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Angaben zur Veröffentlichung / Publication details:

Rotich, Brian, Harison Kipkulei, Abdalrahman Ahmed, Azaria Stephano Lameck, Isaiah Maket, Bernard Soi, Stanley Makindi, and Mark Boitt. 2026. "Spatio-temporal variation of ecosystem service values in response to land use/land cover changes: the case of Baringo County, Kenya." *Modeling Earth Systems and Environment* 12 (2): 81. https://doi.org/10.1007/s40808-026-02729-4.

Modeling Earth Systems and Environment (2026) 12:81
https://doi.org/10.1007/s40808-026-02729-4

ORIGINAL ARTICLE

Spatio-temporal variation of ecosystem service values in response to land use/land cover changes: the case of Baringo County, Kenya

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Received: 12 July 2025 / Accepted: 25 January 2026

Abstract

Land Use and Land Cover (LULC) changes due to human activities and natural factors significantly influence the variation in Ecosystem Service Values (ESVs). This study assessed the spatio-temporal dynamics of ESVs in Baringo, an Arid and Semi-Arid Land (ASAL) county located in Kenya's Great Rift Valley, over 24 years (2000–2024). The Benefit Transfer Method (BTM) was employed to estimate ESV changes using LULC data for the years 2000, 2014, and 2024, alongside updated valuation coefficients from the Ecosystem Services Valuation Database (ESVD) published by de Groot and others in 2020. The analysis revealed a substantial decline in the total ESVs in Baringo County, from United States Dollars (US$) 25.70 billion in 2000 to US$14.92 billion in 2024, representing a loss of US$ -10.78 billion (-41.9%). This translates to an average annual ESV loss of approximately US$ -448.96 million. Forestland reduction emerged as the primary driver of this decline, whereas expansion of water bodies contributed positively to the total ESV in the study region. These findings underscore the urgent need to combat deforestation and forest degradation while promoting the sustainable management of water resources. Such measures are essential for reversing ESV losses and achieving key Sustainable Development Goals (SDGs), particularly SDG 6 (Clean Water and Sanitation), SDG 13 (Climate Action), and SDG 15 (Life on Land).

Keywords Biomes · Ecosystem services · Benefit transfer method · Ecosystem services valuation database

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Published online: 09 February 2026

Introduction

Ecosystem services (ES) are vital for the survival and well-being of humans by providing benefits for individual utility and economic development in addition to acting as a link between people and nature (Costanza et al. 1997; Fisher and Kerry Turner 2008; Mengist et al. 2022; Pearce 1998). The Millennium Ecosystem Assessment identified four broad categories of ES, namely provisioning services, supporting services, regulating services, and cultural services (Millennium Ecosystem Assessment 2005). Regulating services comprise processes that guarantee long-term ecosystem functioning by ensuring ecosystem characteristics are maintained within a stable range; provisioning services are the tangible products obtained from ecosystems; cultural services represent the intangible benefits that enhance aesthetic experiences, spiritual thought, recreational, and educational development; while supporting services are the underlying ecosystem services that enable the aforementioned services to function (Millennium Ecosystem Assessment 2005).

Ecosystems' ability to continue providing these services is dependent on both anthropogenic and natural factors that can alter the ecosystems (Millennium Ecosystem Assessment 2005; Styers et al. 2010). Changes in landscape patterns caused by human activities are among the most significant driving factors affecting the spatial structure of ecosystems, their components, and functions, thereby significantly impacting ES (Kipkulei et al. 2025; Rotich and Ojwang 2021). Land Use Land Cover (LULC) changes are good indicators of the ES gained or lost on a given landscape. LULC changes can, therefore, be used as a surrogate for quantifying ES variations over spatial and temporal scales. The quantification of the benefits obtained from ecosystems can be achieved through the valuation of ES goods and services in monetary units (Costanza et al. 1997, 2014; De Groot et al. 2020; Groot et al. 2012; Kindu et al. 2016; Mengist et al. 2022). Ecosystem Service Values (ESVs) are estimated using market and non-market valuation techniques, which consist of ecosystems' use and non-use value (Brander et al. 2024; Mengist et al. 2020).

Several studies have been conducted to estimate variations of ESVs in the context of LULC changes globally including Africa (Arowolo et al. 2018; Assefa et al. 2021; Gashaw et al. 2018; Kindu et al. 2016), Asia (Hu et al. 2008; Ligate et al. 2018; Sharma et al. 2019; Xie et al. 2017; Yuan et al. 2019), Europe (Cabral et al. 2016; Quintas-Soriano et al. 2016), North America, (Kreuter et al. 2001; Lawler et al. 2014; Polasky et al. 2011; Yi et al. 2017) and South America (Mendoza-González et al. 2012; Zilio et al. 2022). The recent surge in such studies underscores the significance of understanding the relationship between LULC change patterns and ESVs for improving regional conservation and establishing ecosystem management strategies (Wang et al. 2022a, b).

Baringo County is classified as one of the 29 Arid and Semi-Arid (ASAL) counties in the Republic of Kenya. It has experienced significant LULC changes over the past three decades (Greiner et al. 2021; Karaya et al. 2021; Mbaabu et al. 2019; Ochuka et al. 2019), yet little research has been done to estimate the impact of these changes on the ESVs in the county. Our study, therefore, seeks to bridge this research gap by using the updated Ecosystem Services Valuation Database (ESVD) coefficients (De Groot et al. 2020) in conjunction with multi-temporal LULC data (Kipkulei et al. 2025) to provide the first spatially explicit and economically quantified assessment of ESV dynamics in Baringo County. The present study aimed to achieve the following research objectives: (a) To find out the impacts of LULC changes on the total ESV in Baringo County (b) To map the spatial distribution of ESVs in Baringo County in 2000, 2014 and 2024 (c) To investigate how LULC changes in Baringo County have affected individual and grouped ESVs. Our study findings will provide important information to the relevant authorities at the county and national government levels for informed policy and management actions toward the achievement of sustainable land management goals.

