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Evaluating the spatiotemporal dynamics of ecosystem service values in response to land use/land cover change in Goang watershed, Northwest Ethiopia

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ABSTRACT

Evaluating the impacts of land use/land cover (LULC) change on ecosystem service values (ESVs) is critical for understanding the implications of land use change on human well-being, identifying trade-offs and synergies between different ecosystem services, monitoring changes in ecosystem health, and informing decisions for land use planning and conservation efforts. As a result, this study aimed to examine the effects of these changes on ESVs during the last four decades (1984–2022) and predicted periods of 2040 and 2060 by utilizing a combination of geoinformation, and economic evaluation approaches. The modified ecosystem service value (ESV) coefficients were used to estimate the influence of LULC change on ESVs. The result revealed that overall ESV has declined from US$390 $\times$ 10^6 in 1984 to US$273.21 $\times$ 10^6 in 2060. However, the effects on various ecosystem services varied, with certain services, such as crop production, pollination, and biological control, increasing in value. These findings also emphasized the necessity of evaluating the implications of land use decisions on ecosystem services and it depicted that it may be possible to retain or improve certain services even in the face of overall declines in total ESVs. Subsequently, the findings of this study, therefore, give important insights for policymakers, land managers, and local people for devising appropriate land use policies and land use plans as well as realizing, and implementing sustainable land use practices that ensure the provision of essential ecosystem services for future generations.

1. Introduction

The Earth's ecosystem provides a wide range of critical services to humans (Costanza et al., 1997; de Groot et al., 2012). These services are known as ecosystem services, which include the commodities and benefits humans derive from ecosystems (MEA, 2005; van der Ploeg et al., 2010). Ecosystem services (ES) are classified into four types: provisioning, regulating, supporting, and cultural services (Costanza et al., 2014; MEA, 2005). The provision of these ES in a specific geographical location is closely related to the types of LULC (Braat and de Groot, 2012; de Groot et al., 2012). However, each LULC provides distinct and irreplaceable services (Hasan et al., 2020). For instance, the ES of dense forests cannot be compensated by the services of other ecosystems, such as woody vegetation (shrubs and agroforestry). Hence, recognizing the breadth of services provided by different ecosystems allows for identifying trade-offs and synergies between different land use options, allowing stockholders to make informed choices that consider the multiple dimensions of ES (Gashaw et al., 2018).

The dynamic transformation of our global landscapes is being propelled by an unprecedented and rapidly accelerating wave of human impacts on ecosystems (Foley et al., 2005; Song et al., 2018). Surprisingly, human activity directly influences over 70% (with estimates ranging from 69% to 76%) of the Earth's ice-free land surface (IPCC, 2019). Among the myriad forces at play, changes in LULC, primarily

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driven by human activities, have emerged as pivotal factors shaping the transformation of our essential ecosystems (Kreuter et al., 2001; MEA, 2005). Over the past few decades, numerous studies have explored the dynamics of LULC, shedding light on its consequences and the urgent need for sustainable land management strategies (Hu et al., 2019; Kreuter et al., 2001; Li et al., 2010; Makwinja et al., 2021; Song and Deng, 2017; Zhao et al., 2004). As to Costanza et al. (1997), the estimated value of the global ES in 1997 was US$ $33 \times 10^{12}/yr^{-1}$, which greatly surpassed the global gross domestic product (GDP) at that time. Nonetheless, it was reduced by US$ 20.2×10^{12} in 2011 due to the LULC change (Costanza et al., 2014). The study by Costanza et al. (1997) prompted a surge in interest in the comprehension and assessment of ESVs. As a result, various research endeavors attempted to calculate ESVs across different temporal and spatial scales (Arowolo et al., 2018; Costanza et al., 2014; de Groot et al., 2012; Hu et al., 2008; Kreuter et al., 2001; Li et al., 2007; Liu et al., 2019; Song and Deng, 2017; Sutton et al., 2016; van der Ploeg et al., 2010). Several project groups and institutional initiatives have also contributed to ES research to provide scientific evaluations and tools for policy support, such as the Economics of Ecosystems and Biodiversity (TEEB) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Costanza et al., 2014; de Groot et al., 2012).

Africa is known for its diverse landscapes and abundant biodiversity, yet the continent is experiencing rapid population growth, urbanization, agricultural expansion, and resource extraction, resulting in significant LULC changes (Olorunfemi et al., 2022). The continent's population is predicted to double by 2050 (United Nations, 2022), likely resulting in a greater need for agricultural land at the expense of the conversion of multifunctional ecosystems (Fenta et al., 2020). Likewise, Ethiopia which is characterized by diverse ecosystems and landscapes, has experienced significant LULC changes driven by population growth, agricultural expansion, and urbanization (Belay and Mengistu, 2019; Gitima et al., 2022; Regasa et al., 2021). The percentage of ES degradation in the country is approximately 17.7%, much higher than the global average of 9.2% (Sutton et al., 2016). Biedemariam et al. (2022) also estimated an annual loss of US$ 85×10^9 as a result of the conversion of forests, wetlands, shrublands, and grasslands into monofunctional landscapes. In the Dire and Legedadi watersheds, Admasu et al. (2023) demonstrated that the conversion of forests to croplands and urban areas resulted in trade-offs between carbon sequestration, water regulation, and biodiversity conservation. However, other studies (Temesgen et al., 2018; Tesfay et al., 2023) reported that the restoration of degraded areas has generated synergies between ecosystem services, such as soil erosion control, water provision, and habitat restoration. These findings indicate that generalizing the results of one study to other areas may lead to erroneous conclusions.

Several approaches have been used to quantify the influence of LULC change from the perspective of characterizing the ESV. Costanza et al. (1997) used the value transfer approach to estimate the value of 17 ES for 16 biomes. However, there have been complaints about the uncertainty of value coefficients (Gashaw et al., 2018;Hu et al., 2008; Kindu et al., 2016; Kreuter et al., 2001; Li et al., 2007; Wang et al., 2006). Despite the critiques, these coefficients have been used by many authors working in data-scarce regions and acquired momentum as a tool for shaping policy decisions (Costanza et al., 2014; de Groot et al., 2012; Kreuter et al., 2001; Perez-Verdin et al., 2016). Following the work of Costanza et al. (1997), researchers developed the TEEB valuation database based on a collection of case studies from worldwide (van der Ploeg et al., 2010), which provided appropriate value coefficients for 11 biomes. However, the adjusted estimates provided by van der Ploeg et al. (2010) are highly generic and do not represent the context of a specific region (Gashaw et al., 2018). A further estimation of global ESV was carried out by Costanza et al. (2014) and de Groot et al. (2012); however, their estimates were criticized due to the overestimates of some ES. As a result, various researchers like Kindu et al. (2016) developed their own modified ES coefficient based on expert judgment and synthesis of information from the TEEB database (van der Ploeg et al., 2010).

