Heliyon 10 (2024) e28798

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Assessing the impact of Land use changes on ecosystem services in the Alledighe rangeland, Ethiopia

Simeneh Admasu [a,b]

[a] Addis Ababa University, Environmental Planning Program (EiABC), Ethiopia
[b] GFA Consulting Group, Biodiversity, and Forests Program in Ethiopia, Ethiopia

ARTICLE INFO

Keywords:
Alledighe wildlife reserve
Ecosystem service values
Land use change
Rangeland Ethiopia

ABSTRACT

Understanding the ecological, social, and economic values of protected areas, as well as assessing the services they provide to both humans and the environment is crucial for informing conservation policies and sustainable land management practices. Using the benefits transfer method, changes in ecosystem service values (ESVs) resulting from spatiotemporal land use dynamics were evaluated in the Alledighe Wildlife Reserve (AWR) spanning from 1998 to 2016. Five distinct habitat types, namely grassland, bushland, woodland, riverine forest, and highland forest, were identified across the landscape. The ESVs were estimated using regional and global ESV values. A decline in the extent of grassland, woodland, and riverine forests by 9.9%, 2.4%, and 1.5%, respectively, was observed while bushland and highland forests increased by 10.6% and 3.3%, respectively. The AWR experienced a loss of roughly 145 km^2 of grassland habitat. Based on regional and global ESVs, total ESVs in the study area decreased by 28.18% from approximately US$ 180 million to approximately US$ 129 million, and by 40.85% from approximately US$ 496 million to approximately US$ 293 million. As per individual ESV assessment, the total ESV decreased by 41% from around US$ 374.5 million to US$ 264.8 million. Provisioning service declined by 41.6% from US$ 100 million to US$ 70.6 million. Regulating service declined by 42.5% from US$ 242.4 million to US$ 170 million. Supporting service declined by 67% from US$ 5.3 million to US$ 3.2 million, and cultural service decreased by 27.8% from US$ 26.7 million to US$ 20.8 million. The larger ESV change was contributed by the expansion of forestland and bushland across previously grassland-dominated areas. The results of this study could render the value of the rangeland more visible in the decision-making process, as well as provide valuable input for future planning and management interventions of the AWR's pristine rangeland, thereby enhancing ecosystem services and the livelihoods of the surrounding communities.

1. Introduction

Spatiotemporal Land Use Land Cover (LULC) changes can be the primary factor of biodiversity loss [1,2] as well as a potential trigger for natural disasters like flooding and drought [3] and the most important factor influencing global and local environmental changes [4,5,6,7,8]. LULC changes could adversely impact biodiversity and ecosystem services [9] and ecosystem processes [10]. Further, influences vegetation distribution, soil, and water availability [11,12]. Land use changes initiated by external and internal drivers have had an impact on traditional rangeland management in pastoral areas [13,14].

E-mail addresses: simeneha2009@gmail.com, simeneh2009@yahoo.com.

https://doi.org/10.1016/j.heliyon.2024.e28798
Received 21 September 2023; Received in revised form 25 March 2024; Accepted 25 March 2024
Available online 2 April 2024

Changes in LULC have been increasing at global and local scales [15] and influencing biophysical systems at all levels [16]. It has a greater impact on natural ecosystems and increases human vulnerability to climate change and socioeconomic crises [16,15,17]; LULC change can be driven by a variety of environmental and social factors [18]. The major factors of LULC changes in Ethiopia are multifaceted; however, contributing factors to ongoing rapid LULC change include a lack of effective land use policy [19] and population growth [20]. Rapid economic, social, and environmental transformations in Ethiopia have increased the demand for socio-economic necessities, putting pressure on natural areas[21–31].

Likewise, most of Ethiopia's protected area systems, including the Bale Mountain Eco-Region [32], Awash National Park [33], Simien Mountains National Park [34], Kafta Shiraro National Park [35], Babile Elephant Sanctuary [36], Alledighe Wildlife Reserve [37] and Nech Sar National Park [38] have considerably changed in terms of LULC. According to these studies, a large portion of grassland habitat has been encroached upon and converted to bushland. These protected area systems face several conservation challenges [39]. The continuation of degradation, primarily highly associated with farmland expansion and intensive grazing land in and around protected areas has hindered the protected area's effectiveness [40,39]. The change in LULC types combined with poor range management practices resulted in rangeland degradation in the Afar region [41]. Herding livestock searching for pasture and water is the prime income for Afar pastoralists [42]. The AWR was created to serve as a wildlife refuge between Awash National Park and Awash West Wildlife Reserve in the 1960s [43,44] and to conserve and propagate wildlife [45]. The reserve was chosen to serve as a corridor between the park and the surrounding plains, thereby protecting Awash National Park's wildlife population through migration [44]. It also serves as a charismatic wildlife area and a reliable rangeland for livestock [42,46].

There has recently been a surge in research on ecosystem services assessment, which includes ESVs for conservation planning [47,48], environmental accounting [49], and land management [50]. ESV and cost estimates of ecosystem degradation are critical for incorporating the value of ecosystem services into policy and planning [51], but these are difficult tasks [52]. Most importantly, the data can be used to underpin the socio-ecological patterns of ecosystems and to forecast the effects of land use management on ecosystem services [53]. Assigning ESVs to different LULC types has been widely used as a proxy to quantify and map ecosystem services [52,54,55,56,57,58,59].

In many natural areas, including protected areas, the value of environmental services exceeds the value of direct benefits from tourism and employment [60]. A lack of understanding of the value of protected landscapes can lead to the ineffective promotion of an ecosystem [61]. The availability of reliable information on the values of ecosystem services can increase the visibility of PAs at the highest levels of decision-making [53,62,63,64,65]; increase public awareness [66] and imply land use management schemes [67,63]. Therefore, this assessment could assist protected area authorities in integrating biodiversity and ecosystem services in planning and demonstrating the landscape benefits to local communities and the national economy [68]. Further, conservationists frequently face difficulties obtaining financial and social support for the protection of landscapes that do not demonstrate societal benefits [69,70]. The ecosystem services approach helps to conserve biodiversity [71–74] by providing sound justification as well as increased and

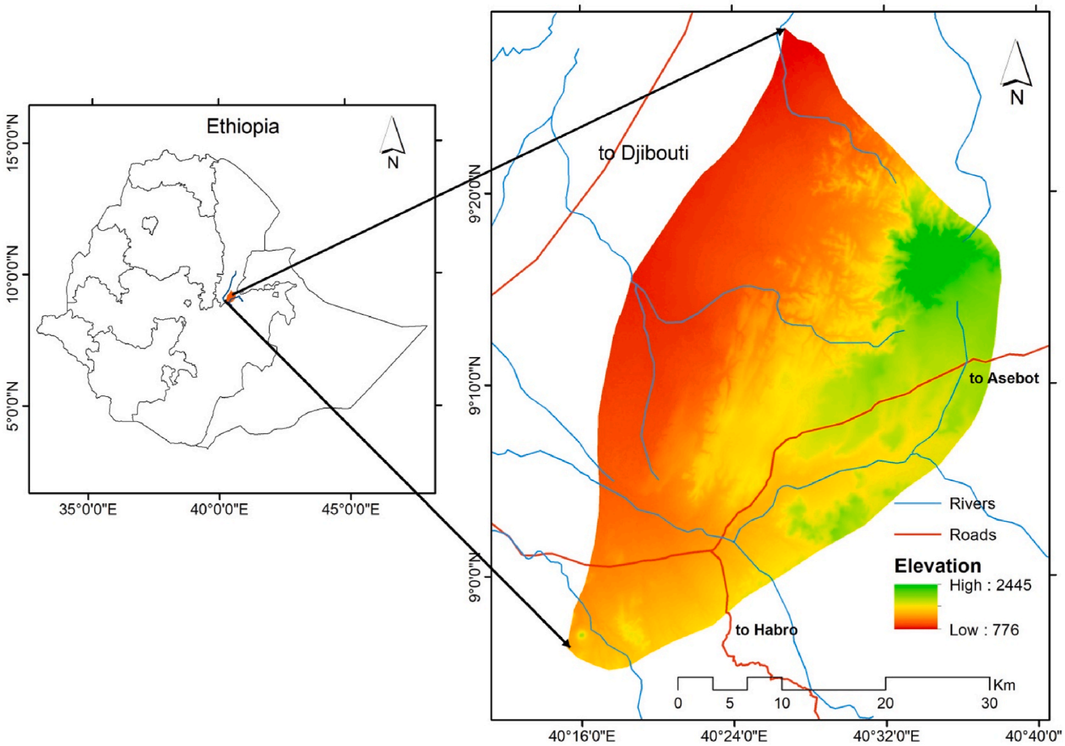

Fig. 1. Location map of the Alledighe Wildlife Reserve.

diversified conservation funding [69,75]. As a result, this study aimed to analyze ESV changes in response to spatiotemporal land use dynamics in an iconic protected area in northeast Ethiopia, to use the information to integrate biodiversity and ecosystem services into the national agenda and imply the need for an ecosystem services approach to prioritize protected areas and accelerate the globally agreed biodiversity framework.

