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Past and Future Land Use and Land Cover Trends across the Mara Landscape and the Wider Mau River Basin, Kenya

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Abstract: The Maasai Mara and the wider Mau River Basin in East Africa provide fundamental ecosystem services that support people, wildlife, livestock and agriculture. The historical indigenous land use of the Mara and wider Mau basin was wildlife conservation and pastoralism with highland agriculture. However, land policy changes, the rise of community conservancies and the increase in human populations have mediated unprecedented land use shifts over time. We analyze land use and land cover change (LULCC) trends from 1990 to 2040 in the Mara and the wider Mau River Basin landscape. The study examines land use and land cover change trends, establishes factors driving the trends, and assesses the implications of these trends on biodiversity. Multi-temporal satellite images, together with physical and social economic data, were collated to generate future scenarios for transitions for forest, shrubland, grassland, cropland, wetlands and built-up areas between 1990 and 2040. Agricultural expansion is the chief driver of LULCC in the Mara and the wider Mau River Basin, particularly since 2015. There was insignificant change to the forest cover after 2015, which was in part due to government intervention on forest encroachment and boundaries. The anthropogenic choice of tilling the land in the basin caused a decline in grasslands, forests and expanded shrublands, particularly where there was clear tree cutting in the Mau forest. Land use and land cover trends have generated undesirable impacts on ecosystem services that support wildlife conservation.

Keywords: land cover change; forests; grassland; shrubland; agriculture conservation

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1. Introduction

Land is a repository of natural capital where forests, wetlands, grasslands and mountains support life and development [1], and it is an interface where human activities, ecological processes and the environment interact [2,3]. Land use creates habitats and shapes land cover, which subsequently modifies habitat types and species behavior [4]. The conversion of land from one specific cover type to another, land use and land cover change (LULCC), is driven by people who want to meet their social, cultural and spiritual needs [5]. Anthropogenic activities have influenced and modified land cover for thousands of years with change accelerating in recent centuries, particularly due to social economic developments [6], population growth [7] and changing climates [8]. This has accelerated biodiversity loss and made it challenging to support people, livelihoods and ecosystems [9]. The African Elephant (*Loxidonta africana*) population, for instance, has declined [10,11], while the Mountain Bongo (*Tragelaphus eurycerus* ssp. *Isaaci*) in the Mau forest is massively impacted and highly threatened [10].

People interacting with environmental processes [11], market trends operating at regional and international scales [12], global historical trends [13], technological advance-

ments, institutions, local and global policies [14] have all driven and shaped LULCC [15]. These are mediated by local policies and acts; for example, Kenya's Sessional Paper, No. 1 of 2017 on National Land Use Policy [16], grants authority and liberty for use of land for any purpose. The Kenya Land Act 2012 (under review) permits the conversion of land from one category to another within the precepts of the law [17]. However, in most cases, these legal frameworks are often more of a guidance than providing a detailed planning framework. In circumstances where the law is followed, politics and local power relationships usually influence the process because of individual interests. A particular example is the Mau forest, where politicians and influential citizens allocated themselves huge chunks of land and incited illegal settlers to resist eviction from the forest [18] at the expense of the forest ecosystem. The forest excision from 1989 to 2009 and blatant human encroachments resulted in the forest ecosystem undergoing the conversion of an estimated 25% (107,000 ha) to agriculture and other land uses [19].

Research has provided insights into the relationships between human activities, rainfall, soil fertility, wildlife, livestock grazing, and deforestation across Eastern Africa [20] over decadal and centennial scales [21,22], particularly with respect to pastoral communities and their links to the conservation of rangelands and wildlife [23]. Anthropogenic pressures are affecting the diverse composition of fauna and flora, thus influencing species interactions, and in extreme cases driving multiple species extinction [24]. LULCC dynamics across eastern Africa have particularly been shaped by rapid population growth that has amplified demands for food, shelter and incomes, leading to an increased ecological isolation of protected areas [25]. These trends have been exacerbated by large-scale land use changes influenced by foreign and local interests, particularly agricultural expansion and wood extraction for local and international consumption [26,27].

Although protected areas are vital for biodiversity conservation, they do not provide complete protection to biodiversity nor completely resolve conservation development-related conflicts [28]. Often, the effects of landscape transformations permeate into the protected areas [28], hence affecting species behavior, abundance and composition as well as ecosystem processes and habitat integrity. More often, nature suffers collateral damage from economic and development activities. LULCC resulting from direct human activities such as settlement [29], livestock grazing [30–32], the harvesting of wild plants and animals and logging impacts have driven species declines, particularly in areas where inhabitants depend on natural resources to support their livelihoods [29].

The Mau-Mara ecosystem in southwestern Kenya comprises the Masai Mara National Reserve (MMNR), neighboring conservancies (Enoonkishu, Lemeki, Ol Chorroua, Oloisukut, Mara North and Mara Conservancy) and the Mau forest (North) and is characterized by diverse land uses. The vast rangeland supports 30% of Kenya's wildlife population [33]. The national reserve, owned and controlled by the County Government of Narok, is exclusively demarcated for wildlife tourism and conservation. The adjacent group ranches and land extending to the northern forested highlands are owned privately or communally and have multiple land uses, ranging from pastoralism, small-scale farming, mechanized farming and wildlife tourism. This landscape also lies on the borders with the Serengeti National Park (SNP) in Tanzania, thus allowing wildlife from Tanzania to migrate and occupy the MMNR and the adjoining conservancies. The resident wildlife species also migrate between the reserve and the connecting dispersal areas. The free ranging migrations by wildlife demonstrate the viability of migratory space for wild species in the landscape and that what happens in the contiguous conservancies has a direct influence on wildlife in the protected areas. A significant number of wildlife (84%) are found in rangelands outside the MMNR [34]. However, the unprotected dispersal ranges are being increasingly transformed by agro-pastoral human communities. Expanding commercial farming [31,35], tourism and other human activities on land adjacent to the MNNR are threatening the sustainable coexistence of pastoral communities with wildlife [36].

Most studies in the Mara landscape have focused on tourism and on specific species declines (e.g., elephants, cheetahs, lions, vultures). Specifically, little research has been con-

ducted to quantify and provide insights into the spatial and temporal dynamics of LULCC at the landscape level. We used satellite imagery software to model and construct the future of the Mau Mara basin in temporality for forests, grasslands, shrubland, agriculture and built-up areas. This study analyzes long-term trends of LULCC in the wider Mau-Mara landscape, extending from the Mau highlands through the Mara catchment to the MMNR. The study establishes where the changes are occurring, examines the potential drivers of these changes and recommends mitigation strategies applicable to reduce the impacts of the changes on the wildlife, people and livestock.

2. Materials and Methods

2.1. Study Area

The study area (Figure 1) was restricted to the Mau-Mara landscape in Narok County. The Mara River Basin covers 8992 km^2 extending 160.8 km north to the upper Mau forest blocks (Transmara, Olposimoru, eastern Mau and south western Mau) and 124.2 km eastward across the MMNR and adjacent rangelands. The basin intersects three counties: Narok, Bomet and Nakuru with over a 60% stretch located in Narok County. The Narok County population in 2019 was 1,157,873; Nakuru 2,162,202 while Bomet County was 875,689 [37]. The Mara landscape (from Transmara to Loita Forest area) is situated in the Narok West subcounty that covers 5452 km^2 with an estimated population of 195,287 [37].