The Goang watershed is rich in biodiversity resources including different forest biome classes, which have ecological and economic importance (Abebaw et al., 2012; Eshete et al., 2012; Yeshineh et al., 2022). However, forests, shrublands, and grasslands in the watershed have been converted to croplands at unprecedented rates due to increased human strains (Sisay et al., 2023). Between 1984 and 2022, forest, grassland, and shrubland decreased by 66.67%, 61.66%, and 34.55%, respectively. The loss of these ecosystems came at the expense of increased farmland (188.9%) and built-up areas (380.96%) (Sisay et al., 2023). However, the impacts of such LULC transformations on ESVs need to be better understood to enhance awareness of the implications and improve decision-making. As a result, this study aimed to investigate the relationship between baseline (1984–2022) and future (2040–2060) LULC trends and ESVs. This research intends to improve our understanding of the effects of human-induced LULC change on the long-term ES provision in the study area. This knowledge can help guide land management decisions and contribute to creating strategies for natural ecosystem conservation and restoration.

2. Methods and materials

2.1. Study area

The Goang watershed is located in the Amhara regional state, northwestern Ethiopia (Fig. 1). The watershed shares a significant portion of the Tekeze River basin and spans from 12°30′00′' to 13°20′00′' North of latitude and 36°20′00′' to 37°20′'00′' East of longitude. The watershed is primarily characterized by its diversified topography and climate. Most of the watershed is lowland (78%), with elevations ranging from 500 to 1500 m above sea level, followed by midland and highland (21%), with heights ranging from 1500 to 2300 and above 2300 m above sea level, respectively.

Because of its varied topography and temperature, the study area is home to various vegetation species and forest resources (Sisay et al., 2023). Crops such as wheat (Triticum), teff (*Eragrostis tef*), barley (*Hordeum vulgare*), maize (*Zea mays*), chickpeas (*Cicer arietinum*), and haricot beans (*Phaseolus vulgaris*) are grown in the midland and highland portions of the watershed. In contrast, cotton (*Gossypium hirsutum L.*), sesame (*Sesamum indicum*), and sorghum are grown in the lowland sections. Tuber crops such as potato (*Solanum tuberosum*) and sweet potato (*Ipomoea batatas*) are grown in the highland and midland regions. At the same time, vegetables like tomato (*Solanum lycopersicum*), onion (*Allium cepa*), and garlic (*Allium sativum*) are grown in almost every region of the watershed. The study area has unimodal rainfall patterns, with the rainy season beginning in June and ending in September. July and August are generally the wettest months in the study area. According to information acquired from the Ethiopian National Meteorological Agency (2020), the mean annual maximum and minimum temperatures for the Metema and Ayikel stations are 35.8–19.4 °C and 24.3–13.5 °C, respectively.

2.2. Datasets and sources

Digital elevation model (DEM), population density map (peoples/km^2), LULC data, and shape file data (roads and maps) were among the secondary data used for this study. High-resolution advanced land observing satellite-phased array-type L-band synthetic aperture radar DEM with 12.5 m x 12.5 m resolution was downloaded from the Atlanta Satellite Facility (https://asf.alaska.edu/) and used to prepare a slope and elevation map. These maps were used as basis variables in a multilayer perceptron (MLP) neural network. The DEM data was also used as input to delineate the watershed boundary and to extract rivers using the ArcMap version 10.8.2 hydrology tool. The population density map was downloaded from the WorldPop database (www.worldpop.or

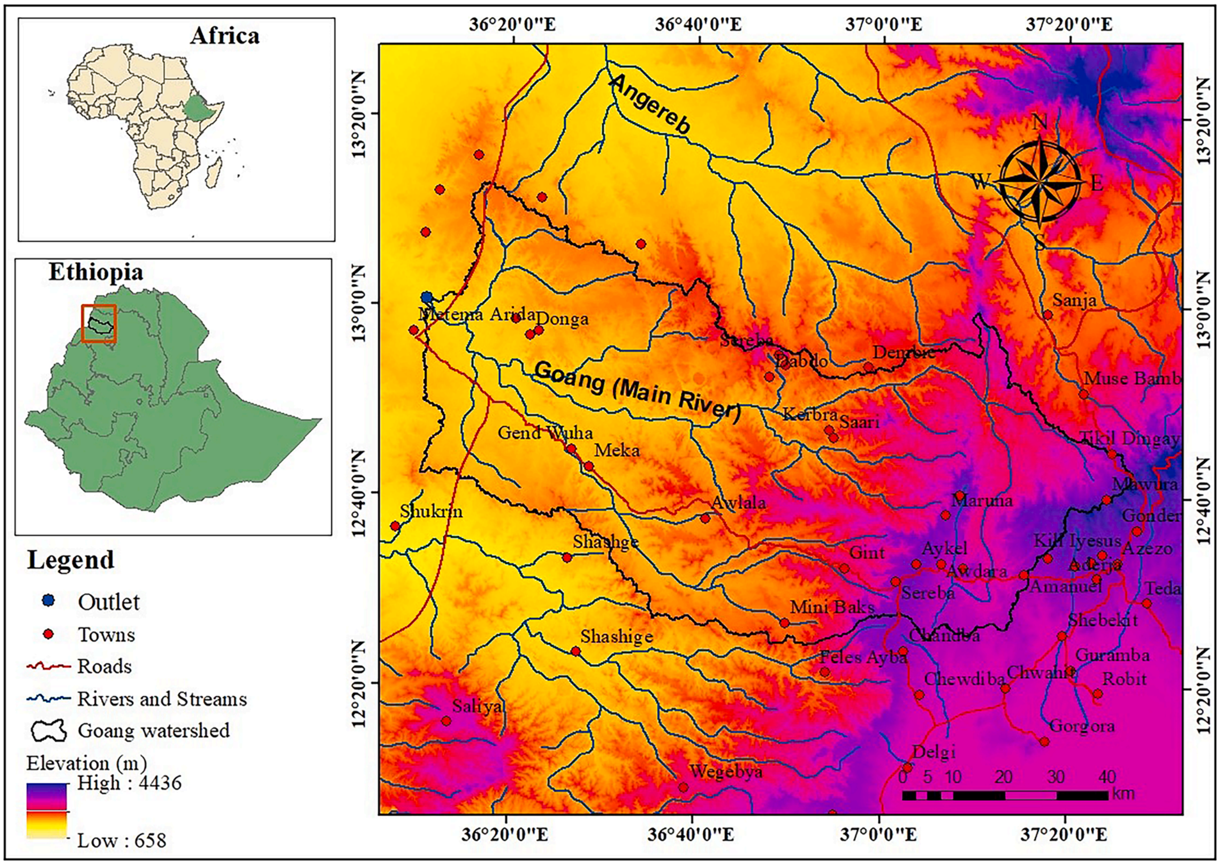

Fig. 1. Map of the study area (Sisay et al., 2023).

g), and the shapefile of road networks and town maps were received from the Federal Democratic Republic of Ethiopia, Ministry of Mines (2019). The LULC datasets for 1984, 2001, and 2022 were obtained from Sisay et al. (2023). Seven LULC classes were identified: forest, shrubland, grassland, farmland, built-up area, waterbody, and barren land. These datasets were used to examine the historical trends in ES value in response to LULC changes. The description of LULC classes can be seen in Table 1.