2. Materials and methods

2.1. The study area

The AWR is located in the Great Rift Valley along the northeastern region of the country between 39°30′ to 40°30′ E and 8°30′ to 9°30′ N. The altitude ranges between 776 m and 2445 m a.s.l (Fig. 1). The area is characterized by a semi-arid ecosystem with annual rainfall ranging between 400 and 700 mm [76]. The mean annual rainfall is 493 mm; the least occurs between October and December, and the maximum during July and August [77]. The mean seasonal temperature ranges from 25 to 30^0 C but the daily maximum temperature may be as high as 38^0 in June while the minimum daily temperature can drop to 15^0 in December [77].

The major soil types in the AWR are Vertic Cambisols and Calcic Cambisol. The chemical analysis showed that the pH of the soil is alkaline and ranges from 8.1 to 9.1. The organic matter (OM) content is low, ranging from 0.5 to 1.9% [78]. The vegetation types include grasslands, bushland, wooded grassland, riverine forest, and highland forest [79,76,42]. About 268 plant species and two types of ecosystems Dry evergreen montane forest and Acacia comiphora ecosystems [79,76], 31 mammals [80,43,81,77], and over 140 bird species have been recorded [80,43,81,77]. The Grevy zebra (*Equus grevyi*), Beisa oryx (*Oryx beisa beisa*), Soemmering's gazelle (*Gazella soemmering*), Gerenuk (*Litocranius walleri*), and Lesser kudu (*Tragelaphus imberbis*) are among the wild animals inhabiting the reserve [42,80,43].

Historically, the grassland plain stretching from the center of the reserve to the northwest was mainly occupied by grasses and occasionally other herbs [42,82]. The bushland is an extensively increasing habitat type that possesses an assemblage of trees and shrubs. The woodland habitat is mainly occurring in the southern, eastern, and northern edges of the landscape [42,82]. The eastern mountainous section of the landscape is characterized by dense highland forest [42]. The riverine forests are a unique ecosystem and are important for the wild animals of the landscape [79].

2.2. Methods

2.2.1. Data collection

Landsat 7 and Landsat 8's Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) images, boasting a resolution of 30 m, were employed in the detection of LULC alterations between the years 1998 and 2016. These years were selected for analysis due to the desire to utilize as much quality data as possible. Further, going as far back as possible to monitor trends of wildlife management policy transformation [63,66] and changes that occurred following the transfer of responsibility for managing the protected area to the federal Ethiopian Wildlife Conservation Authority in 2008 can also be attributed to this study.

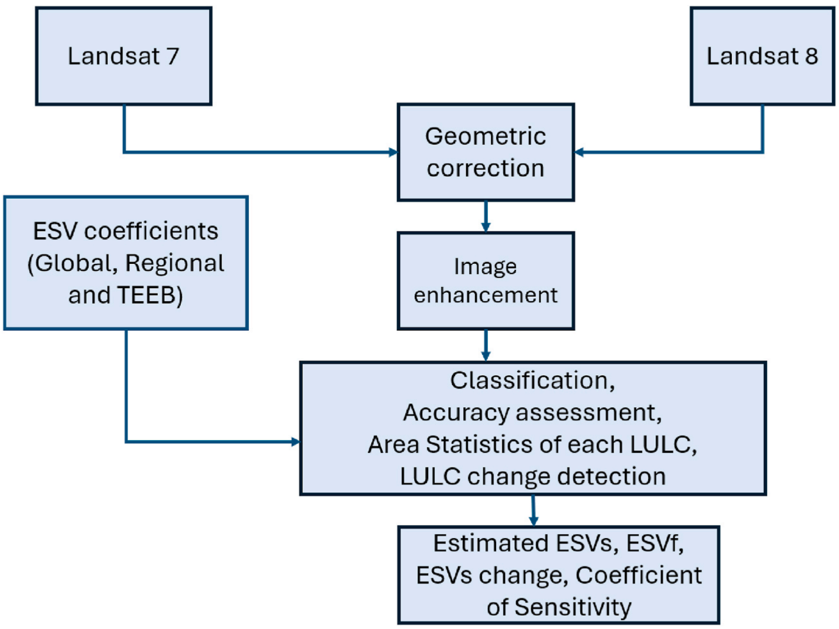

Fig. 2. The methodological flow chart of the study.

2.2.2. LULC classification

Landsat images obtained from the US Geological Survey (USGS) website were acquired as compressed files for the years 1998 and 2016 and were subsequently converted to TIFF format. The data underwent projection to the Universal Transverse Mercator (UTM) projection system zone 37 N with a datum of World Geodetic System 84 (WGS84) to guarantee consistency and compatibility [63].

The entire suite of images underwent classification using a supervised classification method with a maximum likelihood classifier [63], whereby representative ground truth data were gathered to train classifiers and associate the reflectance property with the object, thus enabling accurate automatic classification [83,84].

2.2.3. Image processing

The reference data were compared to evaluate and quantify the accuracy of a classified image [85]. By comparing the classified map to reference data, this method was used to estimate the accuracy of image classification, and a field study was also conducted with key informants from the local community to confirm the accuracy of the land classification undertaking. As a result, an accuracy assessment including overall accuracy, user accuracy, and producer accuracy was conducted [63] (Fig. 2; Table 1).

2.2.4. LULC change detection

The comparison of LULC change during the study periods was executed using Equation 1 as described by Ref. [86]. Additionally, Equation (2) was employed to compare the rate of change in each LULC type within the study period. The identification of the directions of changes in each land cover type was determined by subtracting the final year from the initial year of each land cover type, then dividing the result by the initial year of each land cover type, and finally multiplying by 100, as described by Refs. [38,54].

$$\text{Total area change} = \text{Area}_{\text{final year}} - \text{Area}_{\text{initial year}} \tag{1}$$

Where an area is the extent of each LULC type; positive values suggest an increase whereas negative values indicate a decrease.

$$\text{Rate of change} = \frac{\text{Area}_{\text{final year}} - \text{Area}_{\text{initial year}}}{N} \tag{Eq. 2}$$

Where N is the time interval between the initial and final years.

2.3. ESVs of LULC types

For this study, the global, regional, and Economics of Ecosystems and Biodiversity (TEEB) ecosystem service values (ESVs) assigned values for distinct LULC types were utilized. The former was based on [52] ESVs, which used a representative biome as a proxy for each LULC type. Later ESVs were more conservative, with expert knowledge of the study landscape conditions and other studies, primarily from the TEEB valuation database, being used to make changes [57,58].

ESVs for the representative biome were included in the TEEB valuation data [87] (Table 2). Despite an inconsistency between LULC type and the proposed biome by Ref. [88], data obtained from Ref. [58] on individual ESVs were incorporated into the East Africa individual coefficient [87] to estimate the individual ESV [63] (Table 3).

2.4. ESV analysis

The analysis of ESVs was conducted on the assigned LULC types, wherein the area of each type was multiplied by its corresponding value to obtain ESV estimates for distinct LULC types. This methodology was adopted as outlined by Ref. [88] and is represented by the formula in Eq. (3).

$$ESV = \sum (A_k * VC_k) \tag{3}$$

Where ESV = Total estimated ES value, A_k = Area (ha) and VC_k = Value ESV (US\$ha^{-1}year^{-1}) for LULC type 'k',

To investigate the variations in value over time, the estimated ESV was adjusted to the year 2022, using the CPI Inflation Calculator, as suggested by Ref. [63]. Additionally, the ESV change between 1998 and 2016 was determined using Eq. (4) [89,56,65].

Table 1
Accuracy assessment.

Habitat types	1998		2016	
	Producer	User	Producer	User
Grassland	75	95.12	75.6	87.5
Bushland	66.6	59.45	86.2	73.5
Highland Forest	63.6	82.35	100	87.5
Riverine forest	50	61.53	100	100
Woodland	85	61.81	70.5	75
Overall accuracy	71.77	71.77	81.14	81.14
Kappa statistics	0.63	0.63	0.75	0.75

Table 2
Reginal and global estimates of ESVs in million US$ for each LULC type.