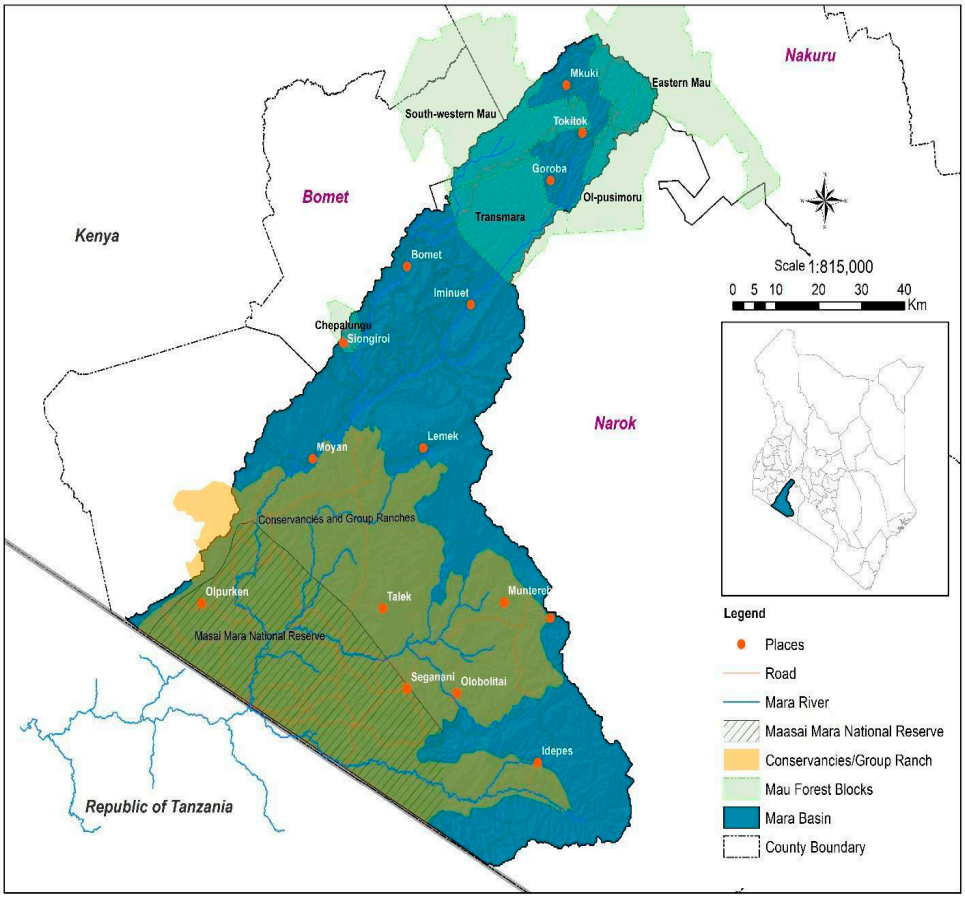


Figure 1. Map of Mara River Basin, Masai Mara National Reserve and the surrounding conservancies, group ranches and the Mau forest blocks and built-up areas.

Rainfall is bimodal (the wet season beginning from June to November and dry season from July to October) with the short rains falling during November–December and the long rains from March to June [38]. Annual rainfall ranges from 800 to 1200 mm with a northwest to southeast declining gradient [36]. The vegetation is predominantly open grass plains and savanna woodlands [38] with undulating ranges characterized by savanna/woodlands

and forest patches southward and northward, respectively. The Mara River flows through the MMNR, which is characterized by the spectacular annual migration of wildebeest (*Connochaetes taurine*), zebras (*Equus burchelli*), and Thomson's gazelle (*Gazella thomsoni*) from the SNP (Tanzania) to MMNR (Kenya) and dispersing to the nearby conservancies.

The Ewaso Ny'iro, Sondu, Mara and Njoro are the main rivers that discharge their waters from the Mau complex to Lakes Natron, Victoria and Nakuru, respectively [39]. Most of the land in the Mau Mara landscape forms part of the unprotected area that surrounds the MMNR and is characterized by a mixture of private and communally owned land. Historically, land was held in a trust for the semi-nomadic Maasai community by the government, and some areas in the east of the landscape still retain this arrangement. Since the 1970s, trust lands were converted into group ranches under local administration [40]. Subdivisions of these group ranches into parcels of privately owned land has embedded significant land transformations including mechanized farming and tourism businesses through conservancy establishments in the north [40].

The Narok County is home to 30% of Kenyas wildlife concentrations [28]. MMNR (1510 km^2) forms a small part of a much larger protected area complex (including the SNP, Ngorongoro Conservation Area, and a number of game reserves), which together cover over 25,000 km^2 [41] (Figure 2). Most of the wildlife is in the Greater Mara Ecosystem that has an estimated 6600 km^2 stretch, consisting of the MMNR and the surrounding conservancies. Voluminous wildlife concentrations sighted in this ecosystem depend on the Mara River flows, its tributary rivers (Talek and Sand Rivers) and springs to supply it with waters.

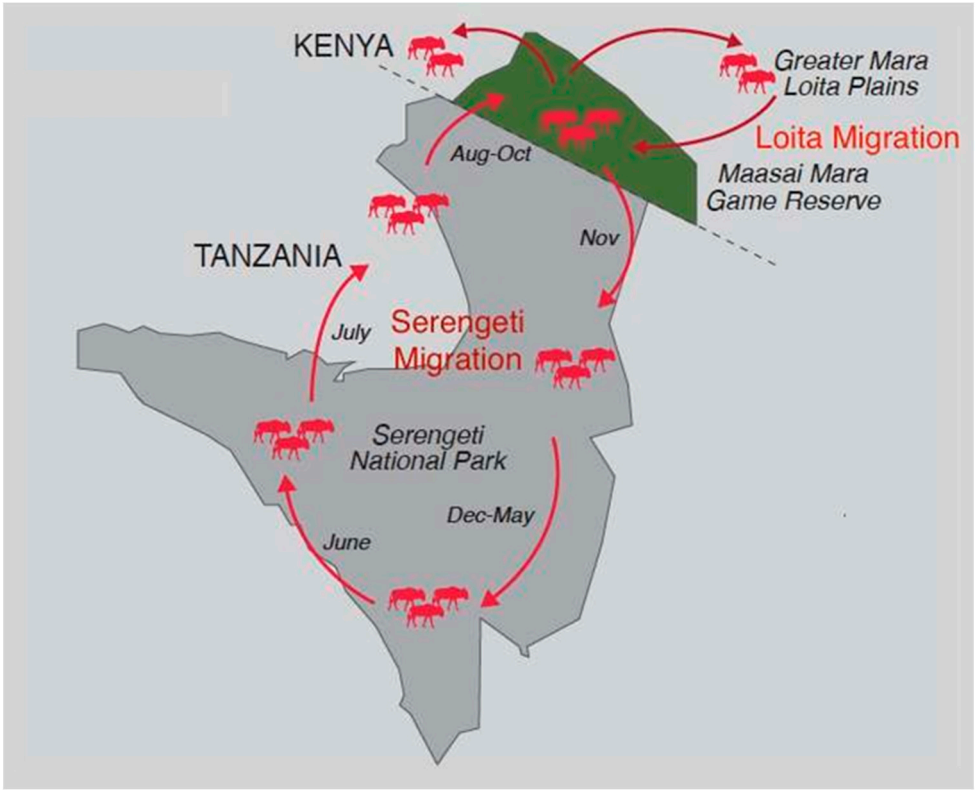


Figure 2. Wildebeest migration in and outside the Serengeti in the Greater Mara Ecosystem.

