Discover

The factors driving land cover transitions and land degradation and the potential impacts of the proposed developments in the Isiolo dam watershed, LAPSSET corridor, Kenya

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Abstract
Isiolo dam is planned to be constructed along the Ewaso Nyiro River to provide water to the planned Isiolo resort city, one of the Lamu Port and Southern Ethiopia Transport (LAPSSET) corridor projects. This paper evaluates the factors driving land cover transitions and their effects, as a consequence of the proposed infrastructure developments with a view to providing evidence-based information for formulating policies and approaches for sustainable land management and development. Landsat images were used to assess Land Use and Land Cover (LULC) change, while land degradation was evaluated based on the United Nations Convention to Combat Desertification guidelines (2000–2020). Spatial overlays of land degradation, LULC change, population, and land tenure were performed to establish their interrelations. The results revealed that water, bareland, built-up, and forest increased by 2043%, 83%, 35%, and 17%, respectively, while shrubland and cropland decreased by 26% and 6%, respectively. Further, 61% of the watershed remained stable, 31% experienced degradation and 8% improved. The main drivers of LULC transitions, and land degradation are population pressure, land tenure, climate change and economic growth. With the development of the LAPSSET projects, it is projected that built-up areas, cropland, and bareland will increase mainly due to population increase, while the forest and shrubland will reduce mainly as a consequence of an increase in built-up areas and potentially poor land management. To achieve sustainable development with net zero loss of natural resources, proper planning for economic investments as well as inclusive land-use planning should be enhanced in drylands such as the Isiolo watershed and similar landscapes.

1 Introduction

Land use and land cover (LULC) change is the most prominent form of global environmental modification happening at varying spatial and temporal scales [74, 91]. According to Carr [11], large-scale land cover change is mostly driven by a rapidly growing population. Alterations in land use often have effects on land resources leading to land degradation, desertification, loss of biodiversity, and habitat destruction, among other deleterious effects [55]. Land degradation is defined as the loss of both economic and biological productivity of the land as a result of natural processes, land uses, or other anthropogenic activities and habitation patterns [85]. Oluwole and Sikhalazo [75] and Bunning et al. [8] define land degradation as the loss of current and future capacity of the land to produce ecosystem goods and services while

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Eswaran [20] defines it as any undesirable change on land. Mulinge et al. [63] reported that Kenya has been facing land degradation with the major issues being the loss of soil fertility through soil nutrients mining, wind and water erosion of the soils,rangeland degradation, deforestation, and desertification. Moreover, other studies have found that land degradation is more evident in Eastern Africa as compared to other parts of Africa and particularly in the North-Eastern part of Kenya [62, 84] while Le et al. [46] noted that 22% of land in Kenya was degraded between 1982 and 2006.

To achieve SDG 15 which aims to "protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss" [67], land use changes have to be controlled especially in fragile ecosystems such as the Isiolo Dam watershed. Many studies have established links between infrastructure development and changes in land use and population density. For example, Forman and Deblinger [23] and Liu et al. [49] established that the construction of a road network led to land fragmentation and change in land use patterns. Additionally, transport development has played an important role in urban development and industrialization [49, 51] and there is a higher likelihood of urban development in areas along major highways than those that are far away from roads [27, 36], while proximity to a rail network affects population distribution [3, 36, 48]. Urbanization involves the outward expansion of population centres [26] and the conversion of non-urban areas to urban areas to accommodate increasing population and urban sprawl [81, 69] leading to changes in the landscape [26]. The common drivers of LULC changes include agricultural encroachment, deforestation, road construction, dams and irrigation, wetland modification, mining, and expansion of urban environments [49]. Kenya has realised a substantial increase in infrastructure development in the recent past, especially in the real estate development, energy, and transport sectors [24]. Land parcels that were originally zoned as agricultural are being leased out for residential and commercial use while original inhabitants are moving out to peri-urban areas [38].

Isiolo dam is planned to be constructed along the Ewaso Nyiro River and its main purpose will be to provide water to the planned Isiolo resort city (one of the Lamu Port South Sudan Ethiopia Transport (LAPSSET) mega-projects). It is also expected to improve the livelihoods of the local communities by providing water for domestic use and irrigation [88] and supplying water to urban areas in Isiolo, Laikipia, and Samburu [12]. However, a dam causes detrimental environmental impacts (e.g. loss of biodiversity, sedimentation, changes in water quality and quantity) and LULC transitions, for example, conversion of natural vegetation cover to croplands motivated by the availability of irrigation water from the dam [72]. Other studies have also revealed that dam construction accelerates land degradation by increasing soil erosion, causing landslides, loss of vegetation, and submerging of croplands downstream due to overflows from the dam [30]. An environmental impact assessment indicated that the dam will have both positive and negative social and environmental impacts [12]. On the positive impacts, the dam is expected to regulate the Ewaso Nyiro River flows by storing floodwater and releasing it later to ensure sustainable water supply during all seasons, reduce water deficit in the region as well as boost opportunities for tourism and economic growth. On the other hand, the negative impacts will include, loss of biodiversity, changes in traditional land use, land degradation, and modifications of the landscape [12]. It is also important to note that most of the proposed Isiolo dam watershed lies within the drylands of Kenya which account for approximately 89% of the total landmass and are home to a third of the total human population [78] and thus more susceptible to land degradation and other environmental threats. Furthermore, these areas have great potential for tourism activities (especially wildlife tourism), renewable energy (both sun and wind), and other natural resources [5] and should therefore be highly prioritized for protection, even as development is balanced with conservation.

The proposed Isiolo dam watershed lies within the LAPSSET corridor and its geographical location is strategic for the envisioned growth in regional trade (DCP [13]. The LAPSSET project is a flagship project for Kenya's vision 2030 [77, 71] and comprises railway lines, road networks, oil pipelines, airports, dams, and resort cities [45]. The transport infrastructures planned for the LAPSSET corridor are aimed at connecting the Lamu port with the landlocked countries of South Sudan and Ethiopia thus enabling the movement of people and cargo, interconnecting the region, as well as spurring trade and economic development [45]. The road network is set to begin from the coastal town of Lamu to South Sudan with another road heading to Ethiopia with an intersection at Isiolo and is expected to transverse Garissa, Isiolo, Meru, Laikipia, Samburu, Tana River, Marsabit, and Turkana counties [45]. Along the construction of a dual carriageway road network will be a railway network, and an oil pipeline [76], DCP [13]. In the past years, a section of the Isiolo-Moyale-Hawassa road has been completed while construction of the Isiolo- Lokichar- Lodwar- Nadapal highway is yet to commence (Fig. 1). The infrastructure development is anticipated to attract substantial investments and subsequently, population influx leading to land fragmentation and encroachment into the grazing fields and hence changes in pastoral livelihoods [79].

Studies have shown that LULC change, population pressure, insecure land tenure, unsustainable land management practices, overgrazing, and economic development contribute to land degradation to a great extent [18]. An assessment of land degradation in Kenya by the Ministry of Environment and Natural resources [58] revealed that the major
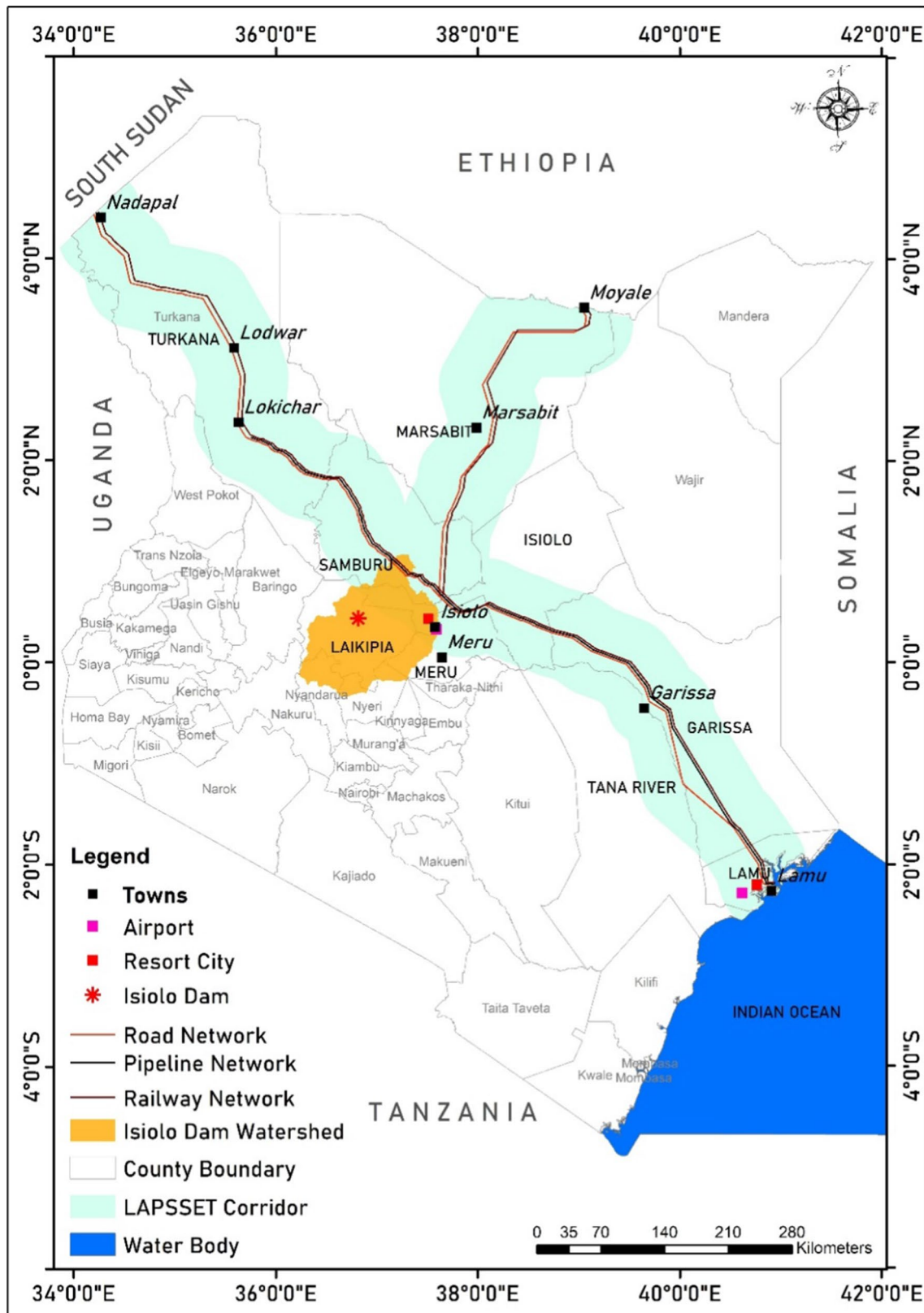
Fig. 1 The LAPPSET corridor and the locations of the key proposed projects within the corridor. Source: WWF—Kenya GIS CoE