LULC types	Equivalent biome		
		Regional	Global
Bush-shrub-woodland	Tropical forest	987	987
Grassland	Grass/rangeland	293	4166
Natural forest	Tropical forest	987	5382

Table 3
Ecosystem functions value coefficients of each LULC type database TEEB of McVittie and Hussain (2013).

Ecosystem function types	ESVs (US$ $ha^{-1}year^{-1}$ in each LULC)			
	Forest	Grassland	Woodland	Bushland/Shrubland
Water supply	178	114.4	4.33	114.4
Food production	67	130	0	130
Flaw material	475.51	19	138.2	19
Biomass fuel	31.34	79	67.28	67.28
Genetic resources	327.68	0.01	0	0.01
Water regulation	15.6	5	0	5
Water purification	275.2	99.71	253.56	99.71
Erosion control	360	55.89	26.76	
Biological control	20.62	30	0	30
Biodiversity protection	263	52.68	11.44	52.68
Climate regulation	569	121.91	383.72	121.91
Gas control	22.12	2.41	0	2.41
Carbon sequestration	1229.79	297.39	8.16	297.39
Nutrient recycling	11.61	0	0	0
Pollination	48.29	32	0	0
Soil formation	3.26	7	0	0
Habitat/regulation	28.057	0	0	0
Recreation	810.68	3.11	0	0
Tourism	73.74	0	0	0

$$ESV\ change\ (\%) = \left(\left(\mathrm{ESV}_{\mathrm{final\ year}} - \mathrm{ESV}_{\mathrm{initial\ year}}\right) / \mathrm{ESV}_{\mathrm{initial\ year}}\right) * 100 \qquad 4$$

Where ESV = *Total estimated ES value. Where positive values suggest an increase whereas negative values imply a decrease in amount.*

2.5. Elasticity of the ESV change with LULC

Given that value, coefficients cannot be used to parametrize accurate ESVs, and biomes may not always be exact matches for LULC types, the elasticity of ESV analyses was conducted to determine the percentage change in ESVs for a given percentage change in the value coefficient [90]. Specifically, the estimated ESV of a particular LULC class was modified by 50% [91], while the remaining ESVs identified for LULC types were held constant. To calculate the Coefficient of Sensitivity (CS) value, a simplified method was utilized [92]. It is important to note that the ESV changes of the CS value should be less than one (Eq. (5)).

$$\mathrm{CS} = \frac{\mathrm{VC_{ik}A_k}}{\mathrm{ESV_i}} \qquad 5$$

Where ESVi is the total ESV (US$ yr^{-1}) from all LULC types identified at i year (US$ yr^{-1}), VCi, k is the total value of ES provided by the k LULC class at i year (US$ yr^{-1}), and Ak is the area coverage (ha) of the k LULC type at i year.

3. Results

3.1. LULC changes (1998–2016)

Each of the five major LULC types is represented by its own set of results: grasslands, bushland, woodland, riverine forest, and highland forest. The study found that important changes in land cover occurred in the AWR between 1998 and 2016. Grassland, woodland, and riverine forest cover have decreased by 9.9%, 2.4%, and 1.5%, respectively, while bushland and highland forest cover have increased by 10.6% and 3.3%, respectively (Fig. 3; Table 4).

The land transition matrix presented in the AWR during the study period revealed the transformation of a substantial amount of woodland into grassland, highland forest, and bushland. The riverine forest experienced a considerable conversion into woodland and

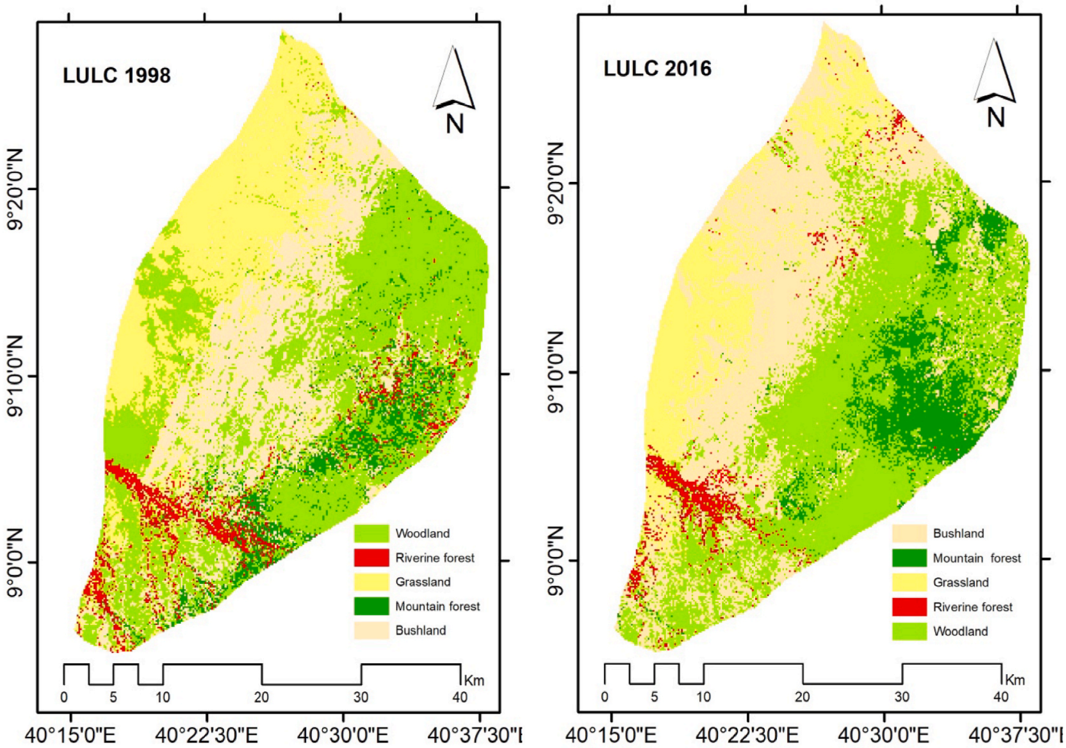

Fig. 3. LULC of the AWR in 1998 and 2016.

Table 4
LULC changes in the AWR (1998, 2016).

Habitat type	1998		2016		Change		Trend
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	
Forest	96.5	6.6	144	9.9	47.5	3.3	Increasing
Woodland	593	40.6	558	38.2	−35	−2.4	Decreasing
Grassland	359	24.6	214	14.7	−145	−9.9	Decreasing
Riverine forest	63.5	4.4	41	2.8	−22.5	−1.5	Decreasing
Bushland	347	23.8	502	34.4	155	10.6	Increasing
Total	1459	100	1459	100			

bushland. The grassland has undergone a substantial conversion into bushland. A considerable portion of the highland forest has been transformed into woodland and bushland. Lastly, the bushland has predominantly been converted into woodland (Table 5).

3.2. *ESVs dynamics in response to land use changes (1998, 2016)*

In the study area, total ESVs decreased. According to the regional ESV, the value decreased by 28.18% from approximately US$ 180 million in 1998 to approximately US$ 129 million in 2016 (Table 6). The global ESV estimate also revealed a 40.85% drop in total ESVs

Table 5
Transition matrix of LUCC in the AWR between 1998 and 2016 (unit: km^2).

Land class 2016							Total
Land class 1998	Land class	Woodland	Riverine forest	Grassland	Highland forest	Bushland	
	Woodland	**309.55**	6.44	70.66	81.09	124.04	591.79
	Riverine forest	25.00	**17.69**	0.95	9.25	10.61	63.49
	Grassland	31.47	11.44	**131.87**	1.88	182.01	358.68
	Highland forest	47.57	0.78	0.03	**35.63**	14.05	98.06
	Bushland	144.21	5.00	10.81	17.14	**169.27**	346.42
	Total	557.8	41.4	214.3	145.0	500.0	1458.4

from approximately US$ 496 in 1998 to approximately US$ 293 million in 2016 (Table 6). According to the regional estimate, woodland was the dominant proportional contributor to ESVs in 1998, accounting for approximately US$ 88.3 million (49.15%), followed by bushland, which contributed approximately US$ 51.7 million (28.76%) (Fig. 5). However, grassland, forest, and riverine forests make up only 8.83%, 8%, and 5.26% of the total.

In contrast, according to global estimates, grassland accounted for the highest ESV of approximately US$ 225.8 million (45.53%), followed by woodland and highland forest, which contributed approximately US$ 88.3 (17.82%) and US$ 78.4 million (15.81%), respectively, in 1998 (Fig. 4). In 1998, both bushland and riverine forests contributed comparably, with approximately US$ 51.7 (10.43%) and approximately US$ 51.6 million (10.41%), respectively (Table 6).

