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Spatio-Temporal Changes in Land Use and Land Cover in Kipkunurr Forest and Its Adjacent Landscapes, Elgeyo Marakwet County, Kenya

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Abstract

The essential status of forests for climate control and biodiversity protection together with supporting local subsistence requires tracking their spatial and temporal patterns. The process of studying land use and land cover dynamics provides fundamental information for proper forest conservation practices along with sustainable resource management schemes. This study focused on spatial-temporal land use and land cover assessment of Kipkunurr Forest and adjacent landscapes in Kenya during the period from 1995 to 2024. The need is to identify the causes behind forest cover changes together with their conservation consequences. Data was collected using remote sensing, household surveys, and key informant interviews. A GIS process applied supervised classification methods to multi-temporal Landsat 5 images (1990, 2004), Landsat 7 images (2014), and Landsat 8 images (2024) to conduct land use land cover changes and change detection analysis. The examined forest data reveals Kipkunurr Forest lost about 12,702 hectares of its original 30,053 hectares during the 1995 to 2004 period due to agricultural development, illegal logging, and settlement expansion. A minimal forest recovery took place from 2014 through 2024, where forest area expanded to about 19,345 hectares. The recovery stems from enhanced conservation rules, reforestation programs, and decreased human encroachment. Shrubland and grassland areas rose slightly while forest areas improved during this period despite ongoing human pressure in activities like firewood collection, illegal logging, and grazing. Geospatial technology use for forest monitoring reveals both the benefits of tracking changes effectively and supports the immediate requirements for integrated forest conservation approaches. The study brings evidence-based findings which help guide local policies and community participation toward sustainable forest practices in the important water catchment areas such as Kipkunurr.

***Keywords**: Change detection, Geographic Information Systems, Land use land cover change, Landsat, Remote sensing*

INTRODUCTION

Forests are defined as intricate ecosystems characterized by an abundance growth of trees, plants, and other types of vegetation (Perry et al., 2008; Oldeman, 2012). The various types of forests include temperate, montane, tropical, and boreal and are classified based on their tree varieties, climate, and terrain (Xu et al., 2022; Thakur et al., 2021). Forests are essential to the continuation of life on Earth providing numerous ecological, social, and economic advantages (Chazdon et al., 2020). Forests act as a home for many plant and animal species offering them food, shelter, and places to breed. Forests are also integral to climate regulation due to their ability to store vast amounts of carbon and mitigate the effects of human activities that emit green house gases into the atmosphere (Mackey et al., 2020). Furthermore, they are essential for watershed protection and water regulation because they assist in maintaining water quality, controlling water flow, lowering the risk of flooding, and lessening soil erosion (Kastridis et al., 2021). Additionally, forests promote tourism and provide leisure and recreational activities, which boost the regional economy. However, forests are threatened by different factors including climate change and land use changes. According to Kissinger et al., (2012), there are two types of forces that cause forest degradation: direct and indirect causes. The direct causes are human activities, such as mining, logging, agriculture, urbanization, grazing animals, and forest fires. On the other hand, the indirect factors interplay between political, socio-economic, cultural, and technical processes. Some include increase in population, poor leadership and corruption. The world's population is increasing from time to time. For instance, in 2020 the world population was about 7.8 billion, and expected to reach 8.6 billion by 2030 and 9.8 billion by 2050. (UN 2020). To accommodate the demands of an expanding population, people are turning forests and other types of land cover into agricultural areas. It is anticipated that forests will continue to be converted into agricultural land in the future due to the growing population (Pellikkaa et al., 2018).

The net forest loss in Africa has increased in three decades since 1990, with the highest annual net forest loss occurring between 2010 and 2020, at 3.9 million ha (FAO, 2020). However, over the past ten years, Africa's efforts to manage its forests sustainably have shown progress; with some nations having seen increases in their forest cover, whereas others continue to see decreases in it (Hove et al., 2013). Demands on land use are reflected in changes in forest area over time. Assessing land use and climate trends is useful for sustainable forest conservation and management. Decision-making processes benefit greatly from an understanding of the features, scope, and pattern of land use land cover change (LULCC) (Armenteras et al., 2019). The use of remote sensing and GIS technologies in mapping and monitoring land use and land cover change is essential because it offers sufficient data for locating conservation hotspots to assist in the development of restoration plans, conservation-related policies and decision-making, and the overall long-term preservation of forest ecosystems (Zafar et al., 2021). Therefore, based on the above background this study assessed] the land use/ land cover changes on Kipkunurr forest and adjacent landscapes, Elgeyo Marakwet County, Kenya.

