preservation.

Compliance with ethical standards

Acknowledgments

This research was funded by the Regional Universities Forum for capacity building in agriculture (RUFORUM) through TAGDev, MasterCard foundation.

Disclosure of conflict of interest

There is no conflict of interest declared by the authors in regard to the findings of this research.

Statement of ethical approval

Prior to conducting fieldwork, ethical clearance was obtained from the Egerton University. Additionally, a research permit was acquired from National Commission for Science, Technology, and Innovation (NACOSTI).

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