Methodology

Study area

Baringo County is one of Kenya's ASAL counties, geographically located in Kenya's Great Rift Valley (GRV) between longitudes 35°30′ and 36°30′ East and latitudes 0°10′ and 1°40′ South (Fig. 1). The county covers an estimated area of 10,951.61 km^2 (Baringo County and Government 2018). The county has a characteristic bimodal rainfall pattern consisting of long rains (March-July) and short rains (September–November) with an average yearly rainfall range of 300–1500 mm (Juma et al. 2016). The temperatures range from lows of 10 °C to highs of 35 °C (Baringo County and Government 2018). The county altitude ranges from 715 m in the lowland Njemps flats to 3014 m at the Lake Baringo catchment areas of the Laikipia Plateau and the Tugen Hills. The county supports a range of pastoral and agro-pastoral livelihoods (Baringo County and Government 2018). The county also makes a significant contribution to Kenya's economy in the tourism sector due to its several tourist attraction sites, including Lake Baringo, Lake Bogoria and Simot waterfalls (Baringo County and Government 2018; Greiner et al. 2021). The study area is mainly

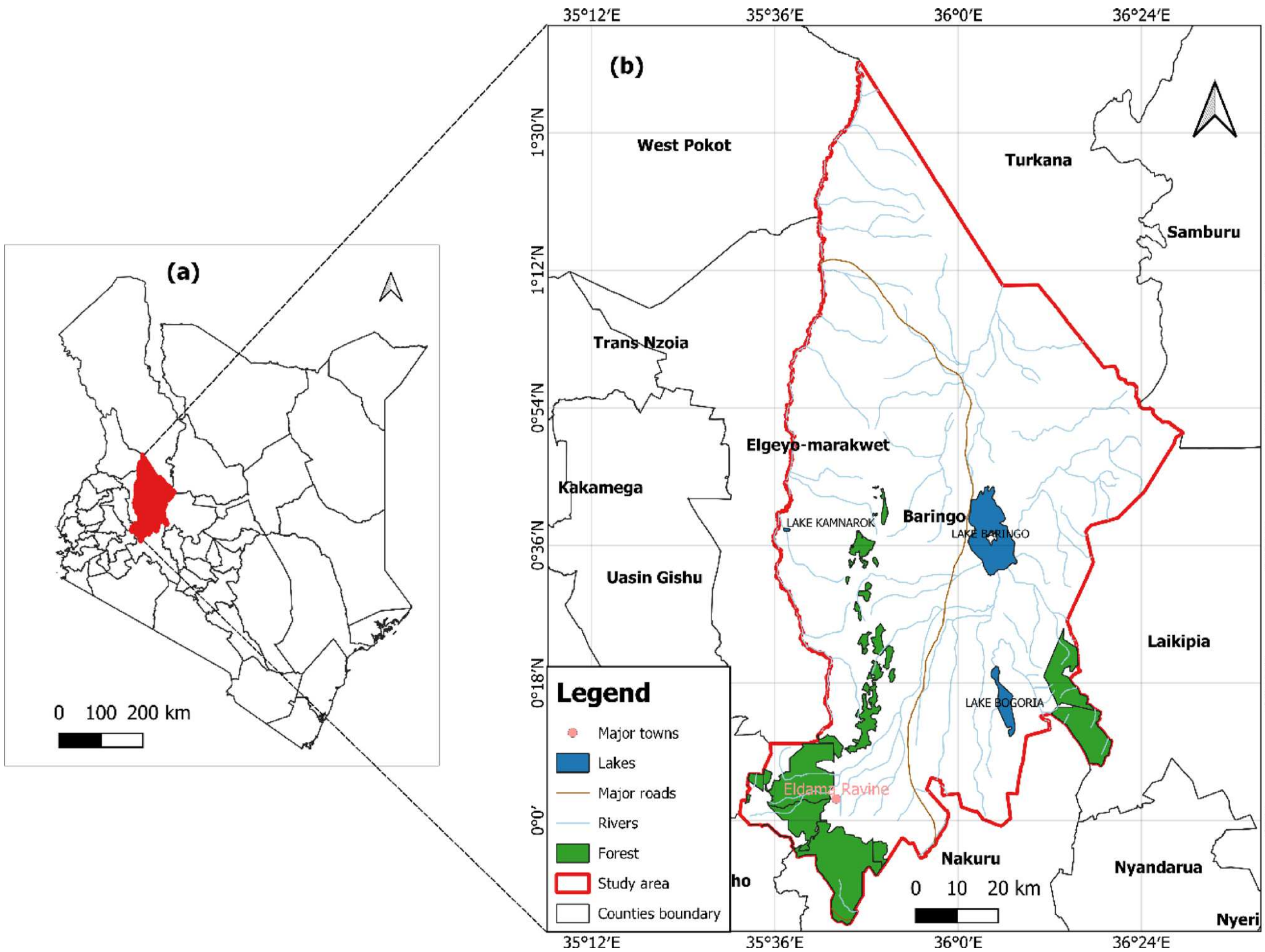

Fig. 1 Map of the study area showing: **a** Location of Baringo County in Kenya, **b** Map of Baringo County

inhabited by three agro-pastoralist ethnic groups, namely the Tugens, Pokots, and Njemps/Ilchamus (Ochuka et al. 2019).