The AWR experienced considerable ESV changes. Between 1998 and 2016, the regional ESV estimated an annual net loss of approximately US$ 50.6 million (28.18%). Over 18 years, the global ESV revealed an annual net decline of approximately US$ 202.6 million (40.85%). The ESV of grassland, riverine forest, and woodland has decreased greatly by 60.5%, 57.2%, and 37.7%, respectively, whereas bushland and highland forest have decreased by only 4.19% and 1.18%, respectively (Table 6).

3.3. Changes in individual ESVs

The ESVs provided by different ecosystem services are presented in Table 7. Like global and regional ESV, the individual ecosystem value assessment showed a dramatic decline in ESV. The total ESV has decreased from roughly US$ 374.5 to US$ 264.8 million. Provisioning and regulating services have declined from US$ 100 to US$ 70.6 million and US$ 242.4 to US$ 170 million, respectively. Further, supporting, and cultural services have declined from US$ 5.3 to US$ 3.2 million and from US$ 26.7 to US$ 20.8 million, respectively.

In the 1998 assessment, the value of regulating services accounted for about 64.7% of the total in the AWR, followed by provisioning services and cultural services, which accounted for approximately 26.7% and over 7.1%, respectively. Support services, on the other hand, have contributed to the lowest levels, accounting for about 1.4%. In the 2016 assessment, the regulating and supporting had slightly declined and the provisioning service remained unchanged, whereas the cultural service showed a slight increase.

Regulatory services, including carbon sequestration, accounted for approximately 20.55% in 1998 and 21.34% in 2016, respectively, followed by climate regulation and water purification services, which accounted for 20.21% and 19.51%; and 13.22% and 12.65% in 1998 and 2016, respectively. Between 1998 and 2016, the provision of flaw material services accounted for approximately 8.56% of all services.

3.4. Sensitivity analysis

The CS value exhibited a value less than one, indicating a relative decrease in the overall carbon sequestration potential. The woodland habitat demonstrated the capacity to enhance ecosystem services in 1998 and 2016, revealing values of 0.49 and 0.43 respectively. In 1998, the bushland habitat demonstrated the second-highest value of CS at 0.29, followed by the grassland habitat at 0.09. The highland and riverine forest habitats demonstrated the lowest CS values at 0.08 and 0.05, respectively. In 2016, the bushland and highland forest habitats showed CS values of 0.38 and 0.11, respectively, followed by the grassland and riverine forest habitats at 0.05 and 0.03, respectively, as presented in Table 8.

4. Discussions

4.1. LULC analysis

Human and livestock incursion is becoming a common phenomenon in most protected areas of East Africa [93]. Natural ecosystem replacement for other land uses such as farmlands, grazing lands, settlements, and urban areas is the prime factor of biodiversity loss, and land degradation [1]. Natural and socioeconomic factors, as well as spatiotemporal operations, influence LULC changes in the area. Accordingly, rapid LULC dynamics have been occurring in the area. According to Ref. [41], woodland and grassland have dramatically decreased, while bushland and cultivated land increased threefold and more than eightfold, respectively [41].

Likewise [42,46], discovered rapid habitat changes within the AWR and its surrounding grazing lands. This study found that important LULC changes occurred between 1998 and 2016. Bush encroachment, livestock incursion, and human interference have all

Table 6
Regional and global ESVs in million US$ for each LULC type and their proportion (1998, 2016). (The value is based on 2022 US$).

Habitat type	Regional ESV				Global ESV			
	1998 US$/yr	%	2016 US$/yr	%	1998 US$/yr	%	2016 US$/yr	%
Forest	14,382,070.50	8.00	14,212,800.00	11.00	78,423,813.00	15.81	77,500,800.00	26.42
Woodland	88,378,941.00	49.15	55,074,600.00	42.64	88,378,941.00	17.82	55,074,600.00	18.77
Grassland	15,883,237.00	8.83	6,270,200.00	4.85	225,834,694.00	45.53	89,152,400.00	30.39
Riverine forest	9,463,849.50	5.26	4,046,700.00	3.13	51,605,307.00	10.41	22,066,200.00	7.52
Bushland	51,715,839.00	28.76	49,547,400.00	38.36	51,715,839.00	10.43	49,547,400.00	16.89
Total	179,823,937.00	100.00	129,151,700.00	100.00	495,958,594.00	100.00	293,341,400.00	100.00

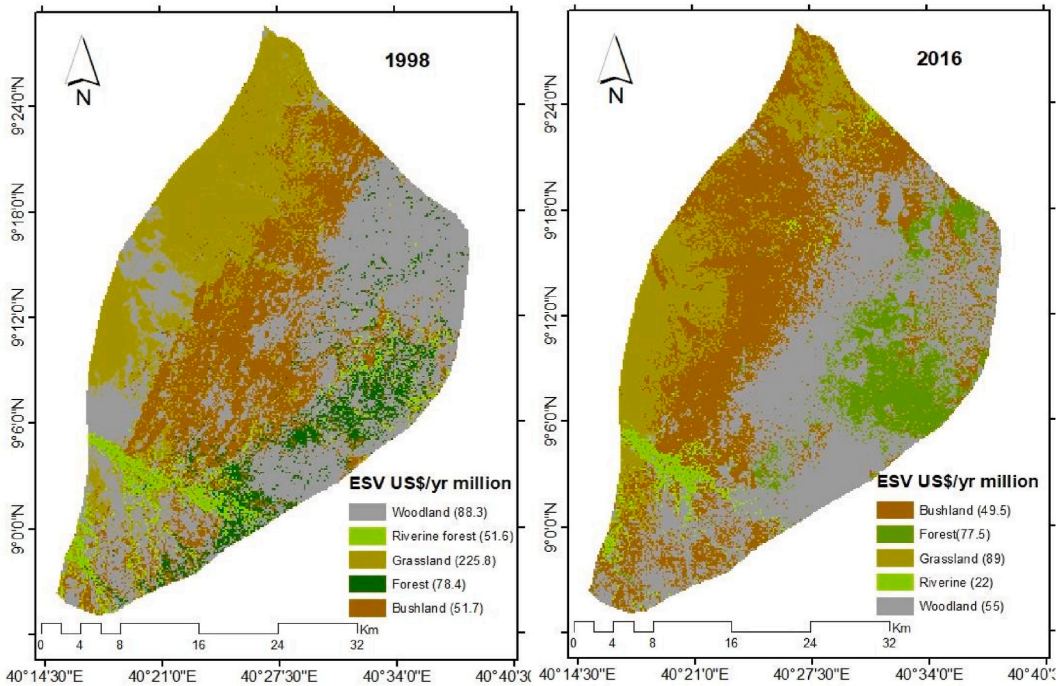

Fig. 4. The distribution of ESV of each LULC type based on the global coefficient (1998, 2016).

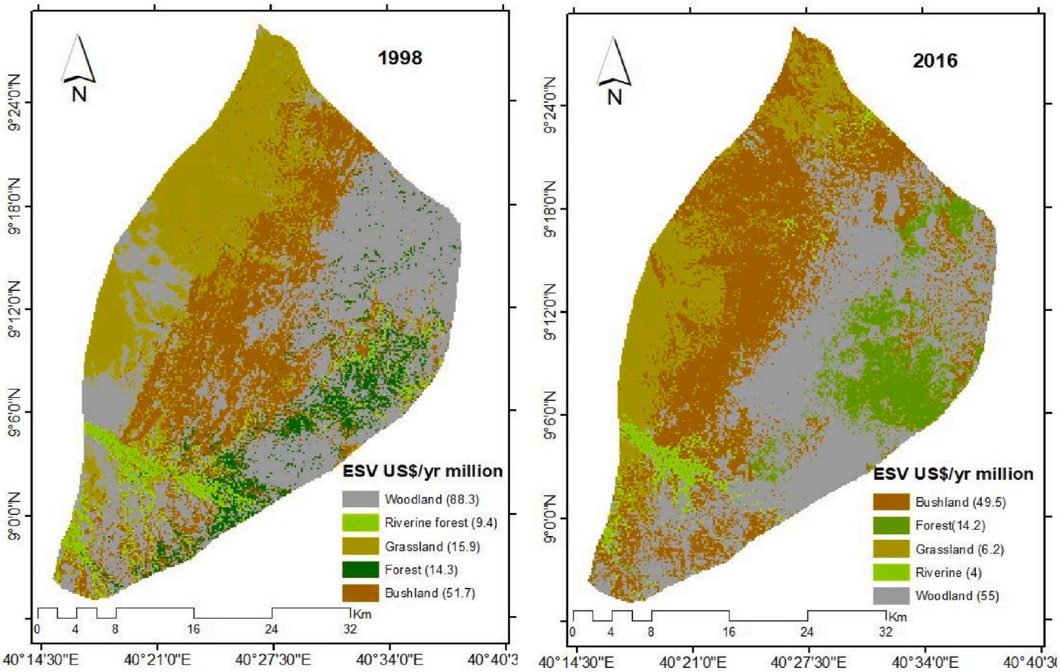

Fig. 5. The distribution of ESV of each LULC type based on the regional coefficient (1998, 2016).

potentially contributed to LULC in the area [42]. The AWR's grassland habitat is the most suitable for large mammals, but it is rapidly dwindling approximately 145 km^2 of grassland habitat has been lost.