2.2. Land Use and Land Cover Mapping

This study integrates information from multispectral remote sensing, modeling, socioeconomic datasets and experience on implementing integrated management programs in the Mara rangelands. The Systems for Land-based Emissions Estimation in Kenya (SLEEK) program has been producing annual land cover products from 1990 to 2015 based on the multispectral remote sensing of a moderate resolution (30 m) Landsat imagery series

(Landsat 5, 6, 7 and 8). The land cover class defines six natural vegetation classes, three human-developed classes and one non-vegetated land use and land cover class based on IPCC guidelines for UNFCCC reporting with Kenya's local definition [42]. To focus on cropland, forest, grassland, urban/rural settlements, shrubland and wetland LULCC, we modified SLEEK's 1990, 2000 and 2015 classified land use and reduced the number of classes from 10 to 7 (Table 1), collapsing the dense, moderate and open forests into one forest class, annual and perennial croplands to one cropland class and introduced urban/rural settlements. The study applied remote sensing to model socioeconomic consequences of LULCCs focusing on cropland, forest, grassland, urban/rural settlements, shrubland and wetlands from 1990 to 2040.

Table 1. List of land use/cover classes.

Code	Land Cover Class	Definition
C	Cropland	Land purposely managed for agricultural activities. It is land characterized by the presence of crops with evidence of tillage.
F	Forestland	Areas occupied by forests are characterized by tree grown cover $\geq$ 15%, an area $\geq$0.5 ha and a tree height $\geq$ 2 m. Includes areas managed for forestry where trees have not attained 2 m height but with potential to do so, and areas that are temporarily destocked.
OG	Grassland	Open grasslands, herbaceous cover, woody vegetation < 10%. Rangelands and pasture land which do not qualify as forestland and cropland. The category includes grassland in wildlands, shrub savannah, in managed and unmanaged systems.
S	Shrubland	Vegetated grasslands are lands with woody vegetation with a height less than 2 m. The total percent shrub cover exceeds 30%. The shrub foliage can be either evergreen or deciduous.
UR	Urban/Rural Settlement	This category includes a mosaic of scattered rural settlements and defined structured built setup in urban areas.
VW	Wetland	Vegetated wetland, permanent mixture of water and herbaceous or woody vegetation.
W	Waterbody	Open waters (oceans, seas, lakes, reservoirs, and rivers).

2.3. Accuracy Assessment

Accuracy validation was assessed with an error matrix and kappa coefficient [43]. This approach produced the overall accuracy of the classified image by comparing how each of the pixels classified versus the definite land cover conditions obtained from their corresponding ground truth data.

2.4. Modeling Projected Land Use/Cover for 2040

The Methods of Land Use Change Evaluation (MOLUSCE) plugin in QGIS was used to simulate future land use land cover scenarios for 2040. The selected plugin was used because it provides a set of algorithms for land use change simulations such as Artificial Neural Networks (ANNs), Linear Regression (LR), and Multi-Criteria Evaluation (MCE). The plugin uses a classic realization of multilayer perceptron. The Artificial Neural Network (ANN), a biologically inspired computational network that uses multilayer perceptrons with backpropagation learning algorithms based on a supervised procedure comprising of three layers: input, hidden, and output [44], was applied. This algorithm was selected since it is deemed effective in predicting the quantitative changes in land use types and related transitions while providing capabilities to simulate the spatial and temporal evolution of land use at greater accuracies [45]. The aggregated neurons were instructed to perform particular transformations with the signals passing through the multiple layers to generate predictive modeling. The input data are the LULC 1990 and LULC 2015 layer with the target output LULC 2040 created using the following transformation.

$$(C - 1)\,(2N + 1)^2 + B\,(2N + 1)^2 \text{ input neurons;}$$

$$w(n + 1) = r \times dw(n) + m \times dw(n - 1)$$

$$E = \frac{t_i - o_i}{d}$$

M output neurons (it depends on sampling mode); in this case, the sampling mode was 25 years hence 2040 forward projection;
C is the count of land use categories
N is the neighborhood size specified by the user,
B is the summary band count of factor rasters (for example, if two factors are one band and three band, then $B = 4$).
M depicted a count of unique categories in the change map ($C2$).

The module uses a classic backpropagation algorithm with momentum for the learning procedure. Weights correction are performed as

where w is a vector of neuron weights
dw is a vector of weight changes
n is an iteration number
r is learning rate
m is momentum.

The training set is divided in two parts: the learning set (80% of samples by default) and a validation set (20% of samples). The module uses online learning with stochastic integration: where a random sample is selected from the learning set, the weights of the net are updated during forward/backward propagation. An error of fitting (for a sample) is the average square error of partial outputs of the net:

E is a sample error
t_i is the target value of an output neuron for a given sample
o_i is the real output value of the neuron
d is the count of output neurons.

The 2015 simulation was validated against the 2015 land cover to test the accuracy and correctness of the prediction, which also implied 2040's prediction possibility. An overall percentage of correctness of 93.15 and overall Kappa of 0.89 were reached for the 2015 simulation.

2.5. Land Use/Cover Change Detection and Analysis

A post-classification change detection method was employed in performing LULCC detection. Pixel-based comparison was used to generate per-pixel change information and thus relate the changes more efficiently, taking advantage of the "-from, -to" information. Classified image pairs were compared based on cross-tabulation in order to derive qualitative and quantitative aspects of the changes for the periods 1990 to 2000, 2000 to 2015, 2015 to 2040 and most significantly long-term changes from 1990 to 2015 and 1990 to 2040. LULCC gains and losses per class/category were then compiled using a land change modeler extension for ArcGIS version 10.6 Arcmap. Mapping and spatial extension tool boxes were used to run analysis and calculations for respective areas.

Predictive data analysis was then applied to comprehend the contemporary trends based on the available historical facts to deduce conclusions that generate predictions about the future trends through information technology and landscape modeling [38] of LULCC in the Mau-Mara landscape. This predictive modeling used the QGIS land use modeler add-on to establish the likely future drivers that might instigate LULCC as elaborated in Section 2.4. Exploratory analysis was applied to understand the connectedness of factors driving LULCC in the Mau-Mara ecosystem in order to generate an understanding of future developments [46].

3. Results

3.1. Current Baseline and Projection Timeline

Our current baseline year is 2015, while the projected timeline is 2040. It falls within an era when the forest cover change was evident because of deforestation when analyzing

classified images from the year 1989 to 2020 [47,48]. The results were obtained after analyzing multi-temporal satellite imageries and classifying LULCCs in different categories thus illustrating major vegetation changes. A pre-analysis of pixel-based comparison classification reports between the years showed that the classifier hit remarkable consistency registering overall land use/cover classification levels for the three epochs ranging from 75% to 89% (Table 2), satisfying the minimum accuracy for satellite-derived land use/cover maps for this study [29].

Table 2. Summary of land use/cover classification accuracies for 1990, 2000 and 2015. The producer accuracy is based on the classification point of view, while the user accuracy shows the reality on the ground based on field validation.