MATERIALS AND METHODS

Study area description

Kipkunurr Forest (Fig. 1) is a subtropical moist forest located in Elgeyo Marakwet County within the Rift Valley region of Kenya. This forest is part of the Cherangani Hills, one of Kenya's five main water towers. It is bordered by the Cherangany Hills to the east, Trans Nzoia County to the west, and West Pokot County to the north. Covering an area of approximately 1,250 square kilometers, it extends from Latitude 1° 15' to 1° 45' North and from Longitude 35° 15' to 35° 35' East (KFS, 2015). Its elevation varies from 1,500 meters to 3,350 meters above sea level. Kipkunurr Forest was gazetted on May 10, 1962, under Proclamation Order No. 15, and was designated as a protected forest area by official notice (KNCHR Report, 2018).

The study included a 5-Kilometer buffer around Kipkunurr Forest to represent the adjacent landscapes. This distance was selected because earlier studies have shown that land use activities such as agricultural expansion, fuel wood collection and illegal grazing that impact the forest occur within this range (Xia et al., 2023).

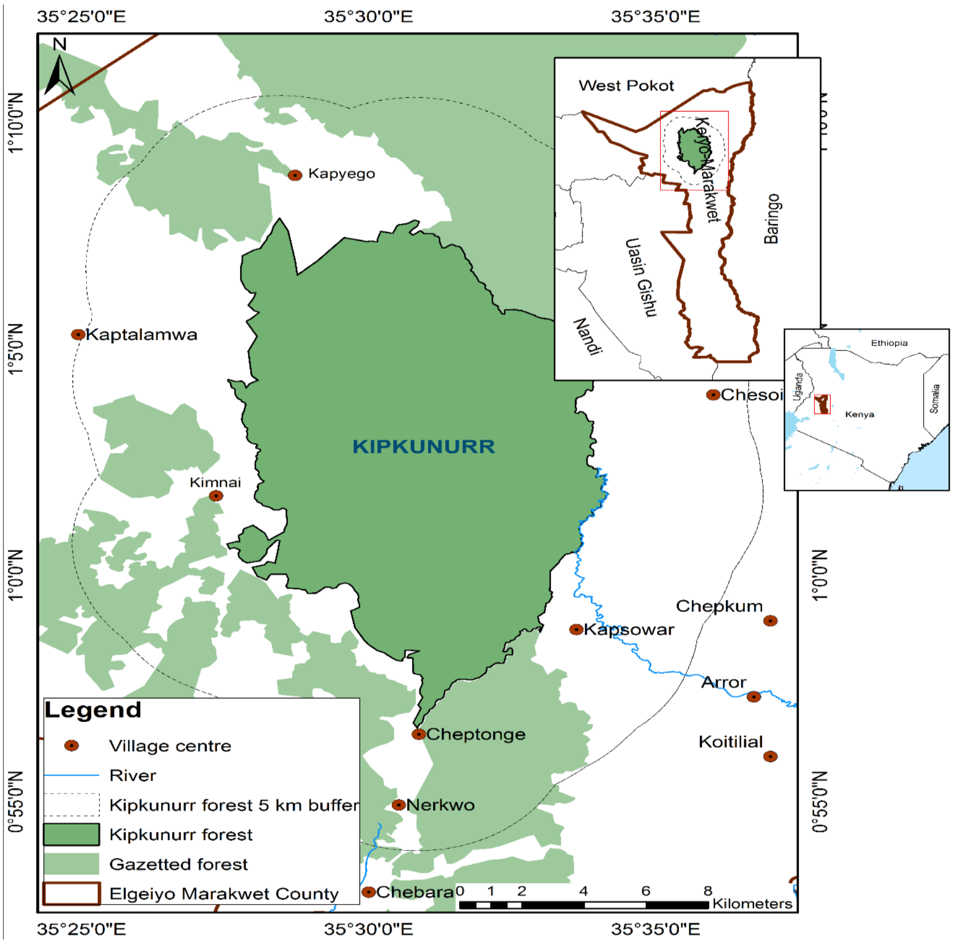

Figure 1: Study area

Research design and methods

Remote sensing together with GIS technologies were employed in this study to assess the spatio-temporal change in land use and land cover in Kipkunurr forest and adjacent landscapes. In addition, household surveys and Key Informant Interviews were used to gather qualitative information about land use transformations in the study area. The study population targeted the residents of five wards in Marakwet East and West, where the forest was located. The five wards and their populations were Kapyego (20,650), Sambirir (7,163), Arror (5,811), Kapsowar (28,402), and Moiben/Kuserwo (15,811). Therefore, the total population of the five wards was 77,837 people. Since this study targets households, the total population was converted into an estimated number of households. According to the Kenya National Bureau of Statistics (KNBS) 2019, the average household size in the study area is 5 people per household. Therefore, the total number of households in the study area was 15,567 households. The proportionate distribution of the sample across five wards were Kapyego (102), Sambirir (35), Arror (29), Kapsowar (140), and Moiben/Kuserwo (78) which adds up to sample size of 384 calculated using Cochrans (1977) sample size determination formula. Households were selected using a simple random sampling technique to ensure unbiased representation across wards.

The key informant interviews were used to collect data from stakeholders. The study identified and selected key informants using purposive sampling who were mostly the forest rangers, foresters, and NEMA representatives.

Data acquisition of remotely sensed data and analysis

The research obtained satellite imagery of Kipkunurr Forest together with the neighboring landscapes for the periods of 1995, 2004, 2014, and 2024. The satellite images originate from USGS Earth Explorer at https://earthexplorer.usgs.gov/ and they were acquired through Landsat 5 TM for 1995 and 2004 while Landsat 7 ETM+ provided images for 2014 and Landsat 8 OLI acquired images for 2024. The selection of these images took place during the dry season months of January and February because vegetation conditions become consistent and cloud interference remains minimal. A cloud cover threshold of less than 5% was applied to ensure clear visibility of land features. The data acquisition for all images involved downloading them with a 30m spatial resolution level.

