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Effect of Development Interventions on Rangelands and Rangelands Management Strategies in Burder Landscape, 1986-2022, Wajir County, Kenya

Abdinasir Mohamed Harret, Simon Maingi, Okeyo Fred

Department of Environmental Sciences and Education, Kenyatta University, Nairobi, Kenya
Email: abdinassir08@hotmail.com

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Abstract

Wajir County is an arid and semi-arid area with little and unreliable rainfall. The main livelihood of her people is livestock production through pastoralism, which enables pastoralists to exploit scarce resources by practicing herd mobility, alternating the wet season and dry season grazing areas with the support of the traditional institutions. However, development interventions in the last 40 years have disrupted these traditional systems of rangeland exploitation. The study assessed the effect of development intervention on pastures and rangeland management strategies. The study employed a mixed research design method and utilized both qualitative and quantitative techniques. Supervised Classification was also utilized to determine land use/cover change from 1986 to 2022. Quantitative data was analyzed using SPPS version 25. The land use analysis grouped the land uses into four common ones in arid and semi-arid areas. The analysis had a Kappa accuracy of 77% and a user accuracy of 84%. Bare land and shrubland have increased from 101,903 and 104,780 hectares in 1986 to 112,137 and 121,817 hectares in 2022, respectively. The land under herbaceous and grassland vegetation shrubs has decreased from 110,180 and 158,088 hectares in 1986 to 89,924 and 151,008 hectares in 2022, respectively. Herbaceous Vegetation had the highest reduction in size at −18.38%, while Shrub land increased significantly at 16.26%. A kernel density assessment on the settlement distances and associated developments indicated that high-density settlements and a reduced distance between settlements resulted in high land degradation and land cover change. Correlation analysis revealed that boreholes and dams are strongly associated with the expansion of shrubland (r = 0.85, $p < 0.01$) and bare land (r = 0.78, $p < 0.01$), while negatively affecting grassland (r = −0.80, $p < 0.01$), herbaceous vegetation (r = −0.88, $p <$

0.01), and herd mobility (r = −0.90, $p < 0.01$). Settlement expansion significantly reduces pasture areas, with strong negative correlations to grassland (r = −0.85, $p < 0.01$) and herbaceous vegetation (r = −0.90, $p < 0.01$), while livestock pressure shows the strongest link to overgrazing (r = 0.95, $p < 0.01$). These findings highlight that development interventions and increased stocking rates are key drivers of land degradation and transformations in indigenous rangeland systems. Therefore, there is a need to revitalize traditional rangeland management institutions and integrate all development interventions with indigenous knowledge-based strategies to sustain pastoralist livelihoods.

Keywords

Indigenous Knowledge, Resource Management, Institutional Development, Rangeland Degradation, Land-Use, Land-Cover Change

1. Introduction

Rangelands are ecosystems covering approximately 45% of the Earth's land surface, consisting of indigenous and introduced grasses, shrubs, and trees that support both livestock production and wildlife conservation (Onyango et al., 2022). These ecosystems play a role in carbon sequestration, biodiversity conservation, and climate regulation, helping mitigate the effects of climate change (FAO, 2021). According to recent studies, over 268 million people globally depend on rangelands for their livelihoods, particularly in arid and semi-arid regions where alternative agricultural practices are limited (Angerer et al., 2023). However, despite their ecological and socio-economic importance, rangelands face increasing pressure from climate change, land degradation, and human interventions, which threaten their sustainability (Abdullahi et al., 2023; Slayi et al., 2024).

In developed countries such as the United States, Australia, and the United Kingdom, rangeland management incorporates technology-driven conservation efforts to promote sustainable land use (Beverley et al., 2018). The United States have over 770 million acres of rangelands, accounting for one-third of the country's land area, where policies emphasize rotational grazing, prescribed burns, and remote sensing for pasture monitoring (Farooqi et al., 2024). Similarly, in Australia, rangelands cover nearly 75% of the country's landmass, with government-led initiatives focusing on integrated grazing systems and land restoration projects to combat desertification (Kariuki et al., 2021). Meanwhile, in the United Kingdom, sustainable grazing models and reforestation efforts have been introduced to balance livestock production with conservation goals. These technological and policy interventions have helped mitigate some of the threats to rangelands, yet challenges remain in balancing economic interests with environmental conservation.

Despite conservation efforts in some areas, across the globe, rangelands are increasingly threatened by climate change, habitat fragmentation, and unsustainable land-use practices. Recent studies indicate that over 60% of global rangelands experience some level of aridity, making them highly vulnerable to desertification (Slayi et al., 2024; Liao et al., 2020). In Africa, Asia, and Latin America, rapid agricultural expansion and infrastructure development have resulted in loss of grazing land, limiting access to essential resources for both livestock and wildlife (Angerer et al., 2023; Stavi et al., 2022; Lind et al., 2020). In Sub-Saharan Africa alone, rangeland degradation has led to a 20% - 50% decline in pasture productivity over the past three decades (FAO, 2021). If no immediate action is taken, rangeland deterioration will threaten global food security, reduce livestock production, and disrupt ecological systems (Sandhage-Hofmann, 2023; Reid et al., 2014). The global and regional gaps call for governments, researchers, and local communities that must work together to implement sustainable grazing practices, rangelands management and climate adaptation strategies to prevent degradation of these ecosystems (FAO, 2021).