Land Use/Cover	1990		2000		2015	
	Producer's %	User's %	Producer's %	User's %	Producer' %	User's %
Cropland	88.7	92.8	78.0	72.7	74.2	78.3
Forestland	86.5	86.1	73	61.3	77.0	71.3
Grassland	78.8	89.7	72.9	81.6	73.8	69.8
Shrubland	94.7	87.3	90.5	89.4	76.2	78.2
Urban/Rural Settlement	92.1	92.1	83.5	90.1	82.8	80.8
Wetland	100	50.0	75	100	77.5	72.5
Waterbody	97.7	97.7	100	100	80	83.7
Overall accuracy	89.5%	–	84.6%	–	75.6%	–
Kappa statistic	**0.8510**	–	**0.7828**	–	**0.7025**	–

Agriculture in particular increased slightly (Table 2) particularly in the Mau area, which has a forest and is surrounded by small and large-scale agricultural farms. In the Mara region, the conservancies act as buffer areas against the expansion of agriculture from Mulot (Bomet County), Olulung'a and Transmara (County) urban areas. The conservancies also prohibit cropland expansion in the Mara landscape as they shield the Mara River from water abstraction, thus denying irrigated agriculture. Culturally, the livelihood of the Maasai community is also more oriented to pastoralism than crop farming, which is perhaps the reason why there is a low expansion of agriculture in the Mara.

3.2. Overall Land Use/Cover Trends in Mara Basin

Dominant categories as of 1990 were open grasslands (54.1%), shrubland (19.8%), forestland (14.4%) and cropland (11.7%), respectively. However, a significant shift in the landscape was registered by the year 2015 as open grasslands declined to 49.4%, shrubland expanded to 27.4%, and croplands increased to 15%. Forests sharply declined to 8.4% (Table 3) because of clear logging on private lands for agriculture and commercial purposes. The projected LULCC scenario for 2040 (as illustrated in Section 2.4 modeling projected land use/cover for 2040) assuming business as usual (no efforts are employed to address LULCC and their impacts) predicts a continuous decline in grasslands (47.1%), forest (7.1%), and a minimal increase in croplands (15.1%). Shrubland is expected to grow to 30.5% by 2040, while settlements are expected to register an increase to 0.1% from 0.002% in 1990.

Urban and rural settlement areas expanded from 13 ha in 1990 to 74.49 ha in 2000, and 505 ha in 2015 with a projection to attain 1009 ha by 2040 (Table 3). This is similar to the shrubland ecosystem that increased from 163,240 ha (19.8%) in 1990 to a predicted 251,298 ha (31%) by 2040. Wetlands are predicted to increase from 43 ha (0.01%) in 1990 to 52 ha in 2040.

An estimated 370 inhabitants were removed from the forest by the government (Figure 3) between 2010 and 2015. Data for this study were conducted in 2019 when people had been removed from the forest habitat, which is the reason why there is a negative. The decision to evict illegal settlers was to reverse the lost 10,000 ha of forest land through logging and 2000 ha in grasslands that had been converted to agriculture. On the contrary, shrubland and

crop land gained an estimated acreage of 60,000 ha and 50,000 ha, respectively. The temporal trends experienced in the basin over the three periods point to significant changes in three vegetative categories: shrubland; forestland; grassland and one land use category: cropland. The shrubland category registered the biggest expansion gaining over 88,058 ha, followed by croplands, which gained an estimated 28,091 ha over the same period (Table 4). Alarmingly, 59,840 ha of forests was lost, followed closely by grasslands, which lost over 57,260 ha. Table 4 provides the rates of change for each of the four categories:

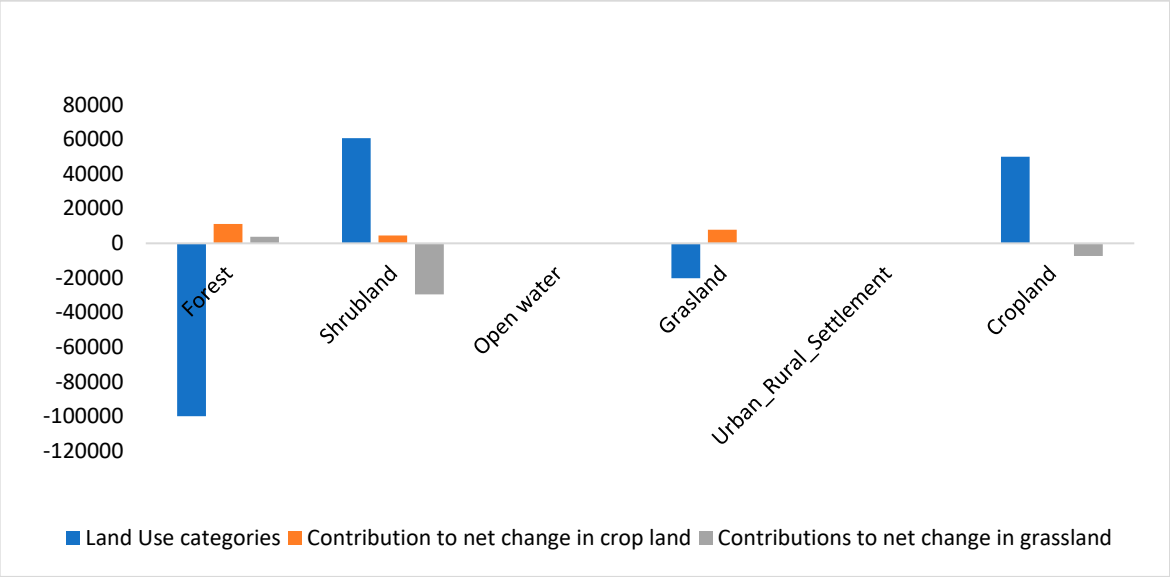


Figure 3. Overall land use/cover change in the Mara basin (1990 to 2015).

Table 3. Area and amount of change in different land use/cover categories in the Mau-Mara River Basin.

Years	1990		2000		2015		2040	
Land Use Cover Categories	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**
Cropland	96,543	11.7	110,272.1	13.4	123,322	15	124,635	15
Forest	118,587	14.4	79,716.19	9.7	69,104	8.4	58,747	7
Grassland	445,534	54.1	428,306.5	52	404,985	49.2	388,273	47
Open Water	54	0.01	51.8	0.01	56	0.01	0	0
Shrubland	163,240	19.8	205,592.7	25	226,048	27.4	251,298	31
Urban/Rural	13	0	74.5	0.01	505	0.1	1009	0.2
Wetland	43	0.01	0.060729	0	0	0.01	52	0.01
Total	**824,014**	**100**	**824,013.9**	**100**	**824,020**	**100**	**824,014**	**100**

Table 4. Major vegetation changes in Mara basin (1990–2040).

Land Use/ Cover Category	1990–2000		2000–2015		1990–2040		Annual Rate Gain/Loss Current Projected		
	Ha	**%**	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**	**%**
Cropland	+13,728.6	+14	+13,050.3	+14	+28,091.46	29	+1121.4	+1.16	+0.79
Forest	−38,870.8	−33	−10,619.8	−9	−59,840.16	−50	−233.9	−1.94	+1.41
Open Grassland	−17,227.6	−4	−23,321.8	−5	−57,260.9	−13	−1638.8	−0.37	+0.3
Shrubland	+42,353.1	+26	+20,455.7	+13	+88,058.3	54	+2799.5	+1.7	+1.5

i. Trends in Forest land—where does change occur?