In contrast, between 1998 and 2016, bushland habitat encroached on approximately 155 km^2 of the landscape; exotic plant species and the invasive *Prosophis juliflora* are thought to be the primary factors of bushland encroachment. The Prosopis was introduced in the late 1970s and early 1980s to aid in water and soil conservation in the Afar region [94]. Later, the species began invading croplands,

Table 7
Ecosystem functions value coefficients of each LULC type in the AWR (The value is based on 2022 US$).

Ecosystem types	Ecosystem service values (US$ ha-1year-1 in each land use land cover							
	Forest land		Grassland		Woodland		Bushland	
Provisioning	1998	2016	1998	2016	1998	2016	1998	2016
Water supply	5,325,760.00	4,182,110.00	7,680,015.20	3,109,163.20	480,158.03	306,849.78	7,423,301.60	7,293,457.60
Food production	2,004,640.00	1,574,165.00	8,727,290.00	3,533,140.00	0.00	0.00	8,435,570.00	8,288,020.00
Flaw material	14,227,259.20	11,172,107.45	1,275,527.00	516,382.00	15,325,136.20	9,793,681.20	1,232,891.00	1,211,326.00
Biomass fuel	937,692.80	736,333.30	5,303,507.00	2,147,062.00	7,460,746.48	4,767,864.48	4,365,731.92	4,289,369.12
Genetic resources	9,804,185.60	7,698,841.60	671.33	271.78	0.00	0.00	648.89	637.54
Subtotal	**32,299,537.60**	**25,363,557.35**	**22,987,010.53**	**9,306,018.98**	**23,266,040.71**	**14,868,395.46**	**21,458,143.41**	**21,082,810.26**
Regulating								
Water regulation	466,752.00	366,522.00	335,665.00	135,890.00	0.00	0.00	324,445.00	318,770.00
Water purification	8,233,984.00	6,465,824.00	6,693,831.43	2,709,918.38	28,117,521.96	17,968,782.96	6,470,082.19	6,356,911.34
Erosion control	10,771,200.00	8,458,200.00	3,752,063.37	1,518,978.42	2,967,443.16	1,896,374.16	0.00	0.00
Biological control	616,950.40	484,466.90	2,013,990.00	815,340.00	0.00	0.00	1,946,670.00	1,912,620.00
Biodiversity protection	7,868,960.00	6,179,185.00	3,536,566.44	1,431,737.04	1,268,593.04	810,707.04	3,418,352.52	3,358,560.72
Climate regulation	17,024,480.00	13,368,655.00	8,184,184.03	3,313,269.98	42,551,094.52	27,192,701.52	7,910,617.99	7,772,250.14
Gas control	661,830.40	519,709.40	161,790.53	65,498.98	0.00	0.00	156,382.49	153,647.14
Carbon sequestration	36,795,316.80	28,893,916.05	19,964,682.87	8,082,465.42	904,870.56	578,266.56	19,297,339.71	18,959,802.06
Subtotal	**82,439,473.60**	**64,736,478.35**	**44,642,773.67**	**18,073,098.22**	**75,809,523.24**	**48,446,832.24**	**39,523,889.90**	**38,832,561.40**
Supporting								
Nutrient recycling	347,371.20	272,776.95	0.00	0.00	0.00	0.00	0.00	0.00
Pollination	1,444,836.80	1,134,573.55	2,148,256.00	869,696.00	0.00	0.00	0.00	0.00
Soil formation	97,539.20	76,593.70	469,931.00	190,246.00	0.00	0.00	0.00	0.00
Habitat/regulation	839,465.44	659,199.22	0.00	0.00	0.00	0.00	0.00	0.00
Subtotal	**2,729,212.64**	**2,143,144.05**	**2,618,187.00**	**1,059,942.00**	**0.00**	**0.00**	**0.00**	**0.00**
Cultural								
Recreation	24,255,545.60	19,046,926.60	208,783.63	84,523.58	0.00	0.00	0.00	0.00
Tourism	2,206,300.80	1,732,521.30	0.00	0.00	0.00	0.00	0.00	0.00
Subtotal	**26,461,846.40**	**20,779,447.90**	**208,783.63**	**84,523.58**	**0.00**	**0.00**	**0.00**	**0.00**
Total	**143,930,070.24**	**113,022,627.65**	**70,456,754.83**	**28,523,582.78**	**99,075,563.95**	**63,315,227.70**	**60,982,033.31**	**59,915,371.66**

Table 8
Change in estimated total ESV and coefficient of sensitivity (CS) after a 50% adjustment of ecosystem services valuation coefficient (VC) in the AWR.

Change of value coefficients	%	1998	%	2016
		CS		CS
Forest VC ± 50%	1.03	0.08	3.45	0.11
Woodland VC ± 50%	1.03	0.49	1.03	0.43
Grassland VC ± 50%	1.16	0.09	5.76	0.05
Riverine forest VC ± 50%	1.03	0.05	3.45	0.03
Bushland VC ± 50%	1.03	0.29	1.03	0.38

grasslands, riverbanks, and roadsides; it has since been identified as the principal threat to biodiversity and livestock production [95].

4.2. ESVs assessments

The most important factor contributing to the differences in the findings was the use of different ESVs [68]. Due to important differences in ESV US$ ha^{-1} yr^{-1} for various land cover types, the estimated ESV also showed important differences in the AWR during the study periods. The rapid encroachment of bushland on grassland habitat is the major contributor to total ESV change. The boundary extension towards Mount Asebot in 2014, on the other hand, has contributed to the legal protection of the highland forest under AWR management and the nearby monastery. The ESV of grassland, riverine forests, and woodland has drastically decreased, whereas bushland and highland forests have increased ESV. According to Ref. [54], the changes in ESVs initiated by LULC dynamics have resulted in a loss of approximately US$ 112 to 1091 million in the Afar region, which contains an important portion of the AWR.

Furthermore [68], reported a slight increase in total ESVs in the Abaya-Chamo basin, but a decrease in total ESV from natural ecosystems (for example, Nech Sar, which is part of the basin). Similar results were reported in previous works by Ref. [56] in the Shashemene Munisa forest [65]in the Andessa watershed of Blue Nile; [96] in the central highlands of Ethiopia; [97] in the Winkie watershed of Omo Gibe basin; and [54] in the Afar region who reported about the declined ESVs for the grazing land, forestland, shrubland, and water body. The annual ESVs of the AWR were estimated to be US$ 84.48 million [60]. The 2015 estimate was lower than the global, regional, and distinct 19 ecosystem services estimate because the 2015 study only evaluated nine ecosystem services, resulting in lower AWR ESVs.

4.3. Limitations of the study

The evaluation of LULC alterations could be restricted by the caliber and determination of the data employed [68]. The data utilized in this investigation are derived from assorted origins, which might be the primary constraint of the research, as it is almost impossible to avoid uncertainties in LULC transformations simulated due to several factors [68]. As a result of the restricted data sources, it was not feasible to measure the effect of forthcoming land-use shifts as well as other significant obstacles, including climate change, on the landscape ecosystem.

When employing this research in policymaking and decision-making methods, it is critical to understand the origins of uncertainty in LULC projections. Moreover, the complexity of assessing ecological changes using land cover types and the corresponding "biome category," to which the assigned ESVs belong in a more comprehensive context, as well as the significant variation that can occur when applied in the local context, is another limitation of this study.

5. Conclusion

This study investigates the alterations in ESVs as a response to LULC dynamics within Ethiopia's protected area system, with a particular emphasis on AWR. The ESVs in AWR were significantly impacted by LULC changes between the years 1998 and 2016. The reduction of grassland and bushland encroachment played a prominent role in ESV changes. Despite the decision-makers acknowledgment of the value of AWR in the conservation of endangered wildlife species, a substantial anthropogenic obstruction to improving the reserve's management persists. Therefore, the results of this study could be utilized to augment decision-maker's comprehension of protected areas in general and more specifically of the AWR, as well as to inform future planning and management initiatives aimed at the conservation of AWR's pristine rangeland. These interventions would, in turn, enhance ecosystem services and improve the livelihoods of surrounding communities.