causes of land degradation were biophysical factors such as soil erodibility, frequent droughts, climate change threats, and topography and unsustainable land uses such as overgrazing, extensive cropland, and deforestation. The unsustainable land management practices, according to Kirui and Mirzabaev, [39], are driven by poverty and insecure land tenure. This paper evaluates the factors driving land cover transitions and land degradation, and the potential impacts of infrastructure development with a view to providing evidence-based information for formulating policies and strategies for sustainable land management and development in the proposed Isiolo dam watershed, LAPSSET corridor, Kenya.

2 Study area

The watershed of the proposed Isiolo dam covers an area of 13,728 km^2 and lies between 35° 30′ and 37° 50′ East and 1° 30′ N and 0° 30′ S (Fig. 2). It spans the humid highland areas of Mount Kenya in the south to the drylands in the north where the dam structure will be located. The watershed, with an altitude range of 849 to 5044 m.a.s.l, is divided into five agro-ecological zones: upper highland zones at the foot of Mt. Kenya and Aberdare ranges; lower highland zones; upper midland zones, and; inner lowland zones in Isiolo and Samburu Counties [57]. The annual rainfall varies from 300 mm in the northeastern areas of the watershed to 1,500 mm per year in the Aberdare range and Mt Kenya. The mean annual temperatures also vary spatially across the watershed and range from less than 10 °C at the top of Mt. Kenya to over 24 °C at Archer's Post [6, 65].

The rivers in the watershed originate from Mt Kenya and the Aberdare Range. Ewaso Nyiro River, which runs through the centre of the watershed, originates from a glacial terminus on Mt Kenya and is joined by Sagera river, a tributary from the Aberdare range forest. Aberdare range forest, Mt Kenya Forest, and Mukogodo forest form the greater forest cover in the watershed while other forests are Ngare Ndare, Marmanet, Rumuruti and Leshau [86]. Below the Mt Kenya
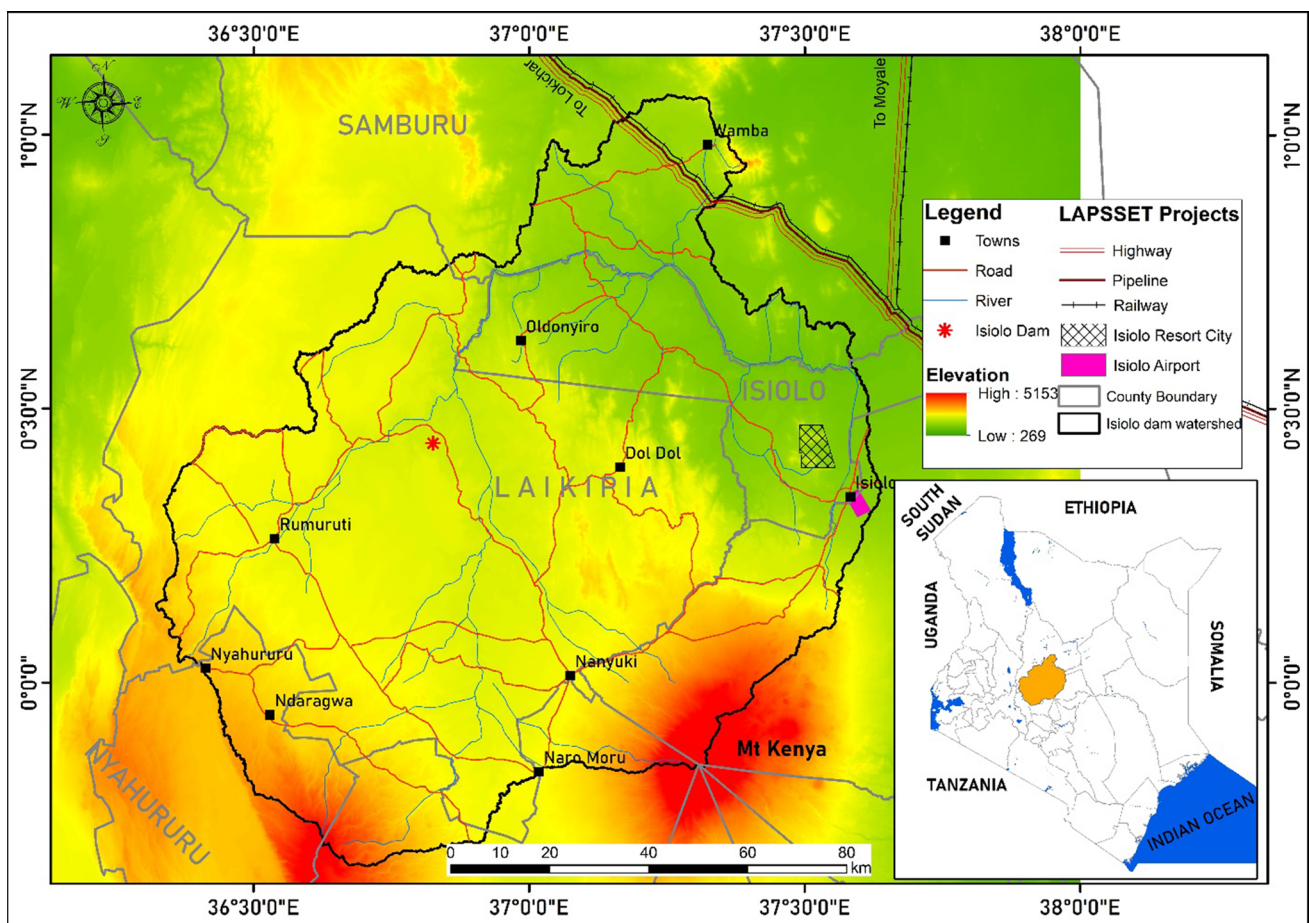

Fig. 2 Location of the proposed Isiolo Dam watershed and LAPSSET projects. Source: WWF—Kenya GIS CoE

and Aberdare Range forest, the Isiolo dam watershed is characterized by dryland indigenous trees, mainly; *Acacia mellifera*, *Acacia sey*al, *Acacia nilotica*, *Acacia senegal* and *Acacia tortillis* and an undergrowth of shrubs and grasses such as *Cyperus esculentus, Cynadon Nlemfuensis, Eragrostis tenuifolia, Eleusine indica, Digitalia* spp. *and Dactylectium* spp. [9]. The watershed covers part of the upper Ewaso Nyiro catchment area whose landscape is composed of communal pastoral lands, community conservancies (areas that are owned by communities and are utilized for other land uses and mostly pastoralism in addition to wildlife conservation), private wildlife conservancies (areas owned and managed by individual land owners, a group of owners or an organization for the purpose of wildlife conservation and other compatible land uses for the benefit of the people), and ranches. The primary livestock in the ranches are cattle (mainly beef cattle), sheep, and goats.

The average population density for the watershed increased from 40 people/km^2 in 1999 to 49 people/km^2 in 2009 and 58 people/km^2 in 2019 [12]. The ethnicity of the inhabitants of the watershed comprises pastoral communities (Samburu, Maasai, Rendile, Gabra, Boran and Somali) living side by side with Turkana, Pokot, Kikuyu, and Meru who are involved in other economic activities such as agri-business. The northern part of the watershed is inhabited by pastoralists and there is widespread overgrazing, soil erosion, and land degradation [19]. The livestock kept include cattle, sheep, goats, camels, and donkeys and the numbers have been increasing over time [12]. The total population of livestock in the three counties (Laikipia, Isiolo and Samburu) within the watershed was 3,032,807 in 2009 and increased to 5,289,085 in 2019 [41, 42].