Data sources

The LULC datasets used for this study were obtained from LULC analysis outputs by Kipkulei et al. (2025), who employed both ancillary and satellite data sources in generating the statistics. The datasets for the different reference years (2000, 2014, 2024) were generated using remote sensing and supervised classification using the Random Forest (RF) algorithm in the Google Earth Engine (GEE). Assessment metrics, including user accuracy, producer accuracy, overall accuracy, and Kappa coefficient, were used to assess the accuracy of the classification. The overall accuracy and Kappa coefficient values of the selected years were all greater than 88% and 0.83, respectively (Kipkulei et al. 2025). Area statistics for seven different LULC types (shrubland, grassland, forestland, cropland, water features, and built-up areas) for the years 2000, 2014, and 2024 were used in this study (Kipkulei et al. 2025).

Estimation of ecosystem service values

The estimation of ESVs plays an important role in conservation ecosystem-based management and planning (Plummer 2009). The Benefit Transfer Method (BTM) was used in the estimation of ESVs of the study area. BTM entails the use of original ESV estimates from pre-existing primary studies at one or more study sites to an unstudied ‘policy site’ with similar characteristics (Johnston and Wainger 2015; Plummer 2009; Richardson et al. 2015). This approach is often used when researchers face constraints of time, funding, and data availability (Kindu et al. 2016; Plummer 2009; Xie et al. 2008). As for the valuation of ESVs, the comprehensive and recently updated ESVD coefficients (De Groot et al. 2020) were adopted for this study. The ESVD is a follow-up to The Economics of Ecosystems and Biodiversity (TEEB) database (Van der Ploeg et al. 2010), which had not been

Table 1 Land use and land cover types, their equivalent biomes, and mean standardized values per ecosystem service biome (De Groot et al. 2020)

LULC type	Equivalent biome	Mean standardized values per Ecosystem Service Biome (US\$ ha^{-1} year^{-1})
Forestland	Tropical forest	119,075
Shrubland	Woodland and shrubland	769
Grassland	Grassland	1597
Cropland	Cultivated areas	8028
Water features	Lakes/rivers	108,360
Built-up areas	Built-up areas	0
Bareland	Desert	0

updated since 2010 and naturally had many gaps across biomes, ecosystems, and services (Brander et al. 2024). The ESVD contains three times as many value records as the original TEEB database (4,042 value records) based on 693 studies and matrices with standardized average values (US\$ ha^{-1} year^{-1}) for all biomes and ES (De Groot et al. 2020). The values recorded in ESVD were sourced from six continents, including Europe (1639), Asia (1140), North America (594), Africa (309 studies), Oceania (223), and South America (109). ESVD further contains additional variables and information on the size, location, and condition of the study sites (Brander et al. 2024; De Groot et al. 2020). Several recent studies in East Africa have similarly employed the updated ESVD in the valuation of ES (Haileslassie et al. 2024; Mathewos and Aga 2023; Mekuria et al. 2021; Simeon and Wana 2025; Wayesa et al. 2025). The seven LULC types from our study area were matched with their corresponding equivalent biomes, and the most representative biome was used as a proxy for each LULC type as shown in (Table 1).

In addition, the 23 individual ES (De Groot et al. 2020) for the respective biomes were also considered for the identified LULC types (Table 2).

The total ESV for each LULC type was obtained by multiplying the area of each LULC type by its corresponding value coefficient, as shown in Eq. 1 (Kindu et al. 2016; Kreuter et al. 2001).

$$ESV = Ak \times VCk \quad (1)$$

The total ESVs for each LULC type were then summed up to get the total ESV for each year, as per Eq. 2 (Tolessa et al. 2018).

$$ESV = \Sigma\ (Ak \times VCk) \quad (2)$$

where ESV = total estimated ecosystem service value, A_k = the area (ha) and VC_k = the value coefficient (USD ha^{-1} year^{-1}) for LULC type ‘k’.

Table 2 Updated ESV coefficients (US\$ ha^{-1} year^{-1}) for the seven LULC types (De Groot et al. 2020)

ES group	ES	Forestland	Shrubland	Grassland	Cropland	Water features
Provisioning	Food	602	8		510	2288
	Water	47,869		313	604	9198
	Raw material	11,739	1	637	6	92
	Genetic resources	16				
	Medicinal resources	3	1			
	Ornamental resources					
Regulating	Air quality regulation	309	7	8	10	
	Climate regulation	658	89	73	10	251
	Moderation of extreme events	108			993	18
	Regulation of water flows	442	71	43	17	4221
	Waste treatment	12			40	50,760
	Erosion prevention	604			173	
	Maintenance of soil fertility	42			34	6189
	Pollination	877			1498	
	Biological control	14			621	142
Habitat	Maintenance of the life cycles of migratory species	19				803
	Maintenance of genetic diversity	7				17,987
Cultural	Aesthetic information		38		395	2276
	Opportunities for recreation and tourism	52,789	124	92	3101	13,633
	Inspiration for culture, art, and design	5	214	284	16	310
	Spiritual experience					76
	Information for cognitive development		214	147		116
	Existence and bequest values	2960	2			
	Total ESV for the LULC Class	**119,075**	**769**	**1597**	**8028**	**108,360**

The ESVs provided by individual ecosystem functions within the study area were also calculated using Eq. 3 (Arowolo et al. 2018; Kindu et al. 2016).

$$\mathrm{ESVf} = \Sigma\ (\mathrm{Ak} \times \mathrm{VCfk}) \quad (3)$$

where ESV_f = calculated ecosystem service value of function' f', A_k =the area (ha) and VC_{fk} = value coefficient of function' f' (Int$/hectare/year; 2020 price levels) for LULC type 'k'.