In Kenya, rangelands constitute approximately 83% of the country's landmass, supporting over 10 million pastoralists (Herrera Calvo, 2024; World Agroforestry Centre (ICRAF) et al., 2024). According to Nyariki and Amwata (2019), the Arid and Semi-Arid Lands (ASALs) found in Northern Kenya serve as a primary resources for livestock production since agricultural Gross Domestic Product (GDP) sectors depend on them for over 50% of their quantities (Government of Kenya, 2012; Opiyo et al., 2015; Akuja & Kandagor, 2019). Wajir County forms part of the North eastern part of Kenya where the annual precipitation registers 240 mm and the climate determines agriculture would succeed through rainfall (Recha, 2019). Somali pastoralists form the majority of Wajir County inhabitants often utilize seasonal animal migration to find optimal grazing areas and adjust their practices according to environmental changes (Ali, 2021; Sharifian et al., 2023). These traditional practices face growing threats from climate change when combined with land fragmentation and development projects, which reduce pasture resources and make livestock production more vulnerable (Ayele et al., 2020; Smith et al., 2020).

Over the past four decades, climate change, prolonged droughts, and government-led development projects have significantly affected Wajir's rangelands, intensifying water scarcity and disrupting traditional pastoral systems (Kaguai, 2023). Widespread overgrazing and sedentarization alongside the elimination of grazing reserves occurred because of implementing boreholes and settlement schemes and water pans (Flintan et al., 2022). Permanent settlement expansion has limited herd mobility and exposed more land to degradation (Legese & Balew, 2021). Traditional grazing institutions failed which resulted in poor pasture management, leading people to increase feeding beyond their natural resources and seek help from governments (Wang et al., 2022).

The study is to explore the effects of development interventions on Rangeland and implications case study of Burder landscape, by assessing the LULC form 1986-2022. The findings are used to examine the changes on land associated with development intervention and define priorities for development interventions and policy makers to arrive at a more sustainable land-use system and reverse rangeland degradation in this process.

2. Materials and Methods

2.1. Study Areas

The study was conducted in Burder landscape of Wajir County as shown in **Figure 1**. The landscape covers surface areas of approximately 2779.0 km^2. The areas falls within arid and semi-arid climate zone, receiving an average annual rainfall between 350 and 900 mm (RECONCILE, 2022; County Government of Wajir, 2024). The rainfall is bimodal, with most of the annual rainfall occurring between March and May (long rainy season) followed by peak between September and November (short rainy season). Long-term variability in the quantity and distribution of rainfall results in recurrent droughts. Savannah vegetation dominates the rangelands with varying proportions of open grasslands, and perennial herbaceous and woody vegetation along the rivers (Palmer et al., 2023).