The accuracy of the LULC classification was evaluated using GPS reference points obtained during field surveys. According to Landis and Koch (1977), a Kappa score of >80% indicates strong classification agreement, while a percentage of 40 indicates poor agreement between the reference and classified data. The accuracy results for all study periods were above 85%, indicating the reliability of data sets. The detailed procedure of satellite image preprocessing, classification algorithms used, and accuracy assessment can be referred from Sisay et al. (2023).

Table 1
Identified LULC classes and their description (Gitima et al., 2022; Sisay et al., 2021).

	LULC type	Description
1	Forest	Areas covered with dense trees formed nearly closed canopy cover of >10%, relatively tall, reaching 5 m in height, and 0.5 ha in area.
2	Shrublands	Areas covered by sparsely distributed bush trees, grasses, and mixed shrubs.
3	Farmland	Areas of land covered with both perineal and annual crops, irrigated areas, commercial farms, scattered rural settlements
4	Bare land	Areas with no vegetation cover due to either erosion, overgrazing, or mismanagement.
5	Water	Freshwater (rivers and streams)
6	Built-up area	Areas with all types of artificial surfaces, including impervious roads, emerging rural towns and villages, and constructions.
7	Grassland	Areas covered with natural grass, including small shrubs or dominated by grass, are areas used for communal grazing that remain for some months in a year.

In addition to secondary data, this study employed primary data collection methods, including key informant interviews (KIIs) and semi-structured interviews to gather comprehensive data on the drivers of changes in ecosystem service values (ESV). The KIIs were designed to gather valuable information from a diverse range of key stakeholders, such as government officials and environmentalists. A total of 11 Key Informants (KIs) were selected using a purposive sampling process to intentionally choose individuals with significant experience, unique insights, and a deep understanding of the topic under investigation. Semi-structured interviews were also used to collect standardized data from 25 elderly community members and they were chosen randomly to ensure representativeness and generalizability.

2.3. Methods of data analysis

2.3.1. Prediction of future LULC change

A combination of MLP neural network, cellular automata, and Markov chain models are suggested in many studies for predicting the trend and spatial structure of different LULC classes using past LULC transitions (Girma et al., 2022; Mishra and Rai, 2016; Saadani et al., 2020). In this study, MLP was used to create transition potential maps, i.e., maps of the potential of land to go through transitions (Eastman, 2016). During the processes, LULC classes that suffer minor area transitions were first filtered using the “change analysis” tab of the LCM module and excluded in the transitions sub-model panel list. Nine transition sub-models, including shrubland to farmland, grassland to farmland, shrubland to bare land, grassland to bare land, farmland to shrubland, bare land to shrubland, forest to shrubland, grassland to shrubland, and shrubland to forest were considered to prepare transition potential maps.

A cellular automata (CA) model was used to simulate the spatial dynamics of LULC. To create the potential transition maps and to improve the accuracy of the model, different driver variables affecting the future dynamics of LULC were considered, including population density at a spatial resolution of 30 arc seconds, distance from roads, distance from rivers, distance from disturbance, distance from towns, elevation, slope, and evidence likelihood. The potential explanatory power of these variables was assessed using the "test and selection of site and driver variables" panel, which is available in the TerrSet 18.31 LCM tool. For details of Cramer's V-values of driver variables and MLP model running parameters, see Sisay et al. (2023). The transitional matrices of the Markov chain (MC) model were used to assess the likelihood of shifting from one LULC class to another. The technique computes how much land is anticipated to transition from the later date to the prediction date based on a prediction of transition potentials. It provides a transition probability file (Eastman, 2016). Finally, the TerrSet validation tool was used to evaluate transition probabilities to estimate potential scenarios for 2040 and 2060.

2.3.2. Approaches of ecosystem service valuation

ES valuation methods are used to estimate the market and non-market worth of ecosystems and their services (Kubiszewski et al., 2013). Several ES valuation approaches have been developed and refined since the work of Costanza et al. (1997) and subsequent reports of MEA (www.millenniumassessment.org) (MEA, 2005) and TEEB (https://teebweb.org/) (van der Ploeg et al., 2010). The TEEB report emphasized the importance of recognizing and incorporating the value of nature into policy and decision-making processes (de Groot et al., 2012). The MEA, on the other hand, is a landmark study conducted by over 1300 experts worldwide who assessed the consequences of ES change for human well-being and provided an integrated framework for evaluating ES (MEA, 2005). Following these influential reports, progress has been made in refining valuation methods and addressing criticisms from Costanza et al. (1997).

Harrison et al. (2018) identified a list of ES valuation approaches by synthesizing various studies. These approaches are broadly categorized into monetary, biophysical modeling, sociocultural, and integrative methods (Harrison et al., 2018). Monetary methods are broadly classified into cost-effectiveness analysis, benefit-cost analysis, stated preference methods, resource rent, simulated exchange, production/cost function, value/benefit transfer, market price/exchange-based methods, and revealed preference methods (Harrison et al., 2018). Benefit transfer applies monetary information collected in a specific context to make inferences about the economic value of an ES in a different decision context. This strategy is beneficial when gathering primary data is not feasible owing to financial or time restrictions, and it extrapolates existing estimates of ES coefficients from preliminary valuation studies of one or more locations to sites presumed to have similar demographic, economic, and ecological characteristics (Perez-Verdin et al., 2016). Costanza et al. (1997) used a benefit transfer approach to estimate the ESV of 17 ES for 16 biomes. However, this approach was criticized due to uncertainties. In this regard, various researchers tried to modify the coefficient of Costanza et al. (1997) based on local data and the incorporation of expert knowledge. Kindu et al. (2016) developed a modified ES coefficient from those employed by Costanza et al. (1997) using specialist judgment and studies from the TEEB valuation database for the Ethiopian condition.

