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Land Cover Change as a Proxy of Changes in Wildlife Distribution and Abundance in Tarangire-Simanjiro-Lolkisale-Mto wa Mbu Ecosystem

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Abstract

This study analyzed the land use and land cover (LULC) changes from 2000 to 2020 and examined its influence on wildlife distribution and abundance. LULC from satellite imagery for 2000, 2012 and 2020 were acquired from the United States Geological Survey (USGS). Supervised classification along with a maximum likelihood algorithm was used to classify satellite imagery into eight LULC classes: bareland, woodland, wetland, shrubland, grassland, waterbodies, cropland and built-up land. The results showed that grassland, wetland and woodland had declined, while shrubland, cropland and built-up land increased from 2000 to 2020. Grassland, wetland and woodland decreased from 48.1%, 14.1% and 4.4% in 2000 to 19.5%, 10.3% and 2.5% in 2020, respectively. Shrubland, cropland and built-up land expanded from 14.8%, 1.9% and 0.0% in 2000 to 39.0%, 17.2% and 1.9% in 2020, respectively. The findings suggest that the decline in grassland, wetland and woodland had affected terrestrial vertebrate species and their habitats through wildlife habitat destruction and land degradation leading to the changes in the wild animals' abundance and distribution. The research highlights the need for continuous monitoring and reporting of land use and land cover changes and its effects on wildlife distribution and abundance.

Keywords: Biodiversity change, Land use and land cover change, Wildlife habitat, Tarangire-Simanjiro.

Introduction

There are increasing land use and land cover changes worldwide as the interactions between humans and their environment continue (Kanianska 2016). As humans struggle to meet their needs (food, building materials, medicines, and raw materials for manufacturing purposes), they cause alterations, transformations and sometimes destruction of the landscape vegetation. This has resulted in landscape natural vegetation cover change which has affected the quantity and quality of the key components of the habitats of terrestrial vertebrates worldwide. The distribution and abundance of wildlife is primarily influenced by the structure and composition of vegetation cover and other key resources. Land use and land cover change means (quantitative) increase or decrease in the areal extent of a given type of land use or land cover, respectively (Briassoulis 2020).

Type of land use may affect land cover and a change in land cover alters land conditions, structure and or functions which in turn may affect land use. Thus, the land use and land cover changes co-exist in a complex manner (Kija et al. 2020). Such complex interactions between land use and land cover significantly affect both biotic and abiotic factors and processes which generally affect the distribution and abundance of both flora and fauna, wildlife habitats, as well as the structure and function of terrestrial ecosystems (Briassoulis 2020).

Many African countries are generally experiencing terrestrial species (including migratory mammals) decline as habitat loss, fragmentation and overexploitation continue to increase at different rates due to changes in a combination of human-induced factors (Bolger et al. 2008, Craigie et al. 2010, Rija 2022).

East African countries including Tanzania like many other countries in Africa have reported increase in biodiversity losses (Maitima et al. 2009, Msoffe et al. 2011), through land use changes which have converted natural vegetation into farmlands, grazing lands, human settlements and urban centres. These major human activities have been reported to cause changes in the natural vegetation cover which leads to changes in the quantity and quality of wildlife habitats and therefore affect the distribution and abundance of large mammal populations (both migratory and resident species) within the Tarangire-Manyara ecosystem among others (Bolger et al. 2008). The increased human activities in most places outside the protected areas have converted the previously used and occupied areas by wildlife into settlements and cropland (Mtui et al. 2017). This reduces dispersal areas as well as blocking wildlife migratory routes, thereby affecting wildlife populations. Kiffner et al. (2015) assessed the effects of land-use on mammal communities in the Tarangire-Manyara ecosystem and they found higher mammal species richness in those areas considered less disturbed (national parks and uninhabited pastoral areas) and lowest species richness in highly disturbed areas such as settled and farmed areas. Therefore, the land use and land cover changes are responsible for the declining biodiversity.