Image pre-processing

Several processes took place in the image pre-processing step before conducting analysis on the acquired satellite data. The imaging process started with radiometric correction which reduced air interference to improve the accuracy of ground representations. The images were then aligned to a single coordinate system via geometric correction, allowing for accurate spatial analysis. Finally, the images were cropped to the boundary of Kipkunurr Forest and the five-kilometer buffer to focus the analysis on the study area using version 10.8 of ArcGIS software.

Land Use/land cover classification

Using training data derived from identified land cover types in Kipkunurr Forest and surrounding landscapes, a supervised classification technique was applied to categorize land use and land cover in ArcGIS software version 10.8. During this process, representative training samples for each type of land cover bare land, crop land, grassland, Shrub land, forest, built up area and Surface water were chosen. Each pixel in the satellite images was then assigned to one of these groups by the maximum likelihood classifier classification algorithm. The accuracy of the classification findings was evaluated using ground truth data in order to verify their validity. The finished product showed the spatial distribution of different land cover categories and included comprehensive land use and land cover maps for each of the chosen years.

Change detection analysis

Change detection analysis was utilized to illustrate land use and land cover modifications across Kipkunurr Forest and surrounding territories from 1995 through 2024. The method involved image comparison to find regions where land cover experienced changes in different years. The method of change matrix analysis combined with post-classification comparison detected the alterations. This analysis was performed through ArcGIS version 10.8.

RESULTS

Number and the type of trees in the respondents' woodlots

Information on number and tree type is useful to understand whether these communities are exerting pressure on natural forests or whether they are supporting their fuel and wood needs on a sustainable basis. The number and type of trees found in the respondent's woodlots are shown in Table 2**.**

Table 2: Number and the type of trees in the respondents' woodlots

Question	Attribute	Frequency	Percentage frequency
Number of trees in respondent's woodlot	less than 50 trees	308	80.6
	50-100 trees	42	11.0
	101-150 trees	14	3.7
	151-200 trees	2	0.5
	201-250 trees	7	1.8
	> 250 trees	9	2.4
	Total	382	100

Land allocation through Shamba System in Kipkunurr forest

Understanding about land allocation in form of the Shamba System helps to know level of human activity within forest areas, the balance between agricultural use and forest conservation, and the consequences for either forest encroachment or recovery. All respondents (100%) indicated that they did not have land allocated through the Shamba System, with no respondents (0%) reporting otherwise.