Thus, this study evaluated the changes in the ESV using the modified ES value coefficients (Kindu et al., 2016), utilized for 11 biomes for Ethiopian conditions. The method involves assigning the monetary value to each LULC class based on its contribution to ESV. Many studies in Ethiopia have also applied this approach (Anley et al., 2022; Gashaw et al., 2018; Mekuriaw et al., 2021; Tolessa et al., 2018; Woldeyohannes et al., 2020). The ESVs of each LULC class were calculated by multiplying their respective ES coefficient with the corresponding land area for each period using Eq. (1), adapted from Li et al. (2010), while the values of the 17 ES were calculated using Eq. (2) (Hu et al., 2008; Li et al., 2010). The estimated ESVs from each LULC category were added up to get the overall watershed's total ESV using Eq. (3) (Gashaw et al., 2018). In addition, the percentage change of ESV during different periods (1984–2001, 2001–2022, 1984–2022, 2022–2040, 2040–2060, and 2022–2060) was calculated using the formula indicated in Eq. (4).

$$ESV_Q = \sum (G_Q * YS_Q) \tag{1}$$

$$ESV_t = \sum (G_Q * VY_Q) \tag{2}$$

$$ESV = \sum AkVCk \tag{3}$$

$$\%\ \text{change of ESV} = \left(\frac{ESVt_1 - ESVt_2}{ESVt_2}\right) X\ 100 \tag{4}$$

Where, ESV_Q and ESV_t, are the estimated ESVs of LULC type Q, and ESV function t respectively, G_Q is the area (ha) of LULC type "Q" and YS_Q is the value coefficient of function t (US \$ ha^{-1} y^{-1}) for LULC category "Q" and VY_Q of value function "t". ESV t_2 and t_1 are ESV at time 1 (recent year) and time 2 (latter year), respectively.

We also did a sensitivity analysis to verify the accuracy of the ESV coefficient by adjusting 50% of the value coefficient of each LULC type up and down; the responses of ESVs to the change of the value coefficient (YS_Q) were calculated using Eq. (5) (Kreuter et al., 2001).

$$CS_{kx} = \frac{ESV_j - ESV_i/ESV_i}{VC_{jk} - VC_{ik}/VC_k} \tag{5}$$

Where CS_{kx}= coefficient of sensitivity for land use type k in year x, ESV_i, and ESV_j are initial and adjusted total estimated ESV, respectively. VC_{ik} and VC_{jk} represent the initial and adjusted coefficients of ESV for land-use type k in year x.

The most representative biomes used as a proxy for each LULC category were cropland for farmland, tropical forest for forest and shrubland, rangeland for grassland, settlement for built-up area, and waterbody for rivers. We compared these LULC classes of the study area to their respective representative biomes and ES coefficients (Tables 2 and 3).

We also assessed the effect of LULC change on ESVs across agro-ecological gradients to provide insights into the relationship between human activities, ecological processes, and ES provisioning to facilitate natural resource inventory and decision-making (Birhanu et al., 2019; Gitima et al., 2022). Thus, the study area was classified into three agroecological classes: highland, midland, and lowland. The respective ESVs of each agroecology were extracted using ArcMap 10.8.2.

3. Results

3.1. Evaluation of the impacts of LULC change on ESVs

The study used classified LULC maps (1984, 2001, and 2022) to assess ESVs from 1984 to 2022. In addition, predicted LULC maps for 2040 and 2060 were used to estimate ESVs from 2022 to 2060. The findings of the study unveiled substantial ESV changes in the study area over the past four decades. The total ESV in 1984 was US\$ 390.35 $\times 10^6$. However, it declined to US\$ 366.8 $\times 10^6$ in 2001 and then to US\$ 286.69 $\times 10^6$ in 2022 (Table 4 and Fig. 2). Fig. 3(a-c) show the variation in the distribution of ESVs across LULC types for each study year. In 1984, for example, shrublands contributed the most to overall ESVs, accounting for US\$ 203.7 $\times 10^6$, followed by forests (US\$ 95.38 $\times 10^6$) and grasslands (US\$ 45.01 $\times 10^6$). By 2001, the supply of ESVs had moved slightly, with shrublands continuing to provide the most (US\$207.57 $\times 10^6$), followed by forests (US\$87.42 $\times 10^6$) and farmland (US\$32.05 $\times 10^6$). The most significant reduction in ESVs was observed in grasslands,

Table 2
LULC classes (ha), equivalent biomes, and modified ES coefficients (Kindu et al., 2016).

LULC class (ha)	Equivalent biomes	Study years					ES coefficient
		1984	2001	2022	2040	2060	US$/ha/y $^{-1}$
Bare land	Desert	76607	145511	54840	14357	6723	0
Built-up area	Urban	1980	2846	9523	9523	9523	0
Farmland	Cropland	129310	142090	373577	461397	492405	225.56
Forest	Tropical forest	96660	88,600	32210	11,009	6230	986.69
Grassland	Grass/rangeland	153480	74934	58835	31,522	16,197	293.25
Shrubland	Tropical forest	206393	210371	135086	136,262	132992	986.69
Water	Rivers/lakes	2112	2190	2471	2471	2471	8103.5
Total area		666,542	666542	666542	666542	666542	

Table 3
Coefficient for ESV functions (ESV_t) of each LULC type.

ES type	ESV of each LULC types (US$/ha/y $^{-1}$)					
	Cropland	Tropical forest/shrub	Urban areas	Grassland	Waterbody	Bare land
Provisioning service						
Water supply	–	8	–	–	2117	–
Food production	187.56		–	–	41	–
Raw material production	–	51.24	–	–	–	–
Genetic resources	–	41	–	–	–	–
Regulating services						
Water regulation	–	6	–	3	5445	–
Climate regulation	–	223	–	–	–	–
Disturbance regulation	–	5	–	–	–	–
Gas regulation	–	13.68	–	7	–	–
Biological control	24		–	23	–	–
Erosion control		245	–	29	–	–
Waste treatment		136	–	87	431.5	–
Supporting service						
Nutrient cycling		184.4	–	–	–	–
Pollination	14	7.27	–	25	–	–
Soil formation	–	10	–	1	–	–
Habitat/refuge	–	17.3	–	–		
Cultural services						
Recreation	–	4	–	0.8	69	–
Cultural	–	2	–	–		–
Total	225.56	986.69	0	293.25	8103.5	0

Table 4
The estimated ESVs (US$ in millions) of each LULC class.

LULC type	ESV			ESV change					
				1984–2001	%	2001–2022		1984–2022	
	1984	2001	2022	US$	%	US$	%	US$	%
Bare land	0	0	0	0	0	0		0	0
Built-up Area	0	0	0	0	0	0		0	0
Farmland	29.17	32.05	84.3	2.9	9.87	52.24	162.99	55.11	188.95
Forest	95.38	87.42	31.79	−7.95	−8.34	−55.63	−63.63	−63.58	−66.67
Grassland	45.01	22	17.26	−23.02	−51.13	−4.733	−21.51	−27.75	−61.65
Shrubland	203.7	207.57	133.32	3.9	1.9	−74.24	−35.76	−70.34	−34.53
Water	17.12	17.75	20.028	0.63	3.7	2.28	12.83	2.91	17
Total	390.35	366.8	286.69						

which decreased from US$ 45.01 × 10^6 in 1984 to US$ 22 × 10^6 in 2001 and again to 17.26 × 10^6 in the 2022 period. Similarly, the ESV of forests fell from US$ 95.37 × 10^6 in 1984 to US$87.4 × 10^6 in 2001 and US $31.79 × 10^6 in 2022 (Fig. 4 and Table 4).