In Tarangire ecosystem, relatively few studies (Msoffe et al. 2011, Kiffner et al. 2015, Mtui et al. 2017) have been conducted to assess the effects of LULC changes on biodiversity. Besides, these few studies focused on a few wards and protected areas (Martin et al. 2019). The current study, therefore, analysed the land use and land cover changes in the Tarangire-Simanjiro-Lolkisale-Mto wa Mbu ecosystem (TSLME) from 2000 to 2020 using remotely sensed data and GIS and examined their implications on the distribution and abundance of wildlife populations.

Materials and Methods

Study area

The study was carried out in TSLME located within the larger Tarangire-Manyara ecosystem, northern Tanzania. The ecosystem is surrounded by various protected areas including the Mto wa Mbu Game Controlled Area (GCA) to the north, the Lolkisale and Simanjiro plains to the east, lake Burunge GCA, the Kwakuchinja open area and Lake Manyara National Park to the west and Mkungunero Game Reserve to the south (Mtui et al. 2017, Rija 2022). The study area (Figure 1) is within the semi-arid zone with a bimodal annual average rainfall around 650 mm (Msoffe et al. 2011). The short rains start in October to December followed by a short dry spell from January to February, while the long rains start in March to May followed by a long dry season spanning from July to September. The vegetation of the area is dominated by grasslands, wooded grassland and open bushland. The landscape is inhabited mainly by the Maasai ethnic group except in Mto wa Mbu with 120 ethnic groups (Krietzman 2019).

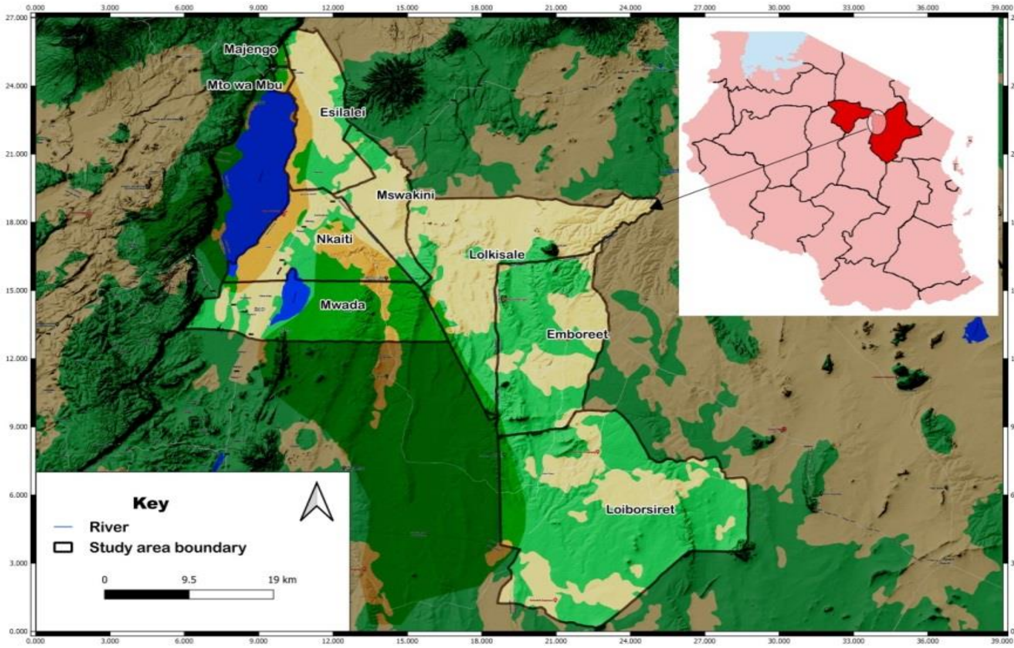

Figure 1: A map showing location of the study area (Source: author, 2021).

Data collection

The Quantum Geographical Information Systems (QGIS 3.18) through its semi-automatic classification plugin (SCP) was used to download free satellite imagery from the United States Geological Survey (USGS) through https://earthexplorer.usgs.gov to obtain data for analysis. Table 1 presents the details of various Landsat images used for LULC mapping.