3 Methodology

3.1 Land Use and Land Cover (LULC) assessment

Landsat-5 TM (for 2000 and 2010) and Landsat 8 ETM (2020) satellite images with a resolution of 30 m from U.S Geological Survey (USGS) (https://glovis.usgs.gov/) were retrieved for classification. Image retrieval was undertaken in Google Earth Engine (GEE). Images of four scenes, (path/ row) 169,060, 169,059, 168,060, and 168,059 were retrieved, selecting images of cloud free (< 5% cloud cover), filtering between January and March, which is generally a dry period thus presenting clear images with minimal cloud cover. The script was configured to cloud masking, image band combination resulting to Landsat mosaic imagery. Supervised classification using maximum likelihood algorithm analysis was performed on the mosaic. Based on the standardized AFRICOVER system for the Africa region [15], six LULC classes were considered, namely,forest, cropland, water, bareland, shrubland and built up. Shrubland LULC class comprised shrubland, grasslands and woodlands and this was based on the description of shrubland as the vegetation of different species with a height of between 10 cm and 2 m [47]. Post classification was done by manually adjusting the classification based on field information. The calculation of the areas covered by various LULC classes was done in ArcMap. Accuracy assessment was performed to validate the classified images and this involved overlaying 200 randomly selected points from the classified images (classified points) and their corresponding points from the google earth images (observed points) in Google Earth Pro. The classified and observed points were tabulated in a confusion matrix to establish the user and producer accuracies [10]. User accuracy is the proportion of the total number of pixels assigned to a particular LULC that are classified correctly, while producer accuracy is the proportion of the total number of pixels belonging to a LULC class that are correctly classified under that LULC class [4, 10].

3.2 Land degradation assessment

Apart from the LULC transitions in the area, we also analysed land degradation over the same period (2000–2020) in the watershed. This is in line with SDG 15 (life on land) which aims "to combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world" by 2030 [67]. The United Nations Convention to Combat Desertification (UNCCD), under good practice guidance, has identified three sub-indicators for determining land degradation, namely,productivity, land cover, and soil organic carbon. Productivity is the biological productive capacity of the land (the source of all the food, fibre and fuel that sustains humans) and is estimated from the analysis of the Normalized Difference Vegetation Index (NDVI). Changes in land productivity point to long-term changes in the health and productive capacity of the land and reflect the net effects of changes in ecosystem functioning on plant and biomass growth. This assessment includes only above-ground productivity and can be applied to all natural and anthropogenic terrestrial environments [80]. Land cover as defined by UNCCD [85] is the observed physical cover of the earth's surface and provides the first indication of a reduction or increase in vegetation,

habitat fragmentation and land conversion. Carbon stock is the amount of carbon in a pool [85]. A pool is defined as a system that can accumulate or release carbon and include biomass (above-ground and below-ground biomass; dead organic matter (deadwood and litter); and soil (soil organic matter) [29].

Land degradation was analysed based on the baseline assessment and evaluation of the three sub-indicators; land productivity, land cover and soil organic carbon (UNCCD, 2005; [56]. Land degradation is determined by assessing the changes in the three sub-indicators which are depicted as positive/improving, stable or unchanging and negative/declining. Land productivity was calculated from NDVI dataset from Modis (MOD13Q1, annual) satellite. The soil organic carbon was evaluated using the inbuilt soil dataset originally obtained from the International Soil Reference and Information Centre (ISRIC) (https://www.isric.org), while the land cover datasets produced during this study were uploaded into the platform and used to evaluate the land cover sub-indicator. The three sub-indicators were computed on cloud based google earth engine platform, linked to the Qgis Trends.Earth Plugin to produce degradation status of the watershed [83]. The land is considered degraded if there is a significant reduction or negative change in any one of the three sub-indicators. The results are presented in percentages (the proportion of land that is degraded over the total land area) [80].

3.3 Factors driving the LULC transitions and Land degradation

Based on previous studies, the factors that were considered were population density, livestock population, and land tenure/ownership [14, 17, 90]. Under the land tenure, we found that the area is classified as either private conservancies, community conservancies, ranches, forest reserves, or protected forests, and the rest are either community or privately owned lands. Community conservancies are areas that are owned by communities and are utilized for other land uses and mostly pastoralism in addition to wildlife conservation. Private wildlife conservancies are those areas owned and managed by individual land owners, a group of owners or an organization for the purpose of wildlife conservation and other compatible land uses for the benefit of the people [9]. Forest reserves are those that are open to the community for grazing and crop growing ('shamba system'), while no community activities are allowed in protected forests. Spatial overlays of population density versus LULC, population density versus land degradation, conservancies/ranches/protected areas versus LULC, and conservancies/ranches/protected areas versus land degradation were performed in ArcGIS to establish the co-relationships between population distribution, land tenure, LULC changes and land degradation. The data on conservancies and ranches (land tenure/ownership systems) were obtained from Butynski & de Jong [9], while the population data were acquired from the census reports [40, 41], and [42]. The data on protected areas was obtained from the Regional Centre for Mapping of Resources for Development (RCMRD).

4 Results

4.1 Accuracy assessment

The overall accuracies for the LULC results were 84% (2000), 86% (2010), and 85% (2020) while the kappa index was the same (0.90) for the three epochs (Table 1). The accuracy results were above the acceptable threshold of 81% [87] and therefore the classified images were considered good for the analysis of LULC transitions in the watershed. The higher accuracy was achieved through post-classification where the classified maps were overlaid with other geo-referenced data e.g. transport networks, water bodies, urban centres, and forests among others [31]. This reduces classification mismatch which is a common challenge in remote sensing data [50].

4.2 Land Use and Land Cover (LULC) patterns

The results show that the Isiolo dam watershed is predominantly dominated by shrubland and bareland (Table 2). The shrubland occupies the central part of the watershed (Laikipia plains), while the north eastern region is covered by bareland (Samburu and Isiolo counties). Croplands are concentrated in the south eastern (Nyeri and Meru counties) and western regions touching the slopes of Mount Kenya and the Aberdare Range. Built-up areas are concentrated in the southern and western parts of the watershed while forests are found mostly in the southern part of the watershed (Fig. 3).

Most part of the watershed was covered by shrubland, followed by bareland, then cropland, forest, built-up and water in that order in the three epochs (Table 2).

Table 1 Accuracy assessment of LULC classification for the Isiolo dam watershed

	2000		2010		2020	
	User Accuracy (%)	Producer Accuracy (%)	User Accuracy (%)	Producer Accuracy (%)	User Accuracy (%)	Producer Accuracy (%)
Shrubland	91	96	94	85	93	90
Cropland	83	71	83	91	92	79
Bareland	90	95	86	93	79	94
Forest	94	83	88	100	93	93
Built up	92	86	90	82	86	100
Water	100	100	100	100	100	100
Accuracy	Accuracy: 84% Kappa: 0.9		Accuracy: 86% Kappa: 0.9		Accuracy: 85% Kappa: 0.9	

Table 2 Land Use and Land Cover distribution in the Isiolo Dam watershed

LULC	Area covered					
	2000		2010		2020	
	km²	%	km²	%	km²	%
Shrubland	8415.00	61.30	6996.00	50.96	6228.00	45.37
Bareland	2255.00	16.43	3364.00	24.50	4121.00	30.02
Cropland	1707.00	12.43	1631.00	11.88	1606.00	11.70
Forest	1050.00	7.65	1384.00	10.08	1225.00	8.92
Built Up	294.00	2.14	330.00	2.40	398.00	2.90
Water	7.00	0.05	23.00	0.17	150.00	1.09
Grand Total	13,728.00	100.00	13,728.00	100.00	13,728.00	100.00

4.3 Land Use and Land Cover Changes in the proposed Isiolo dam watershed

From the analysis, we noted that bareland, built up and water areas increased, while cropland and shrubland reduced in the entire period (Table 3). Forest had an interesting trend in that there was an increase in the 2000–2010 period and a decrease in the 2010–2020 period, with an overall increase in the entire period (2000–2020). For the LULC classes that increased the highest change was in the water (+ 2042.86%), then bareland (+ 82.75%), built-up (+ 35.37%) and lastly forest (+ 16.67%). On the declining LULC classes, the highest was shrubland (− 25.99%), followed by cropland (− 5.92%). It is important to note that the percentage changes in all the LULC classes were higher in the period 2000–2010 except for the water and built-up areas where more changes took place in the period 2010–2020.

4.4 Land degradation assessment in the proposed Isiolo dam watershed

Analysis of land degradation between 2000 and 2020 indicates that 60.71% of the entire watershed has remained stable with no degradation, 31.32% has experienced degradation while 7.97% of the land has improved. Degradation has occurred largely in the north eastern part of the watershed; the western and southern regions have remained stable while the transition zone (between the stable and degraded areas) in the central part of the watershed has improved over the entire period (Fig. 4).