Unlike grasslands and forests, the ESV of farmland climbed considerably from US$29.17 × 10^6 in 1984 to US$ 32.045 × 10^6 in 2001 and again to US$84.3 × 10^6 in 2022. However, this was compensated by significant decreases in ESVs for forests (66.67%), grasslands (61.65%), and shrubland (34.53%) (Table 6). These findings further suggest that the observed changes in ES are expected to persist within the projected time frame spanning from 2022 to 2060 under a business-as-usual scenario (Table 5 and Fig. 3d-e). The result also shows that the total ESV is anticipated to fall from US$286.7 × 10^6 in the baseline to 278.65 × 10^6 in 2040 and then to US$ 273.2 × 10^6 in 2060. The value of farmland is expected to rise over time, while the value of forests, grasslands, and shrublands is expected to fall sharply. This trend suggests that changing natural ecosystems to agricultural land use will have a considerable negative impact on the overall value of ES in the study area.

3.2. The effects of LULC change on the individual ES functions

Table 6 shows the impact of LULC changes on individual ES functions. The study found that water regulation and water supply ES functions increased somewhat between 1984 and 2001 but dropped during the following study years. On the other hand, food production ES first declined from US$52.07 × 10^6 in 1984 to 45.11 × 10^6 in 2001.

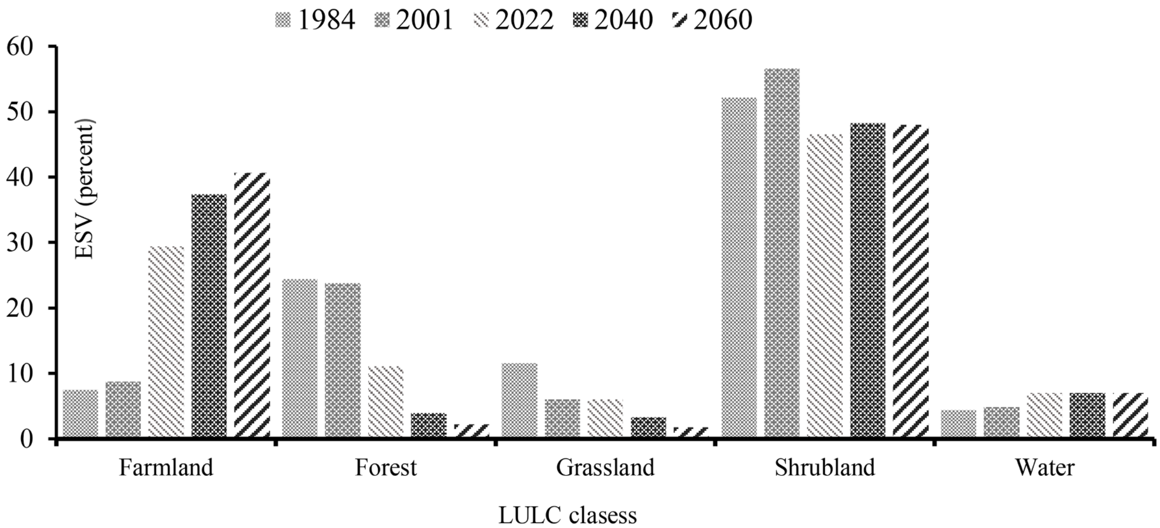

Fig. 2. Land use/land cover and the respective percentage share of total ESVs.

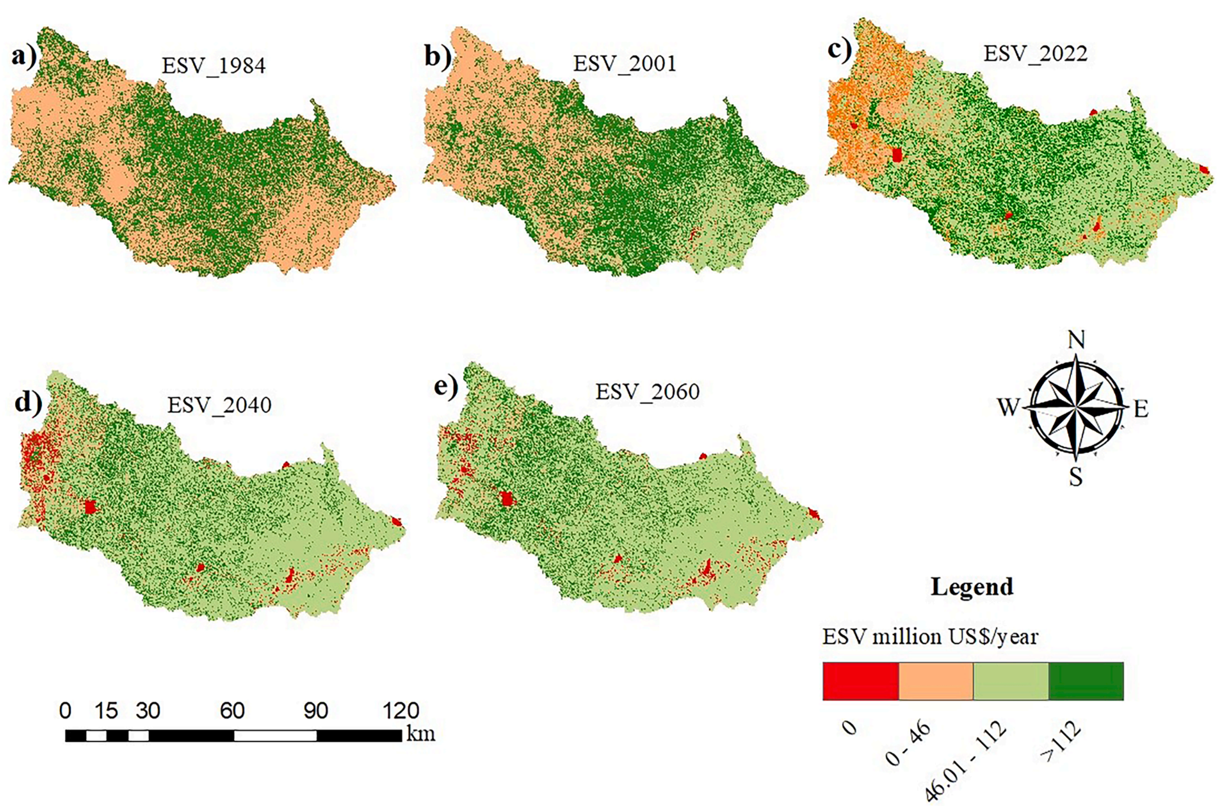

Fig. 3. Past and projected distribution of ESV; a:1984, b:2001, c: 2022, d:2040, and e: 2060.