Table 1: Details of the Landsat images used

Satellite imagery	Date acquired	Path	Row	Resolution	Source
Landsat 7 ETM+	27/01/2000	169	62	30 x 30 m	USGS
Landsat 7 ETM+	21/02/2000	168	63	30 x 30 m	USGS
Landsat 7 ETM+	05/01/2012	168	63	30 x 30 m	USGS
Landsat 7 ETM+	06/02/2012	168	62	30 x 30 m	USGS
Landsat 8 OLI	03/01/2020	168	63	30 x 30 m	USGS
Landsat 8 OLI	03/01/2020	168	62	30 x 30 m	USGS

All images were downloaded during the short dry season between January-February with a resolution of 30 × 30 m, because images in the dry season are believed to have relatively less cloud cover than wet season images (Kija et al. 2020).

The wildlife populations data used in this study were both secondary and primary. The secondary data were collected from wildlife population census reports (TAWIRI 2016). The wildlife populations for the year 2020 (not covered by census report) were computed using the midpoint extrapolation method. The primary data were collected from July-August 2021 using researcher administered semi-structured questionnaires to the 322 randomly selected household heads aged above or equal to 18 years from sub-villages in Esilalei, Losirwa, Jangwani, Magadini, Loiborsiret, Narakauo, Olasiti and Vilima vitatu villages, located adjacent (closer) to protected areas.

Image pre-processing

The QGIS 3.18 was used to accomplish image pre-processing tasks such as geometric correction, visual enhancement and satellite imagery mosaicking. All images were geometrically corrected and projected into World Geodetic System (WGS) 1984 Universal Transversal Mercator (UTM) ZONE 36S to align them to their exact positions on the Earth's surface. This was followed by visual enhancement to increase the visual quality of the images. The region of interest required two satellite images that were mosaicked into one satellite imagery. Stacking of mosaic imagery and clipping the area of interest (AOI) were done in ArcMap 10.8 by using extraction by mask algorithm in Spatial Analyst Tools.

Image classification

The maximum likelihood algorithm was used to perform supervised image classification which resulted into eight LULC classes. The individual land use and land cover (LULC) classes are described in Table 2.

Table 2: Description of various land use and land cover (LULC) classes

LULC	Description
BL	Areas with exposed soils, sand and rocks, excluding those associated with agriculture
WL	A vegetated area covered by woody vegetation with a height between 6−15 m
WT	Areas covered by stagnant water and other vegetation types
SL	Land with multi-stem plants with a height between 3−5 m and open bush
GL	Areas covered by grasses, used primarily for wildlife and livestock grazing
WB	Areas that are covered by water, such as rivers, dams/ponds, reservoirs and lakes
CL	Areas that are used for subsistence or commercial farming
BU	Areas covered by residential, commercial, industrial and transportation facilities

Note: BL = Bareland, WL = Woodland, WT = Wetland, SL = Shrubland, GL = Grassland, WB = Water bodies, CL = Cropland, BU = Built-up land. Source: Modified from Kija et al. (2020).

Accuracy assessment

Classification accuracy assessment is an important component in the land mapping process, normally produced at the end of the classification process (Rwanga and Ndambuki 2017). It compares the classified map to another data source that is considered to be accurate or ground truth data in a confusion matrix. The overall accuracy, producer's accuracy, user's accuracy, and Kappa coefficient were computed following the formulas by Lillesand et al. (2015). The Kappa coefficient typically ranges from 0 to 1, where 0 means total disagreement and 1 means perfect agreement.

Land use and cover change detection

The detection of land use and land cover change was done using the normalized difference vegetation index (NDVI) differencing method and the comparison of the LULC classifications method (Sahebjalal and Dashtekian 2013). The NDVI values ranged from -1 to +1, where the values from -1 to 0.1 indicate non-vegetation such as bareland, built-up land, and waterbodies. The values from 0.2 to 0.5 indicate the grassland and shrubland covers. The high values from 0.6 to 1 indicate the dense vegetation such as forests. The comparisons of the two independently classified satellite images (2000 and 2020) were used to estimate the percentage changes between the two images. The classified imageries from ArcMap were exported to QGIS where quantification was done using

Semi–Automated Classification Plugin in QGIS software (Kija et al. 2020).

