Online ISSN: 2588-3526

Journal of Wildlife and Biodiversity

Volume 8(3): 103-121 (2024) (http://www.wildlife-biodiversity.com/)

Research Article

Land cover changes and impact on the African elephant (*Loxodonta africana*) conservation in Omo National Park, Ethiopia

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Received: 11 January 2024/ Revised: 19 April 2024 / Accepted: 26 April 2024/ Published online: 03 May 2024. Ministry of Sciences, Research, and Technology, Arak University, Iran.

How to cite: Jeza, T.G., Bekele, A. (2024). Land cover changes and impact on the African elephant conservation in Omo National Park, Ethiopia. Journal of Wildlife and Biodiversity, 8(2), 103-121. **DOI**: https://doi.org/10.5281/zenodo.11108561

Abstract

Land Use Land Cover (LULC) changes are a major cause of natural habitat alterations and biodiversity losses affecting wildlife habitats, species distribution, and movement patterns. Understanding the impact of LULC changes on wildlife and their habitats is crucial for the implementation of effective conservation measures, especially in and around conservation areas. LULC changes between 1993, 2003, 2013, and 2023 in Omo National Park (ONP) and adjacent areas were classified and monitored. Landsat Satellite Imagery was used to determine the spatiotemporal patterns of LULC changes using a geographic information system and remote sensing techniques. We found that LULC changed over the last three decades and that LULC changes in surrounding buffer areas influenced the status of the elephant population more than changes within ONP. In ONP, open grassland decreased while the other land covers such as savanna wooded grassland, bushland, woodland, forest land and water bodies increased, whereas in the surrounding buffer areas of ONP, forest land and open grassland decreased and agricultural land increased sharply. The main cause of the contribution of land-cover change in the study area was agriculture related to the expansion of on-site farms and large-scale agricultural investment, which increased by about 284% over the 30 years. Habitats suitable for African elephants outside the eastern Park boundary were converted to sugar cane plantations leading to a decline in the African elephant population and its range, especially in the last 15 years after a Mega Sugar Project was launched in the region in 2010 to develop sugar industry. Our results have shown that large-scale agricultural investments and associated human activities have contributed to the changes in LULC affecting the suitable habitats and migration corridors of the African elephant in the study area.

Keywords: African elephant, change detection, GIS and RS technology, supervised classification, Omo National Park

Introduction

Land is commonly defined as the solid, dry surface of the earth on which environmental resources and economic assets are located (Park & Allaby, 2013; UN, 2017; UNCCD, 2017). Land refers to the cover of biophysical land type of the earth's surface, e.g forests, woodlands, bush-lands, grasslands, rivers, shallow lakes, wetlands, the non-marine fauna and flora (biosphere), the lower parts of the atmosphere (troposphere), groundwater reserves and to land use which is the functional aspects of the land, usually based on the modification of natural habitats or land cover, including the physical results of human activities on the land, such as agriculture, settlements, housing, industry, pastures, mining and recreational areas (Briassoulis, n.d.; Burka, 2008; FAO & JRC, 2012; NRC., 2014; Patel and Verma, 2019; UNCCD, 2017). Currently, anthropogenic activities which are directly correlated with the consumption needs of the growing population, are an important issue in the context of changes in the natural environment or LULC changes that have significant implications for biodiversity and climate change (Carr, 2004; Cheruto et al., 2016; Houghton et al., 2012; NRC., 2014; Pandian, 2014; Phalan et al., 2011; Rogan & Chen, 2004; Sr et al., 2011; Meyer & Turner, 1994). LULC changes are the result of the combined action of many influencing factors such as nature, society, economy and politics (Wu et al., 2022). Potential forces driving LULC changes include population growth; level of affluence; technology; political economy and structure; attitudes and values, each with their empirical basis and rationale (Turner et al., 1993; Wu et al., 2022). Global compassion shows that population and poverty are associated with negative changes in the natural environment/LULC while affluence and advanced technology are associated with positive impacts on the same(Carr, 2004; Cheruto et al., 2016; Wubie et al., 2016; Young & Wang, 2001).

LULC changes reflect the dynamics of anthropogenic activity, which can be triggered by various factors affecting nature, with significant consequences (Houghton et al., 2012; Kissinger, et al., 2017; NRC, 2014; WWF, 2022). Globally, land degradation, wildlife habitat fragmentation and species decline, as well as the conversion of natural forests, woodlands, bush-lands and water bodies to agricultural land or settlements due to LULC changes pose a major threat to biodiversity, as they directly affect the distribution and movement of wildlife species and drastically reduce ecosystem services (Liu et al., 2020; Powers & Jetz, 2019). In addition, natural connectivity (wildlife corridors) and wildlife movements between protected areas are increasingly threatened, mainly because anthropogenic activities affect the maintenance of ecosystem services and biodiversity conservation (Popp et al., 2014; Trincsi et al., 2014; Winkler et al., 2021).

In recent years, ONP in Ethiopia has increasingly been affected by LULC changes, resulting in the loss of wildlife corridors, habitat fragmentation and reduction of suitable habitats, with particular implications for the conservation of the African elephants (EWCA, 2017: 2020; Jeza & Bekele, 2023). In particular, the LULC changes have undergone visible land cover changes due to increased resource utilization (livestock grazing and seasonal farming) by the local community in conjunction with ongoing government-led interventions under the Mega Sugar Project, including the construction of long detour canals (> 200 km), conversion of large areas of natural forest and grassland to sugar plantations (> 300 km^2), establishment of sugar factories and employee villages, significantly impacting the number and distribution of African elephants in ONP (EWCA, 2017; Jeza & Bekele, 2023). The conservation of African elephants is increasingly threatened by LULC changes as suitable habitats and migration corridors in ONP are degraded and fragmented. However, so far, there is no systematic information on the trends and extent of LULC changes and their impact on the conservation and management conditions of the African elephant population in ONP and surrounding areas. Therefore, this study examines the drivers and trends of LULC changes between the years 1993-2023 and their impact on the conservation and management of the African elephant, an umbrella species in and around ONP, and to understand local community perceptions and attitudes towards LULC changes in ONP.