However, it significantly increased during the rest of the study periods. Similarly, biological control decreased between 1984 and 2001, though it rebounded in 2022. Unlike provisioning services such as food production and water supply and regulating services such as biological control and water regulation, the remaining ES functions dropped linearly. Fig. 4 depicts the relative contribution of the four kinds of ES to the overall ES services of the study area over time. According to the findings, in 1984, most ES were gained from regulatory services, followed by provisioning services (22.3%) and supporting services (18.5%). In 2001, regulatory and provisioning services accounted for the lion's share of total ESVs, accounting for 58.6% and 21.75%, respectively. The remaining ESVs came from supporting services (18.94%) and cultural services (0.6%). Provisioning services climbed from 22.3% in 1984 to 36.5% in 2022 and 39.47% to 43% in 2040 and 2060, respectively. Regulating services, on the other hand, fell from 58.6% in 1984 to 47.86% in 2022 and then to 42.55% in 2060.

Except for crop production services and biological control, most ES functions will decrease between 2022 and 2060 (Table 6). Water supply services, raw materials, and genetic resources are predicted to fall by 0.07×10^6, 0.40×10^6, and 0.96×10^6, respectively. Furthermore, water regulation, climate regulation, disturbance regulation, erosion control, gas regulation, and waste treatment are predicted to decrease with net change values of US$0.09, US$1.8, US$0.04, US$0.11, and US $2.44, respectively.

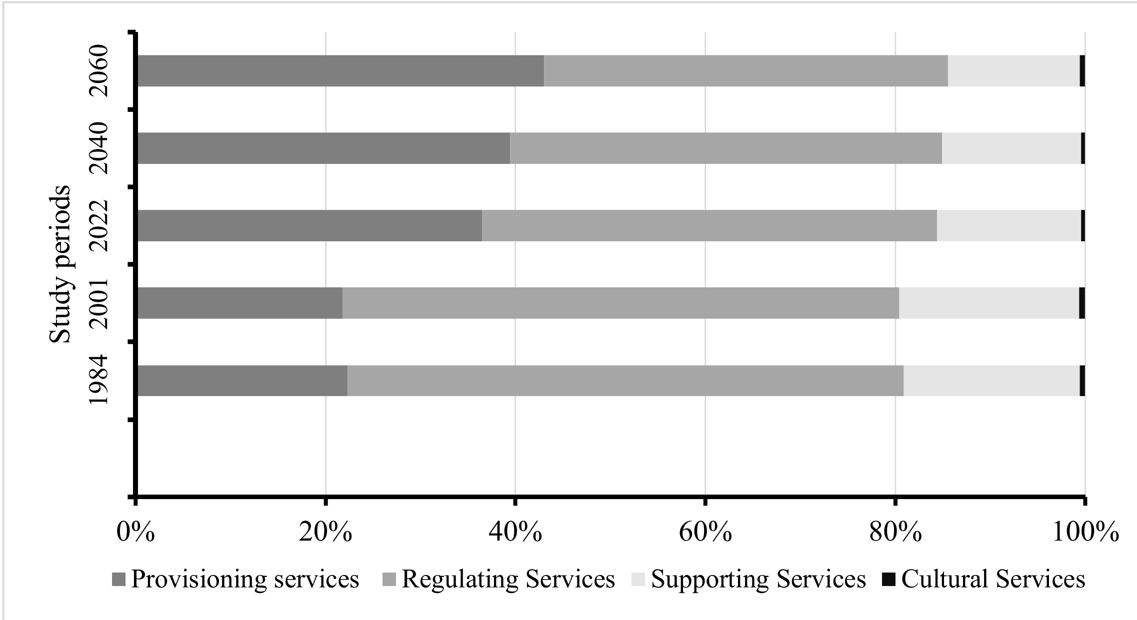

Fig. 4. ES groups and spatio-temporal changes (1984–2060).

Table 5
Estimated ESVs (in millions of US$) for each LULC type between 2022 and 2060.

LULC type	2022	2040	2060	2022–2040	Change (%)				
					%	2040–2060	%	2022–2060	%
Bare land	0	0	0	0		0		0	
built-up area	0	0	0	0		0		0	
Farmland	84.3	104.07	111.06	19.78	23.47	7	6.72	26.77	31.76
Forest	31.79	10.86	6.14	−20.93	−65.8	−4.71	−43.4	−25.64	−80.66
Grassland	17.26	9.24	4.75	−8.02	−46.45	−4.5	−48.6	−12.51	−72.5
Shrubland	133.32	134.45	131.22	1.122	0.84	−3.22	−2.4	−2.104	−1.57
Water	20.03	20.03	20.03	0					
Total	286.97	279.07	273.2						

Table 6
The estimated individual ES functions (***ESV$_t$***in US$ millions/year).

	Type of ES	ESV$_t$ 1984	ESV$_t$ 2001	ESV$_t$ 2022	ESV$_t$ 2040	ESV$_t$ 2060	Net change	
1	Provisioning services						1984–2022	2040–2060
	Water supply	6.9	7.02	6.5	6.41	6.34	−0.4	−0.07
	Food production	52.07	45.11	82.36	86.54	98.8	30.29	12.26
	Raw material	15.53	15.31	8.57	7.54	7.133	−6.96	−0.407
	Genetic resources	12.42	12.25	6.86	6.03	5.07	−5.56	−0.96
2	**Regulating services**							
	Water regulation	13.78	13.94	14.63	14.43	14.34	0.85	−0.09
	Climate regulation	67.58	66.67	37.31	32.84	31.04	−30.27	−1.8
	Disturbance regulation	1.51	1.49	0.83	0.73	0.69	−0.68	−0.04
	Gas regulation	5.22	4.61	2.7	2.01	1.9	−2.52	−0.11
	Biological control	6.63	5.13	10.32	11.8	12.19	3.69	0.39
	Erosion control	78.7	75.4	42.7	37	34.58	−121.4	−2.42
	Waste treatment	55.5	48.13	28.9	23.84	21.4	−26.6	−2.44
3	**Supporting services**							
	Pollination	7.85	6.03	7.92	8.32	8.31	0.07	−0.01
	Habitat/ Refugia	5.24	5.17	2.89	2.54	2.4	−2.35	−0.14
	Nutrient cycling	55.88	55.13	30.85	27.157	25.67	−25.03	−1.487
	Soil formation	3.18	3.06	1.73	1.5	1.4	−1.45	
4	**Cultural services**							
	Recreational services	1.72	1.64	1.02	0.9	0.85	−0.7	−0.05
	Cultural services	0.6	0.59	0.33	0.29	0.78	−0.27	0.49