   The results also revealed that between 2000 and 2020, land productivity remained unchanged in most of the watershed (61.56%), reduced (31.26%) and increased (7.19%) in the watershed. The areas whose productivity has remained stable include Rumuruti and Nanyuki, those that have experienced productivity loss are Wamba, Doldol and Oldonyiro, while Kisima, Mpala, Sosian and Ngare Ndare conservancies have experienced increased productivity. The tree-covered and artificial (built-up) areas increased while shrubland, cropland, and wetland reduced during the period. Further analysis on the land cover transition revealed that 0.29% of tree-covered areas were converted
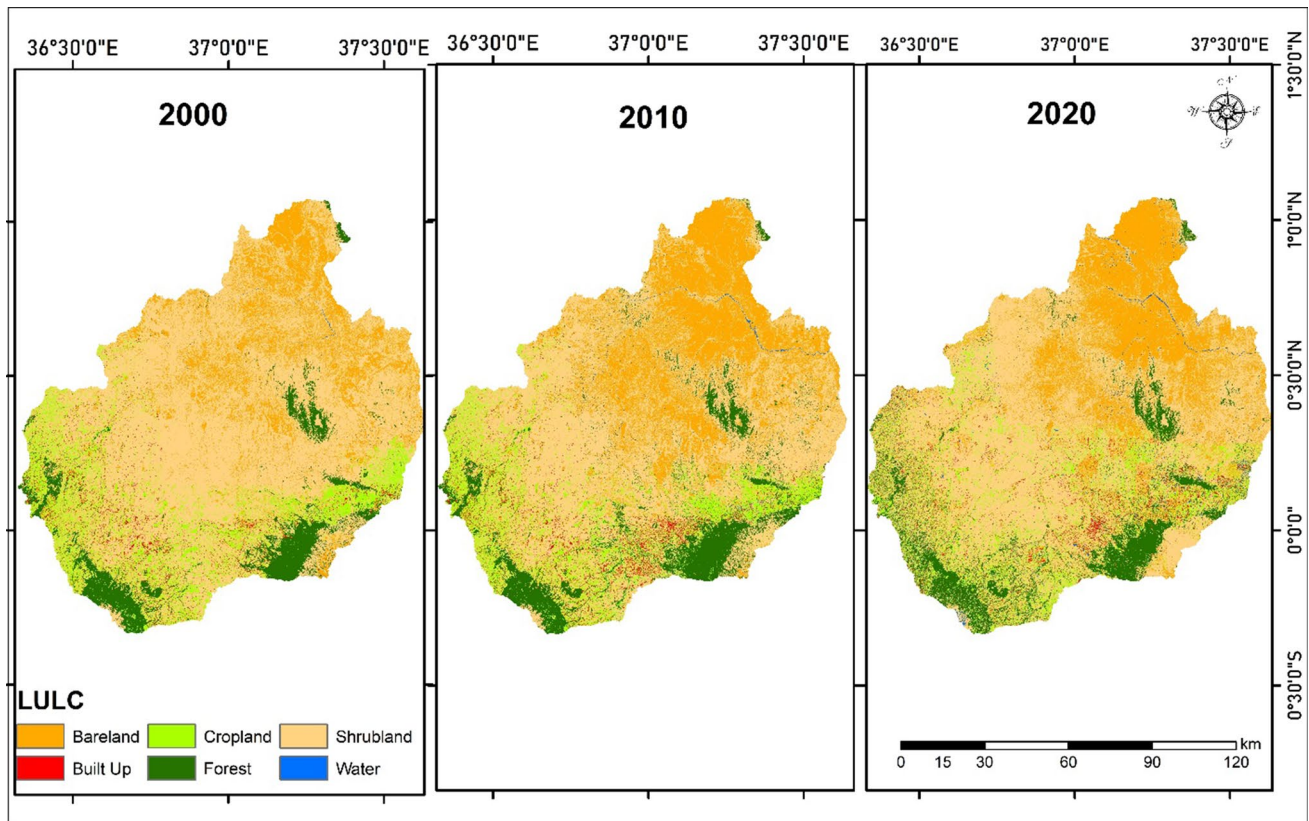
Fig. 3 Land Use and Land cover in Isiolo dam watershed 2000–2020

Table 3 LULC changes in the proposed Isiolo dam watershed

LULC	Changes					
	2000–2010		2010–2020		2000–2020	
	km²	%	km²	%	km²	%
Shrubland	− 1419.00	− 16.86	− 768.00	− 10.98	− 2187.00	− 25.99
Bareland	1109.00	49.18	757.00	22.50	1866.00	82.75
Cropland	− 76.00	− 4.45	− 25.00	− 1.53	− 101.00	− 5.92
Forest	334.00	31.81	− 159.00	− 11.49	175.00	16.67
Built up	36.00	12.24	68.00	20.61	104.00	35.37
Water	16.00	228.57	127.00	552.17	143.00	2042.86

to shrubland; shrubland was converted to cropland (0.06%), artificial areas (0.01%), and others (0.001%); cropland was converted to tree-covered (1.90%), and shrubland (0.20%), while 1.90% of the wetlands was converted to shrubland. Organic carbon stocks in the tree-covered areas increased by 7.38%, artificial areas experienced a 300% increase and other land cover increased by 0.26%. However, shrubland, wetlands and croplands lost 2.62%, 1.86% and 1.46% of their carbon stocks, respectively.
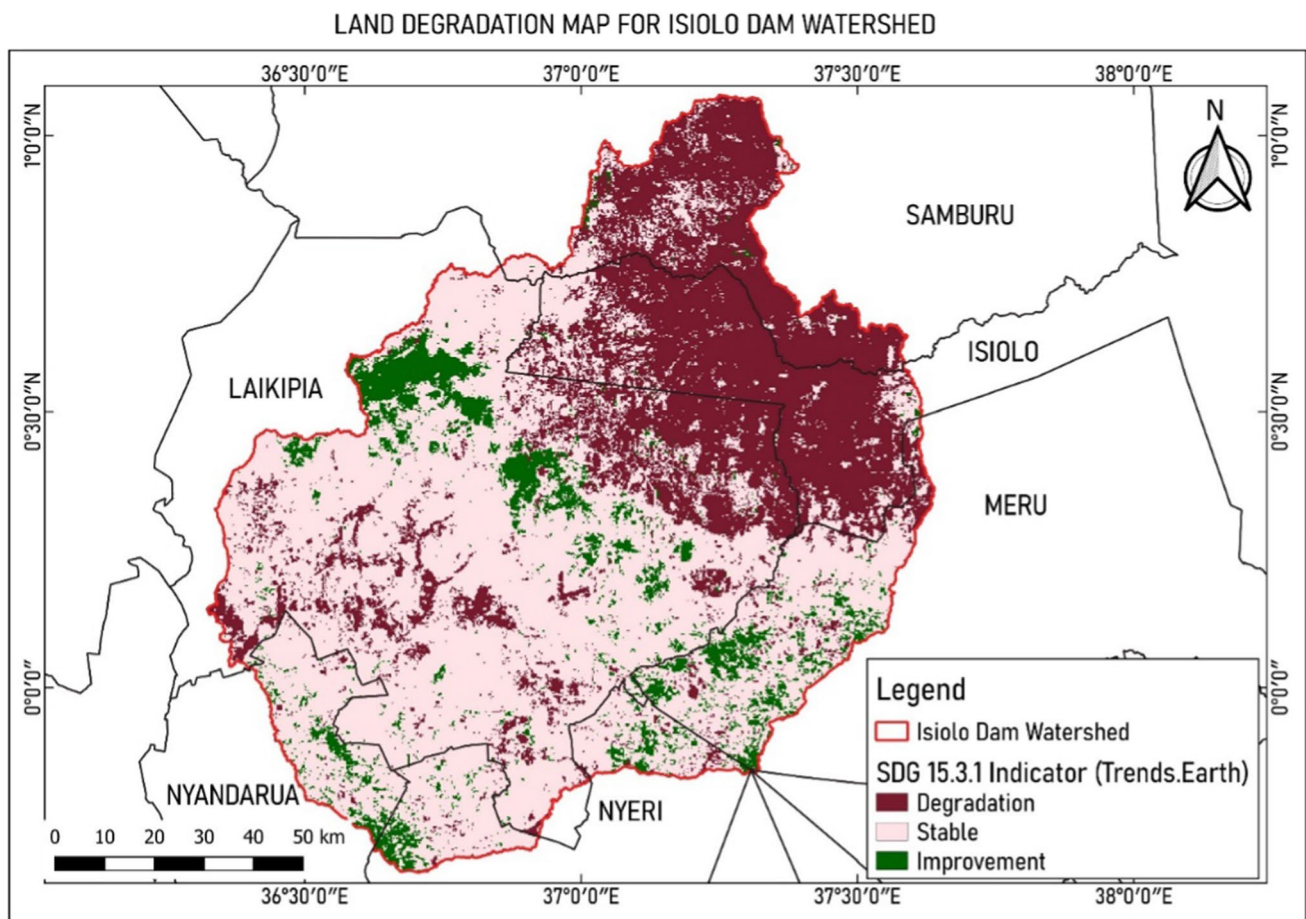
Fig. 4 Land degradation in Isiolo dam watershed

4.5 Factors driving LULC changes and Land degradation in the proposed Isiolo dam watershed

4.5.1 Land tenure and land degradation

The analysis of degradation in relation to the land ownership/tenure system in the area shows that most of the ranches have either remained stable or improved over the study period (Fig. 5).

The results further show that some of the forest reserves such as Marmanet, Rumuruti and Mukogodo have been degraded while the protected forests (Aberdare and Mt Kenya) have generally experienced improvement and stability with very small portions of degradation. The forest reserves have been degraded because they are open to community activities such as livestock grazing and crop growing, while such activities are prohibited in the protected forests. It is also important to note that the two protected forests are also classified as water towers and national parks and thus a lot of protection and conservation measures have been put in place, especially in the last two decades.