Material and methods

Description of the study area

ONP is one of the largest protected areas in the country. It is located in the lower Omo Valley in southwestern Ethiopia and is connected by the few remaining natural wildlife corridors to other protected areas such as Mago National Park and Tama Wildlife Reserve (currently Tama Community Conservation Area) in the east and Bandingilo National Park in South Sudan (north of the Ilemi Triangle (no man's land between Ethiopia, Kenya and South Sudan)(EWCA, 2020). ONP is located between 05° 30'to 06° 40'N and 35° 20' to 36°00'E and has a total estimated area of 5,157 km^2 (Fig. 1). The area exhibits both temporal and spatial variations in precipitation, humidity and temperature. Rainfall in the area is low and erratic, with a mean annual rainfall below 482 mm (ESC, 2019). A bimodal rainfall period is observed: The long rains usually begin in March and last until the end of April, while the short rains fall in October and November. The driest season is from December to January. Limited rain may fall in any month of the year (Cherie Enawgaw, 1996). The mean seasonal temperature ranges from 23 to 36°C, although the daily maximum temperature in February can reach 40°C, while the daily minimum temperature can drop to 16°C in April (ESC, 2019). The predominant topographic features of the Park are flat, grassy plains surrounded by Maji Mountain to the west and the Sai escarpment to the north. The Omo and Nerube rivers flow to the east and south, respectively (Fig. 1). Elevations range from 450 to 1541 m ASL. The Park is characterized by extensive savanna plains interspersed with forested grasslands associated with deciduous forests and riparian formations (Lamprey, 1994; Stephenson & Mizuno, 1978; EWCA , 2020). The Park covers extensive open grasslands interspersed with forest stands and herbaceous and shrubby vegetation at the edges.

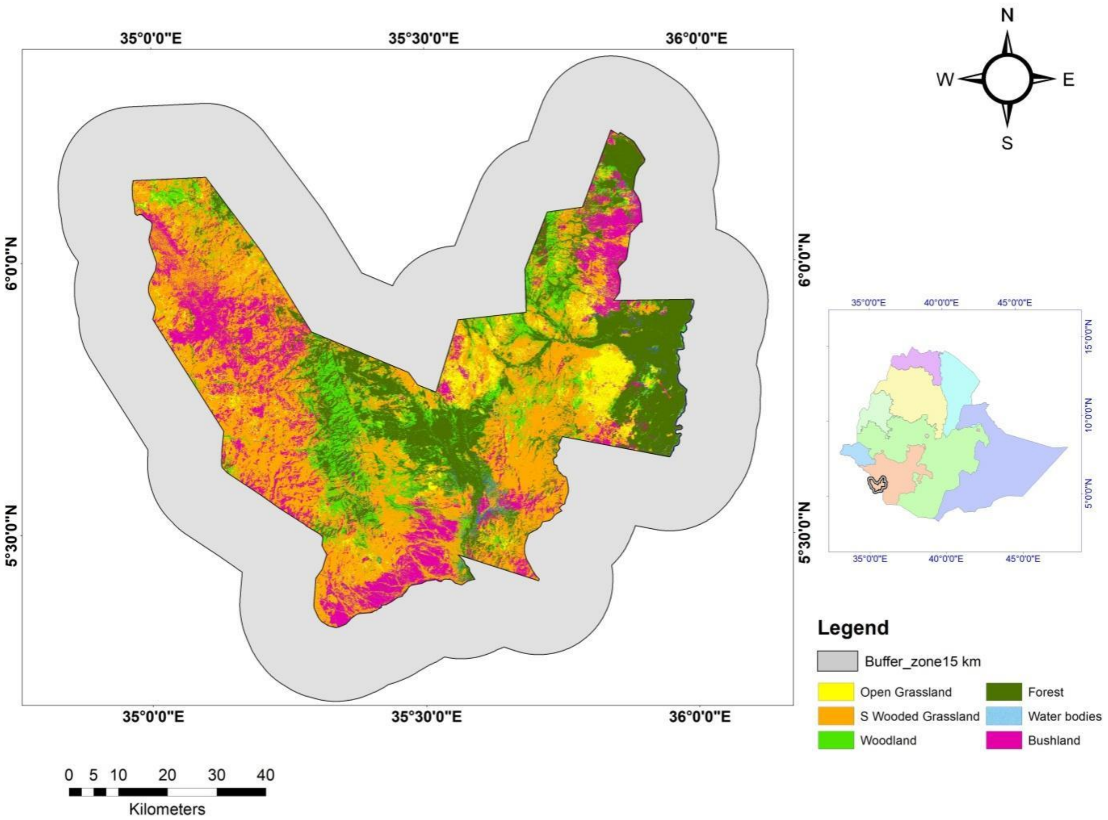

Figure 1. Map of the study area (ONP and the surrounding buffer areas)

ONP was established in the late 1950s (Hillman, 1993). The Park possesses numerous water sources and is rich in wildlife resources. So far 73 large and medium-sized mammals, 312 species of birds of which 2 are endemic to Ethiopia have been recorded (Asbl C/ & Fortrop, 2008; Cherie Enawgaw, 1996; Ferguson, 2021). At present, the Park serves as a buffer area for the adjacent protected areas (Tama Wildlife Reserve, Mago National Park, Murule and Wolishet Sala Controlled Hunting Areas) (Cherie Enawgaw et al., 2011).