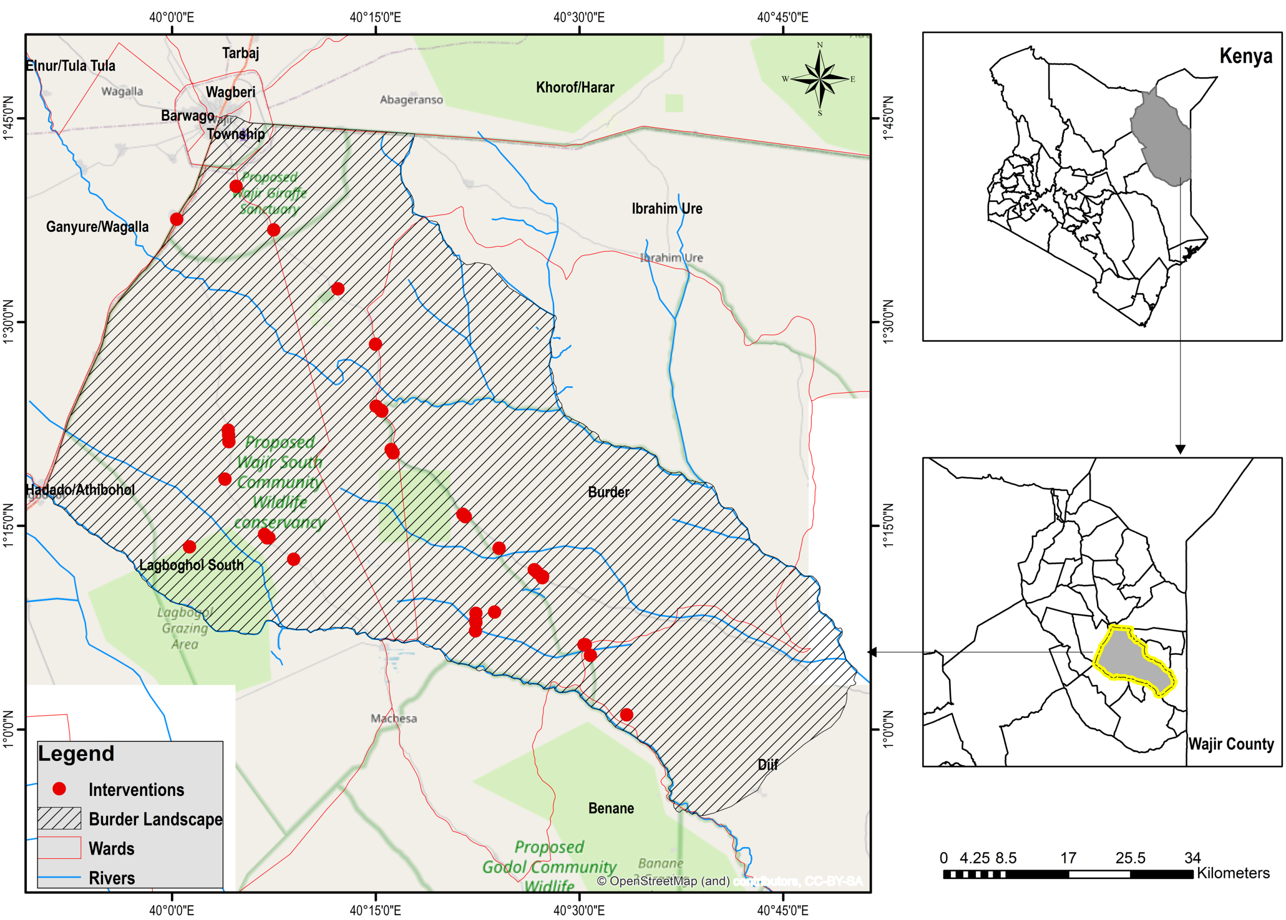


Figure 1. Study area (Source: ESRI, 2023).

2.2. Research Design

The utilized descriptive survey research design, and as such, it employed mixed methods of research design; questionnaires and Key informants Interviews (KII) to collected data and satellite images to as the land use land cover changes during the study period.

2.3. Data Analysis

Statistical Package for Social Sciences (SPSS) (version 25) was utilized. The study also adopted regression analysis to assess the association (development Intervention) and land use changes.

2.4. Land Use and Land Cover Change Analysis

Before conducting any quantitative or qualitative analysis, the collected data underwent pre-processing. Quality control measures were implemented to ensure the data's accuracy, reliability, and relevance for the study. The primary methods of quantitative analysis used in this research were time series analysis and change detection analysis aided by ArcGIS Image classifier tool. Multiple images representing different bands were stacked to enabled various combinations of RGB to be displayed in the view for assessment of different land use cover types based on the colour signatures (Abbas & Jaber, 2020)

As indicated in **Figure 2**, satellite imagery from Landsat sensors (TM, ETM+, and OLI) for the years 1986, 1996, 2016, and 2022 were downloaded from the USGS Earth Explorer. Image pre-processing steps included radiometric calibration,

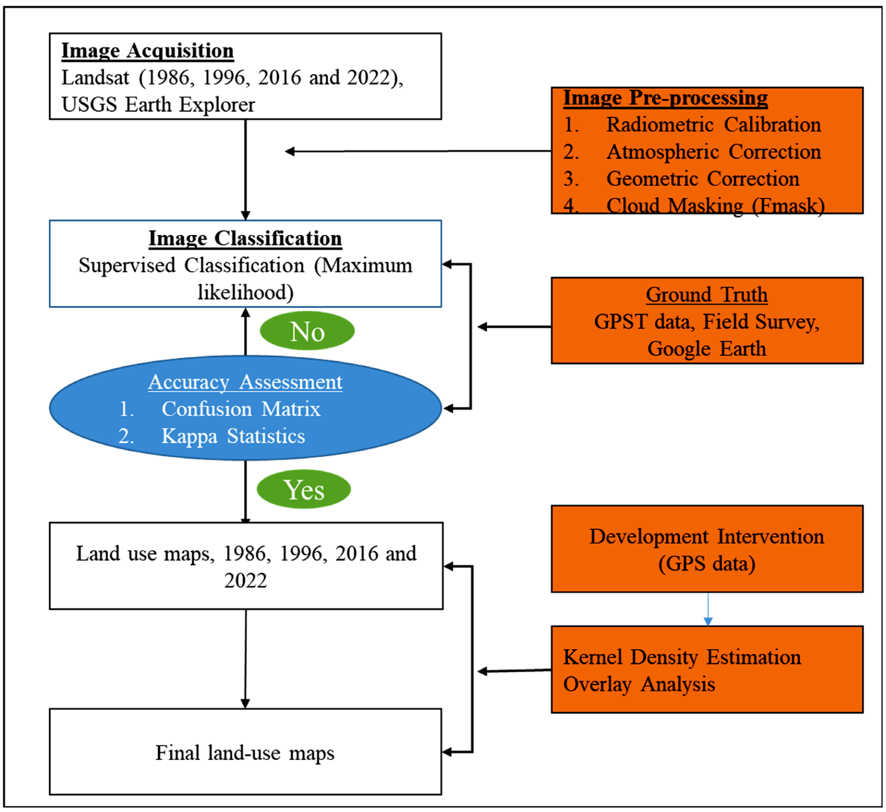


Figure 2. Flowchart of the LULC classification adopted from (Toma et al., 2023).

atmospheric correction using the Dark Object Subtraction method, and geometric correction to ensure spatial alignment. Cloud masking was performed to exclude cloud-covered pixels in the raster images, using the Fmask algorithm (Qiu et al., 2019).

Supervised classification was conducted using the Maximum Likelihood Classification algorithm in ArcGIS Pro 3.1 (Sisodia et al., 2014). Training samples were derived from ground truth data collected during field surveys (including the point's reference to developments intervention) and Google Earth imagery to improve thematic accuracy. Post-classification refinement included a majority filter and editing of misclassified pixels. An accuracy assessment was performed using confusion matrices and Kappa statistics, with overall accuracy exceeding 85% and Kappa values above 0.8 across all classified land uses, indicating strong agreement between the classification results and reference data.