Most of the areas covered by conservancies are drylands and have been degraded substantially except the Ol pejeta, Borana and Lewa conservancies which have remained stable with minimal degradation. The only conservancies that have encountered some improvement are Loisaba and Ol Jogi wildlife conservancies. In essence, the community conservancies have been degraded while the private wildlife conservancies have undergone improvement or generally remained stable (Fig. 5).
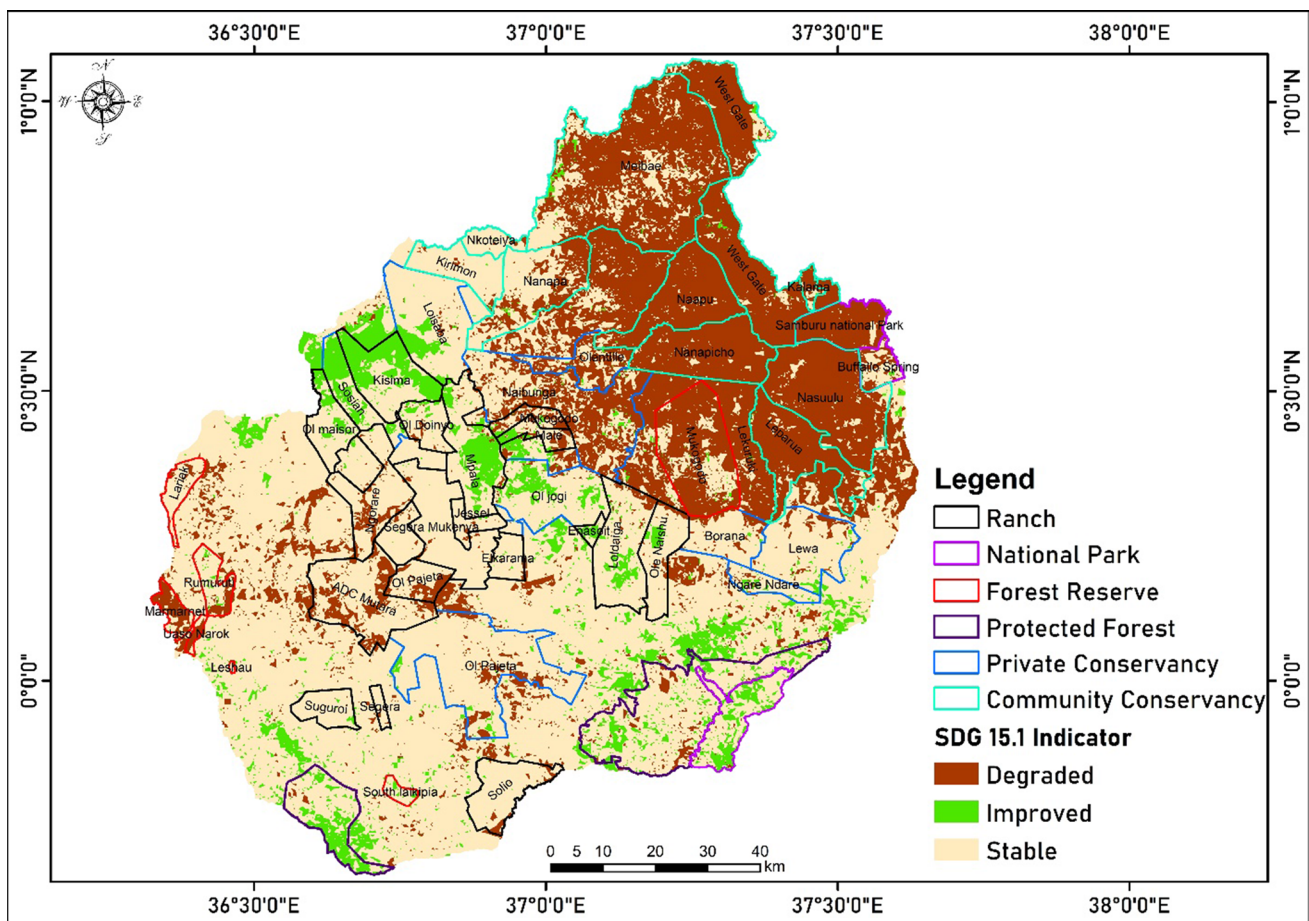
Fig. 5 An overlay of degradation and land tenure/ownership systems

4.5.2 Population density and land degradation

The counties in the watershed, i.e. Isiolo, Samburu and Laikipia have experienced high population growth between 2000 and 2020, with an increase of 165%, 116% and 61%, respectively [40–42]. We analysed the impact of population density on land degradation in the watershed in the period 2000 to 2020 and the results indicate a positive correlation between population density and the land degradation status (Fig. 6). The results also revealed that the areas that have either encountered improvement or remained stable have also maintained their population densities with negligible changes. We also noted a lot of degradation in areas around Marmanet and Rumuruti forest reserves and this could be due to the increased population density over the period (Fig. 6).

We also noted that the areas inhabited by pastoralists (communal or community-owned lands) have undergone a high degree of degradation which could be related to a high increase in livestock population in the fragile dryland ecosystem. For example, Samburu, Isiolo and Laikipia have experienced a high increase in livestock population in the period between 2009 and 2019: Isiolo, cattle (36.88%) sheep (136.22%), goats (158.21%) and camels (280.87%); Laikipia, cattle (42.38%), Sheep (80.04%), goats (42.37%), camels (179.24%); Samburu, cattle (54.68%), sheep (46.19%), goats (30.11%), camels (46.76%). Besides, the results of the overlay of degradation and conservancies (Fig. 7), show that the areas occupied by community conservancies have experienced high rates of degradation as compared to the wildlife conservancies.

4.5.3 Population density and LULC

We overlaid population density and LULC cover to elucidate the spatial and temporal variation of population density in relation to LULC (Fig. 7).
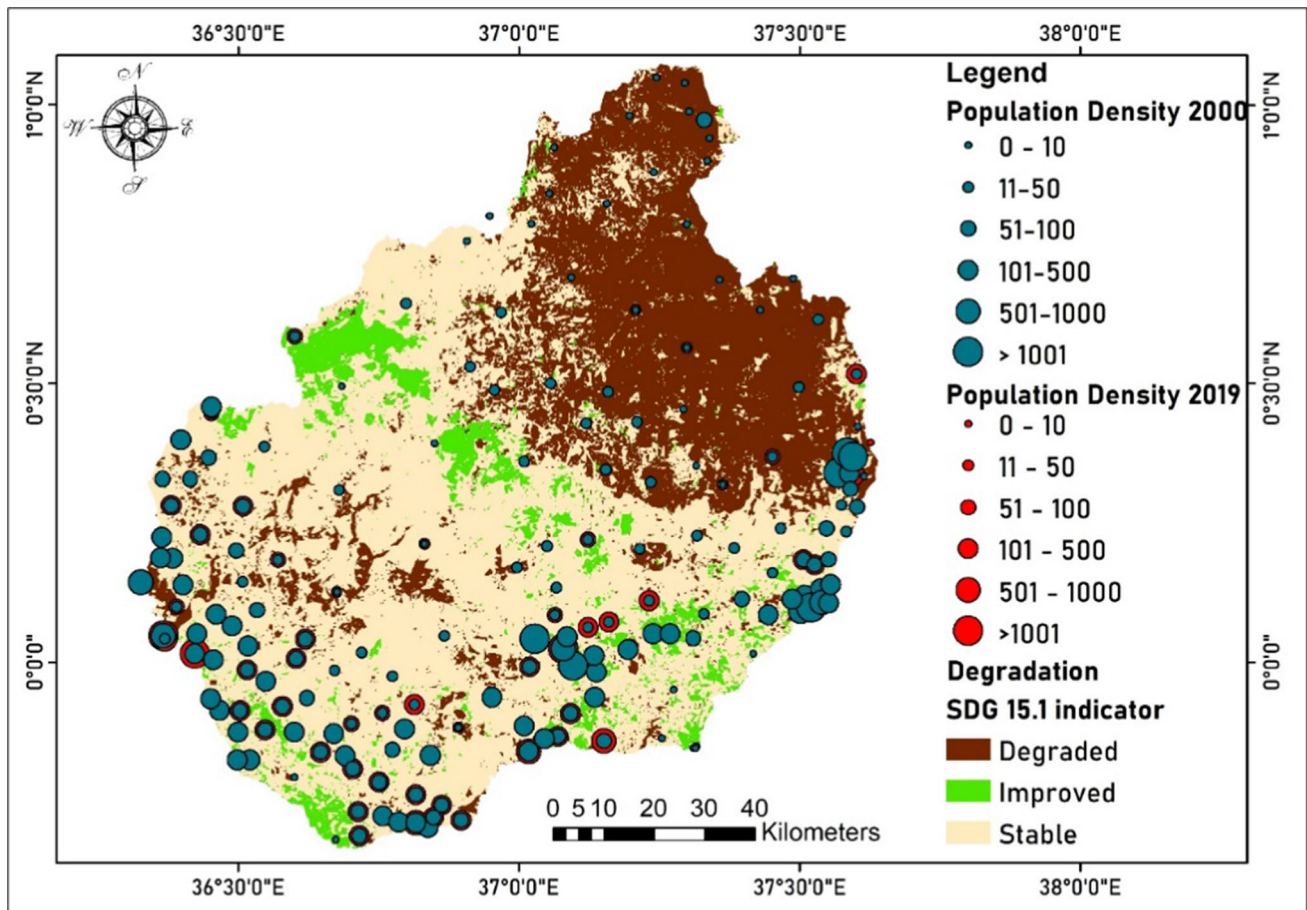
Fig. 6 Population density versus land degradation

The results on the LULC and population density revealed that urban areas in the watershed have experienced increased population density and built-up areas in the period between 1999 and 2019, while the rural areas have maintained low population density. Agricultural areas in the watershed have also experienced a rise in the human population. We also observed that the population is denser in the agricultural areas as compared to bareland and shrubland (Fig. 7).