Apart from the country's largest river, the Omo River, which flows from north to south, the Park is traversed by various rivers that are tributaries, most of which, apart from the Kibish River, flow into the Omo River. Some of these rivers include Kuma, Sherma, Mui, Gimwuha and Kibish River. The Park is bordered by several conservation areas: Tama Community Conservation Area, Mago National Park, Murule Controlled Hunting Area to the east and Bagandilo National Park in South Sudan to the south. The Park is surrounded by sedentary agriculturalists, pastoralists and semi-pastoral people. These people include the sedentary Dizi community who practice agriculture and are located to the west of the Park; the pastoral Surma community to the southwest, the pastoral Nagangatom to the southeast, Muguji to the east, Surma to the northeast and the northwestern Sheram community.

The wildlife includes much of the typical East African fauna and offers one of the wildest and most extraordinary animal panoramas in Ethiopia. ONP is considered an important habitat for animal populations such as the African buffalo, African elephant, eland, hippos, warthog, tiang, lewel hartebeests, lesser-kudu, greater-kudu, duiker, Grant's gazelle, gerenuk, giraffe, cheetahs, wild dogs, lions, leopards, guereza monkeys, common baboons, De'braza's and Vervet's monkeys.

Landsat Image acquisition, per-processing, classification and analysis

During the dry season in December of each year, confirmed cloud-free Landsat imagery from 1993, 2003, 2013 and 2023 at a spatial resolution of 30 x 30 m was downloaded from the United States Geological Survey (USGS) (website. htpp://www. usgs. gov) and to analyze LULC change in ONP and its surrounding buffer areas (Fig. 1). This Landsat image was suitable to better visualize the LULC due to the less cloud cover and fire effects. All Landsat images were from Collection 2 and Level 2 science products released by in early 2021. They are application-ready Level 2 science products derived from Landsat Collection 2 Level 1 (USGS, 2021). Level 2, Landsat imagery is a time series of observational data processed for consistency and continuity to measure the effects of environmental change (USGS, 2021). It is possible to use imagery from different satellites for detecting and comparing changes in the historical time series of LULC classification as long as the Landsat imageries used are from the same level/sensor (USGS, 2021). There may also be slight differences in the wavelength of the different satellites in the same level, but these do not have a significant impact on the final result and the images are comparable (USGS, 2021 and direct email conversation with USGS). Thus, level 2 images are already corrected for radiometric, geometric and atmospheric effects and thus considerably reduce the per-processing activities required before the actual classification of LULC. These are the Landsat images of time series level-2: 5, 7, 8 and 9 (1993, 2003, 2013 and 2023, respectively) which are considered for this study that have the same path and row (170 and 056) acquired in the same season in December (supplementary Table 1). Secondly, a composite data set images were created for each year and clipped to a polygon shape-file of the study area (the ONP and its surrounding buffer of 15 km distance) using the imported Landsat images of the respective years (1993, 2003, 2013, and 2023) in ArcGIS 10.8 software. Image processing and analysis using the imported Landsat imagery was performed in ArcGIS software (version 10.8) to create LULC maps. For further analysis, the geographic coordinate system World Geographical System (WGS) 1984 was used and projected onto the UTM zone. Third, the actual classification of the images: According to Lillesand, et al., (2004), the purpose of image classification is to allow the user to categorize all pixels of an image into different categories. In this study, ArcGIS 10.8 software was used to create a temporal inventory of LULC using a supervised classification approach. Different band combinations of land sat images were used for image classification. Samples with known identities were used to classify pixels with unknown identities based on the similarity of cases to obtain predefined classes that were spectral characterized: These sites are commonly referred to as training sites (Kalura et al., 2017; Lillesand et al., 2004). For the ONP and neighboring buffer areas, Landsat images were processed using image composition, masking, clipping and mosaicking to create a composite dataset for each year. Supervised classification using the maximum likelihood classifier was used for image classification and the creation of base maps for change detection. Supervised classification is chosen because it classifies land use based on training patches assigned by the classifier (Table 1). Pixel-based classification methods automatically categorize all pixels of an image into land-use classes based on spectral similarities (Erener, 2013; Lillesand et al., 2004).

Table 1. LULC classes description used for ONP and surrounding areas.

LULC classes	General description
Open Grassland (OG)	Area of land on which the existing vegetation cover is grass
Savannah Wooded Grassland (SWG)	Savanna areas or grassy woodland ecosystems characterized by the trees being widely spaced with an unbroken herbaceous layer consisting primarily of grasses.
Woodland	Areas dominated by *Acacia* species having a more open canopy and sparser tree density,
Bushland	Land covered with shrubs and small trees or comprised of plants that are multi-stemmed from a single root base.
Forest	Area occupied by tree clusters resulting from natural vegetation / such as riverine association; groundwater forest/. The vegetation is usually evergreen due to continuous water supply from the rivers and /or the high ground water table.
Agricultural land	Crop fields and fallow lands or land plough or prepared for crop growing
Water bodies	Freshwater surfaces including perennial and non-perennial rivers and streams, permanent and seasonal lakes/ ponds

Fourth: It is important to evaluate the accuracy of the classification results to confirm the extent to which the classification produced is comparable to the actual conditions on the ground (Owojori & Xie, 2003). The classified images were compared with reference data obtained randomly from Google Earth and during the fieldwork for each class of the land cover and used for accuracy assessment and analysis in ArcGIS 10.8. The accuracy of the classified image can be evaluated using the error matrix. The result values of the kappa coefficient were used to determine the degree of correspondence of the classification with the actual situation of LULC (Rahman et al., 2004). The formula of Congalton and Kass, (2009) was used to create and evaluate confusion matrices (Congalton, 2001). The producer, user and overall accuracy and the kappa coefficient for 1993, 2003, 2013 and 2023 were calculated. Finally, based on the classified images from different periods, the change detection function in ArcGIS 10.8 was used to detect the changed areas and to know which land use was changed to which. In this way, it was possible to compare change detection between 1993 and 2003 and 2013 and 2023 using a change detection matrix in ArcGIS software.