Results and Discussion

Land use and land cover types

The Landsat images covering the study area of interest for the years 2000, 2012 and 2020 were classified into eight (8) different land use and land cover (LULC) classes as presented in Figure 2.

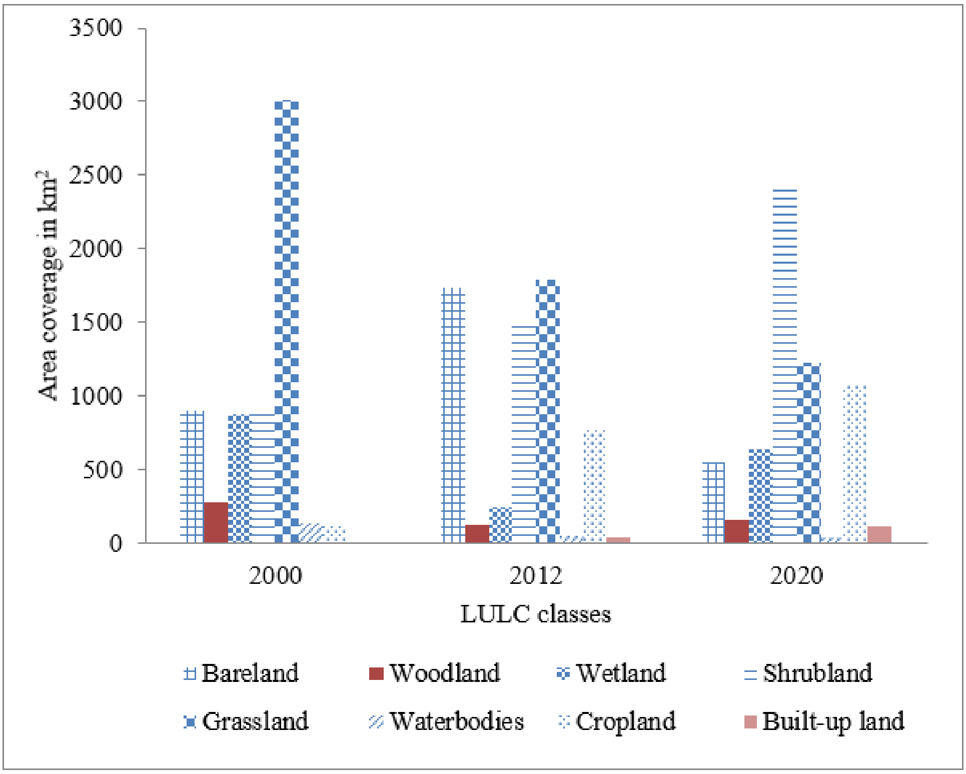

Figure 2: Area covered by each LULC types (2000-2020).

The results show that the larger portion of the land in 2000 was dominated by grassland (48.8%), followed by shrubland (14.8%), bareland (14.4%) and wetland (14.1%). The analysis of 2012 Landsat imagery has again shown grassland (28.7%) as the dominant LULC type, followed by bareland (27.8%), shrubland (23.7%) and cropland (12.3%). As opposed to the years 2000 and 2012 where grassland was the dominant LULC type, in 2020 the dominant LULC type was shrubland (39.0%), followed by grassland (19.5%), cropland (17.2%), wetland (10.3%) and bareland (8.9%). Other LULC classes: woodland, built-up land and waterbodies had relatively low area coverage over the study periods. The woodland, shrubland, grassland and wetland are the terrestrial ecosystems that provide habitats and resources to various terrestrial animal species. Different wildlife species have different requirements for both habitats and resources for their survival. Table 3 presents the widely distributed and most abundant species (wildebeest, zebra, buffalo and impala) and their associated habitat preferences.

Table 3: Selected wildlife species and their habitat preferences

Wild animals	Habitats preference
Wildebeest	They prefer grassland and open woodland habitats.
Zebra	Zebra habitats include treeless grasslands and savanna woodlands.
Buffalo	Buffalo habitats include grasslands, savanna, bushlands, rainforests, woodlands, marshes and wetlands.
Impala	They prefer areas with open grass plains, grasslands, thorn bush and savanna woodlands

Sources: Mtui et al. (2017) and TAWIRI (2016).