Availability of data and material/data availability

The author wants to declare that data can be submitted at whatever time based on request. The data used for the current study are available from the corresponding author upon reasonable request.

Code availability (software application or custom code)

Not applicable.

CRediT authorship contribution statement

Simeneh Admasu: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Data curation, Conceptualization, Formal analysis, Investigation, Methodology, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The author is thankful for the kind cooperation of ecological monitoring experts of the AWR and EWCA and rangers of AWR and the journal's anonymous reviewers and Editor in Chief are also thanked for their critical comments that improved the manuscript.

References

[1] J.M. Maitima, S.M. Mugatha, R.S. Reid, L.N. Gachimbi, A. Majule, H. Lyaruu, D. Pomery, S. Mathai, S. Mugisha, The linkages between land use change, land degradation and biodiversity across East Africa, Afr. J. Environ. Sci. Technol. 3 (2009) 310–325.
[2] M.A. Wubie, M. Assen, M.D. Nicolau, Patterns, causes and consequences of land use/cover dynamics in the Gumara watershed of lake Tana basin, Northwestern Ethiopia, Environ. Syst. Res. 5 (2016) 8.
[3] R.S. Dwivedi, K. Sreenivas, K.V. Ramana, Land use land cover change analysis in part of Ethiopia using landsat thematic mapper data, Int. J. Rem. Sens. 26 (7) (2005) 1285–1287.
[4] B.A. Bryan, Incentives, land use, and ecosystem services: synthesizing complex linkages, Environ. Sci. Pol. 27 (2013) 124–134.
[5] R. Costanza, R. de Groot, P. Sutton, S. van der Ploeg, S.J. Anderson, I. Kubiszewski, S. Farber, R.K. Turner, Changes in the global value of ecosystem services, Global Environ. Change 26 (2014) 152–158.
[6] R.A. Houghton, J.I. House, J. Pongratz, G.R. van der Werf, R.S. De-Fries, M.C. Hansen, C. Le Quéré, N. Ramankutty, Carbon emissions from land use and land-cover change, Biogeosciences 9 (2012) 5125–5142.
[7] E.F. Lambin, H.J. Geist, E. Lepers, Dynamics of land-use and land-cover change in tropical regions, Annu. Rev. Environ. Resour. 28 (2003) 205–241.
[8] T. Lasanta, J.C. González-Hidalgo, S.M. Vicente-Serrano, E. Sferi, Using landscape ecology to evaluate an alternative management scenario in abandoned Mediterranean mountain areas, Landsc. Urban Plann. 78 (2006) 101–114. Li, J., Wang, W., Hu, G., Wei, Z., 2010. Changes in ecosystem service values in Zoige Plateau. China. Agric. Ecosyst. Environ. 139, 766–770.
[9] H. Yi, B. Güneralp, U.P. Kreuter, İ. Güneralp, A.M. Filippi, Spatial and temporal changes in biodiversity and ecosystem services in the San Antonio River Basin, Texas, from 1984 to 2010, Sci. Total Environ. 619 (2018) 1259–1271.
[10] R. Li, G. Zhu, S. Lu, L. Sang, G. Meng, L. Chen, Y. Jiao, Q. Wang, Effects of urbanization on the water cycle in the Shiyang River basin: based on a stable isotope method, Hydrol. Earth Syst. Sci. 27 (2023) 4437–4452.
[11] Amare Sewnet, Land use/cover change at infraz watershed, northwestern Ethiopia, Journal of Landscape Ecology 8 (1) (2015) 69–83.
[12] Saeed Ahmadizadeh, Maryam Yousefi, Mehdi Saghafi, Land use change detection using remote sensing and artificial neural network: application to Birjand, Iran, Computational Ecology and Software 4 (2014) 276.
[13] D.J. Campbell, D.P. Lusch, T.A. Smucker, E.E. Wangu, Multiple methods in the study of driving forces of land use and land cover change: a case study of SE Kajiado district Kenya, Hum. Ecol. 33 (2005) 763–794.
[14] R.S. Reid, P.K. Thornton, R.L. Kruska, Loss and fragmentation of habitat for pastoral people and wildlife in East Africa: concepts and issues. Afr. J. Range for, Science 21 (2004) 171–184.
[15] X. Lin, M. Xu, C. Cao, R.P. Singh, W. Chen, Land-use/land-cover changes and their influence on the ecosystem in chengdu city, China during the period of 1992–2018, Sustainability 10 (2018) 3580.
[16] J.A. Foley, R. DeFries, G.P. Asner, C. Barford, G. Bonan, S.R. Carpenter, F.S. Chapin, M.T. Coe, G.C. Daily, H.K. Gibbs, Global consequences of land use, Science 309 (2005) 570–574.
[17] S. Saha, A. Saha, M. Das, A. Saha, R. Sarkar, A. Das, Analyzing spatial relationship between land use/land cover (LULC) and land surface temperature (LST) of three urban agglomerations (UAs) of Eastern India, Remote Sens. Appl.: Society and Environment 22 (2021) 100507.
[18] W. Gong, L. Yuan, W. Fan, P. Stott, Analysis and simulation of land use spatial pattern in Harbin prefecture based on trajectories and cellular automata—markov modelling, Int. J. Appl. Earth ObsGeoinf 34 (2015) 207–216.
[19] Teka Kassa, Anton Van Rompaey, Poesen Jean, Assessing the role of policies on land use change and agricultural development since 1960s in northern Ethiopia, LandUsePolicy30 (2013) 944–995.
[20] H. Hurni, K. Tato, G. Zeleke, The implications of changes in population, land use, and land management for surface runoff in the upper Nile basin area of Ethiopia, Mt. Res. Dev. 25 (2) (2005) 147–154.
[21] Aklilu Amsalu, L. Stroosnijder, J. De Graaff, Long- term dynamics in land resource use and the driving forces in the Beressa watershed, highlands of Ethiopia, J. Environ. Manag. 83 (4) (2007) 448–459.
[22] Belay Tatek, Mengistu Daniel, LULC dynamics and drivers in the Muga watershed, Upper Blue Nile basin, Ethiopia, Remote Sensing Applications. Society and Environment 15 (2019) 100249.
[23] Belay Tegene, Land cover/use changes in the derekolli catchment of the south welo zone of amhara region, Ethiopia, E. Afr. Soc. Sci. Res. Rev. 18 (1) (2002) 1–20.
[24] Bewket Woldeamlak, Land cover dynamics since the 1950s in Chemoga watershed, Blue Nile basin, Ethiopia, Mt. Res. Dev. 22 (3) (2002) 263–269.
[25] Garedew Efrem, M. Sandewall, U. Söderberg, B.M. Campbell, Land-use and land-cover dynamics in the central Rift Valley of Ethiopia, Environ. Manag. 44 (4) (2009) 683–694.
[26] Emiru Birhane, Haregeweini Ashfare, Ayele Almaw Fenta, Hadgu Hishe, M.A. Gebremedhin, Hailemariam G. Wahed, Negasi Solomon, LULC changes along topographic gradients in Hugumburda National Forest priority area, Northern Ethiopia, Remote Sens. Appl.: Society and Environment 13 (2019) 61–68.
[27] Gashaw Chakilu, Mamaru Moges, Assessing the land use/cover dynamics and its impact on the low flow of Gumara Watershed, Upper Blue Nile Basin, Ethiopia, Hydrol. Curr. Res. 7 (2017) 2.
[28] Tadesse Getachew, Zavaleta E, Shennan C, M. FitzSimmons, Prospect of forest-based ecosystem service in forest-coffee mosaics as forest loss continues in southwestern Ethiopia, Appl. Geogr. 50 (2014) 144–151.
[29] Gete Zeleke, H. Hurni, Implications of Land Use and Land Cover dynamics for mountain resource degradation in the northwestern Ethiopian highlands, Mt. Res. Dev. (2001) 184–191.
[30] Girmay Kassa, GIS-Based Analysis of Land Use/land Cover, Land Degradation and Population Changes: A Study of Boru Metero Area of South Wello, Amhara Region, MA Thesis, Department of Geography, Addis Ababa University, 2003, p. 110.