It is projected that a total of 50% of forests in the basin, representing approximately 59,840 ha, will be lost by the year 2040. The annual rate of loss of forests in the basin currently stands at 1.94% or 2333 ha. Most of the forest (around 38,870 ha) was lost from 1990 to 2000; this rate is expected to decline to 1.41% beyond the year 2015, yet it is still

alarming to forest cover and links to water productivity and management in the basin. As of 2015, the main contributors to forest loss (Figure 4) were shrubland conversion, which accounted for the loss of over 28,518.51 ha of forest land, followed by conversion to cropland and grassland, which cumulatively accounted for over 14,814 ha loss of forest land in the basin. Significant loss in the forest habitat will have a tremendous impact on species behavior, distribution and numbers. More specific is the potential in the rise of the bush meat trade, because part of the forest is shared by communities that are not wildlife conservators.

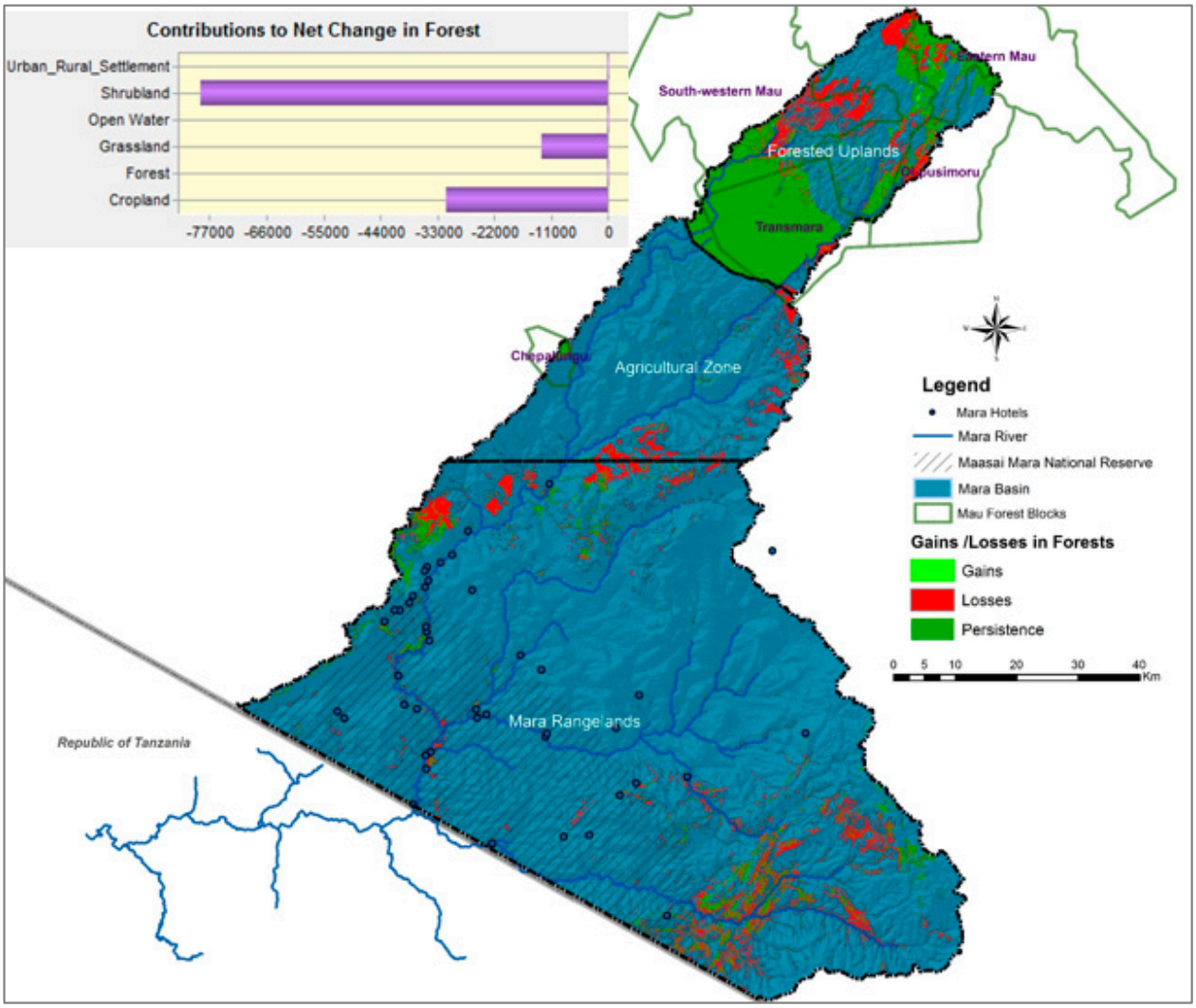


Figure 4. Gains and losses in forest cover in Mara River Basin (1990–2015).

While the conversion of forests to cropland and grassland is attributed to anthropogenic disturbance, mainly agriculture, other factors include overgrazing, encroachment by human settlement, and historical natural resource conflicts in the area, among other non-sustainable land use practices that commonly occurred in the middle agricultural and forested upland zones of the basin, e.g., around Chepalungu, southwestern Mau and Eastern Mau forest blocks (Figure 4). Forest to shrubland conversion predominantly in the southeastern parts of the Mara rangelands in the basin was not evident.

ii. Trends in Grasslands an Shrubland—where does change occur?

The majority of the Mara River Basin is predominantly a grassland savannah ecosystem dominated by open grasslands at 49% and shrubland at 27.4% as of 2015 (Table 3). However, the two categories have been registering contrasting trends over the 1990–2015

period. While grassland gained over 36,000 ha at an annual rate of 1.7% (2561.03 ha) (Figure 5), shrublands lost over 37,037 ha at an estimated annual rate of 0.37% (1499 ha). This study noted that the biggest threat to shrinking grasslands in the basin is its conversion to shrubland (Figure 3), accounting for the loss of over 29,629 ha of grassland followed by encroachment from agriculture accounting for around 7407 ha of the grassland area. Most of the grassland conversion occurs in the southeastern parts of the basin, including areas south of Montorben toward the Siana and Olderkesi conservancies regions. Grasslands lost through agriculture expansion are common in the border areas of the rangelands and the middle agricultural section of the basin around Olchoroua and Enonkishu conservancies that borders Mulot town in Bomet County. Bomet town is mostly inhabited by the Kipsigis community that practices crop farming. Their proximity to the Mara rangelands signals a likely expansion of crop agriculture in the future that will trigger LULCC particularly, thus exerting pressure on the Enonkishu and Olchoroua conservancies.