Reconnaissance survey and community interaction

Before the actual fieldwork, general information such as the current natural habitats and prevailing land use practices about African elephant movement and habitat uses, human population and activities, and livelihood strategies in and around the ONP were obtained during the reconnaissance survey. During the actual field observation, information on the LULC types was collected using GPS (recording the X-Y coordinate points and the corresponding attributes) to assess the accuracy of the LULC classification. Stratified random sampling techniques were used to collect a total of 184 sample points to ensure an equitable distribution among the different LULC types of study areas (Das, 2009). LULC photographs were also collected to aid image processing.

Interviews in the form of households, key informants and focus group discussions guided by structured questionnaires were used to collect data on LULCC forces over the past 30 years (1993-2023), which were finally analyzed qualitatively. A total of 132 households were selected using simple random sampling from the total number of households (1400) in the Kebeles of the study area using Kothari's sample size formula(Kothari, 2004). The respondents were 28 years of age and above and had been living in the area for the last 20 years or more. Knowledge of the respondents about the historical LULC types; LULC change trends in the last 30 years, the driving forces of LULC change and its impacts on the movement and distribution of African elephants and their suitable habitats in ONP and its surrounding areas were taken into account. Focus group discussions were additionally carried out with 12 people (who were mainly local leaders and elders who could remember events in land transformation) in and around ONP. The discussions were distributed in the three sampled Kebeles that involved elders, local leader (administrator), senior rangers and Park wardens using the checklist of questions related to land-use changes and its drivers as well as their effect on elephant habitat and conservation in the ONP and the surrounding buffer area. The information obtained from the interviews with the local communities and the experts was analyzed qualitatively.

During the fieldwork and interviews, it was found that population growth and human activities in ONP and surrounding areas increased significantly, especially after the start of the government mega project, Kuraz Sugar Development Project in 2010. The years 1993 and 2003 were more or less similar in terms of human population and human activities in the ONP and surrounding buffer areas. Therefore, the year 2003 was considered the baseline year before higher levels of population growth and human activity occurred, while the subsequent years 2013 and 2023 were the years of higher population growth and human activity in and around the Park.

Results

Classification and accuracy assessment

Our result has shown the LULC classes of the study area; the noted change and effects as well as driving forces in the years between 1993, 2003, 2013 and 2023 (Figs 2 and 3). The overall accuracy of the Landsat-derived classified images was 93.1%, 87.8%, 91.7% and 92.6%, with the result of kappa indices of agreement 0.92, 0.85, 0.88 and 0.89 for years 1993, 2003, 2013 and 2023, respectively (Supplementary Table 2). The results showed a perfect level of agreement between the classified images and the referenced data and in line with the standard land cover mapping accuracy level (85%-90%).

LULC Changes

During the study period, land cover changes occurred in both ONP and the surrounding buffer areas, though the degree had varied and with different annual rate of changes (Tables 2- 4; Figs. 2 and 3). In 1993, open grassland occupied the largest area in ONP at 57% and steadily declined to 6.67% in 2023. Open grassland was the most altered with an annual rate of change -213.4 km^2/year in the first period (1993-2003) and increased at a rate of 12.4 km^2/year in the second period (2003-2013) and decreased at a rate of -58 km^2/year in the third period (2013-2023). Savanna wooded grassland showed the strongest increase from 11% in 1993 to 39% in 2023 with the highest annual rate of change of 203.7 km^2/year in the first period (1993-2003), followed by bush land increasing from 3% in 1993 to 16% in 2023, woodland from 8% in 1993 to 18% in 2023. Forest and water bodies showed a rather stable and smaller increase from 20% in 1993 to 21% in 2023, and from 1% in 1993 to 2% in 2023, respectively (Tables 2 and 3).

Assessment of LULC changes in the surrounding buffer areas of the ONP (15 km from the boundary of the Park) showed, in the last 30 years, vast land cover changes had been observed in the agricultural land which increased from 735 km^2 (10.2%) in 1993 to 2823 km^2 (39.1%) in 2023 or increased by about 2088 km^2 (284%) (Table 4). Savanna wooded grassland increased from 1715 km^2 (23.7%) in 1993 to 1968 km^2 (27.2%) in 2023, followed by water bodies increase from 280 km^2 (3.9%) in 1993 to 442 km^2 (6.1%) in 2023. Among the other LULC classes that showed a decreasing trend between 1993 and 2023 were forest land by 1906 km^2 (−73.4%), open grassland by −600 km^2 (−60.6%), woodland by −36 km^2 (−12.2%) , and bushland by −39 km^2 (−6.3%) (Tables 4 and 5).

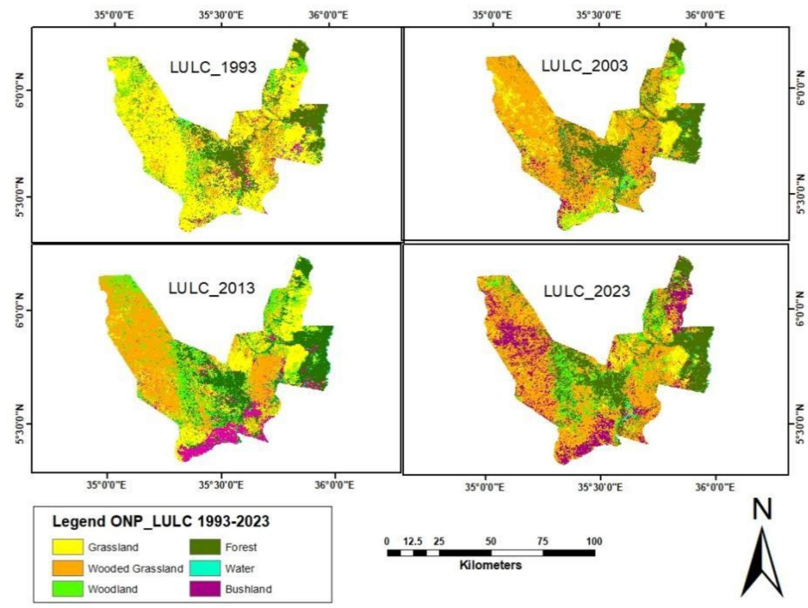

Figure 2. Comparative maps showing the actual LULC change from 1993 to 2023 in the ONP