Land use-land cover change (2000-2020) and its implication on wildlife distribution and abundance

The results, from Figure 3 and Figure 4 show that vegetation classes have been gaining (+) and losing (-) between 2000–2012, 2012–2020 and 2000–2020.

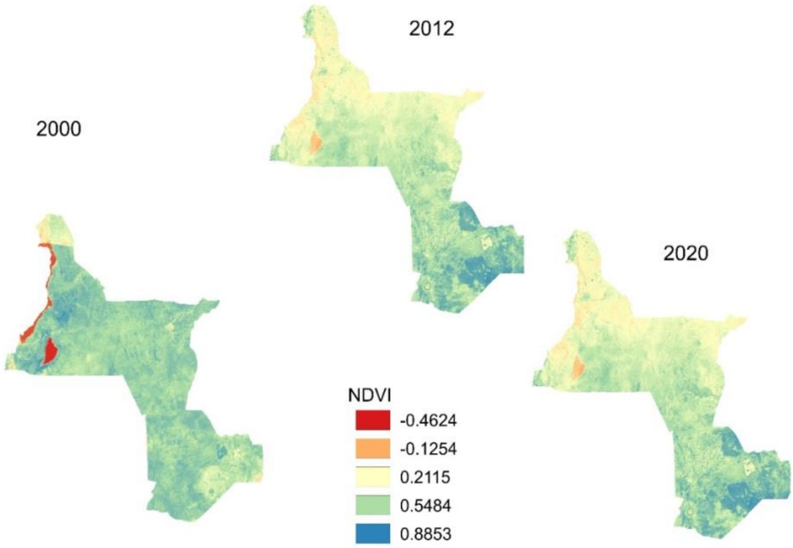

Figure 3: The NDVI image values during 2000–2020.

It is highlighted in Figure 4 that the shrubland, cropland and built-up land coverages had gained areas, while woodland, grassland, waterbodies and wetland lost their area coverages over the entire study period (2000–2020). For example, the cropland area increased from 120 km2 (1.9%) in 2000 to 771 km2 (12.3%) in 2012 to 1078 km2 (17.2%) in 2020 and the built-up land area had gradually grown from 2 km2 (0.0%) in 2000 to 118 km2 (1.9%) in 2020. While the grassland showed a decline from 3011 km2 (48.1%) in 2000 to 1797 km2 (28.7%) in 2012 to 1222 km2 (19.5%) in 2020, the woodland coverage decreased in the period between 2000 and 2012, followed by an increase in area coverage during the study period between 2012 and 2020. These results show that the shrubland, cropland and built-up land areas had been gradually increasing from 2000 to 2020 at the cost of other land types (woodland, grassland and wetland). The results are consistent with the findings of a previous study conducted by Msoffe et al. (2011) who analysed the drivers and impacts of land use changes on the Tarangire ecosystem in the Maasai steppe of northern Tanzania. Their results indicated that the wildlife migratory routes and rangelands in dispersal areas of Tarangire NP decreased between the years 1984 and 2000. The loss and gain of natural and semi natural vegetated land was used as a proxy for animal species distribution and abundance (Neldner 2018). Human disturbances in the ecosystem have been attributed to the reduced food availability, shelter, water resources, space for survival and reproduction of several wildlife populations as the areas occupied by grasslands, woodlands, shrublands and wetlands decline, hence directly or indirectly affect the ability of terrestrial animals to meet their basic needs. Therefore, species that fail to relocate their ranges or adapt to the new environment after human disturbance may accordingly decline and eventually go extinct. For example wildebeest populations in the Mara region of Kenya and Tarangire-Manyara ecosystem were reported to decline from 119,000 to 22,000 in the periods between 1977 and 1997 and declined from 44,534 to 13,603 in the years between 1990 and 2016, respectively, due to extensive conversion of woodland and grassland habitats into cropland and human settlements (TAWIRI 2016, Mtui et al. 2017).