The training data sets for satellite images were created by sub-setting and using aerial photographic interpretation from Google Earth and ground truth data. This helped identify feature classes herbaceous vegetation, bare land, grasslands, and shrubland. Settlement, being small in spatial extent, could not be identified; however, the attribute was associated with bare land. Forest and riparian vegetation was associated with herbaceous vegetation, as wood and thorny vegetation was associated with shrub vegetation as shown in **Table 1**.

Table 1. Land cove types.

No.	Land Cover Type	Description
1	Shrub savannah	This includes the open woody vegetation, shrubs, herbs and other isolated vegetation that characterizes arid areas (Bhardwaj, 2019).
2	Herbaceous vegetation	This describes the vegetation lining up streams or seasonal rivers, including drainage channels (lagga) that get filled with water occasionally. Such vegetation usually thrives during the wet seasons then wither away once the rains are over (FAO, 2021).
3	Bare land	This describes areas left without vegetation cover resulting from abandoned grazing areas, eroded land due to land degradation, or general aridity (World Agroforestry Centre (ICRAF) et al., 2024).
4	Grassland	This is the area of land that is used for rearing animals. The farm has vegetation cover that animals graze (Petermann & Buzhdygan, 2021).

Adopted from (Nedd et al., 2021).

3. Result and Dissuasions

3.1. Land Cover 1986-2020

For the study, 1986 served as the baseline year due to the increased number of developments in the area of interest. The land sizes as presented in **Figure 3** presented the changes in land sizes. The spatial extent and changes of the selected land covers and uses over the period of interest as presented in in **Figure 4**.

In 1986, bare land formed the largest land cover class in the study area. It accounted for about 50% land cover while shrub savannah and sparse herbaceous vegetation accounted for 40% and 10% land cover, respectively. In this year, sparse herbaceous vegetation lined up laggas around Burder and Shimbiray area.

The baseline year for LULC analysis, 1986, bare land was the dominant cover type, accounting for approximately 50% of the study area. Shrub savannah covered around 40%, while sparse herbaceous vegetation made up the remaining 10%, predominantly along laggas in the Burder and Shimbiray areas. By 1996, the landscape had undergone noticeable changes. Bare land and shrubland were still dominant at 32% each, while grassland and herbaceous vegetation declined to 19% and 17%, respectively. Notably, bare land increased significantly by 47.29%, from 104,780 ha in 1986 to 154,335 ha in 1996, while herbaceous vegetation experienced the steepest decline (−27.96%), followed by shrubland (−11.73%) and grassland (−4.32%).

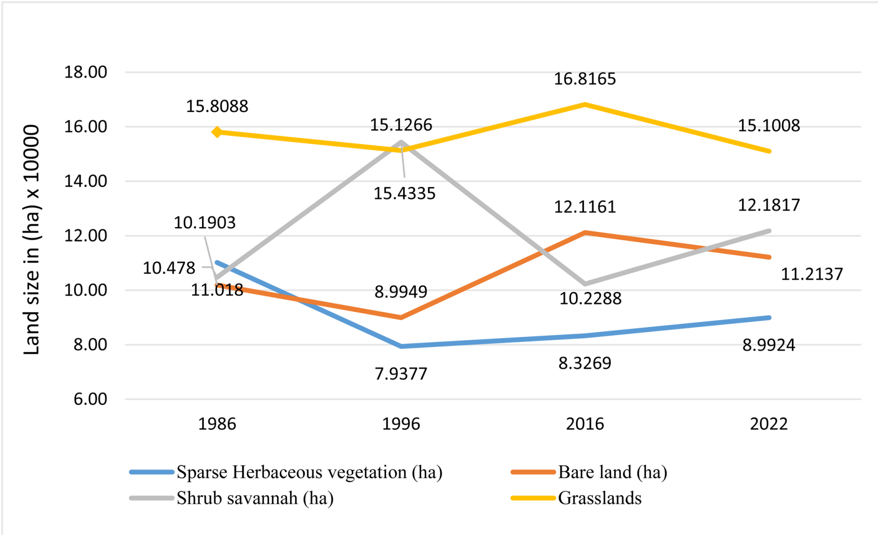
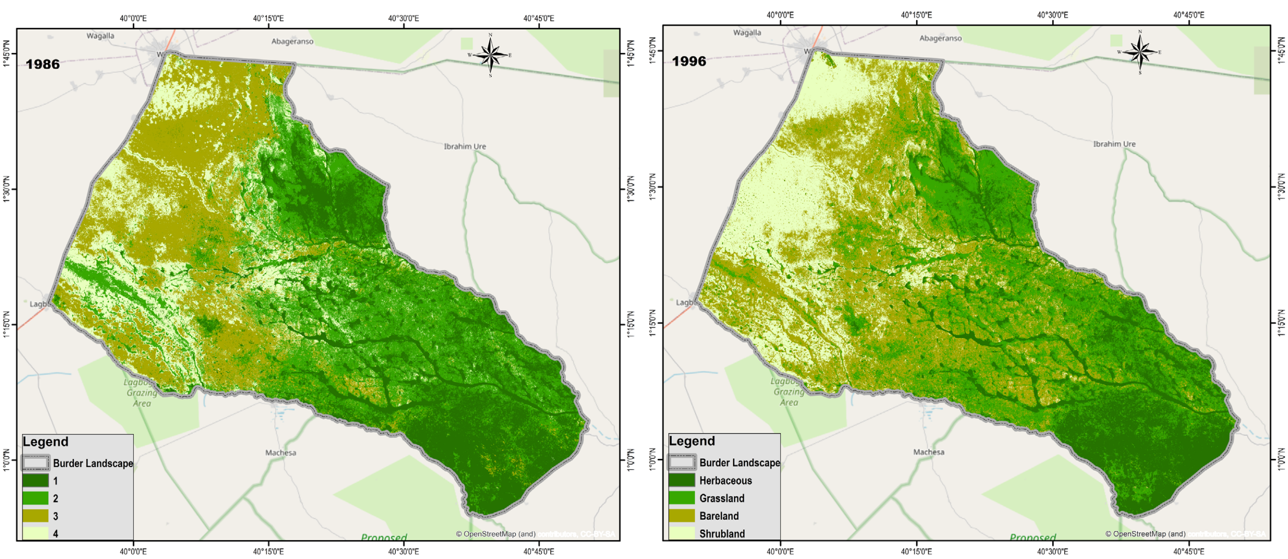