Table 2. LLULC type, area (in km^2) and percent coverage (%) in ONP

LULC type/Year	1993	%	2003	%	2013	%	2023	%
OGL	2940	57.01	805	15.61	929	18.01	349	6.77
SWG	549	10.65	2586	50.15	1793	34.77	2100	40.72
WL	400	7.76	319	6.19	912	17.68	564	10.94
BL	168	3.26	186	3.61	402	7.79	819	15.88
FL	1035	20.06	1196	23.18	1059	20.55	1196	23.19
WB	65	1.26	65	1.26	62	1.2	129	2.50
Total	5157	100.00	5157	100.00	5157	100.00	5157	100.00

Table 3. LULC changes and area proportion in the three study periods in ONP

	(1993-2003)			(2003-2013)			(2013-2023)		
LULC type	Change (km2)	% change	Change rate (km^2/ year)	Change (km^2)	% change	Change rate (km^2/ year)	Change (km^2)	% change	Change rate(km^2 /year)
OGL	-2135	-72.6	-213.5	124	15.4	12.4	-580	-62.43	-58
SWG	2037	371.4	203.7	-793	-30.67	-79.3	307	17	30.7
WL	-81	-0,2	-8.1	593	185.9	59.3	-348	-38.16	-34.5
BL	18	10.71	1.8	216	116.1	21.6	417	103.73	41.7
FL	161	15.56	16.1	-137	-11.45	-13.7	137	12.94	13.7
WB	0	0	0	-3	-4.62	−0.3	67	108.06	6.7

Key:- OGL: Open Grassland; SWG: Savanna Wooded Grassland; WL: Woodland; BL: Bushland; FL: Forest land; AL: Agricultural Land

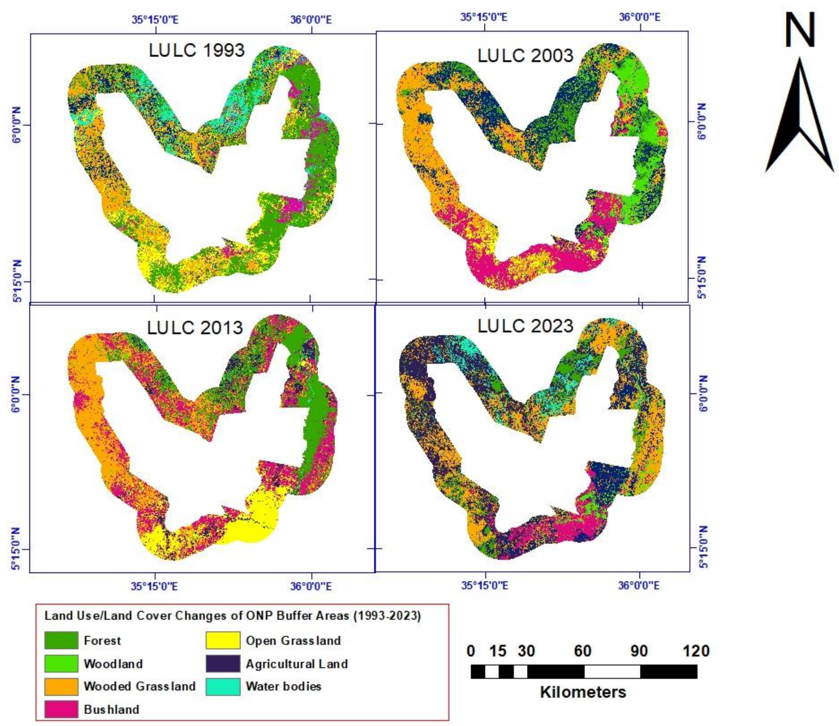

Figure 3. Comparative maps of LULC change in the buffer areas of ONP from 1993 to 2023

Table 4. LLULC type, area (in km^2) and percent coverage (%) in ONP buffer areas

LULC type/Year	1993	%	2003	%	2013	%	2023	%
OG	990.2	13.7	435	6.0	402	5.6	390	5.4
SWG	1615.1	23.7	1825	25.2	995	13.8	1968	27.2
WL	94.5	4.0	504	7.0	1072	14.8	260	3.6
BL	520.2	8.6	733	10.1	1268	17.5	659	9.1
FL	2597.5	35.9	1846	25.5	949	13.1	689	9.5
AL	735.2	10.2	1708	23.6	2345	32.4	2823	39.1
WB	678.3	3.9	180	2.6	200	2.8	442	6.1
Total	7231	100	7231	100	7231	100	7231	100

Table 5. LULC changes and area proportion in the three study periods in ONP buffer areas

	(1993-2003)			(2003-2013)			(2013-2023)		
LULC type	Change (km^2)	Percent change	Change rate (km^2/ year)	Change (km^2)	Percent change	Chang e rate (km^2/ year)	Change (km^2)	Percent change	Change rate (km^2/year)
OGL	-555	-56.1	-5.6	-33	-7.6	0.8	-12	-3.0	-58
SWG	290	16.9	29	-1010	-50.4	-101	973	97.8	97.3
WL	208	70.3	20.8	568	112.7	56.8	-812	-75	-81.2
BL	113	18.2	11.3	535	73.0	53.5	-609	-48	-60.9
FL	-749	-28.9	-74.9	*-897*	-48.6	-89.7	-260	-27.4	-26.0
AL	973	132.4	97.3	*637*	37.3	63.7	478	20.4	47.8
Water	-100	-35.7	-10	20	11.1	2.0	242	121.0	24.2