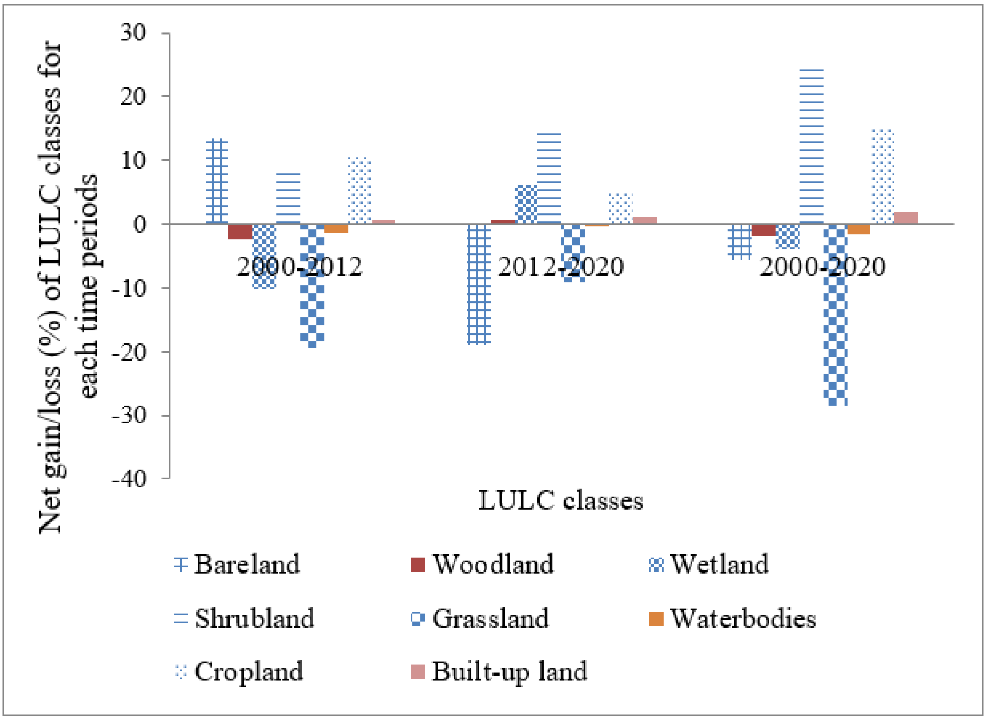

Figure 4: Land use and land cover changes (%) during 2000-2020.

Land use and land cover transitions and their impacts on wildlife distribution and abundance

The transition area matrix was generated by overlaying a previously classified LULC map with the current one for different periods, specifically the periods between 2000 and 2020. The quantities (areas in km^2) of each LULC classes changed from one land type to another (Nath et al. 2018) between time T_1 (2000) and T_2 (2020) are presented in Table 4. The diagonal and off-diagonal values in the transition area matrix indicate the areas of each LULC classes remained unchanged and the areas of LULC classes lost/gained to/from other classes, respectively. Table 5 displays the net area gained/lost for each LULC class between 2000 and 2020. The results derived from transition area matrix indicate several conversions among different land types. The large area of grassland was converted to shrubland and cropland. The woodland was converted to shrubland and the shrubland cover was then converted to grassland and cropland. These findings are in line with the findings from a similar study by Kija et al. (2020) who found that the transformations of vegetation cover into other land types such as cropland and built-up land covers were mainly linked to human population increase, settlement expansion, and agricultural activities undertaken in the study area as people struggle to meet their food needs and income. As no single land cover fits all wildlife species' needs, the conversion of one land cover to other may create favorable or unfavourable conditions among different wildlife species. The conversion of grassland to agriculture and built-up land as influenced mainly by human population growth in wildlife migratory and dispersal areas has created unfavorable conditions which led to the decline by 60% of some large wild grazers such as wildebeest, zebra, Grant's gazelle, eland and buffalo populations between 1975 and 2007. Woodland transformation into grassland and shrubland can result in an increase in grazers and browsers. The increase in shrubland resulting from the woodland conversion is reported to increase the number of buffalo, impala and greater kudu (Mtui et al. 2017).