4.5.4 Land tenure and LULC

Overlays of LULC and land tenure systems were also performed to ascertain the influence of land tenure systems on the LULC changes in the watershed (Fig. 8).

The results on the LULC revealed that forests increased in the period 2000–2020 (Table 2) and on overlaying the LULC maps with the land tenure systems, we found that most of the forest increases are within the protected forests such as Mt Kenya and the Aberdare (Fig. 8). The results also show that a substantial amount of trees have been planted within the privately-owned agricultural lands over the period, especially in the southern part of the study area. The overlay results further show that some wildlife conservancies have changed from bareland to other LULC e.g. most of Loisaba changed from bareland to shrubland while most of Ol Jogi changed from bareland to shrubland and croplands, and this conforms with the degradation analysis results that showed improvements in these two conservancies. Most of the lands outside the conservancies and protected areas have had an increase in built-up areas which have replaced most of the agricultural lands and shrubland. It is quite apparent from our results that the highest increase in the built-up class has occurred in the cropland areas (Fig. 8). We also observed that most changes in LULC took place in the community conservancies and in the areas inhabited by the communities (privately or communally owned) while the protected areas, ranches and wildlife conservancies experienced minimal changes. The results on the LULC assessment are in harmony with those of land degradation analysis. The areas of the watershed within Samburu and Isiolo have experienced a reduction in biomass
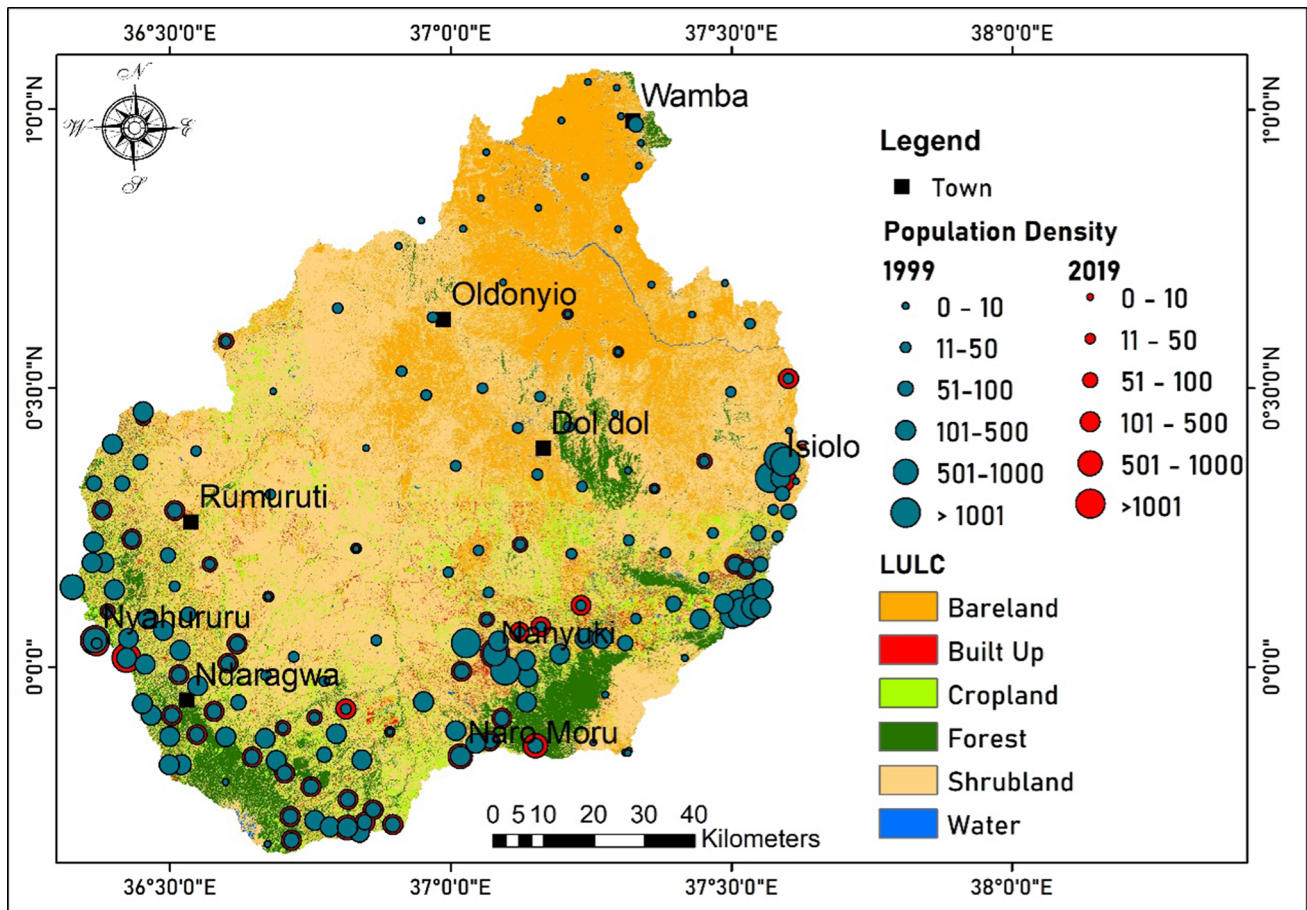
Fig. 7 LULC 2020 versus population density (1999–2019)

due to increased bareland thus high degradation, whereas forested areas of Mt. Kenya and Aberdare have experienced an improvement due to increased biomass occasioned by increased forest cover.

4.6 Hotspots of LULC changes in the proposed Isiolo dam watershed

A map based on the spatial distribution of the negative LULC changes vis-a-vis the proposed LAPSSET developments, the existing roads and towns, shows a clear relationship between the magnitude and direction of LULC changes and the location of the roads and towns (Fig. 9). The negative changes entailed the changes from shrublands/grasslands or forests to built-up, bare land or crop land; and conversion from cropland to either built-up or bareland. It was noted that most of the conversions to built-up areas occurred along the roads and also around the urban centres/towns. This is a clear indication that if more urban centres and roads are developed without proper planning then more negative transitions will occur in the watershed in the future. We also noted that some of the changes to bareland occurred along the roads though not as significant as those that occurred in the drylands (northern part of the watershed) which are mainly conversions from shrublands. The conversions to croplands seem to be occurring alongside the roads and in places where built-up areas and settlements are concentrated.

5 Discussion

5.1 Land use and land cover transitions

The results of the LULC analysis indicate that LULC transitions have occurred in the study area over the period 2000–2020 and different factors have influenced the changes and spatial distribution of the LULC to varying extents. The watershed is
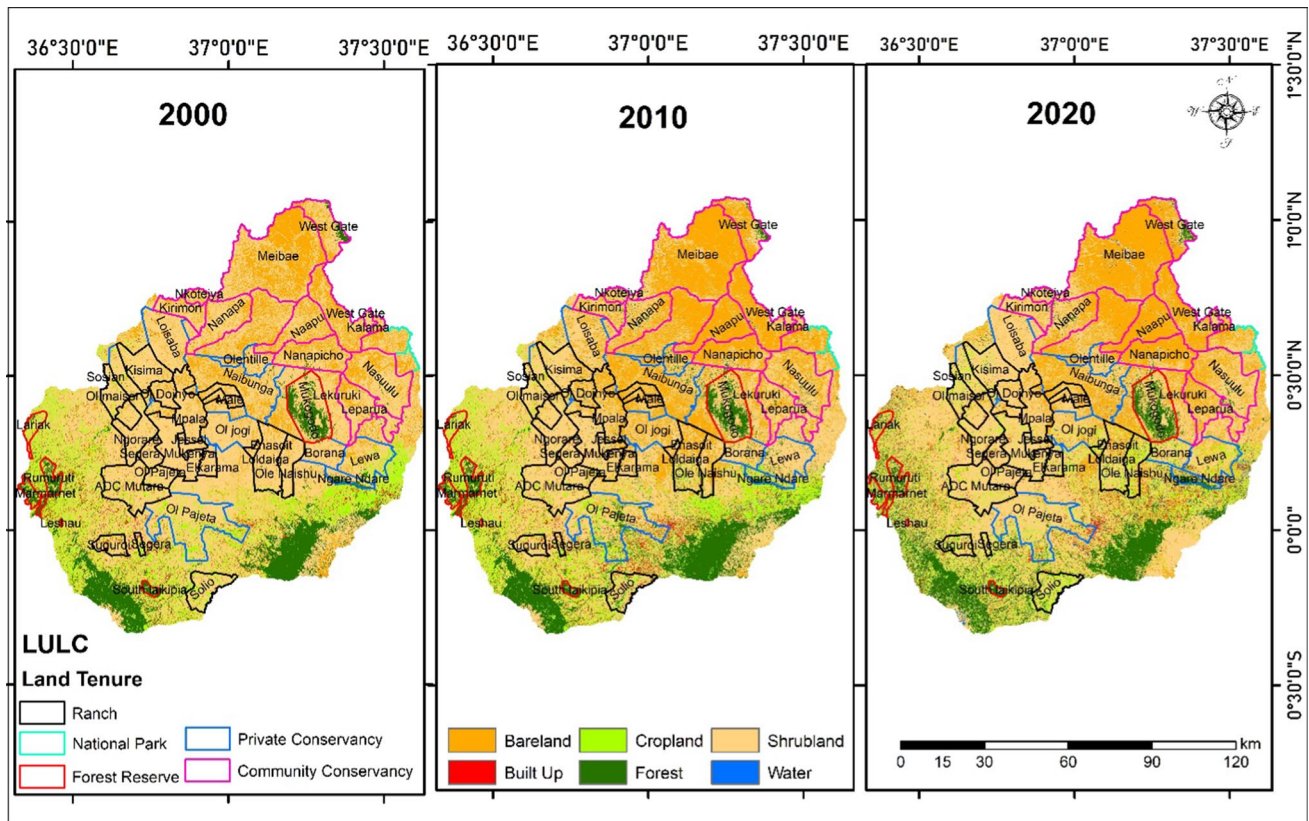
Fig. 8 LULC versus land tenure/ownership 2000–2020