The percentage (%) changes in ESVs were also calculated by comparing the values of the last and first years, as depicted in Eq. 4 (Gashaw et al. 2018).

$$\%\ ESV\ change = \left(\frac{ESV\ final\ year - ESV\ initial\ year}{ESV\ initial\ year}\right) \times 100 \quad (4)$$

Elasticity of ESV change with LULC types

Elasticity analysis was conducted to assess the relative responsiveness of ESVs to changes in LULC types over the study period. Elasticity, in this context, quantifies the percentage change in total ESV in response to a given percentage change in the area of a specific LULC class, thereby helping to identify the influence of each land use category on the overall value of ecosystem services (Gaglio et al. 2017a). To compute the elasticity, the value coefficient (VC) for a given LULC type was adjusted by ± 50%, while the coefficients of all other LULC types were held constant (Gaglio et al. 2017b). This analysis prioritized the importance of each LULC type in influencing the total natural capital value, rather than testing the robustness of the coefficient transfer method itself (Mengist et al. 2022).

The Coefficient of Sensitivity (CS), which reflects this elasticity, was calculated using the simplified formula by Aschonitis et al. (2016) as shown in Eq. 5.

$$CS = \frac{VC_{\mathrm{ik}} \times A_{\mathrm{k}}}{ESV_{\mathrm{i}}} \quad (5)$$

where: CS = Coefficient of Sensitivity, VCi_k = Total value of ES provided by the k LULC class at i year (US$ year^{-1}), A_k = Area of LULC type k (ha) in year i,, $ESVi$ = Total ESV from all LULC types identified at i year (US$ year^{-1}).

A higher CS value indicates that a particular LULC class has a stronger influence on the total ESV, suggesting its strategic importance in maintaining the ecosystem's economic value. This method allows for identifying priority areas for conservation or management intervention, especially in landscapes experiencing rapid LULC transitions such as Baringo County.

Results

Overview of the LULC statistics

Grassland and shrubland were the dominant LULC types in the study area throughout the study period, while water features and built-up areas occupied the least area coverage of the county (Table 3).

Total ecosystem service values

The total ESV of Baringo County for the years 2000, 2014, and 2024 were US$25.70 billion, US$21.24 billion and US$14.92 billion, respectively (Table 4). These values constituted a sum of the individual ESVs for the different LULC types. The two major contributors to the total ESVs over the study period were forestland and water features. Grassland, cropland and shrubland had minor contributions to the total ESVs during the study period, while bareland and built-up areas had no contributions due to the nil valuation of their coefficient values as detailed in Table 4.

Changes in total ecosystem service values

The total ESV decreased by US$ -4.46 billion between 2000 and 2014 and US$ -6.32 billion from 2014 to 2024, leading to an overall decline of US$ -10.78 billion from

Table 3 Statistics of the major LULC types in Baringo County in 2000, 2014 and 2024 (Kipkulei et al. 2025)

LULC type	2000		2014		2024	
	ha	(%)	ha	(%)	ha	(%)
Grassland	508,446	46.43	453,901	41.45	467,792	42.71
Shrubland	272,154	24.85	298,778	27.28	313,998	28.67
Forestland	187,621	17.13	140,221	12.80	81,913	7.48
Cropland	49,312	4.50	120,246	10.98	168,936	15.43
Water features	17,890	1.63	24,198	2.21	26,052	2.38
Bareland	59,608	5.44	53,727	4.91	26,718	2.44
Built-up area	130	0.01	4090	0.37	9751	0.89
Total Area	**1,095,161**	**100.00**	**1,095,161**	**100.00**	**1,095,161**	**100.00**

Table 4 Total ESVs for the different LULC types (2000, 2014, 2024)

LULC type	Total ESV (Million US$ year^{-1})					
	2000		2014		2024	
	ESV	%	ESV	%	ESV	%
Grassland	811.98	3.16	724.88	3.41	747.06	5.01
Shrubland	209.29	0.81	229.76	1.08	241.46	1.62
Forestland	22340.97	86.94	16696.82	78.61	9753.79	65.37
Cropland	395.88	1.54	965.33	4.55	1356.22	9.09
Water features	1938.56	7.54	2622.10	12.35	2823.00	18.92
Bareland	0.00	0.00	0.00	0.00	0.00	0.00
Built-up area	0.00	0.00	0.00	0.00	0.00	0.00
Total ESV for the year	**25696.68**	**100.00**	**21238.89**	**100.00**	**14921.53**	**100.00**

Table 5 Changes in total ESVs and annual rates of ESV changes in the study area

LULC type	Changes in total ESVs (Million US$)			Annual rate of ESV changes (Million US$ year^{-1})		
	2000–2014	2014–2024	2000–2024	2000–2014	2014–2024	2000–2024
Grassland	-87.11	22.18	-64.92	-6.22	2.22	-2.71
Shrubland	20.47	11.70	32.18	1.46	1.17	1.34
Forestland	-5644.16	-6943.03	-12587.18	-403.15	-694.30	-524.47
Cropland	569.46	390.88	960.34	40.68	39.09	40.01
Water features	683.53	200.90	884.43	48.82	20.09	36.85
Bareland	0.00	0.00	0.00	0.00	0.00	0.00
Built-up area	0.00	0.00	0.00	0.00	0.00	0.00
Total change in ESV for the period	**-4457.80**	**-6317.35**	**-10775.15**	**-318.41**	**-631.74**	**-448.96**

2000 to 2024, equivalent to a -41.9% decrease. Between 2000 and 2014, forestland and grassland experienced a reduction in their ESVs, while cropland, shrublands and water features had increased ESVs due to the increase in their LULC. The period between 2014 and 2024 had only one biome with reduced ESV (forestland), while the rest (cropland, shrubland, grassland, and water features) showed positive ESV changes (Table 5). There was an average annual ESV loss rate of US$ -448.96 million per year over the 24 years (2000–2024). The annual rates of ESVs change worsened from a loss of US$ -318.41 million per year between 2000 and 2014 to US$ -631.74 million per year from 2014 to 2024 (Table 5).