Table 4: Land use and land cover changes transition area matrix from 2000 and 2020 in km^2

Year 2000	**Year 2020** BL	WL	WT	SL	GL	WB	CL	BU	**Total 2000**	**Gross loss**
BL	330.2	27.3	36.1	62.8	236.0	7.1	174.5	27.2	**901.2**	570.9
WL	1.0	37.8	6.0	214.7	1.0	2.8	13.6	0.8	**277.6**	239.8
WT	13.3	7.1	169.8	511.1	55.9	3.4	88.8	33.5	**883.0**	713.1
SL	2.4	19.9	142.9	622.4	32.7	1.1	98.3	5.5	**925.2**	302.8
GL	132.2	60.9	278.7	997.7	825.5	6.1	668.2	41.8	**3010.9**	2185.4
WB	57.2	2.9	5.1	19.2	4.7	22.9	16.8	8.8	**137.6**	114.7
CL	16.4	0.2	4.6	21.2	63.9	0.4	13.3	0.2	**120.0**	106.7
BU	1.0	0.1	0.4	0.1	0.1	0.0	0.1	0.3	**2.1**	1.8
Total 2020	**553.6**	**156.2**	**643.5**	**2449.2**	**1219.6**	**43.8**	**1073.6**	**118.1**	6257.6	
Gross gain	223.4	118.4	473.7	1826.8	394.1	20.9	1060.3	117.8		

Table 5: Overall LULC classes net area changes from 2000 to 2020 in km^2

LULC Classes	BL	WL	WT	SL	GL	WB	CL	BU
Gross gain	223.4	118.4	473.7	1826.8	394.1	20.9	1060.3	117.8
Gross loss	570.9	239.8	713.1	302.8	2185.4	114.71	106.7	1.8
Net area change	-347.5	-121.4	-239.4	1524.0	-1791.3	-93.8	953.5	116.0

Population changes for the four selected wildlife species in TSLME

The main reasons for the rapid decline in the populations of the four selected species (wildebeest, zebra, buffalo and impala) as reported in the first phase (1990–2007) trend were attributed to the extensive losses of the woodland and grassland covers which may have been caused by commercial and subsistence agricultural expansions in Babati, Monduli and Simanjiro districts (for example seedbeans farming for domestic and export markets in Monduli and Simanjiro districts), population growth, increased human settlements, lack of national wildlife policy before 1998, promotion of policies that emphasize expansion of agriculture and clearing vegetation, and cultural changes of Maasai people from traditionally semi-nomadic pastoralists (practising only livestock keeping) to agro-pastoralists (practicing livestock keeping and agriculture) derived from non-pastoralists ethnic groups immigration (Msoffe et al. 2011). In the second phase (2007–2016) a bit of good news on biodiversity was realized by a slight increase in the population of the four selected species. The main reasons why wild animals (the selected species) had increased over the past 10 years in the second phase can be attributed to the increased forest, wetland and shrubland as the result of the abandonment of agriculture and settlements in areas that were previously used by wildlife, planting trees, good enforcement of the laws related with wildlife conservation, implementation of national wildlife policy, good neighbourhoods between protected areas and surrounding communities, and introduction of wildlife management areas (WMAs), for example, Burunge, Randilen and Makame WMAs. These WMAs are community-based conservation areas aimed to increase community involvement and participation in wildlife management by addressing wildlife habitat fragmentation, disjointed conservation and rural poverty (WWF 2014). It was also noted that the results from a survey of local people's perception of wildlife populations over the past ten (10) years show that the majority of respondents perceived that the wildebeest, zebra, buffalo and impala had increased by (81.1%, 62.2%, 64.9%, and 82%), respectively. Some perceived the population had not changed (4%, 6.8%, 7.8%, and 6.8%), while others thought the numbers had declined (14.9%, 5.9%, 17.7%, and 8.4%). The rest of the respondents (0%, 26.1%, 9.6%, and 2.8%) did not know the status for the species in question.