Figure 3. Land size change (ha).



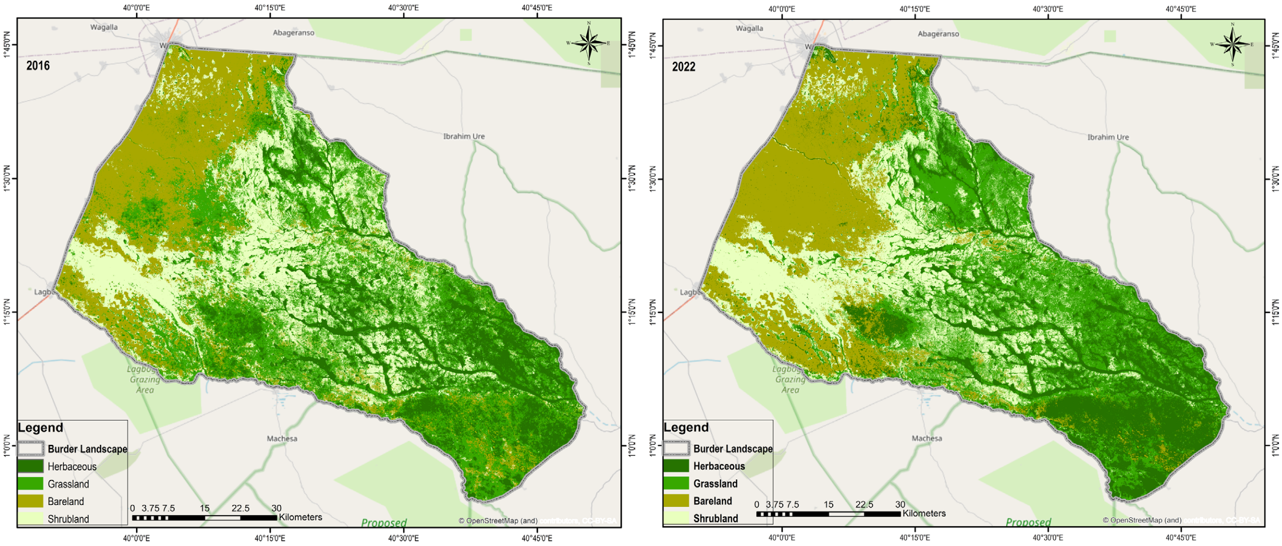


Figure 4. Land cover change 1986-2022I.

In 2000, bare land expanded further to dominate around 55% of the total area, while shrub savannah remained at 40%, and herbaceous vegetation decreased to 5% similar findings on LULC trend were reported by Maitima et al. (2009) that land use changes across East Africa was predominantly driven by agriculture, settlement expansion, and infrastructural development. The study emphasized that these transformations lead ecosystem degradation and influence of the traditional livelihood systems, especially in rangelands.

However, this trend shifted in 2016, a year marked by increased rainfall across the region. As a result, grassland expanded significantly to account for about 35% of the land cover, followed by shrubland (22%), bare land (25%), and sparse herbaceous vegetation (18%). The increased rainfall reportedly contributed to the conversion of shrubland into agricultural plots and the development of water pans, while also promoting pasture regrowth. Despite this improvement in vegetation cover, shrubland decreased by 33.7%, indicating continued pressure from land use activities and shifting ecological dynamics.

In 2022, land cover patterns once again reflected degradation patterns; Grassland recorded the most substantial reduction (−10.2%), decreasing from 168,165 ha in 2016 to 151,008 ha. Shrub savannah also declined by 7.45%, while sparse herbaceous vegetation experienced a modest increase of 3.09%, reaching 19% of total cover. These changes suggest a mixed recovery pattern, with some vegetative cover rebounding due to climatic conditions, while others continued to decline due to human-induced changes. The observed LULC dynamics over the study period underscore the significant impact of both natural factors (e.g., rainfall variability) and anthropogenic interventions (e.g., agricultural expansion and water infrastructure) on the region's ecological landscape.