Livestock Kept by respondents

Understanding the kind and number of livestock kept by respondents helps in determining the level of forest degradation caused by livestock. Figure 2 shows the livestock the respondents possess.

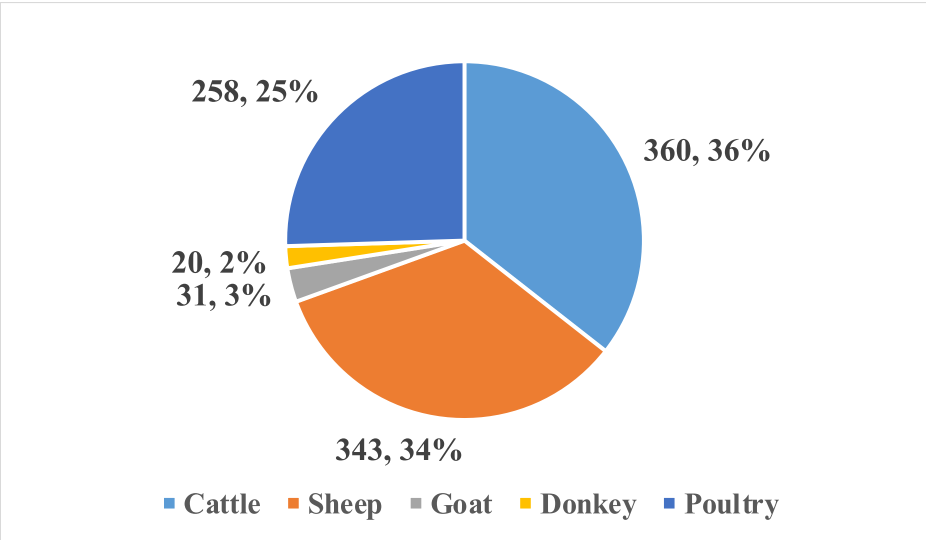

Figure 2: Livestock kept

Existence of beacon between respondent's farms and the forest

Beacon presence research contributes to the discovery of locations at risk to encroachment or boundary conflict. Figure 3 shows the existence of a beacon between the respondent's farms and the forest

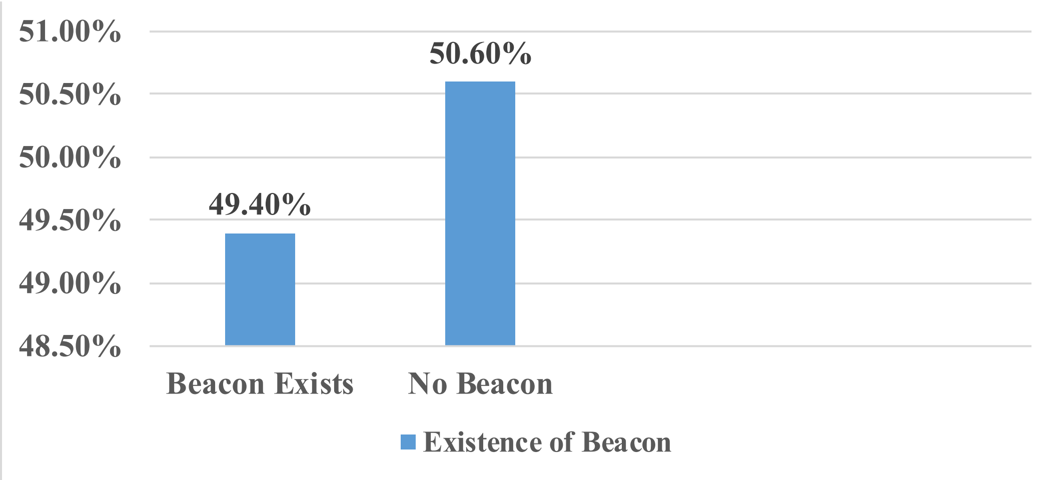

Figure 3: Existence of beacon between farm and the forest

Source of energy used by respondents

Understanding the energy source for cooking helps in knowing the extent of dependency on forest biomass. Figures 4 depict the respondents' energy sources for cooking.