Spatial distribution of ecosystem services values

The spatial distribution of the ESVs over the three study years was mapped as shown in Fig. 2. The ESVs in Baringo County displayed spatial heterogeneity as areas with high ESV were mainly concentrated in the southern region around Eldama Ravine and the south-eastern edges of the County (Loruk, Nyalilpuch) due to the presence of forests and lakes. Areas with low ESV were mainly bare land with scarce vegetation, which covered most of the northeastern parts of the county around Chemolingot and Kapedo. The remaining parts of Baringo County were filled with areas with medium ESV. There was also a notable fade out of the high ESVs in the northern and midwestern areas of Baringo throughout the study period (Fig. 2).

Individual ecosystem service values

As for the individual ESVs, opportunities for recreation and tourism, water provision, and raw material supply contributed the most to the total ESVs across the three reference years (2000, 2014, and 2024). In contrast, medicinal resources and ornamental resources had the lowest contributions, consistent with their relatively low per-hectare valuation and limited spatial extent within the study area (Table 6).

An in-depth analysis of 23 individual ecosystem services across the LULC categories in Baringo County revealed substantial variations over the study period. Out of the 23 individual ecosystem services assessed, 10 showed a general decline, 12 registered an increase, while 1 (ornamental resources) remained constant over the 24 years (Table 6). The most significantly reduced services were opportunities for recreation and tourism and water provision, with net decreases of US$ -5.10 billion and US$ -4.93 billion, respectively (Table 6).

In contrast, the most significantly increased services were waste treatment, which rose by US$417.82 million, and Maintenance of genetic diversity, which increased by US$146.07 million (Table 6). Other services registered moderate gains, including Maintenance

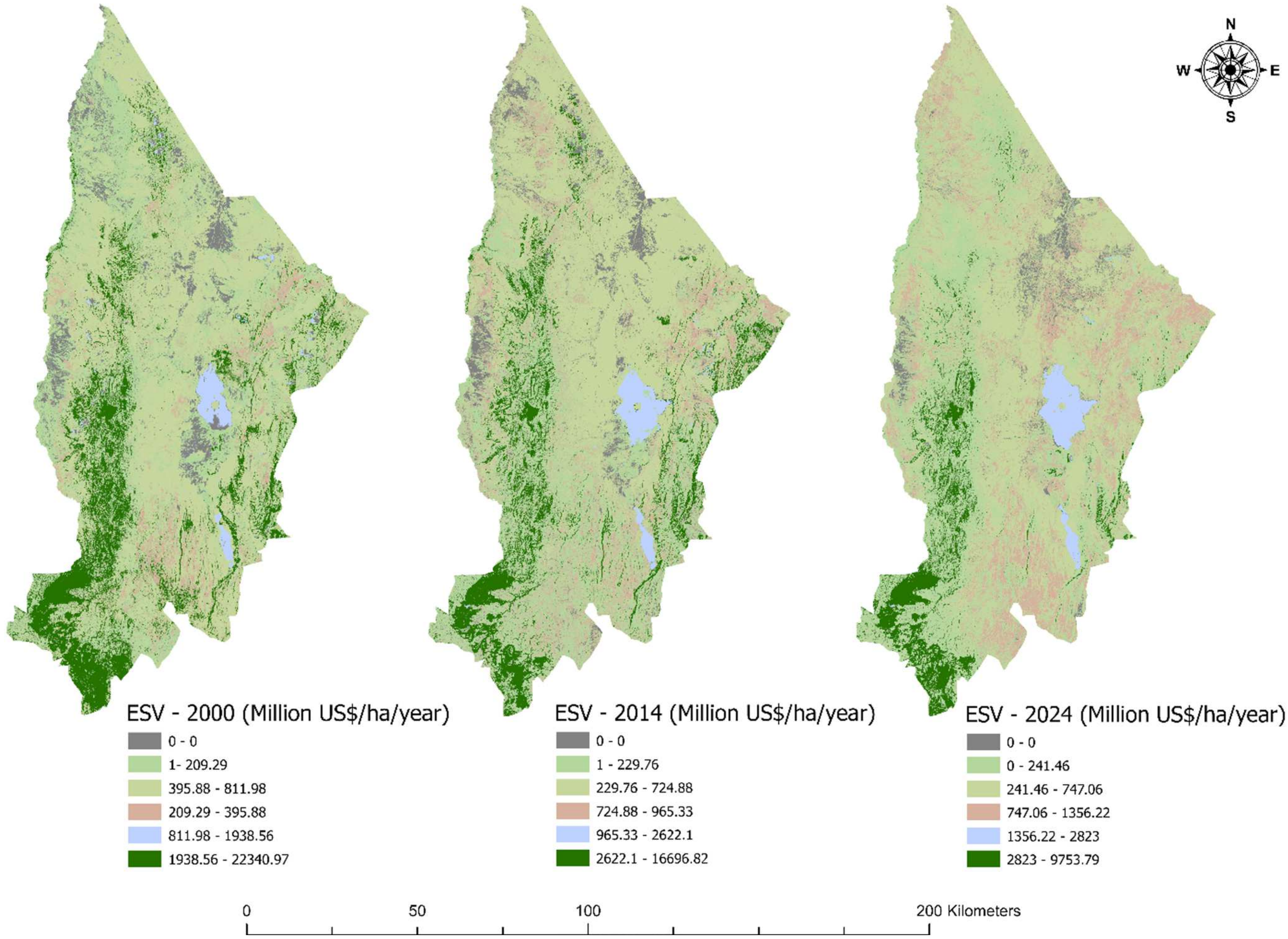

Fig. 2 Maps showing the spatial distribution of ESVs in Baringo County (2000, 2014 and 2024)

of soil fertility (US$50.14 million), aesthetic information (US$67.42 million), and inspiration for culture, art, and design (US$1.33 million).