[31] Selamyihun Kidanu, Using Eucalyptus for Soil and Water Conservation on the Highland Vertisols of Ethiopia, Wageningen University, The Netherlands, 2004. Ph.D. Thesis.
[32] Sisay Nune Hailemariam, Teshome Soromessa, Demel Teketay, Land use and land cover change in the Bale Mountain Eco-Region of Ethiopia during 1985 to 2015, Land 5 (2016) 41.
[33] Solomon Belay, Aklilu Amsalu, Eyualem Abebe, Land use and land cover changes in Awash national park, Ethiopia: impact of decentralization on the use and management of Resources, Open J. Ecol. 4 (2014) 950–960.
[34] Wondie Menale, W. Schneider, Assefa Melesse, Demel Teketay, Spatial and temporal land cover changes in the simen mountains national park, a world heritage site in northwestern Ethiopia, Rem. Sens. 3 (2011) 752–766.
[35] Temesgen Fitsum, Warkineh Bikila, Hailemicael Alemayehu, Seasonal land use land cover change and the drivers in Kafta-Sheraro National Park, Tigray, Ethiopia (2022).8 (2022) e12298.
[36] D.W. Sintayehu, M. Kassaw, Impact of land cover changes on elephant conservation in Babille elephant sanctuary, Ethiopia, Int J. Biodiversity 3 (2) (2019) 65–71.
[37] Simeneh Admasu, Modeling habitat quality using the InVEST model in the Alledighe wildlife reserve Ethiopia: front, Environ. Sci. Sec. Environmental Informatics and Remote Sensing 11 (2023), 2023.
[38] Aramde Fetene, Thomas Hilker, Kumelachew Yeshitela, Ruediger Prasse, Warren Cohen, Zhiqiang Yang, Detecting trends in land use and land cover change of Nech sar national park, Ethiopia, Environ. Manag. 57 (2016) 137–147.
[39] Admasu Simeneh, Paul Scholte, Berhanu Lakew, The state of protected areas and conservation of Ethiopia's iconic large mammals: implications for the post-2020 global biodiversity framework, J. Int. Wildl. Law Pol. (2023).Volume 26, 2023 - Issue 3.
[40] F.W. Duckworth, An Assessment of Ethiopia's Wildlife Situation. Ethiopian Reporter, Ethiopia, 2002.
[41] Dires Tsegaye, Stein R. Moe, Paul Vedeld, Ermias Aynekulu, Land use/cover dynamics in Northern Afar rangelands, Ethiopia, J.Agri,Ecosys and Envt 139 (2010) (2010) 174–180.
[42] Almaz Tadesse, Sustaining the Alledeghi Grassland of Ethiopia: Influences of Pastoralism and Vegetation Change. (PhD Dissertation), Utah State University, Logan, 2009.
[43] J.C. Hilliman, Compendium of Wildlife Conservation Information: Information on Wildlife Conservation Areas, NYZS and EWCO, Addis Ababa, 1993.
[44] C.A. Schloeder, M.J.M. Jacobs, The Awash National Park Management Plan (1993-1997). NYZS and EWCO, 1993.
[45] Negarit Gazeta, Regulation issued to the game proclamation of 1944 and the wildlife conservation order of 1970, Legal notice No. 416 of 1972 7 (1972).
[46] Fanuel Kebede, Afework Bekele, D. Patricia, Moehlman, P.H. Evangelista, Endangered Grevy's zebra in the Alledeghi Wildlife Reserve, Ethiopia: species distribution modeling for the determination of optimum habitat, J. Endang. Species Res. 17 (2012) 237–244.
[47] C. Albert, C. Galler, J. Hermes, F. Neuendorf, C. von Haaren, A. Lovett, Applying ecosystem services indicators in landscape planning and management: the ES-in-Planning framework, Ecol. Indicat. 61 (1) (2015) 100–113.
[48] B. Egoh, B. Reyers, M. Rouget, D.M. Richardson, D.C. Le Maitre, A.S. van Jaarsveld, Mapping ecosystem services for planning and management, Agric. Ecosyst. Environ. 127 (2008) 135–140.
[49] J. Boyd, S. Banzhaf, What are ecosystem services? The need for standardized environmental accounting units, Ecol. Econ. 63 (2007) 616–626.
[50] E. Nelson, G. Mendoza, J. Regetz, S. Polasky, H. Tallis, D. Cameron, K.M.A. Chan, G.C. Daily, J. Goldstein, P.M. Kareiva, E. Lonsdorf, R. Naidoo, T.H. Ricketts, M. Shaw, Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales, Front. Ecol. Environ. 7 (2009) 4–11.
[51] J. Boyd, Economic valuation, ecosystem services, and conservation strategy. In Measuring Nature's Balance, Ecosystem Services Seminar Series, Coastal Quest and Gardon and Betty Moore Foundation, 2011, pp. 177–189.
[52] R. Costanza, R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O'Neill, J. Paruelo, G.R. Raskin, P. Sutton, M. van der Belt, The value of the world's ecosystem services and natural capital, Nature 387 (1997) 253–260.
[53] R.S. De Groot, R. Alkemade, L. Braat, L. Hein, L. Willemen, Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making, Ecol. Complex. 7 (2010) 260–272.
[54] Hailu Shiferaw, Woldeamlak Bewket, Tena Alamirew, Gete Zeleke, Demel Teketay, Ketema Bekele, Urs Schaffner, Sandra Eckert, Implications of land use/land cover dynamics and Prosopis invasion on ecosystem service values in Afar Region, Ethiopia, Sci. Total Environ. 675 (2019) 354–366.
[55] H. Huabin, W. Liu, C. Min, Impact of land use and land cover changes on ecosystem services in Menglun, Xishuangbanna, Southwest China, Environ. Monit. Assess. 146 (2008) 147–156.
[56] Mengiste Kindu, T. Schneider, Demel Teketay, T. Knoke, Changes of ecosystem service values in response to land use/land cover dynamics in Munessa–Shashemene landscape of the Ethiopian highlands, Sci. Total Environ. 547 (2016) 137–147.
[57] T. Knoke, O.-E. Steinbeis, M. Bösch, R.M. Román-Cuesta, T. Burkhardt, Cost-effective compensation to avoid carbon emissions from forest loss: an approach to consider price–quantity effects and risk-aversion, Ecol. Econ. 70 (2011) 1139–1153.
[58] van der Ploeg and De Groot RS, The TEEB Valuation Database–A Searchable Database of 1310 Estimates of Monetary Values of Ecosystem Services, Foundation Sustainable Development, Wageningen, The Netherlands, 2010.
[59] Wondimagegn Mengist, Teshome Soromessa, Gudina Legese Feyisa, Estimating the total ecosystem services value of Eastern Afromontane Biodiversity Hotspots in response to landscape dynamics, Environmental and Sustainability Indicators 14 (2022) 100178.
[60] Hugo van Zyl, The Economic Value and Potential of Protected Areas in Ethiopia. Report Prepared for the Sustainable Development of the Protected Areas System of Ethiopia (SDPASE) and the Ethiopian Wildlife Conservation Authority (EWCA), 2015.
[61] S.R. Frazee, R.M. Cowling, R.L. Pressey, J.K. Turpie, N. Lindenberg, Estimating the costs of conserving a biodiversity hotspot: a case study of the Cape Floristic Region, South Africa, Biol. Conserv. 112 (2003) 275–290.
[62] S. Sannigrahi, S. Chakraborti, P.K. Joshi, S. Keesstra, S. Sen, S.K. Paul, U.P. Kreuter, P.C. Sutton, S. Jha, K.B. Dang, Ecosystem service value assessment of a natural reserve region for strengthening protection and conservation, J. Environ. Manag. 244 (2019) 208–227.
[63] Simeneh Admasu, Kumelachew Yeshitela, Mekuria Argaw, Impact of Land Use and Land Cover changes on ecosystem service values in the Dire and Legedadi watersheds, central highland of Ethiopia, Heliyon 9 (2023) e15352.
[64] X. Sun, Q. Ma, G. Fang, Spatial scaling of land use/land cover and ecosystem services across urban hierarchical levels: patterns and relationships, Landsc. Ecol. 38 (3) (2023) 753–777.
[65] Temesegen Gashaw, Taffa Tulu, Mekuria Argaw, Abeyou Worqlul, Terefe Tolessa, Mengiste Kindu, Estimating the impacts of land use/land cover changes on Ecosystem Service Values: the case of the Andassa watershed in the Upper Blue Nile basin of Ethiopia, Ecosyst. Serv. 31 (2018) 219–228.
[66] Tatek Belay, Tadele Melese, Abebe Senamaw, Impacts of land use and land cover change on ecosystem service values in the Afro-alpine area of Guna Mountain, Northwest Ethiopia, Heliyon 8 (2022) (2022) e1224.
[67] J.J. Lawler, D.J. Lewis, E. Nelson, A.J. Plantinga, S. Polasky, J.C. Withey, D.P. Helmers, S. Martinuzzi, D. Pennington, V.C. Radeloff, Projected land-use change impacts on ecosystem services in the United States, Proc. Natl. Acad. Sci. U.S.A. 111 (20) (2014) 7492–7497.
[68] A. Ashbir Woldeyohannes, M. Cotter, Webanesh Desslegn, Girma Kelboro, Assessing changes in ecosystem service values over 1985–2050 in response to land use and land cover dynamics in Abaya-Chamo basin, southern Ethiopia, Land 9 (2) (2020) 37.
[69] R.L. Goldman, H. Tallis, P. Kareiva, G.C. Daily, Field evidence that ecosystem service projects support biodiversity and diversify options, Proc. Natl. Acad. Sci. U. S.A. 105 (27) (2008) 9445–9448.
[70] N. Robertson, S. Wunder, Fresh Tracks in the Forest: Assessing Incipient Payments for Environmental Services Initiatives in Bolivia, CIFOR, Bogor, Indonesia, 2005, p. 152.
[71] J. Maes, M.L. Paracchini, G. Zulian, M.B. Dunbar, R. Alkemade, Synergies and trade-offs between ecosystem service supply, biodiversity, and habitat conservation status in Europe, Biol. Conserv. 155 (2012) 1–12.