3.3. Distribution of ESV across the agroecological zone

We evaluated the spatiotemporal distribution of ESVs based on agroecological gradients. The results demonstrated considerable disparities in ESV changes between the upstream, midstream, and downstream areas of the watershed. Between 1984 and 2001, the overall ESV increased from US$70.94 × 10^6 to US$76.84 × 10^6 in midstream and upstream areas, but it dropped to US$48.87 × 10^6 in 2022. Consistent ESV declines were particularly observed in downstream areas. For example, the ESV of downstream in 1984 was US$ 319.26 × 10^6. However, this value fell to US$289.6 × 10^6 in 2001 and US$236.65 × 10^6 in 2022. Between 2022 and 2040, a marginal increase in total ESV is projected in the downstream section of the study area, i.e., US$236.65 × 10^6 in 2022 to US$240.3 × 10^6 in 2040. However, this increase is short-lived, as the ESV is expected to decrease again to US$236.5 × 10^6 by 2060. Likewise, the total ESV in the midland and highland of the study area is also expected to reach US$38.3 × 10^6 by 2040 and further decline to US$36.63 × 10^6 by 2060.

4. Discussion

4.1. Spatiotemporal changes in ESV

Many land use practices are important to human well-being because they supply essential ES like food, fiber, shelter, and freshwater (MEA, 2005). On the other hand, some land uses degrade the ES on which humans rely (Foley et al., 2005). As a result, it is critical to recognize that LULC change is neither good nor bad; instead, the repercussions for ESV rely on the specific context and type of change (Foley et al., 2005; Lambin et al., 2003). This study assessed the impact of observed and projected LULC change on ESVs in the Goang watershed. The study results revealed a rapid decline in overall ESV. In 1984, the total ESV of the study area was estimated at US$390.35 × 10^6. However, this value steadily declined to US$279.07 × 10^6 in 2001 and further reduced to US $286.69 × 10^6 in 2022. Shrubland, forest, and grassland contributed more to the total ESV in 1984, but their contribution declined substantially after 1984. For example, in 1984, forest produced 24.43% of total ESV, but declined to 23.83% in 2001, 11.08% in 2022, 3.89% in 2040, and 2.24% in 2060 (Fig. 2). A significant shift in farmland distribution was observed in the watershed, with a gradual move towards ecologically rich lowland regions at the expense of forests since 1984. This finding is also supported by KIs, who noted increasing trends of farmlands in the study area, primarily due to rising demand for arable land, fueled by population pressure from natural growth and internal migration, particularly from degraded highland areas to fertile lowlands. Landless youths and farmers seeking sustenance temporarily come to the study area's lush lowlands via rent or sharecropping arrangements. However, their minimal participation in land management activities has an impact on natural ecosystems, notably forests. KIs also highlight that resettlement programs and expansion of large-scale commercial farming may have negative environmental consequences, caused by unsustainable land use practices including disruption of ecosystems through conversion of forests to crop fields, forest fire, and overgrazing among others. In line with this, other studies also report that while resettlement programs in Ethiopia aim to relocate people from overcrowded and degraded areas to more fertile and less densely populated areas, they fail to conduct adequate environmental impact assessments (Mustefa, 2023), which leads to deforestation and unsustainable use of land resources (Yadeta et al., 2022).

This study finding is consistent with the previous studies in various parts of Ethiopia (Admasu et al., 2023; Anley et al., 2022; Gashaw et al., 2018; Kindu et al., 2016; Mekuria et al., 2021; Tolessa et al., 2017a), which found that the alarming expansion of farmland and settlement areas at the expense of natural habitats reduced overall ESV. Specifically, Biratu et al. (2022), in the Rift Valley system of central Ethiopia, reported a loss of US$58.8 × 10^6 between 1986 and 2021 due to the significant reduction of forests, wetlands, grassland, and shrubland. Similarly, Anley et al. (2022) in the Rib watershed, Admasu et al. (2023) in the central highlands of Ethiopia, and Belay et al. (2022) in the Afro-alpine area of Guna mountain, Arowolo et al. (2018) in Nigeria, Makwinja et al. (2021) in Lake Malombe, Southern Malawi, and Rotich et al. (2022) in the Cherangany Hills water tower of Kenya also reported similar results.

Table 6 illustrates the supply of individual ES functions in different periods. The result revealed that food production ES function has increased with a net change of US$30.29 × 10^6 between 1984 and 2022 and again by US$16.44 × 10^6 between 2022 and 2060 as cropland has expanded. Similarly, biological control rose from US$ 6.63 × 10^6 in 1984 to US$10.32 × 10^6 in 2022. However, except for the water supply, the remaining fourteen ES functions saw rapid and persistent reduction during the study periods. For example, the water supply ES grew slightly between 1984 and 2001 (Table 6) due to a slight rise in shrublands in the study area. The increase in water supply ES between 1984 and 2001 periods coincides with the studies by Berihun et al. (2021) in the Guder watershed, who reported that water supply ES increased from US$ 1.1 × 10^6 in 1982 to US$ 1.3 × 10^6 in 2017, attributed to the expansion of *Acacia decurrens* plantation.

Similarly, Anley et al. (2022) in Rib watershed reported that the water supply ES function showed a considerable increment, US$0.69 × 10^6 in 2010 to US$ 2.4 × 10^6 in 2020 period, mainly due to the increment of surface water bodies in the area ascribed to the construction of a dam on Rib river. Generally, the study revealed that the transformation of forest, grassland, and shrublands to agricultural landscapes reduced most of the ES except crop production, pollination, and biological regulation services. The result of this study is complimented with prior research (Anley et al., 2022; Biratu et al., 2022; Gashaw et al., 2018), which found that expanding agricultural landscapes improved food production provisioning services while also providing crucial ES like crop pollination and biological control.

Unless sustainable land management practices are implemented in the study area, the observed reduction of ESV is expected to continue for 2040 and 2060. The ES of forest and grassland are projected to drop by 80.66% and 72.5%, respectively, between 2022 and 2060 (Table 5). The loss of these natural habitats will come at the expense of an increase in crop production (31.76%), which could be linked to rising population growth and corresponding agricultural land demands in the area. The result is concurrent with most studies in Ethiopia, which revealed the decline of natural habitats mainly at the expense of agricultural land expansion to meet the food demands of the rapidly growing population (Belay et al., 2022; Berihun et al., 2021; Sisay et al., 2021; Yadeta et al., 2022). The majority of the population of Ethiopia (84%) lives in rural areas where economic opportunities are scarce; many people harvest natural resources for personal use or sell them to supplement household income (Egoh et al., 2012). According to some studies, the country's population will double by 2050 (Josephson et al., 2014; UN, 2022), and more natural forests will be transformed into agricultural and urban areas, demanding sustainable land use practices that balance ecological services with economic development.