Key:- OGL: Open Grassland; SWG: Savanna Wooded Grassland; WL: Woodland; BL: Bushland; FL: Forest land; AL: Agricultural Land

LULC trends

In ONP, forest areas were not much changed during the study period (1993-2023) as 76% remained the same, followed by savanna wooded grassland at 74.2%, woodland at 30.9%, bushland at 17%, open grassland at 9.5% and water bodies with 6.3%. The highest conversion took place in the water area as almost 37% of the total area was converted to forest, 25.4% to woodland and the rest to savanna wooded grassland (16.3%), bushland (8.9%) and woodland (3.1%). Most of the open grassland was converted to savanna wooded grassland (50.2%), bushland (22.4%), forest (8.9%), woodland (8.3) and water bodies (0.7%). Most bushland habitats were converted to savanna wooded grassland (34.7%), to forest (29%), woodland (10.2%) and open grassland (6.1%). Forest changed relatively little, gaining 36.9% (24.4 km^2) of water bodies, followed by bushland 48.6 km^2 (29%), woodland 51.9 km^2 (13%), open grassland 260.2 km^2 (8.9%), and savanna wooded grassland 23.1 km^2 (4.2%). In contrast, OGL habitat was converted to savanna wooded grassland 1475.5 km^2 (50.2), bushland 658.9 km^2, forest 260.2, woodland 243.4 km^2, water bodies 21.1 km^2 and only 279.7 km^2 (8.9%) of open grassland remained unchanged (Table 6). Relatively larger changes occurred in the conversion of open grassland to savanna wooded grassland.

On the other hand, in the surrounding buffer areas of ONP, agricultural land has changed less compared to the other LULC types during the study period (1993-2023), as 54.7% of agricultural land remained the same, followed by water bodies with 27.2%, savanna wooded grassland 26%, open grassland 19.2%, forest land 14.4%, bushland 8.8% and woodland 1.8%. Thus, the highest conversion took place in the woodland habitats as almost 98.2% of the total area was converted to agricultural land (38.1%), water bodies (22.1%), savanna wooded grassland (18.6%) and the rest to open grassland (7.5%), forest land (7.7%) and bushland (4.2%). A total of 91.2% of the bushland was converted to agricultural land (51.9%), forest land (12.3%), savanna wooded grassland (12.2%), water bodies (6.4 %) and woodland (2.7%). In terms of area, forest habitats (85.6%) were converted to different land cover types during the study period, about 34.1% to agricultural land, 28.4% to savanna wooded grassland, 9.9% to bushland, 7.1% to woodland, 4.7% to water bodies and 1.5% to open grassland. In the buffer areas of the ONP, there were relatively smaller changes in agricultural land, rather gained 836.8 km^2 (51.8%) from savanna wooded grassland, followed by forest land 886.9 km^2 (34.1%), water bodies 246.0 km^2 (36.2%), open grassland 145.2km2 (14.7%), bushland 269.7 (51.9%) and from woodland 36.4 km^2 (38.1%). So there were major changes in the conversion of savanna wooded grassland and forest land to agricultural land during the study period in the buffer areas of the ONP (Table 7).

Table 6. LULC change matrix of ONP between the years 1993 and 2023

LULC Classes			2023					
		Unit	BL	Forest	OG	SWG	WB	WL
1993	BL	(km2)	28.4	48.6	10.2	58.2	5.0	17.2
		%	17.0	29.0	6.1	34.7	3.0	10.2
	FL	(km2)	62.4	786.2	12.5	72.7	7.8	93.3
		%	6.0	76.0	1.2	7.0	0.8	9.0
	OG	(km2)	601.0	260.2	279.7	1475.5	79.0	243.4
		%	22.4	8.9	9.5	50.2	0.7	8.3
	SWG	(km2)	24.8	23.1	22.7	407.9	1.9	69.5
		%	4.5	4.2	4.1	74.2	0.3	12.7
	WB	(km2)	5.9	24.4	2.0	10.8	6.3	16.8
		%	8.9	36.9	3.1	16.3	9.4	25.4
	WL	(km2)	37.8	51.9	22.5	160.2	3.7	123.4
		%	9.5	13.0	5.6	40.1	0.9	30.9

Table 7. LLULC change matrix of ONP buffer area between the years 1993- 2023

			2023						
LULC Types		Unit	AL	BL	FL	OG	WB	SWG	WL
1993	Al	km²	**402.0**	4.6	33.8	11.1	15.5	265.3	2.9
		%	**54.7**	0.6	4.6	1.5	2.1	36.1	0.4
	BL	km²	269.7	**45.7**	64.0	29.7	33.3	63.4	14.0
		%	51.9	**8.8**	12.3	5.7	6.4	12.2	2.7
	FL	km²	886.9	256.8	**373.6**	38.3	121.5	737.1	183.2
		%	34.1	9.9	**14.4**	1.5	4.7	28.4	7.1
	OG	km²	145.2	257.8	18.0	**189.8**	1.8	351.3	25.7
		%	14.7	26.1	1.8	**19.2**	0.2	35.5	2.6
	WB	km²	246.0	5.0	116.6	10.7	184.9	113.2	2.8
		%	36.2	0.7	17.2	1.6	27.2	16.7	0.4
	SWG	km²	836.8	85.4	76.1	103.0	63.8	**419.1**	29.9
		%	51.8	5.3	4.7	6.4	4.0	**26.0**	1.9
	WL	km²	36.4	4.0	7.4	7.2	21.1	17.8	**1.7**
		%	38.1	4.2	7.7	7.5	22.1	18.6	**1.8**

Key:- OGL: Open Grassland; SWG: Savanna Wooded Grassland; WL: Woodland; BL: Bushland; FL: Forest land; AL: Agricultural Land

African elephant population and distribution

Studies and reports on African elephants have shown that their population has decreased in and around ONP over the last 30 years The results of the interviews and focus group discussions indicate that respondents were aware about the effects of habitat alteration on wildlife particularly on African elephants. More than 75% of the respondents confirmed that as a result of change in land cover /forest clearance, some species of wild animals previously conspicuous in the area disappeared and others were reduced. About 98% of the respondents were aware of the presence of African elephants, 64% were aware of the seasonal movements and distribution of African elephants in the different LULCs and about 47% were aware of decline of African elephants.