[72] J. Maes, L. Camino, T. Anne, E. Markus, L.P. Maria, I.B. José, G. Bruna, C. Ana, S. Francesca, E.P. Jan, M. Andrus, R.G. Eva, Z. Nihat, K. Peter, B. Annemarie, B. Katarzyna, P. Chiara, E. Benis, D. Patrick, F. Christel, S.M. Fernando, N. Vytautas, V. Jan, M.P. Henrique, B. Jan, G. Kremena, Marta-P Cristina, S. Tord, E. Christine, Jesus-S.M, P.S. Marta, Grêt-R Adrienne, I.L. Ana, A.M. Dania, C. Sophie, M. Jon, C. Bálint, G.D. Evangelia, Z. Grazia, L. Carlo, An indicator framework for assessing ecosystem services in support of the EU Biodiversity Strategy to 2020, Ecosyst. Serv. 17 (2016) 14–23.

[73] Stephen Polasky, Nelson Erik, Pennington Derric, Kris A. Johnson, The impact of land use change on ecosystem services, biodiversity and returns to landowners: a case study in the state of Minnesota, Environ. Resour. Econ. 48 (2010) 219–242, 2011.

[74] O.E. Sala, F.S. Chapin, J.J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. HuberSanwald, L.F. Huenneke, R.B. Jackson, A. Kinzig, R. Leemans, D.M. Lodge, H. A. Mooney, M. Oesterheld, N.L. Poff, M.T. Sykes, B.H. Walker, M. Walker, D.H. Wall, Biodiversity: global biodiversity scenarios for the year 2100, Science 287 (2000) 1770–1774.

[75] R.L. Goldman, H. Tallis, A critical analysis of ecosystem services as a tool in conservation projects: the possible perils, the promises and the partnerships, Ann. N. Y. Acad. Sci. 1162 (2009) 63–78.

[76] Endris Ahmed, Seid Ali, Addisu Asefa, Structure and regeneration of woody plants in the hallideghie wildlife reserve, north-east Ethiopia, Int. J. Biodivers. Conserv. 9 (6) (2017) 200–211.

[77] Simeneh Admasu, Population Size and Structure of Beisa oryx and its Habitat Overlap with Sympatric Species in Alledeghi Wildlife Reserve, NE, Ethiopia, Addis Ababa University, Addis Ababa, 2016. MSc thesis.

[78] WARC (Werer Agricultural Research Center), Annual Report 2003/04, Werer, 2003.

[79] Addisu Asefa, Seid Ali, Endris Ahmed, Floristic composition and community analysis of woody plants in hallideghie wildlife reserve, north-east Ethiopia, Ethiopian Journal of Environmental Studies & Management 10 (7) (2017) 917–930.

[80] Fanuel Kebede, Ecology and Community Based Conservation of the Grevy's zebra (Equus grevyi) and the African wild ass (Equus africanus) in the Afar region. Ethiopia PhD Dissertation, Addis Ababa University, Addis Ababa, 2013.

[81] Simeneh Admasu, Afework Bekele, Addisu Assefa, Population size and structure of beisa oryx and its habitat overlap with sympatric species in alledeghi wildlife reserve, NE, Ethiopia, Ethiop. J. Biol. Sci. 15 (1) (2016) 37–54.

[82] Selamnesh Tesfaye, Impact of *Prosopis Juliflora* on Plant Biodiversity at Alledeghi Wildlife Reserve and Surrounding Local Community, Ethiopia, Addis, Ababa University, Addis Ababa, 2015. MSc thesis.

[83] B.S. Muzein, Remote Sensing and GIS for Land Cover, Land Use Change Detection, and Analysis in the Semi-natural Ecosystems and Agriculture Landscapes of the Central Ethiopian Rift Valley, Verlag nicht ermittelbar, 2006.

[84] D. Tewabe, T. Fentahun, Assessing land use and land cover change detection using remote sensing in the Lake Tana Basin, Northwest Ethiopia, Cogent Environmental Science 6 (1) (2020) 1778998.

[85] G.M. Foody, Status of land cover classification accuracy assessment, Rem. Sens. Environ. 80 (1) (2002) 185–201.

[86] Alemayehu Fasika, Motuma Tolera, Gizaw Tesfaye, Land use land cover change trend and its drivers in Somodo watershed southwestern, Ethiopia, Afr. J. Agric. Res. 14 (2) (2019) 102–117.

[87] A. McVittie, S. Hussain, The Economics of Ecosystems and Biodiversity-Valuation Database Manual, Sustainable Ecosystems Team at Scotland's Rural College, Edinburgh, 2013.

[88] U.P. Kreuter, H.G. Harris, M.D. Matlock, R.E. Lacey, Change in ecosystem service values in the San Antonio area, Texas, Ecol. Econ. 39 (3) (2001) 333–346.

[89] P. Cabral, C. Feger, H. Levrel, M. Chambolle, D. Basque, Assessing the impact of land-cover changes on ecosystem services: a first step toward integrative planning in Bordeaux, France, Ecosyst. Serv. 22 (2016) 318–327.

[90] J. Li, W. Wang, G. Hu, Z. Wei, Changes in ecosystem service values in Zoige Plateau. China, Agric. Ecosyst. Environ. 139 (2010) 766–770.

[91] Mattias Gaglio, Vassilis George Aschonitis, Marta Maria Mancuso, Juan Pablo Reyes Puig, Francisco Moscoso, Giuseppe Castaldelli, Elisa Anna Fano, Changes in land-use and ecosystem services in tropical forest areas: a case study in Andes mountains of Ecuador, International Journal of Biodiversity Science, Ecosystem Services & Management 13 (1) (2017) 264–279.

[92] V.G. Aschonitis, M. Gaglio, G. Castaldelli, E.A. Fano, Criticism on elasticity-sensitivity ESV for assessing the robustness and sensitivity of ecosystem services values, Ecosyst. Serv. 20 (2016) 66–68.

[93] D. Pomeroy, J. Tukahirwa, S. Mugisha, R. Nanyunja, M. Namaganda, N. Chelimo, Linkages between Change in Land Use, Land Degradation and Biodiversity in SW Uganda, 2003.

[94] Y. Ayanu, A. Jentsch, D. Müller-Mahn, S. Rettberg, C. Romankiewicz, T. Koellner, Ecosystem engineer unleashed: prosopis juliflora threatening ecosystem services? Reg. Environ. Change 15 (2014) 155–167.

[95] R.T. Shackleton, C. Le Maitre, N.M. Pasiecznik, D.M. Richardson, Prosopis: a global assessment of the biogeography, benefits, impacts and management of one of the world's worst woody invasive plant taxa, AOB Plants 2014 (6) (2014) plu027.

[96] Terefe Tolessa, Feyera Senbeta, Tariku Abebe, Land use land cover analysis and ecosystem services valuation in the central highlands of Ethiopia, Forests, For. Trees Livelihoods 26 (2) (2016) 111–123.

[97] Abreham Berta, Teshome Soromessa, Eyasu Elias, The effect of land use/land cover changes on ecosystem services valuation of Winike watershed, Omo Gibe basin, Ethiopia, Hum. Ecol. Risk Assess 26 (10) (2019) 2608–2627.