Grouped ecosystem services values

The total ESVs for Baringo County were categorized into four main groups: provisioning, regulating, habitat, and cultural services (Table 6). Overall, provisioning and cultural grouped ES were the two highest, while habitat was the least in all three study years (Fig. 3). Provisioning services (food, water, raw materials, medicinal and genetic resources) showed a net decrease in value from US$12.05 billion in 2000 to US$5.87 billion in 2024, representing a total loss of approximately US$ -6.18 billion (Table 6). Regulating services, which include climate regulation, water flow regulation, air quality, and erosion control, exhibited a slight increase over the study period. The total value increased from US$1.95 billion in 2000 to US$2.54 billion in 2024, marking a net gain of US$586.71 million (Table 6). Habitat-related services, particularly the Maintenance of genetic diversity and life cycles of migratory species, increased from US$341.03 million in 2000 to US$491.65 million in 2024, marking a gain of US$150.62 million. Cultural services (recreation, aesthetic values, and spiritual and cognitive benefits) suffered a marked decline over the study period, decreasing from US$11.35 billion in 2000 to US$6.02 billion in 2024, representing a net loss of US$ -5.34 billion (Table 6).

Sensitivity analysis results

The sensitivity analysis results (Table 7) revealed that forestland and water features were the most sensitive LULC categories across all three time points (2000, 2014, and 2024). Forestland exhibited the highest CS values (0.67 in 2000, 0.46 in 2014, and 0.26 in 2024), indicating a strong influence on the total ESV, particularly in 2000 when forest cover was highest. Similarly, water features had CS values of 0.42, 0.25, and 0.19, respectively, reflecting their significant contribution to ESV, especially

Table 6 Estimated individual and grouped ESV trends in Baringo County

Grouped ES	Individual ES	Individual and grouped ESV (Million US$ year^{-1})			Overall individual and grouped ESV changes (Million US$ year^{-1})
		ESV_f 2000	ESV_f 2014	ESV_f 2024	2000–2024
Provisioning	Food	181.21	203.49	197.59	+ 16.38
	Water	9334.71	7149.51	4409.18	-4925.53
	Raw material	2528.58	1938.44	1263.28	-1265.30
	Genetic resources	3.00	2.24	1.31	-1.69
	Medicinal resources	0.84	0.72	0.56	-0.28
	Ornamental resources	0.00	0.00	0.00	0.00
	Subtotal provisioning	***12048.34***	***9294.40***	***5871.92***	***-6176.42***
Regulating	Air quality regulation	64.44	50.25	32.94	-31.50
	Climate regulation	189.78	159.27	124.22	-65.56
	Moderation of extreme events	69.55	134.98	177.07	+ 107.52
	Regulation of water flows	200.47	206.89	191.45	-9.02
	Waste treatment	912.32	1234.78	1330.14	+ 417.82
	Erosion prevention	121.85	105.50	78.70	-43.15
	Maintenance of soil fertility	120.28	159.74	170.42	+ 50.14
	Pollination	238.41	303.10	324.90	+ 86.49
	Biological control	35.79	80.07	109.76	+ 73.97
	Subtotal regulating	***1952.89***	***2434.58***	***2539.60***	***+ 586.71***
Habitat	Maintenance of the life cycles of migratory species	17.93	22.10	22.48	+ 4.55
	Maintenance of genetic diversity	323.10	436.23	469.17	+ 146.07
	Subtotal habitat	***341.03***	***458.33***	***491.65***	***+ 150.62***
Cultural	Aesthetic information	70.54	113.93	137.96	+ 67.42
	Opportunities for recreation and tourism	10381.66	8183.71	5285.12	-5096.54
	Inspiration for culture, art, and design	209.91	202.97	211.24	+ 1.33
	Spiritual experience	1.36	1.84	1.98	+ 0.62
	Information for cognitive development	135.06	133.47	138.98	+ 3.92
	Existence and bequest values	555.90	415.65	243.09	-312.81
	Subtotal cultural	***11354.43***	***9051.57***	***6018.37***	**-5336.06**
Total	Grand Total ESV	**25696.68**	**21238.88**	**14921.54**	**-10775.15**

ESV_f: ecosystem service valuation function

through services like water provision, waste treatment, and recreation.

In contrast, grassland and cropland showed relatively low sensitivity, with CS values ranging from 0.03 to 0.06 across the years. Shrubland had even lower CS values (≤ 0.004), indicating a minimal effect on total ESV from changes in its VC. Bareland and built-up areas consistently recorded a CS of 0.00 due to their negligible or zero valuation coefficients. Overall, the CS values for all LULC classes were below 1 (Table 7).

Discussion

Total ecosystem service values changes

Our study findings show a link between LULC changes and ESV changes, mainly from the interaction between anthropogenic activities and the ecological environment. These findings reiterate earlier findings by other researchers who have demonstrated that LULC changes are among the leading contributors to ESV gains and losses globally (Cabral et al. 2016; Karki et al. 2018; Li et al. 2019; Mengist et al. 2022; Muleta et al. 2021; Munthali et al. 2022; Yuan et al. 2019). The changes in LULC types in Baringo were driven by several proximate and underlying factors, among them deforestation, alien species invasion, agricultural expansion, and population growth (Kipkulei et al. 2025).