The changing land use conditions within the ONP did not negatively affect the elephant population as the extent of forest, shrub land and savannah wooded grasslands as well as the water bodies required by the elephants have somewhat increased during the study period. However, the trend of the elephant population in ONP has been declining during the study period, indicating the presence of other factors for the decline. The results of LULC changes over the last 30 years in ONP indicate that the elephant population has been severely impacted, with ivory poaching and changes in land use conditions occurring mainly outside rather than within the current boundaries of the Park. The assessment of LULC changes in the ONP buffer areas (buffer 15 km outside from the Park boundary) showed a strong dependence of elephant population on the season and in some areas also independent of the season as the home range of elephants extended beyond the current boundary of the Park (Fig. 3; Tables 6 and 7).

The boundaries of ONP were modified several times especially the last boundary modification (in 2019) excluded many of the suitable habitats of the African elephants for the mega sugar development project (Cherie Enawgaw et al 2011; EWCA, 2017). More than 108 km^2 of optimum suitable forest habitats along the Omo River (the northern Sai land and the southern land below the Elelbai hot spring) were excluded from the ONP which were very important elephant habitats in both wet and dry seasons.

Similar forest and woodland habitats (more than 50 km^2) on the other sides of the Omo River (the so-called Tama Wildlife Reserve and now the Mursi Community Conservation area) were also converted for a sugar plantation command area. Besides, the most known elephant corridors from Omo to Tama and to Mago were blocked (Gimwuha, Mui River) due to sugar cane plantation, affecting local and seasonal migration and movement of the African elephants.

Land cover changes and driving forces

Analyses of land cover changes inside the ONP have revealed the transformation of one land cover type into another over the last three decades (1993-2023). There was a tremendous decrease in open grassland converted to savanna wooded grassland, woodland and bushland habitats suggesting that environmental variables such as fire and livestock grazing can be considered as the main driving forces favouring the conversion of grassland to other land cover types in the ONP. Based on our field observations and interviews with Park rangers and locals, the uncontrolled seasonal occurrence of fires and the uncontrolled livestock grazing could be the probable main reason for the loss of grassland and the increase of other land cover types. In contrast, the analyses in the buffer areas of the ONP revealed significant changes in the vegetation cover that would have major effects on the African elephant population in the study area. Farms around the ONP have expanded from about 735 km^2 in 1993 to over 2823 km^2 in 2023, indicating that agricultural expansion has been one of the main drivers of land cover changes in the study area. African elephants require a vast home range covering natural habitats away from the Park boundaries.

From the responses of surrounding residents it appears that several factors are responsible for agricultural expansion happening at the expense of natural vegetation (including forest, woodland, and bush-land) that are important for wildlife, especially for African elephants. The causes of the driving forces for the land cover change are mainly related to the demand of the growing human population and government policy in the area. Apart from the needs of the growing population for agricultural land, livestock grazing in the area, the government development intervention introduced in 2010 for the mega Kuraz Sugar Development project has greatly changed the natural land cover of the ONP and the surrounding buffer areas.

On the other hand, in the buffer areas of the park, a large area of natural forests decreased during the study period from 2595 km^2 in 1993 to about 689 km^2 in 2023, and open grassland habitats decreased from 990 km^2 in 1993 to 390 km^2 in 2023. Agricultural expansion is therefore a major threat to the conservation of African elephants as most of the converted natural forests around the ONP are important habitats and dry-season refugia for the African elephant population in the study area. At the same time, livestock population trends of the last three decades showed that the number of livestock in and around the ONP has greatly increased. The grazing pattern of livestock within the Park has increased and has now become permanent and dominant in the southeast and southwest of the parkland by the Ngnagtom and Surma pastoral communities.

Discussion

The LULC classification and the time series analysis of this study illustrate the impact and consequences of the LULC changes of the last three decades on wildlife conservation, mainly on the African elephant population in ONP and the surrounding areas. LULC classification is an important technique to understand the spatial distribution of land features and to assess their relationship between the environment and human activity (Darem et al., 2023; Singh et al., 2021). Understanding and evaluating LULC changes and associated driving forces in ONP would be central to advancing potential conservation measures. In the northern highlands of Ethiopia, LULC change was considered an indication of plant and wildlife species loss (Miheretu & Yimer, 2018). In this study, LULC changes in the different LULC classes were found between 1993 and 2023, indicating that within ONP, large areas of open grassland were converted to savanna wooded grassland, bushland and woodland, while outside the ONP (buffer areas) most of the land cover (forest land, open grassland, bushland, woodland) suitable for African elephants were converted to agricultural land. The result confirms that the reduction in the African elephant population of the study area may have been influenced by changes in land use conditions that occurred outside, rather than within, the current boundaries of the park. This is consistent with the finding of Kideghesho et al., (2013) that areas adjacent to protected areas have long faced a range of new problems and challenges that complicate their management, putting resources at risk of overexploitation and extinction. Thus, in the surrounding buffer areas of ONP, we found that Agricultural lands have increased the most at the expense of natural forests compared to the other land cover types. The annual clearing of forests is mainly due to the expansion of agriculture (John et al., 2013). The degradation and loss of forests threaten the survival of many species and reduce the ability of forests to provide essential services (Gobush & Wittemyer, 2021)Progressive deforestation and habitat loss can have far-reaching impacts on the survival of species and the ecological function of protected areas(Newmark, 1996, 2008).