dominated by shrublands which are mostly under communal land trust ownership and private ranches [88]. Agricultural activities are concentrated at the footslopes of Mt Kenya and Aberdare ranges because of water availability from the rivers that originate from these two water towers. It is also important to note that the footslopes of Mt Kenya receive high precipitation and have high soil fertility [9, 52]. Additionally, the landmasses of Mt Kenya and Aberdare Range provide a significant climate influence favourable for agricultural activities [25].

5.1.1 Croplands

The study established that cropland has reduced over the study period and this conforms with the findings of Butynski & de Jong [9] which revealed that the reduction of farmland is common in many rural landscapes. According to our results, most of the croplands have been converted to tree-covered areas and shrubland. With climate changes witnessed in recent times, the Mt. Kenya water tower which feeds the Ewaso Nyiro River is undergoing a rapid change with a decline in glaciers [66, 70, 89]. Due to receding glaciers, the water flows in the Ewaso Nyiro river (the source of most irrigation water in the catchment) have reduced thus affecting agricultural production since agriculture in the region is mostly dependent on irrigation from surface water [22, 34]. Crop production has also been negatively affected by the rise in temperature linked to climate change [28, 32, 54].

5.1.2 Forest

The results indicated a general increasing trend in forest cover in the period between 2000 and 2020 in the watershed [21, 37]. According to Muriithi [64], Mt Kenya forest experienced rapid deforestation in the 1980s and this led to a concerted effort among the government and other environmental conservation bodies to restore and conserve the forest. The 'shamba system', one of the measures that were introduced in Kenya in 1910 to curb deforestation by allocating plots at the forest edge to farmers to take care of tree seedlings as they cultivate food crops accelerated the conversion of forestland to cropland and was thus banned in 1987 by a presidential decree [33]. Additionally,
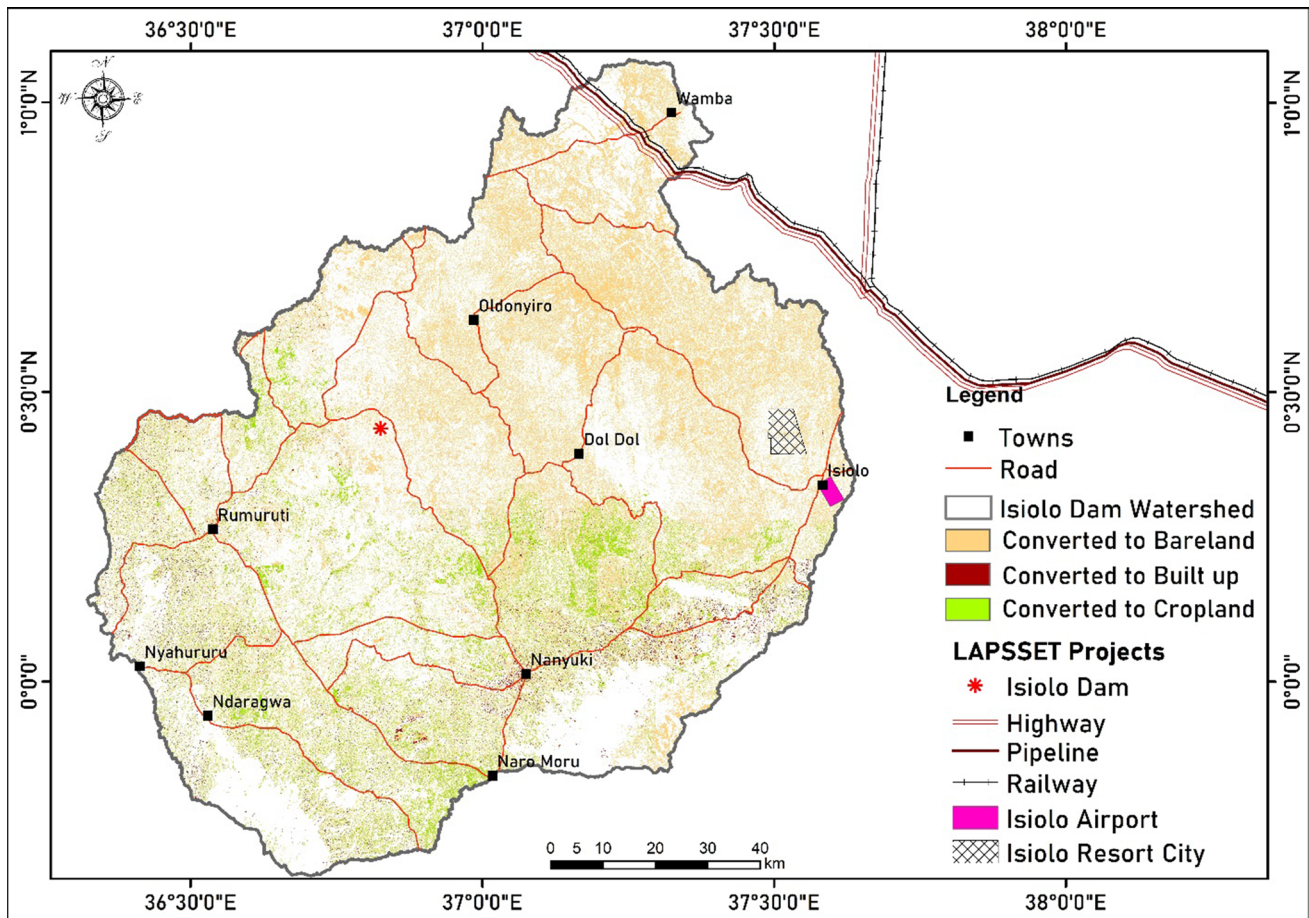
Fig. 9 The undesirable LULC transitions in relation to the location of the existing roads and towns as well as the key proposed LAPSSET developments

the forest was declared a UNESCO world heritage site in 1997 [35], and this enhanced forest conservation in Mount Kenya. Other forest conservation areas include Ngare Ndare which is a community-owned forest that was declared a UNESCO world heritage site in 2013. Another effort that has led to the conservation of forests is the formation of the Laikipia Wildlife Forum (LWF), which provides the communities with sustainable ecosystem management skills for the conservation of the natural environment [9, 52, 86].

5.1.3 Shrubland and bare land

We also noted that there has been a decline in shrubland and an increase in barelands and built-up areas and this is mainly attributed to human and livestock population pressure. This indicates that the shrubland was converted mostly to bareland or built-up areas, particularly in the lowland areas of the watershed. This change can be attributed to overgrazing due to the increased livestock population while the conversion to built-up areas is due to the rising human population and urbanization. This agrees with the findings of Muriithi [64] which indicate that most regions of East Africa have been experiencing a decline in vegetation cover mainly due to population pressure. This also conforms with Mutiga et al. [65], who noted that LULC changes are closely linked to an increase in human and livestock populations. The conversion from shrubland to bareland could also be due to climate variability and change which is being experienced in the region. Studies have found that climate variability and change evidenced by erratic and low rainfall, frequent and intense droughts being experienced especially in the drylands have had adverse impacts on vegetation cover among other social and environmental effects [53, 54, 60].

5.1.4 Built-up areas

Built-up areas have increased in the study area due to an upsurge in population that has been accelerated by the development initiatives in the area. The development projects e.g. airport and roads have contributed to the growth of urban centres by spurring investment in real estate, and hotels due to an increased number of tourists visiting the area because of improved accessibility, among many other developments. Many job opportunities have come up causing a massive influx of investors and job seekers. Similar observations were made by Mohammed and Oduori [59] who reported that the area around the Isiolo airport which was previously dominated by acacia trees and grazing livestock, is now being heavily dominated by real estate development. This explains the increase in the built-up areas in the watershed over the study period as shown by our findings. Nnaji et al. [68], also observed that most rangelands have been converted to residential and croplands due to an upsurge in urbanization and enhanced food production to meet the demand of the increasing population.