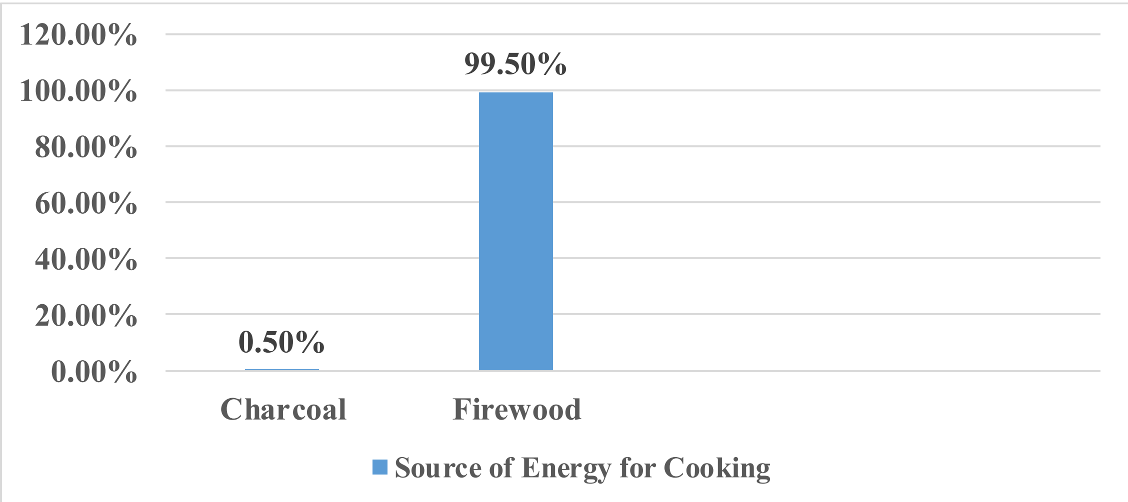

Figure 4: Source of energy for cooking

Wood fuel source for the respondents

Understanding the source of wood fuels therefore helps in quantifying the pressure on forests, identifying illicit harvesting, and promoting alternatives such as woodlots managed by the community. Figure 5 shows where the respondents get or source their energy

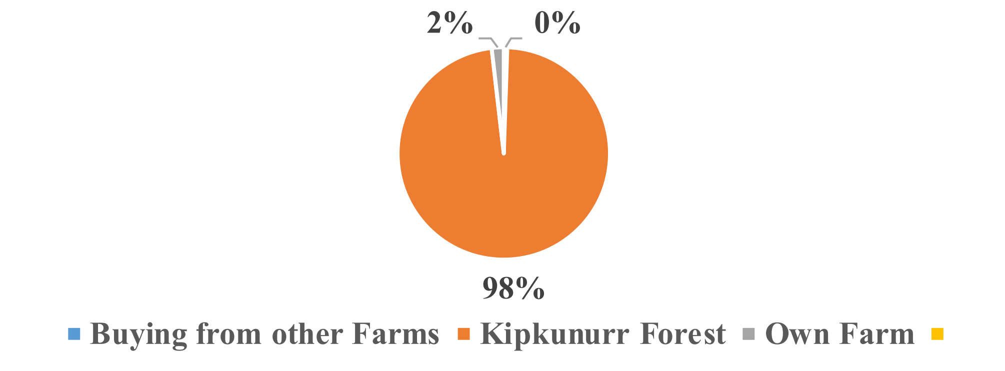

Figure 5: Wood fuel source

Spatio-temporal changes in land use and land cover in Kipkunurr forest between 1995 and 2024

Table 3 presents the land use and land cover (LULC) changes in Kipkunurr Forest between 1995 and 2024, showing variations in bareland, cropland, grassland, shrubland, forest cover, surface water, and built-up areas.

Table 3: Land use and land cover in hectares and percentages

		Year		
LULC	**1995**	**2004**	**2014**	**2024**
Bareland	4229.25	9147.52	8691.16	5834.00
	(8.08%)	(17.48%)	(16.61%)	(11.15%)
Cropland	4385.34	6918.48	6919.02	5999.67
	(8.38%)	(13.22%)	(13.23%)	(11.47%)
Grassland	6286.95	8187.57	8168.67	9009.09
	(12.02%)	(15.65%)	(15.61%)	(17.22%)
Shrubland	6541.12	8823.87	8824.59	10050.19
	(12.50%)	(16.87%)	(16.87%)	(19.21%)
Forest	30053.79	18340.01	18368.01	19349.50
	(57.45%)	(35.06%)	(35.11%)	(36.98%)
Built-up area	21.00	89.00	545.00	1276.00
	(0.04%)	(0.17%)	(1.04%)	(2.44%)
Surface water	800.00	811.00	801.00	799.00
	(1.53%)	(1.55%)	(1.53%)	(1.53%)
Total area in hectares	52317.45	52317.45	52317.45	52317.45
	(100.00%)	(100.00%)	(100.00%)	(100.00%)