The results Presented in **Table 2** between 1986 and 2022, there is a reduction in herbaceous and grassland vegetation by 18.38 and 4.4% from their original size and a significant increase in bare and shrub land vegetation by 10.04% and 16.26%

from their original sizes in 1986. This can be attributed to the increase in the number of development interventions in the area. An introduction of livestock watering points, boreholes and water pans would encourage farmers to increase the size of the livestock. In turn, the increased livestock size would strain the pastures in the grazing areas. With reference to the overlay analysis, the areas witnessing development interventions experienced a decline in shrub savannah and sparse herbaceous vegetation as shown in Figure 4 and Figure 5.

Table 2. Computed changes in land cover area.

Land Uses	1986		1996		2016		2022	
	Change	%	Change	%	Change	%	Change	%
Herbaceous vegetation (ha)	0		79,377	−28.0	83,269	4.90	89,924	7.99
Bare land (ha)	0		89,949	−11.7	121,161	34.70	112,137	−7.45
Shrub savannah (ha)	0		154,335	47.3	102,288	−33.7	121,817	19.09
Grasslands (ha)	0		151,266	−4.3	168,165	11.17	151,008	−10.2

The observed land use and land cover (LULC) changes in the study area from 1986 to 2022 align with broader regional trends documented in similar studies across Kenya and East Africa. For instance, research in Kibwezi West, Eastern Kenya, identified significant LULC transformations between 1990 and 2021, largely driven by population growth, urbanization, and agricultural expansion (Munyalo et al., 2024). These drivers mirror the anthropogenic influences observed in the current study, particularly the conversion of shrublands into agricultural lands and the development of water infrastructure, similar finding were found by (Singh et al., 2024).

Similarly, studies conducted in the Mara and Mau River Basin landscapes have attributed significant reductions in forest and grassland areas to agricultural expansion and land fragmentation since 2015 (Nyamweya et al., 2024). This trend is consistent with the decrease in grassland cover noted in the study area between 2016 and 2022. In addition, analysis of land use change in the Cherangany Hills Water Tower over a 37-year period reported substantial impacts on ecosystem service values, underlining the ecological consequences of LULC transformations (Otieno et al., 2022).

These comparative studies underscore the widespread and complex nature of LULC dynamics in the region, influenced by both climatic variability and human activities. The findings from this study therefore contribute to the broader discourse on land use planning and call for enhanced strategies that promote sustainable land management in ecologically sensitive areas.

3.2. Development Intervention

To understand the spatial of association of the LULC and development intervention in the study area, kernel density estimation was used to assess how development may influence pastureland in a study area Raza et al. (2019). The study-utilized field collected data of settlements and distance between one settlement location and the other as shown and analyzed land use map obtained from the Landsat images in **Figure 5** and associated land use.

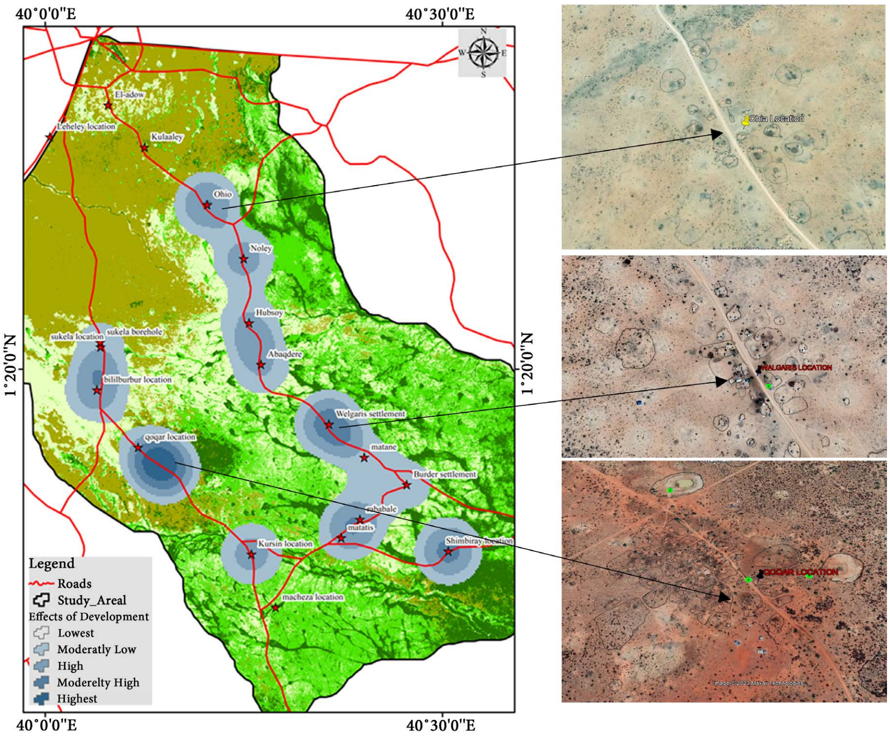


Figure 5. Kernel density of settlements on land uses.

The generated density surfaces, indicates that the patterns of development are closely associated with changes in pastureland. The Google Earth images, shown in **Figure 6**, indicates that the areas where development/settlement density was high, there was observable bare lands composed of brown soil and as a result also have lower pasture land density, (grasslands) (Tilahun, 2015).