Since their establishment, protected areas have been under threats that function through conflicts related to land use exacerbated by the increasing human population and demands (Rechciński et al., 2019; Redpath et al., 2015). Himanshu & Peter Lanjouw, (2016) Villages located adjacent to protected forests are the most vulnerable sites as human and wildlife needs intersect each other in these areas. A study in Tanzania protected areas has shown how planning land uses adjacent to protected areas maintains low human density and reduces conflicts between local people and wildlife (Lewis, 1996; Newmark et al., 1993). African elephants and wildlife conservations land use needs are mostly a competition for the use of limited natural resources (Kremen & Merenlender, 2018). In the study area, we found that agricultural land expansion associated with the government-led mega sugar development project (mechanized agriculture) in the region has become a serious threat to the ecological integrity of elephant habitats in and around the ONP, leading to blockage of natural migratory routes and habitat fragmentation, as well as high pressure and competition for resources. African elephant populations are threatened by agricultural expansions as they are less and less free to move and corridors between wildlife reserves are blocked (Breuer & Ngama, 2020; Dejene, 2016; Sintayehu & Kassaw, 2019). The conversion of forests and rangelands to agricultural land displaces elephants by reducing their natural habitat and corridors (Hoare, 1999; Kusena, 2009). Continual agricultural expansion at the expense of forest and woodland is common in most parts of Ethiopia (Deribew & Dalacho, 2019; Gashaw et al., 2014; Tadese et al., 2021).

Wildlife corridors play an important ecological role in promoting biodiversity and the survival of a large number of species (Kideghesho et al., 2013). However, in the study area, most elephant corridors are seriously threatened because .of the conversation of elephant suitable habitats to sugarcane plantation coupled with lack of specific laws and strategy to protect the corridors against such unsustainable intervention. Strict regulations should be promulgated for the protection of wild animals to maintain their natural habitat and humans should sensitize to move away from the buffer zone of the protected area (Wahab et al., 2021).

In and around ONP, elephants were mainly distributed and locally migrated to the Mago National Park crossing the southern Tama Wildlife Reserve (Mursi Community Conservancies) through

Gimwuha and also in the middle through Mui riverine forest (Cherie, 1996; EWCA, 2017). Elephants also still migrate based on seasons to Padingilo National Park (in South Sudan) and vice versa (Jeza & Bekele, 2023). Within the ONP, elephants are distributed and inhabit along Mui, Sherma and Kuma Rivers and the Omo River and Kibish River to the south (Jeza & Bekele, 2023).

The rapid expansion of agriculture and human settlements has simplified natural ecosystems and harmed the earth's biodiversity (Mariye et al., 2022). Apart from the conservation areas (Tama Wildlife Reserve and Mago National Park), adjacent to the ONP, the riverine forests that were part of the ONP before 2010 (i.e. before the onset of mega sugar development in the area) were the preferred habitats for African elephants in the study area including the Omo, Kuma and Sherma Rivers (Cherie 2013; Cherie Enawgaw et al., 2011; Cherie Enawgaw, 1996b; Ethiopian Wildlife Conservation Authority(EWCA), 2015; Ethiopian Wildlife Conservation Authority (EWCA), 2017; Jeza & Bekele, 2023) African elephant suitable habitats and migratory corridors associated with the ONP have been affected by a sharp decline in forest and woodland habitats due to agricultural expansion. This shows agricultural land expansion; especially for individual farmland and the sugar cane plantations are and will be a threatening factor for the suitable elephant habitats (forest and woodlands) and this situation will be potential sources of the sugar project-elephant conflict in the near future unless mitigation measures are taken in advance in the area. Elephants are significantly involved in crop riding and in most economic loss and human fatalities (Parajuli, 2020; Tsegaye,et al., 2023). Local communities sharing landscapes with elephants incur a huge cost due to human-elephant conflict (Sampson. et al., 2019; *Tsegaye*, et al., 2023). The status of the ONP and its surrounding buffer area and wildlife therein has been decreasing with time, particularly the cover and connectivity of natural vegetation and water bodies which are required by the elephants. The management of habitats is a must to ensure enough availability of food and water resources required for wildlife (Bhandari et al., 2020). We, thus, highlight that the wildlife corridors (Mui River, Gimwuha) comprise a fragile ecosystem of woodland and riverine forest association where large-scale agricultural activities (sugarcane plantation) are becoming increasingly expanded replacing the natural forests, which needs particular attention for the protection to guarantee human–wildlife coexistence.

Conclusion

Our results emphasize the urgent need for holistic conservation approaches to ensure the survival of elephants in the ONP and surrounding areas. There is a need to ensure the protection of Umbrella species' habitats and natural corridors through enhanced collaboration and cooperation between stakeholders, including the sugar development project, local community and Wildlife Conservation Authority (EWCA). Human Wildlife Conflict will be a major challenge and should be an important issue for all stakeholders to reduce the expected conflicts. Development policies, projects, and government interventions in protected areas should be subject to environmental and social impact assessment. EWCA needs to diversify funding sources and ensure sustainable finance for proper management and address ONP conservation problem. There is a need to ensure that anthropological activities, which are known to be the main cause of LULC changes, are reduced, along with mitigation and adaptation measures taken to climate changes impacts and in the management of ONP. Further specific studies are required to assess the future impacts of the sugar development project on wildlife, particularly on African elephants and the management of the enviable sugar project and elephant conflict in the future in and around ONP.

Acknowledgement

We extend our deep thanks to the Ethiopian Wildlife Conservation Authority for their support and provision of permits, especially Kumara Wakjira, Solomon Mekonnen, Fanuel Kebede, Fekede Regassa, Arega Mekonnen and Adane Tsegaye. We are grateful to the ONP Chief Warden, Nuru Ahmed and all the rangers who participated in data collection during the study period. Department of Zoological Sciences, Addis Ababa University, Bezawork Afewrok, Abebe Getahun, Habte Jebessa, Tilahun, Mesele Yihune and Anagawu Atickem are highly appreciated for their constructive advice during the study period.

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