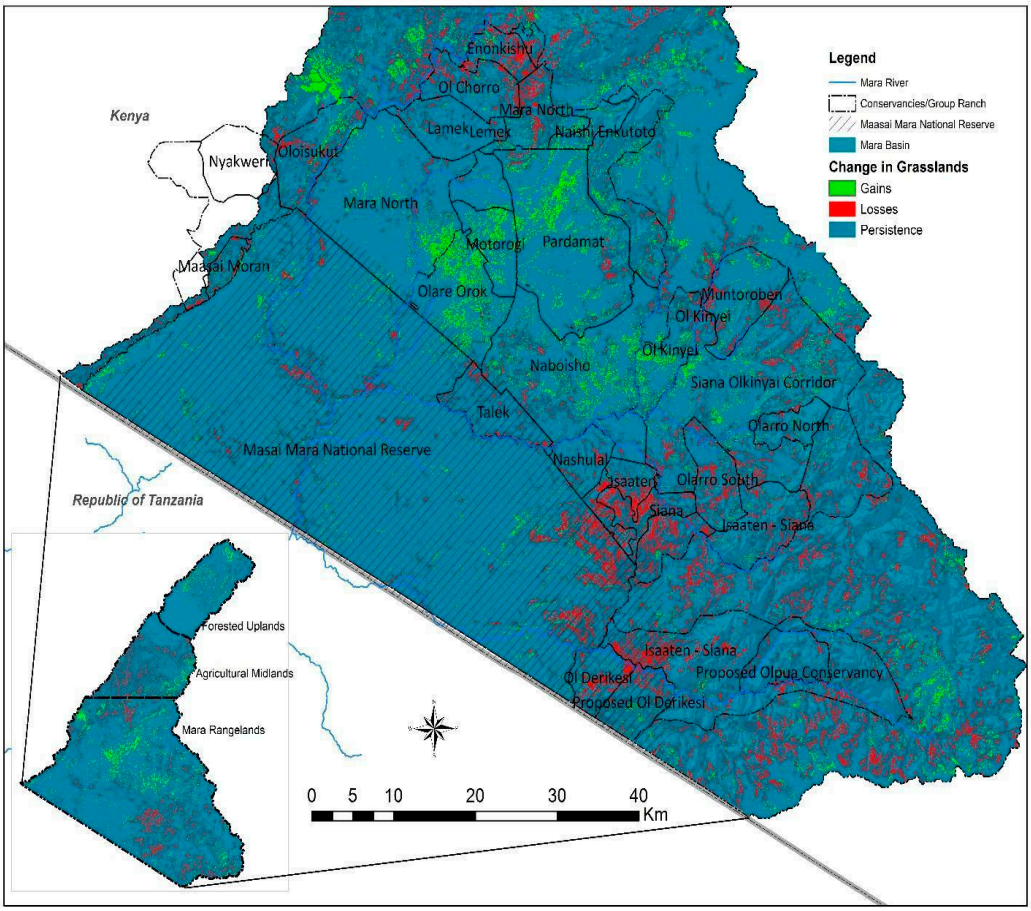


Figure 5. Grassland changes (gains and losses) in Mara basin in the period 1990–2015.

iii. Trends in Cropland—where does change occur?

Croplands predominantly occupy the densely populated areas, i.e., the agricultural and forest uplands zones of the Mau Mara landscape. Most croplands are a result of encroachment into the forest (11,000 ha), grassland (8000 ha), and shrubland (4500 ha) (Figure 6).

New and existing agriculture fields had drastically fragmented the forest into blocks. The agricultural gains were mostly at the edge of the remaining forest blocks. Agriculture areas that had continuously been cultivated had little or no live tree canopies.

At 2040, cropland will have shrunk part the forest with the grasslands and build up area also expanding (Figure 7). The most encroached forest blocks as a result are southwestern Mau and eastern Mau.

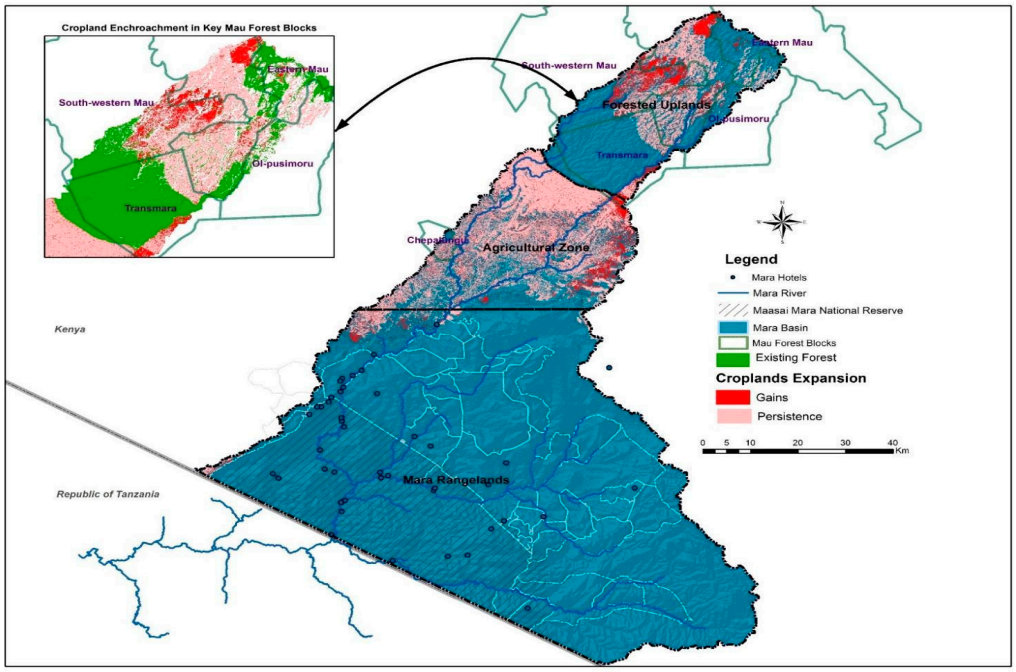


Figure 6. Cropland expansion and related forest encroachment in Mara basin (1990–2015).