The results compares with a study that applied kernel density analysis to assess the impact of development on pasture land in a research project is "Assessing the Impact of Land Use Change on Pasture Land Using Kernel Density Estimation and Distance Analysis in the Karakoram Mountains of Pakistan" by Raza et al. (2019). The study used kernel density analysis to create a density surface of development locations and distance analysis to identify the areas of pasture land that were most at risk of being affected by development.

3.3. Relationship between Development Interventions, Indigenous Range Management Systems and LULC

This study examined the relationship between selected development interventions and indigenous range management systems land uses in the study area. The analysis was guided by the Political Ecology Theory, which posits that environmental change is shaped by broader socio-political and economic structures that often marginalize traditional ecological knowledge (Reid et al., 2014). Supporting this theory, recent research by Akall (2021) found that water infrastructure and land privatization in pastoral regions of East Africa contributed to reduced herd mobility, localized overgrazing, and the disruption of customary grazing governance systems. Figure 7 details the development interventions that were collected from the key informant interviews.

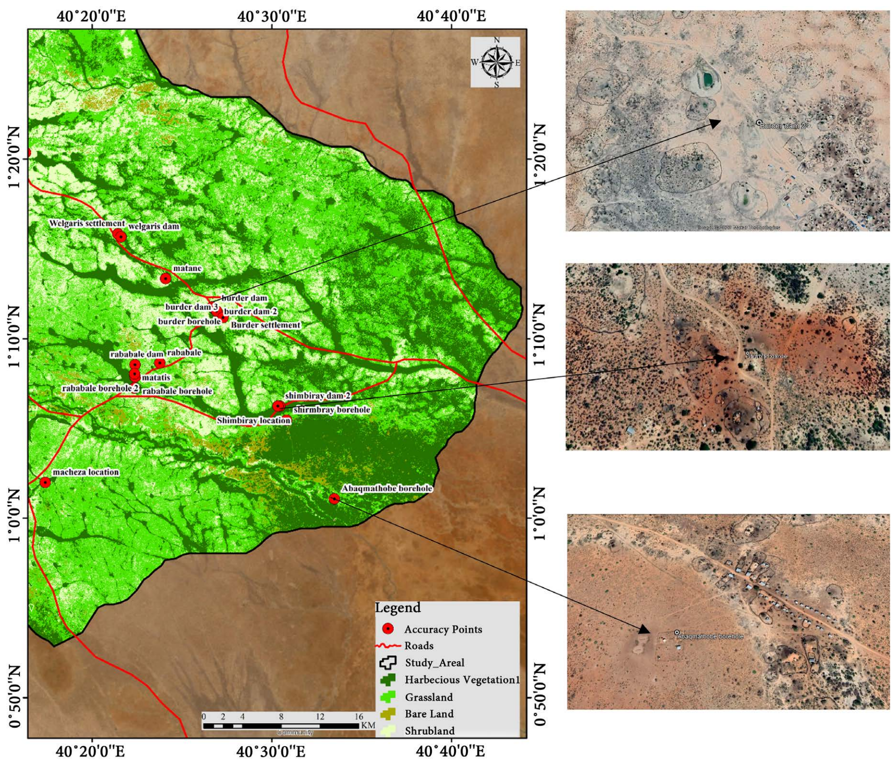


Figure 6. Image map showing different land uses.

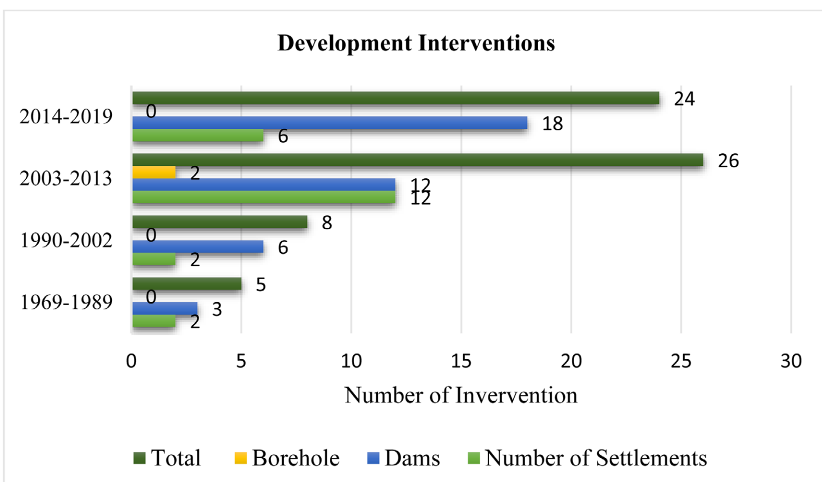


Figure 7. Temporal changes in developmental interventions in Burder landscape.

Table 3 presents respondents' perceptions regarding the impact of development interventions on rangeland degradation within the Burder landscape.

Table 3. Impact of development and drought on land degradation.

Development on Land degradation	Frequency	Per cent
Yes	349	92.10%
No	30	7.90%
Frequency of Drought	Frequency	Percentage
Between 3 - 5 years	69	18.20%
Every 2 years	136	35.90%
Every 1 year	174	45.90%
Drought on land degradation	Frequency	Percent
No	37	9.80%
Yes	342	90.20%
Total	379	100%

The findings point to a strong community perception that both development activities and recurring droughts are major contributors to land degradation in the study area. A vast majority of respondents (92.1%, n = 349) indicated that development interventions have contributed to land degradation, while only 7.9% disagreed. These findings suggest that, while development efforts may aim to improve local livelihoods, they may also inadvertently intensify environmental degradation—particularly in rangeland ecosystems.