Fig. 3 Grouped ecosystem services trends in Baringo County (2000, 2014, 2024)

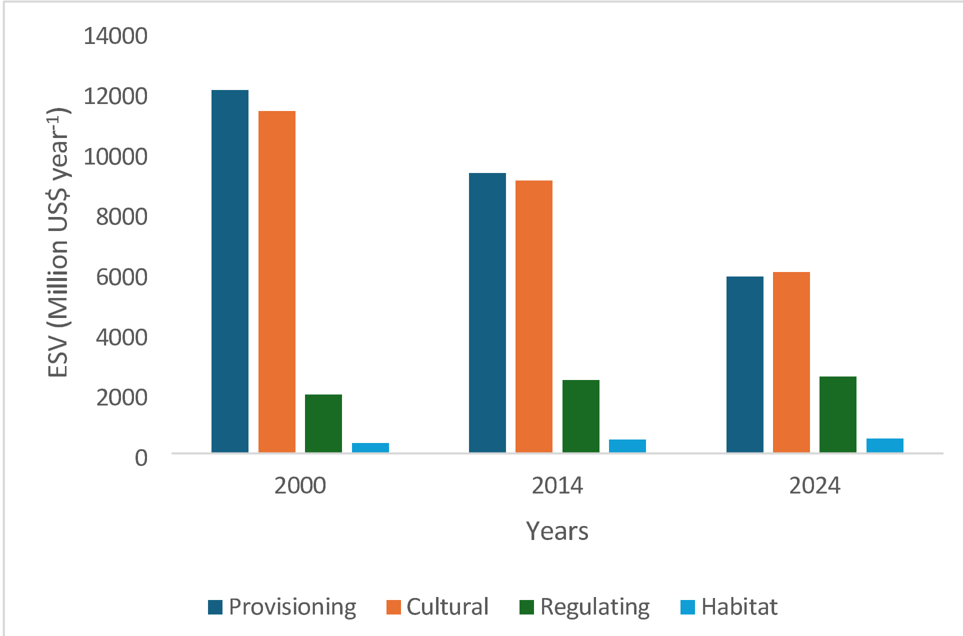

Table 7 Percentage change in estimated total ESVs and coefficient of sensitivity after a 50% adjustment of valuation coefficients

LULC Type (VC ± 50%)	2000		2014		2024	
	Δ% in ESV	CS	Δ% in ESV	CS	Δ% in ESV	CS
Grassland	± 3.11	0.06	± 2.77	0.06	± 2.85	0.06
Shrubland	± 0.15	0.003	± 0.19	0.004	± 0.20	0.004
Forestland	± 33.48	0.67	± 22.93	0.46	± 13.09	0.26
Cropland	± 1.56	0.03	± 3.41	0.07	± 5.66	0.11
Water features	± 21.16	0.42	± 12.35	0.25	± 9.47	0.19
Bareland	± 0.00	0.00	± 0.00	0.00	± 0.00	0.00
Built-up area	± 0.00	0.00	± 0.00	0.00	± 0.00	0.00

VC: value coefficient; CS: Coefficient of Sensitivity; ESV: Ecosystem Service Values

Forestland's decline was the major contributor to the decline in the total ESV, with substantial losses occurring over both study periods. Agricultural expansion and rapid population growth are the key drivers of forest loss in Kenya, including in the study area (Ministry of Forestry and Wildlife 2013; Rotich et al. 2020, 2025). These results endorse earlier research findings (Gashaw et al. 2018; Mekuria et al. 2021; Rotich et al. 2022), which showed that reductions in forests lead to a significant decline in ES due to the high coefficient value attached to forests and the variety of ES provided by forests (Nasi et al. 2002). The net increase in areas covered by grassland and shrublands had a minimal impact on the total ESV due to their low coefficient values. Mbaabu et al. (2019) note that the invasive and rapidly expanding *Prosopis juliflora* shrub (hereafter referred to as Prosopis) has negatively affected the delivery of traditional ecosystem services provided to agro-pastoralists, due to its continuous invasion of grasslands and cropland. The loss of biological diversity is a major mechanism through which the invasive shrubs affect ecosystem functions in Baringo County (Linders et al. 2019).

The spatial distribution and changes of ESVs were subsequently influenced by the LULC types and changes, which varied across the county, hence the heterogeneity in ESV distribution and changes. Similar findings have been reported by other researchers in the Dedza district of Malawi (Munthali et al. 2022) and the Nansihu Lake basin of China (Jiang et al. 2019). Liu et al. (2022) further echo the significance of the spatial spillover effects of LULC changes on ESVs in different regions with different economic levels.

Individual ecosystem service value changes

The ESVD of 2020 classifies 23 individual ESVs with the notable addition of existence and bequest values as a service from the original TEEB list of 2010 (De Groot et al. 2020; Van der Ploeg et al. 2010). There was a mix of increases and decreases in the individual ES by the various LULC changes.

A notable increase in pollination, food, biological control, moderation of extreme events, and aesthetic information can be linked to the steady expansion of croplands in the study area. This finding echoes the work of other scholars who view the expansion of croplands as a food security measure to cater to the ever-growing population, resulting in increased select individual ES (Arowolo et al. 2018; Berihun et al. 2021; Muleta et al. 2021; Rotich et al. 2022). The increase in waste treatment is due to a net increase in water features in Baringo County. On the other hand, water, opportunities for recreation and tourism, raw material, existence, and bequest values exhibited a reduction in their ESVs. These declines are mainly associated with the marked reduction in forestland, which plays a critical role in supporting hydrological cycles and ecotourism.