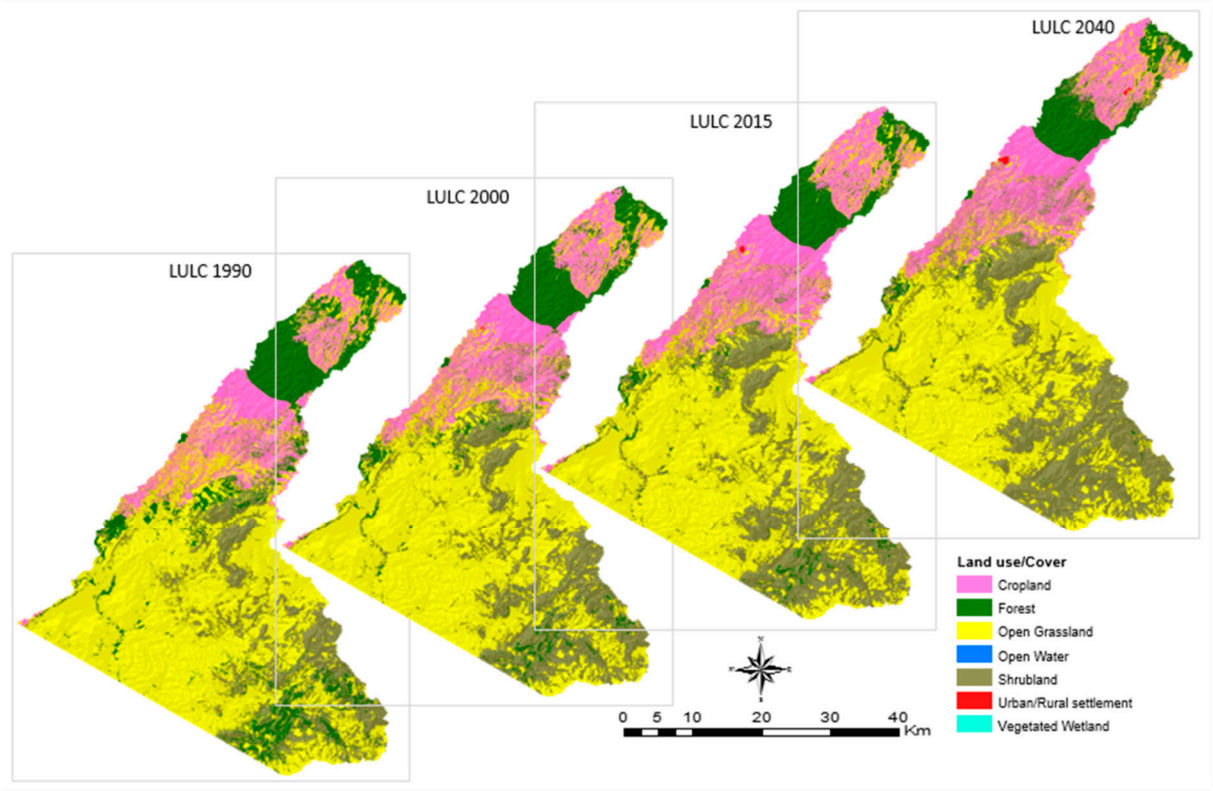


Figure 7. Land use/cover maps of Mara basin derived from satellite data for 1990, 2000, and 2015 and projected for 2040.

4. Discussion

4.1. Land Use Transition in Rangelands

The severe environmental and biodiversity degradation (gullies, emergency of invasive species, loss of habitats forage and other plant species) resulting from the need for more land to increase food production will worsen by 2040, which is when food demand

will increase by 70% [49]. The primary drivers of this outward aggregate shift in food demand are population growth, improved wages per person, and urbanization [50]. In the Maasai Mara rangelands, the use of fires and livestock to manage grass, emerging farms and the acceleration of built-up areas are defining and giving the landscape a new shape. There has been widespread mechanized farming on selected mono-crops such as maize and wheat varieties [51] in areas like Lemek, Nkorinkori, Ololunga, Nairage Enkare, Suswa, etc. [52], which might have generated shifts in the preferred locations for the ungulates and in their numbers due to human influence. For example, noticeable and dramatic LULCC in Tanzania rangelands from 1975 to 2015 [3] have destabilized hotpots for free-ranging ungulate populations (wildebeest) in the SNP [53,54] as land is being converted to small-scale agriculture on the protected area peripheries with routine livestock encroachment in search of pasture [55]. This trend is similar in the northwest of Tanzania around the Loliondo Greater Conservation Area, the northern parts of Lolkisale, and the wider Arusha District, where the construction of infrastructure and expanding agriculture will exert pressure on wetlands, settlements and forests [15].

In southern Kenya (Amboseli, Loita and Maasai Mara), increased rainfall variability (23%), an increase in formal school enrollment (15%), the need for financial stability (13%), land subdivision (12%), socioeconomic development (10%), and population growth (8%) are all key and interacting drivers behind land use change [15]. Diverse park management regime approaches and the use of 13,635 [56] fires as a management tool to burn c. 8001 km^2 (24.1%) of Mara–Serengeti protected areas and 116 km^2 (3.2%) of the buffer zones between 2001 and 2014 have been key drivers in the rangeland change [56]. Perhaps that is why grasslands dominate in the confines of Mara–Serengeti while more woodlands are evident in the contiguous surrounding lands (conservancies and community areas). This variation has impacts on species distribution, as some species prefer grasslands (i.e., gazelles and cheetahs), while other dominate in the forest (i.e., giraffes).

4.1.1. Impacts of Deforestation on Mau Mara Landscape

Water resource availability and increased demand mean that the water resource is highly stressed [57], which is a situation exacerbated by LULCC [58]. Agricultural expansion is the principal driving force of deforestation, land degradation and the associated loss of ecosystem biodiversity [59] across the Mau-Mara landscape. Large-scale commercial farming, primarily tea farming, has reduced the size of the forest from 15% in the year 1989 to 13% in 2010 [39]. There was a gradual 0.6% yearly increase in small-scale farmlands from forested areas for a period of 40 years from 1973 with the greatest change being evident from 1994 to 2008 [46]. The 40,000 occupants of the forest from Enoosokon, Enkaroni, Enoosaen, Enekishomi and Sisiyian group ranches had asked the environmental court to seek redress for forceful eviction in 2018 [60], which is a factor that the environmental court did not consider in its 2022 ruling.

Although the sustainable management of agricultural operations can preserve and restore critical habitats, help protect watersheds, and improve soil health and water quality, they can also yield substantial negative impacts on people and the environment if managed unsustainably [61]. Agriculture activities accounted for 40% of tropical deforestation between 2000 and 2010 with the local expansion of subsistence agriculture accounting for 33% [58]. From 2000 to 2010 is the period when the Mau forest was undergoing immense anthropogenic influence, particularly illegal logging and the unlawful settlement of people, which also led to a decrease in water levels of the Mara River [39,62]. Degrading a forest ecosystem like the Mau that supports multiple environmental niches usually causes multiple cascading effects on people, livelihoods and biodiversity in adjacent ecosystems. The reduced forest cover might affect the local hydrological cycle that supports social economic activities like agriculture, grass for livestock and wildlife (like in the grasslands of the Mara landscape) [23]. A reduction in water levels because of less precipitation endangers the aquatic and other terrestrial lives either directly or indirectly and would have a big impact on the nation's economy. The tourism sector that contributes 10% to

Kenya's GDP would be impacted, as a significant portion of this socioeconomic activity is wildlife oriented, particularly in the Maasai-Mara region, which depends on the Mara River Basin ecosystem for its survival [63].

The rivers that flow through communally owned lands like the Ewaso Nyiro might not discharge adequate water to support livestock and wildlife during the dry season periods. Rivers that flow through agricultural zones like Amala and Nyangores (that source their waters from the Mau forest and discharge them into the Mara River) might trigger a change from rain-fed agriculture to irrigated food production. This might cause an over-abstraction of water, which can change a river's volume flow status from permanent to seasonal. Furthermore, as the farms are located on steep land, when it rains, the fertile topsoil is washed into the rivers, which is a tragic loss of an important resource. Hydrological modeling indicates that the depleting forest cover is making flows less stable with higher peak flows and reduced dry season flows [63] resulting in decreased resilience across the landscape. Intensified agriculture has resulted in deforestation, a reduction in shrubland, water abstraction, water access and biomass competition with wildlife, agrochemical pollution and excess nutrient discharge [57]. Domestic and agriculture (large-scale) water demands have skyrocketed to 20,967 m^3 as of 2010 with a projected increase of up to 33,918 m^3 in 2030 [61]. The total five daily water demand in the Mara River Basin was estimated as 20,967 m^3 in 2010 and projected to be up to 33,918 m^3 in 2030 [64]. Livestock water demand in the Mara catchment was estimated to increase by 69 m^3 yr^{-1} from 1990 to 86 m^3 yr^{-1} in 2010 [65]. A lack of capacity to enforce water abstraction permits has increased water usage by farmers [66]. In addition to flow, the use of inorganic fertilizers might cause eutrophication that increases algal and/or epiphyte biomass growth related to anthropogenic nutrient loading; this can be followed by more severe impacts such as a loss of submerged aquatic vegetation, oxygen depletion, imbalanced food webs, reduced biodiversity, altered biogeochemical cycling, fish kills and the formation of "dead zones" [67,68].