Change in Land Use/ Land Cover from 1995-2024 in Kipkunurr Forest and adjacent landscapes

Figure 6 shows analysis of land use and land cover maps of Kipkunurr Forest and adjacent landscapes for the years 1995, 2004, 2014 and 2024. The maps illustrate the trend of LULC change in the 29-year period.

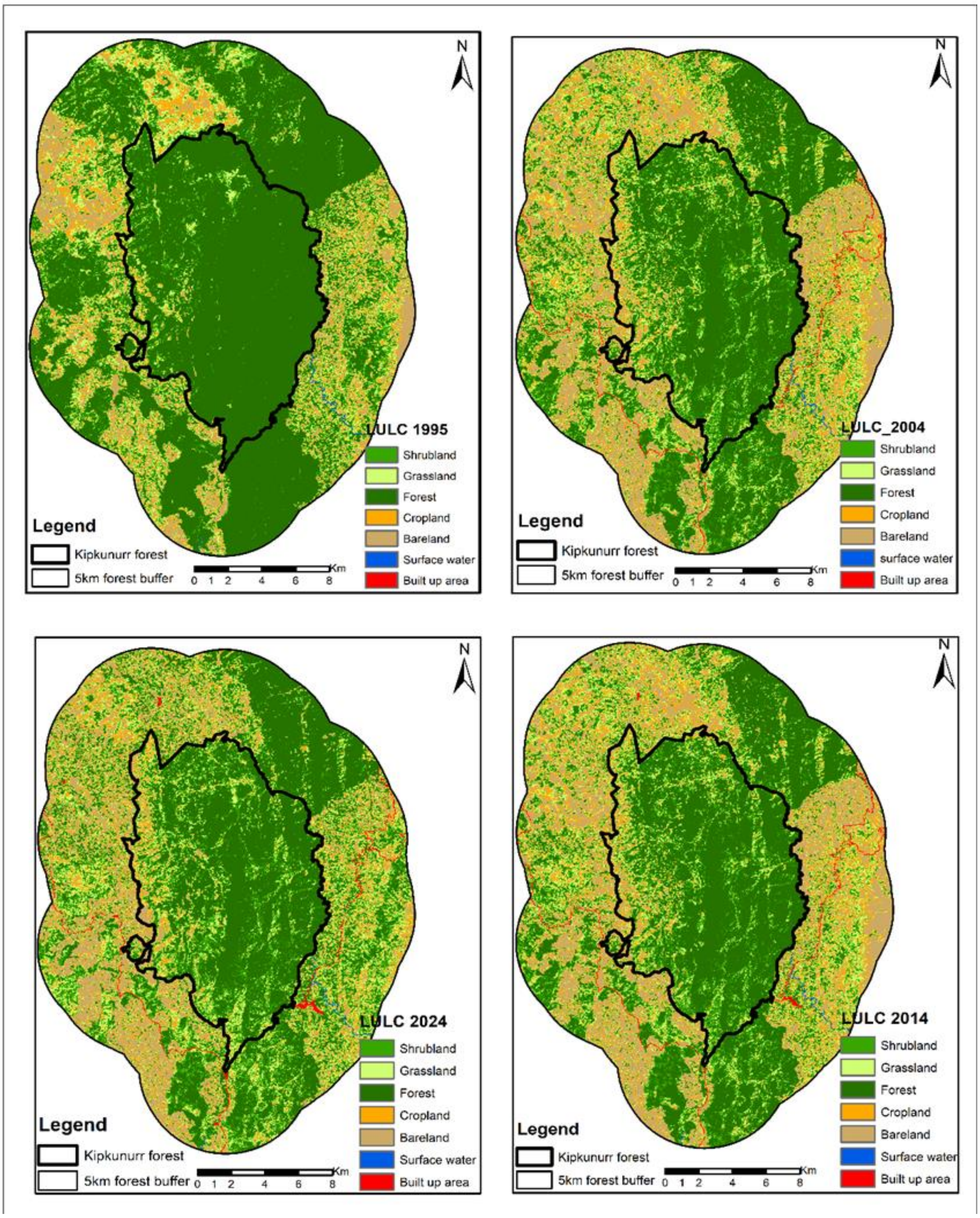

Figure 6: Spatio-temporal changes in land use and land cover in Kipkunurr forest between 1995 and 2024