The study in terms of climatic stressors, drought frequency emerged as a significant concern, with a patterns that points to increasing climate variability and the growing intensity of drought events in the region. Additionally, when respondents were asked about the impact of drought on land degradation, 90.2% of respondents confirmed that drought had contributed to degradation. This reinforces the understanding that droughts—through loss of vegetation cover and reduced regeneration of grasslands as pointed in the LULC maps.

The correlation analysis presented in **Table 4** a patterned association between selected development interventions land use and indigenous range management systems. Specifically, the establishment of boreholes and dams shows a strong positive correlation with the expansion of shrubland ($r = 0.85$, $p < 0.01$) and bare land ($r = 0.78$, $p < 0.01$). These findings suggest that increased access to permanent water sources contributes to vegetation shifts and accelerated land degradation. These interventions are negatively correlated with grassland ($r = -0.80$, $p < 0.01$) and herbaceous vegetation ($r = -0.88$, $p < 0.01$), indicating that enhanced water availability encourages livestock concentration and overgrazing, leading to diminished pasture quality and extent. Herd mobility is also adversely impacted by the proliferation of permanent water sources, as demonstrated by a strong negative correlation (r = −0.90, $p < 0.01$). This reflects the sedentarization of pastoral communities around water points, which reduces the spatial flexibility necessary for sustainable rotational grazing. Overgrazing and land degradation also had a significant increase (r = 0.92, $p < 0.01$), further threatening rangeland resilience.

Table 4. Correlation of development intervention.

Development Intervention	Shrubland Increase	Bare Land Increase	Grassland Reduction	Herbaceous Vegetation Reduction	Herd Mobility	Overgrazing & Land Degradation
Boreholes & Dams	0.85**	0.78**	−0.80**	−0.88**	−0.90**	0.92**
Settlements Expansion	−0.65**	−0.72**	−0.85**	−0.90**	−0.88**	0.75**
Increased Livestock Pressure	0.80**	0.85**	−0.78**	−0.82**	−0.87**	0.95**

Settlement expansion is another critical factor associated with rangeland changes. It exhibits moderate negative correlations with shrubland (r = −0.65, $p < 0.05$) and bare land (r = −0.72, $p < 0.05$), suggesting that urban development contributes to the disturbance of natural vegetation (Boas, 2022). The correlations are even stronger with grassland (r = −0.85, $p < 0.01$) and herbaceous vegetation (r = −0.90, $p < 0.01$), underscoring the significant reduction in pasture areas due to human settlements. Herd mobility is again negatively affected (r = −0.88, $p < 0.01$), indicating that land fragmentation from development restricts traditional grazing routes. Additionally, overgrazing and land degradation continue to rise (r = 0.75, $p < 0.01$) as communal grazing reserves decreases. The pressure exerted by increased livestock numbers is also significantly correlated with changes in land cover as also pointed by Bolo et al., 2019; Getabalew & Alemneh, 2019. Positive correlations with shrubland (r = 0.80, $p < 0.01$) and bare land (r = 0.85, $p < 0.01$) demonstrate that intensified stocking rates exacerbate land degradation. Simultaneously, grassland (r = −0.78, $p < 0.01$) and herbaceous vegetation (r = −0.82, $p < 0.01$) experience significant declines, highlighting the depletion of forage resources due to overgrazing. The reduction in herd mobility (r = −0.87, $p < 0.01$) under high stocking pressure points to a breakdown of traditional rotational grazing systems. The strongest observed relationship was between livestock pressure and overgrazing (r = 0.95, $p < 0.01$), emphasizing on the critical role of stocking intensity in driving rangeland degradation. Recent studies corroborate the observed relationship between increased livestock pressure, reduced herd mobility, and rangeland degradation. For instance, Gebeyehu et al. (2021) identified that in Ethiopia's Lower Omo Valley, large-scale agricultural developments have restricted traditional livestock migration routes, leading to overgrazing and significant fodder deficits in high-density grazing areas. Additionally, Piemontese et al. (2024) found that over-reliance on permanent water infrastructure in pastoral drylands reduces climate resilience by encouraging sedentarization and concentrating grazing pressure around water points. This leads to vegetation degradation and undermines traditional adaptive strategies like herd mobility.

4. Conclusion

The findings of this study reveal that development interventions such as borehole construction, dam development, and settlement expansion have significantly resulted to LULC patterns in the study area between 1986 and 2022. Bare land and shrub savannah have increased in areas associated with boreholes, roads, settlement and dams while grasslands and sparse herbaceous vegetation decreased in the same areas. The LUCLC are closely associated with increased livestock pressure, reduction in herd mobility, and the collapse of traditional rotational grazing systems, as evidenced by strong correlations. Application of Kernel density analysis further showed that development hotspots coincide with areas experiencing vegetation loss, confirming the spatial relationship between human interventions and ecological change. These patterns are consistent with broader regional findings which emphasize that poorly coordinated development and the over-concentration of livestock near water infrastructure disrupt indigenous rangeland management practices and promotes land degradation in these areas. The study finding points to the need for integrated land management approaches that promotes traditional ecological knowledge while accommodating modern development.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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