5.1.5 Water

Water covered the smallest area of the watershed and water resources are very limited though our results show a high percentage increase over the study period. This could be attributed to a slight increase in rainfall in some sections of the watershed linked to climate change and variability [28]. The changes in land use especially the rise in built-up areas results in high storm runoff [44] and hence more water observed in the region.

Generally, most changes in LULC took place in the community conservancies and in the areas inhabited by the communities (privately or communally owned) while the protected areas, ranches and wildlife conservancies experienced minimal changes. This could be due to the local communities, neglecting to collectively manage natural resources in a more sustainable manner, or their lack of financial and/or technical capacity necessary for the effective adoption and implementation of sustainable land management practices.

5.2 Land degradation

Generally, the land degradation results showed that most of the watershed has remained stable and this agrees with the findings by CAS [12] which showed that a significant part of the watershed (especially the areas occupied by communal and private ranches) has remained stable with minimum human modification due to low population density (less than 42 people/km^2). Our study further revealed that a portion of the watershed (31.26%) has lost productivity over the study period and this indicates reduced net productivity of the land. Land degradation is manifested by desertification which is characterized by increased bareland. Essentially one of the indicators of degradation is the loss of vegetation [56] which is often occasioned by land use change. As indicated by our results, the watershed and especially the northern part (mostly Samburu and Isiolo counties) has experienced an increase in bareland due to conversions of shrubland to bareland and this conforms with the degradation analysis results that show that most degradation has taken place in the northern region of the watershed (Fig. 4). The degradation of land, therefore, caused a reduction in shrubland and an increase in bareland during the study period. Further, the loss of vegetation accelerates soil erosion [7] and consequently land degradation. With the increase in human and livestock population, areas within the watershed are experiencing degradation due to interference of the natural ecosystems by human activities e.g. overgrazing in drylands (characterized by sparse vegetation, low rainfall and high temperatures). Our data clearly indicate that areas whose population densities have remained the same or changed slightly have either encountered improvement or remained stable in the period 2000–2020. Conversely, the areas that have experienced a rise in population density have undergone a lot of degradation over the same period. It is also evident from the results that community-owned lands inhabited by pastoralists have undergone a high rate of degradation which could be attributed to a high livestock population growth as indicated in our results.

The data also show that the amount of organic carbon stock also varies with the type of land cover or use and the highest increase was registered in the artificial (built-up) areas. This concurs with Edmondson et al. [16] who found that urban greenspaces and pervious surfaces had high capabilities of storing large quantities of organic carbon. It is also evident from our results that the tree-covered areas store large amounts of organic carbon stock and this is consistent with the observations of Ahirwal et al. [1] and Moradi and Shabanian [61].

Climatic factors have also influenced land degradation in the watershed [43, 82]. Areas of high rainfall around Mt. Kenya and the Aberdare Range have generally improved or remained stable while dry areas with low rainfall and high

temperature around Samburu, Isiolo and the northeastern part of Laikipia have experienced degradation. These results are consistent with the findings of Sivakumar and Stefanski [82] who noted that high temperatures and low rainfall lead to poor organic carbon storage and also influence the vegetation type and the amount of biomass on land. The Mt Kenya and Aberdare Range forests have also remained stable due to their status as protected areas. This conforms with the findings of de Espindola et al. [14] who observed that protected areas reduce the chances of deforestation (one of the sub-indicators of degradation). The data further indicate that barring other confounding factors like climate, (1) the ranches have remained stable or improved due to sole ownership, good capacity and resources for effective ranch management (2) the national parks have improved because of their protected status (3) the forest reserves are degraded due to insufficient regulation of community use and (4) community conservancies are degraded perhaps due to lack of capacity/resources to manage them while wildlife conservancies have conversely improved or are stable because the owners have capacity and resources to manage them.

5.3 Potential land cover transitions and impacts as a consequence of rapid infrastructure developments

The development of transport infrastructure (road network, railway and airport) and other proposed LAPSSET development projects in the watershed and its surroundings are expected to accelerate LULC transitions and land degradation in the region. This conforms with the findings of Ellison et al. [17] who observed that infrastructural development, population pressure, and increased livestock keeping accelerate LULC transitions resulting in land fragmentation and degradation. Furthermore, the availability of water from the proposed Isiolo dam is anticipated to spur agricultural activities, especially irrigated agriculture. Similarly, the development of transport infrastructure will improve market accessibility for agricultural produce thus motivating the communities to intensify crop farming and livestock keeping hence improving the livelihoods of the local communities and the economy of the region. However, if agricultural activities and livestock size are not managed appropriately, land degradation could be aggravated. Moreover, the increased water availability and irrigated farming, improved connectivity, and the development of the resort city will attract more job seekers and investors thus increasing the population density of the area. This is verified by our results on the LULC and population density analysis which have clearly revealed that urban areas in the watershed have experienced a rise in population density and an upsurge in the built-up areas over the last two decades. The results further indicate that the human population has increased substantially and is denser in agricultural areas as compared to the other LULC classes e.g. barelands, shrublands and forested lands. As also reported in previous studies, the increase in population will mean that more of the presently uninhabited land will be utilized for residential and commercial purposes among others, and communal land is likely to be privatised and undergo sub-division into smaller portions [3, 48].

   Furthermore, the development of new transport infrastructure and other associated developments may aggravate conflicts between the owners of ranches and conservancies and the surrounding pastoral communities as they get increasingly pushed from communal grazing grounds that are around the fringes of the urban centres. For example, the recently completed Nairobi- Isiolo –Moyale road, has led to a rise in economic activities along the highway where commercial premises and residential houses have been developed in lands that were previously communal grazing fields [59]. The hospitality industry is also expected to grow due to increased tourism occasioned by the improved road network and the new airport given the huge potential for tourism because of the presence of national game reserves in the region. More roads are also expected to be constructed to connect the villages to the highways and thus improve the mobility of the rural communities. The roads constructed may also cause a depletion of natural vegetation such as grassland, shrubland and forest as well as land fragmentation in the areas that they will traverse. Many studies, for example [36], have found that proximity to a road network often gives rise to more employment opportunities and conversion of LULC such as agriculture and grasslands to various urban uses e.g. commercial and industrial development. Alturk and Konukcu [2] also observed that the construction of new roads and the development of towns and industrial areas among other anthropogenic activities cause a decline and fragmentation of agricultural lands. The LULC transitions triggered by the infrastructure development and its associated development projects often affect the natural functioning of ecosystems [73]. With increased population pressure, and the destruction of natural vegetation coupled with climate change, the watershed is at risk of undergoing further degradation due to depletion of the already fragile dryland ecosystem. To achieve sustainable development in the watershed, planners and developers should consider dryland dynamics occasioned by anthropogenic activities and environmental changes, and their consequences as they implement the mega projects planned for the LAPSSET corridor. In addition, the communities should be encouraged to practice conservation agriculture to avoid further land degradation, restore degraded lands and consequently achieve sustainability.

6 Conclusion

The study adopted various research approaches to understand the implications of infrastructure development on LULC transitions and land degradation in the proposed Isiolo dam watershed. Shrubland and cropland reduced while the forest, built-up, bareland and water increased over the twenty-year interval (2000–2020). The key drivers of these changes are human and livestock population increase, climate change, rapid urbanization and economic development (especially infrastructure development). More than half of the watershed has remained stable but about a third of it is degraded while only about 8% has undergone improvement. The main factors responsible for land degradation are climate change, overgrazing, and LULC change occasioned by infrastructure development and population pressure. Since most of the degradation and the undesirable LULC transitions take place mostly in the community lands (privately or communally owned) as compared to the wildlife conservancies, ranches and protected areas, it is important to target the community to build their capacities to sustainably manage the environment. The proposed infrastructure developments, coupled with population pressure, climate change and potentially poor land management, will lead to the region experiencing drastic LULC transitions and increased land degradation, particularly in natural ecosystems such as forests, conservancies, and shrubland, which will be cleared to provide space for settlement for the incoming population of investors and job seekers. In addition, the irrigated agricultural area is expected to expand mainly due to the availability of water from the Isiolo dam and improved market accessibility to some extent. However, sustainable development of infrastructure, with net zero loss of natural resources, protection of forest ecosystems and conservancies, proper planning for economic investments, inclusive and scenario-based land use planning involving suitability analyses, as well as effective land use policies will minimize the undesirable LULC transitions and hence land degradation. Besides, there is a need for public awareness and community empowerment so as to enhance the capacity of the local communities for sustainable natural resources management.

Essentially, understanding the dynamics and effects of human-nature interactions is crucial for the realization of sustainable development. This paper demonstrates the implications of the interactions between society and the environment and how these interactions impede the efforts for sustainable development, especially in the drylands that are being opened up for economic development. The findings of this study can be used to formulate policies and strategies and implement measures that can promote sustainable land management in the drylands and other areas facing rapid population and economic growth among other uncertainties. This will ultimately contribute to sustainable development in the face of climate change, population pressure and economic growth in the LAPSSET corridor and beyond.

Data availability All data generated or analysed during this study are included in this published article.

Declarations

Competing interests The authors declare no competing interests.

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