DISCUSSION

An analysis of land use and land cover (LULC) transformations in Kipkunurr Forest and adjacent landscapes over the last twenty-nine years shows that the forest cover declined between 1995 and 2024, from 30,053 hectares in 1995 to 18,350 hectares in 2004, before a recovery to 19,345 in 2024. These findings align with findings by Kamau et al. (2018) and Otieno et al. (2017), who observed similar trends in other Kenyan forests because of deforestation pressures and later on conservation efforts. The slight increase in forest coverage after 2014 is attributed to improved protection efforts, reforestation initiatives such as the government initiative of planting 15 billion trees by 2032, and increased awareness of forest conservation. However, the recovery remains fragile as people living around the forest depend heavily on forest resources as they have no alternative livelihoods.

In addition, the household survey revealed that Shamba system is not practiced at all in Kipkunurr Forest based on 100% of participant feedback. The Shamba system is prohibited since the forest categorized as a natural forest. This is contrary to findings by Wanjira et al. (2020, who documented the practice of agroforestry in other Kenyan forests such as Kakamega. The prohibition in Kipkunurr forest helps preserve the ecosystem but also limits the communities' ability to benefit from forest land use increases cases of encroachment. The most prevalent land use next to the forest was livestock rearing, with the most common varieties being cattle (36%), sheep (34%), and poultry (25%). Livestock graze in the forest, particularly the sheep and cattle that serve the local populations surrounding Kipkunurr forest. This result is in line with findings from Ndengwa et al. (2022) and Mutai et al. (2023), who documented comparable patterns in other Kenyan protected forests. The main causes of the dependence on forest regions for grazing are the scarcity of pasture and water.

Another major issue is boundary demarcation; 49.4% of respondents said they could see forest boundary beacons in their vicinity, and 50.6% said they could not see. This agrees with findings by Florence (2021), who pointed out that Kenyan forests often have poorly designated borders, thus causing encroachment and conflicts between the local communities and forest officials. The unclear boundaries of Kipkunurr could be due to insufficient financing or lack of community involvement in boundary maintenance. The situation renders forest conservation policies less effective and makes it more difficult for the Kenya Forest Service to implement them. Extraction of fuel wood is another major pressure imposed on the forest. Most of the firewood used for cooking in a large majority of the houses (99.5 %) is taken directly out of Kipkunurr Forest. This is in line with national figures from KNBS (2019) and Golar et al. (2020), which states that rural Kenya is heavily reliant on forest biomass. This dependence continues due to the scarcity to access other sources of energy like electricity, biogas, or LPG. This highlights how urgently forest conservation methods that offer accessible and reasonably priced energy alternatives are required.

According to these findings, constrained livelihood flexibility together with personal needs contribute most to landscape transformation in Kipkunurr and the adjacent landscapes. Kipkunurr forest experienced significant decline between 1995 and 2004 due to likely high human impact which seemed to arise from limited land resources combined with expanding population numbers. Forest conservation in Kipkunurr requires more than protection strategies since it needs alternative sources of income and energy solutions to minimize local dependence on forest resources.

CONCLUSIONS AND RECOMMENDATIONS

This study conducted geospatial-based LULC investigations across Kipkunurr Forest and its surrounding 5-kilometer zone from 1995 to 2024 utilizing four Landsat satellite datasets. The analysis revealed a significant decline in forest cover from 57.45% in 1995 to 35.06% in 2004, primarily driven by agricultural expansion, settlement, and illegal logging. However, a modest recovery between 2014 (35.11%) and 2024 (36.98%) indicates that reforestation efforts and conservation measures are beginning to yield positive results. Although Kipkunurr Forest showed modest signs of recovery in forest cover between 2014 and 2024, it remains vulnerable to ongoing threats like unsustainable land use and overexploitation of resources.

To sum up, this research stress the necessity for the Kenya Forest Service in collaboration with Elgeyo Marakwet County Government to undertake a demarcation of forest boundaries using strong, visible, long-lasting markers.

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