Previous studies have established that forests are significant water catchment areas in addition to providing raw materials, recreation, and tourism services (Imo 2012; Kenya Water Towers Agency 2020; Wass 1995). The deterioration of genetic resources can be attributed to the rapid expansion of the invasive Prosopis, which alters the biodiversity of the landscape. Similar findings have been reported in the East African drylands of Kenya and Ethiopia, where an increase in Prosopis cover led to a significant decrease in plant species diversity, richness, and herbaceous biomass (Becker et al. 2016; Clement et al. 2020). Ornamental resources remained constant, as they had nil valuation for all seven LULC types within the study area (De Groot et al. 2020; Mekuria et al. 2021).

Grouped ecosystem services trends

The 23 individual ES were further categorized into four groups: provisioning (6), regulating (9), habitat (2), and cultural (6) (De Groot et al. 2020). Respective changes in the individual ESVs consequently altered the grouped ESVs over the study period. Provisioning and cultural ES showed high values over the three reference years due to the high coefficients attached to forests and water features and associated opportunities for recreation, tourism, and water provisioning. The decline in forests subsequently led to their diminished ESVs as forests support high provisioning and cultural values such as freshwater supply, raw materials and aesthetic information opportunities for recreation and tourism. This poses a threat to the tourism and recreation sector in Baringo County if the trend continues unabated. Similar findings were reported by Mekuria et al. (2021) in the Central Rift Valley of Ethiopia. Regulating ES's steady rise was contributed partly by the increase in water features between 2000 and 2024, resulting in improved waste treatment. Water bodies are vital in waste treatment, as highlighted by (Vasistha and Ganguly 2020) and (Wang et al. 2014).

ESVs sensitivity

Previous research has shown that considering the land-cover elasticity of ESV coefficients improves assessments of large land-use changes (Knoke et al. 2024). In the present study, forestland and water features were the most sensitive LULC categories, reflecting their significant contribution to ESV, especially through services like water provision, waste treatment, and recreation. Overall, all the CS values were below 1.0, indicating that the total ESV estimates are relatively robust to variations in the unit values applied. This supports the reliability of the ESV results in Baringo County, despite the inherent uncertainties in benefit transfer methods (Pinke et al. 2022). The results underscore the critical role of forest and aquatic ecosystems in sustaining the region's ecosystem service base and emphasize the need for prioritizing their conservation in land management and policy frameworks in Baringo County.

Limitations and future directions

There is an active scientific debate on the ethical aspects and methodological issues related to the economic valuation of ES (Pinke et al. 2022). The BTM results' accuracy is dependent on the LULC dataset quality and the coefficient values per unit area of the corresponding biome. It is therefore subject to several possible errors, the first of which may occur when existing sites are not exact matches for the ecosystems under consideration. This may introduce inaccuracies in value transfer when doing an economic valuation of ES (Pinke et al. 2022; Plummer 2009). The LULC classification accuracy can also lead to errors since, in most cases, they are not 100% but rather above the acceptable/recommended minimum of 80% (Ahmed et al. 2024; Kindu et al. 2013; Landis and Koch 1977; Munthali et al. 2022). Additionally, this study evaluated ESV changes for three reference years (2000, 2014, and 2024), which may fail to capture the exact year/s when major LULC changes occurred, thereby impacting the ESVs. The future direction to reduce this uncertainty will therefore be the use of a year-by-year dataset in the evaluation of ESV changes in response to LULC changes (Wang et al. 2022a, b). Notwithstanding these shortcomings, the BTM is often the best or only available option to policymakers and natural resource managers for a timely assessment of multiple ES over large geographical areas such as Baringo County, especially when primary data is not available (Arowolo et al. 2018; Wang et al. 2015).

Conclusions

The present study employed the BTM to assess the changes in ESVs due to LULC changes in Baringo County from 2000 to 2024. The county experienced a net total ESV loss of US$ -10.78 billion (-41.9%) at an average yearly ESV change of US$ -448.96 million, indicating considerable degradation in the county's natural capital. Forestland and grassland, which comprise key contributors to high-value ecosystem services such as climate regulation, water provision, and biodiversity support, experienced significant reductions, which in turn led to notable losses in provisioning and cultural services. The most affected individual ESVs were opportunities for recreation and tourism and water provision, each declining by over US$ -5 billion and US$ -4.9 billion, respectively. Conversely, some services such as waste treatment, pollination, and Maintenance of genetic diversity recorded increases, primarily linked to expanding shrubland and cropland areas. These gains, however, were insufficient to offset the broader ecological and economic losses stemming from deforestation, bareland expansion, and biodiversity decline. The sensitivity and elasticity analyses further emphasized the disproportionate influence of certain LULC types (particularly forestland) on the total ESVs. The high sensitivity of the total ESVs to changes in forestland underscores the urgent need for policy interventions geared toward sustainable forest management (SFM) and ecological restoration. Overall, the study results highlight the urgent need to integrate ESVs into land use planning, environmental policy, and conservation strategies. Safeguarding and restoring high-value ecosystems, especially forests and wetlands, is critical for sustaining ecosystem functions and improving the well-being of communities that rely on these services for their livelihood. Failure to address these trends could undermine long-term ecological sustainability and socio-economic development in Baringo County and similar dryland ecosystems.

Acknowledgements We appreciate the anonymous reviewers for their valuable comments and suggestions.

Author contributions BR: Conceptualization, Formal analysis, Validation, Writing-Original Draft HK: Visualization, Writing-Original Draft, AA: Methodology, Writing-Review & Editing AL: Writing-Review & Editing, IM: Writing-Review & Editing BS: Writing-Review & Editing, SM: Writing-Review & Editing, MB: Writing-Review & Editing.

Funding Open Access funding enabled and organized by Projekt DEAL.

Data availability The datasets used and/or analysed during the current study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare no competing interests.

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