There were 32% and 14% decreases in dense and open woodland forest cover. This is attributed to clear logging to pave the way for the expansion of tea plantations between 1973 and 2000. The rangelands (shrubland, grassland and savannah) have decreased by 34% as a consequence of the expansion of cropland, which has increased by 20% [64]. Meanwhile, the wetland area in Tanzania has increased by 131% because of sediment build-up downstream as a consequence of soil erosion in the catchment [64]. This was perhaps caused by poor agricultural methods on the slopes of the Mau forest hills and amplified by tree logging upstream, thus necessitating easy soil removal during the rainy season. High sediment load estimates of between 113 and 432 tons/day were swept into wetlands and water bodies as a result of human actions [69]. This scenario might well amplify in the future, as unsustainable land utilization persists and as inorganic farming supplements are embraced to meet the food demand threshold. The riparian vegetation might also be jeopardized particularly when land is tilled to river bank buffers, thus limiting water sinks and absorption capability, which is a factor that will necessitate more sediment and chemical disposal.

4.1.2. Impact of the Forest on Wildlife

The current 75% decline for Mara wildlife populations [26], resulting from large-scale cultivation [32,35,70], in-migration [71], sedentarization [70,72], and settlement expansion [70], would be massively impacted by change in the Mara River flows. All the poaching cases recorded during the elephant dung estimate survey exercise in the Mau forest in 2020 was evident particularly in the southwestern Mau, Transmara and northern Tinderet forests blocks. Three carcasses of wild animals were recorded: one for elephant (old), colobus monkey, and bush buck [73]. This is substantially less than in 2016 when 19 carcasses were recorded: 4 for elephants, 9 bushbuck, 3 monkeys, 1 red duiker, 1 rat and 1 mongoose. The drop in poaching incidences is a result of law enforcement in the forest

that has minimized human activities. Poaching incidence cases were mostly intended for bush meat.

Critically endangered species of the Mountain Bongo found in the forest would likely become extinct. The inferential figure for this critically endangered antelope [74] that lives in forest ecosystems was less than 100 individuals [10], which is significantly below the critically endangered threshold of 250 mature individuals [72]. In May 2013, new discoveries of this antelope species were made with the preliminary results indicating that the Maasai Mau Forest Complex hosts some 20 individuals, while the southwest of the Mau Forest supports less than 10 individuals [72]. An elephant dung survey in 1995 recorded 1003 individuals compared to 652 in 2016, representing a deplorable 35% decline [11]. The 1990s and early 2000s was a period when Kenya lost a significant number of elephants and Rhinos to poaching. The situation will further be aggravated by prolonged droughts [31,38] that can be a trigger for poaching [73] as a fallback for survival.

As the forest habitat is depleted, human wildlife conflict incidence cases and threshold levels also become rampant because of natural resource competition. The areas adjacent to the MMNR, for example, have high rates of Human–Wildlife Conflicts (HWCs) per year. In 2015, Narok County, for example, reported 258 HWC cases through the KWS community department. The cases entailed 26 fatalities caused by retaliation attacks, 112 cases of property damage caused by leopards, snakes, and lions, 58 cases of crop destruction caused by zebras, buffaloes, and waterbucks, 57 incidents of livestock predation whereby 90 animals were predated upon, and 5 cases of injuries caused by buffaloes, snakes, and hippopotamus [74].

4.1.3. Impact of Changing Land Use Policies

Land subdivision of the entire Mara landscape is almost complete with the Loita Plains and Olderkesi being the only remaining areas currently undergoing the demarcation process. It is presumed that owning a land title deed permits freedom of tilling, selling, and obtaining returns from wildlife [35]. Land use change and production study in the Masai-Mara landscape confirmed that over 50,000 ha of the subdivided land had already been sold to peasant non-Maasai farmers (Kisii, Kalenjin and Kikuyu) [66]. This figure might be higher now because of the earmarked infrastructure developments (an international airport in Transmara, upgrading of three roads, the Narok-Sekenani (complete), one from Narok via Mararianta to Lemek area and the second to Mulot via Nyekweri Forest Conservation Area, Oloisukut Conservancy, Emarti, Enoonkishu Conservancy). The Transmara landscape has recently also been a target for the more affluent in Kenya, who are strategically buying extensive tracts of land for future investments. As the land is subdivided, the likelihood of it falling to peasant farmers will persist especially in Siana and Olderkesi, where land allocations are as small as 2 acres per person. This fragmentation will hinder large-scale production that is usually embraced in large farms.

4.2. New Steps and Feeding Land Use and Land Cover Change into Policy for Better Management Decisions

The Mau-Mara landscape is transitioning from its traditional land uses as the contemporary needs and demands also change. Massive "land grabbing", infrastructure developments like roads and the development of an international airport in the landscape will spur sporadic developments that will need policy interjection. The need to review existing or enact new policies to mitigate future LULCC might guarantee the sustainability of the landscape. The completed spatial plans for Bomet County and Narok Counties plus the Maasai Mara Greater Ecosystem Management plan is a clear demonstration of the good intentions of the multiple stakeholders in the landscape in arresting future impacts of land uses on ecosystems, people and wildlife. However, political will (at the national and county level) and assimilating other stakeholders' views can mitigate some of the unprecedented LULCC outcomes, which is a crucial element of future sustainable land use planning.

Limitations of the Study

The length of Mara River is approximately 395 km from Kenya to Tanzania with 60% being in Kenya [75]. This study was limited to the Mara River Basin on the Kenyan side. It is anticipated that the findings of the study will guide the County Government of Narok in developing policies and frameworks that will assist address contemporary and future threats facing the Mara River basin. Similar studies in Tanzania are recommended to guide the government on interventions they can pursue to counter problems facing the river basin. The studies from both countries can aid the two countries avoid pitfalls and overlaps when implementing recommendations. Periodic satellite imagery updates on land use change driver categories like agriculture and built-up areas and their impacts on ecosystem (wildlife, forests, water, grasslands) should be undertaken to advise on prompt measures that governments can pursue to descale and mitigate their acceleration. Focus studies on the impacts of the river and the forest on specific wildlife species along the river basin and within the Mara and Serenget landscapes is encouraged to understand their demographics and behaviors for swift decision action.

5. Conclusions

The Mau Mara landscape remains important for the sustenance of people, livelihoods and biodiversity for contemporary and future generations. The diverse stakeholders in the landscape (tourism sector, farmers, pastoralists, conservancies, civil society organizations, researchers, national and county government) can play a fundamental role in mitigating myriad potential threats. The development of joined up landscape management plans to organize land use outside the protected area and the Narok county spatial plan are fundamental to instigate change in land uses across the landscape. This will entail the methodical distribution and organizing of land use activities earmarked for safeguarding the available natural resources in protected areas [66]. Understanding potential pathways of future land cover change can open debates as to what policy and management interventions are required to achieve conservation and development targets, or at least to avoid undesirable futures.

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