Although it is seen that the four selected species are now slightly increasing (Figure 5), the overall populations of all selected species show negative trends from the 1990s. The slight increase may be due to some successes in conservation interventions undertaken by respective stakeholders.

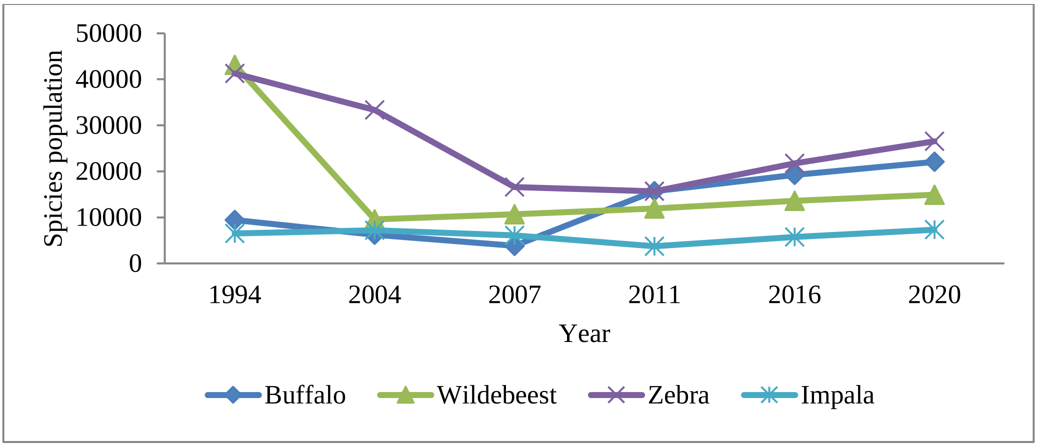

Figure 5: Selected species population trends (Source: TAWIRI 2016 census report).

Accuracy assessment

The results derived from the confusion matrix (Table 6) indicate an overall accuracy of 82.4% and Kappa coefficient of 77.0% and interpreted as guided by Rwanga and Ndambuki (2017). The kappa coefficient value suggests that the classified image is in substantial agreement with reference data.

Table 6: Confusion matrix of LULC classification for 2020 landsat image

Classified Image	Reference Data BL	WL	WT	SL	GL	WB	CL	BU	Total	User's accuracy, %
BL	1588	12	90	41	139	14	31	40	1955	81.2
WL	20	204	0	10	4	0	8	8	254	80.3
WT	48	0	409	21	14	5	0	0	497	82.3
SL	29	18	10	534	16	0	3	0	610	87.5
GL	183	21	16	18	1515	0	55	4	1812	83.6
WB	5	0	16	1	1	212	0	0	235	90.2
CL	54	4	3	4	39	0	367	1	472	77.8
B U	32	6	3	3	4	3	3	115	169	68.1
Total	1959	265	547	632	1732	234	467	168	6004	
Producer's accuracy, %	81.1	77.0	74.8	84.5	87.5	90.6	78.6	68.5		
Overall accuracy = 82.4%										

Conclusion

This study examined land use and land cover change and its implications on wildlife distribution and abundance in the TSLM ecosystem based on satellite images. The 2000, 2012 and 2020 satellite images were acquired from USGS. The images were classified into eight land types (bareland, woodland, wetland, shrubland, grassland, waterbodies, cropland and built-up land) using maximum likelihood classification procedures in ArcMap 10.8 software. The analysis of land use and land cover changes over the past 20 years showed that the study area has experienced an increase in shrubland, cropland and built up land coverages. On the other hand, wetland, woodland and grassland covers had declined. The implications of LULC changes on wildlife distribution and abundance are reflected in natural vegetation cover changes (Nyamasyo and Kihima 2014). As cropland and human settlement expansions proceed, the habitat quantities and habitat quality (suitability) are affected. The changes in habitat both quantitatively and qualitatively can affect species either positively or negatively depending on their sensitivity to changes and ecological requirements or ecological niche. For example, the losses of habitats in a landscape can isolate patches of suitable habitats thereby reducing dispersal rates and altering the spatial distribution of resources and hence affecting species distribution and abundance.

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