4.2. Distribution of ESV along an agroecological gradient

The distribution of ESV was investigated in terms of agroecology to assist in identifying locations that demand special attention during sustainable land management interventions (Gitima et al., 2022). The overall ESV in the lowlands declined from US$316.25 × 10^6 in 1984 to US$289.56 × 10^6 in 2001 and then again to US$236.65 × 10^6. Despite continual decreases in total ESV due to documented LULC shift, the lowland agroecological zone contributes to the most significant share of total ESV in the study location, accounting for 81.89% in 1984, 79.03% in 2001 and 82.6% in 2022. Lowlands contribute the most to overall ESV due to the existence of high-value ecosystems as well as a considerable area share in the study area (78.02%), followed by midland (21.16%), and highland (0.82%). In 1984, the lowland areas relied heavily on forest and shrubland (79.35%) and grassland (12.33%) to provide ES. By 2001, the contribution of forest and shrubland had increased somewhat (83.64%) over the 1984 period, while grassland's ESV had declined to 6.637%. Despite a significant reduction in forest ESV in 2022 (60%), forests and shrublands were the largest providers of total ESV in the lowland section of study area, followed by farmland (24.43%). The rapid decline of natural ESV aligns with the observations of KIs and elderly community members who have noted an increase in human pressure on natural habitats, particularly since the initiation of the resettlement program. A significant influx of temporary and permanent immigrant farmers has occurred in the lowland portion of the study area, attracted by its perceived fertility for cultivating cash crops and sorghum, resulting in the conversion of multifunctional landscapes.

In the midland, the total ESV increased from US\$ 68.86 $\times 10^6$ in 1984 to US\$74.34 $\times 10^6$ in 2001, though it was reduced to 48.14 $\times 10^6$ in 2022. Similarly, the ESV increased from US\$ 2.08 $\times 10^6$ in 1984 to US \$2.49 $\times 10^6$ in 2001 in the highland areas of the watershed. The increase in ESV between 1984 and 2001 in the midland and highland portion of the study area was attributable to a modest rise in shrublands (Sisay et al., 2023), which could be due to the expansion of *eucalyptus* plantations. This result agrees with Debie Anteneh (2022) in the Gilgel Abay watershed, who reported an increase of ESV by US\$59.23 $\times 10^6$ between 1984 and 2021, owing primarily to the rise in expanding *Acacia* and *Eucalyptus* tree plantations. Berihun et al. (2021) found that the remarkable spread of plantations in the Guder watershed resulted in a 54% increase in ESV. Tan et al. (2020) also noted that the implementation of ecological projects boosted the value of ES in Northwest China, highlighting the importance of considering and promoting sustainable land management practices to conserve and enhance ecosystem services.

4.3. Implications for landscape management and future directions

The current utilization of land globally, along with the appropriation of ES and the resulting loss of biodiversity, is reaching unprecedented levels in human history (IPCC, 2019). Our study has revealed a concerning trend of rapid depletion in ESVs, primarily attributed to the conversion of natural ecosystems into human-dominated landscapes. Specifically, the conversion of forests, shrublands, and grasslands into farmland and settlements could have an impact on biodiversity loss, loss of carbon sink, soil erosion and degradation, runoff, surface temperature changes, and desertification in the study area. This underscores the urgent need to address the drivers of LULC change in the study area to prevent further degradation of ES.

Agricultural lands are an essential component of the ecological environment as they directly provide the necessary resources to sustain human populations through food production, as well as indirectly through biological control and pollination services (Hasan et al., 2020). However, the expansion of these lands should not be at the expense of delicate ecological systems and must be managed sustainably to ensure the long-term protection of the environment while meeting the nutritional needs of a growing population (Hasan et al., 2020). Hence, to maintain crop productivity and improve environmental quality and ES in the study area, this study recommends the implementation of sustainable land management practices such as agroforestry, agronomy, water harvesting and conservation, conservation agriculture (no-tillage, crop residue retention, diverse cropping systems, and permanent cover crops), minimum soil disturbance, and organic fertilizer. However, the use of these techniques must take into account the diverse agroecology of the study area and physical environment, as the mitigation capacity of every sustainable land management approach differs based on soil and climate conditions (Branca et al., 2013). Additionally, actions such as cooperatives, carbon credits, and payment for ES offer opportunities to increase vegetation areas and generate income for farmers in the study area.

4.4. Limitations of the study

It is critical to recognize some of the limitations of this research during the policy and decision-making processes. Firstly, the study relied on remote sensing data and modeling approaches, which may limit the accuracy of LULC classifications and ES estimates. While we employed Landsat and Sentinel-2A satellite images, the resolution may not have been sufficient to catch fine-scale LULC changes over short periods. Secondly, while the LULC analysis technique can give information on surface-level land cover changes, it does not fully account for the intricacies of water dynamics that occur below the surface. Infiltration, subsurface flow, and groundwater recharge are all important factors in water availability and river flow patterns, and the LULC approach may not accurately capture them. On the other hand, the monetary valuation ES are primarily concerned with physical LULC and fails to capture the full range of cultural values and ecosystem benefits that are deeply embedded in social, historical, and cultural contexts (IPCC, 2019).To address these limitations, future studies should consider combining hydrological modeling for water ES and qualitative research methodologies for cultural ES. Furthermore, some driving variables are included in this research, which are thought to have influenced future LULC dynamics. Nonetheless, additional biophysical elements influencing LULC change, such as climate and socioeconomic factors, may have been overlooked. Therefore, understanding the sources of uncertainty in land cover projection is critical when applying this research to policy and decision-making processes.

5. Conclusions

This study assessed the impact of observed and projected LULC changes on ESVs in the Goang watershed. The findings revealed a significant reduction in the total ESV and individual ES due to LULC changes. The total ESV of the watershed decreased from US\$390.35 in 1984 to US\$279.07 $\times 10^6$ in 2001 and declined to US\$286.69 $\times 10^6$ in 2022. Shrubland, forest, and grassland provided the highest ESVs in 1984, with forest contributing US\$95.38 $\times 10^6$ and grassland (US\$45.01 $\times 10^6$). However, by 2001, the ESVs of forest and grassland had decreased by 8.34% and 51.13%, respectively. Between 2001 and 2022, shrubland experienced the greatest fall in ESVs, with a 74.24% decrease, followed by forest (55.63%) and grassland (4.733%). The reduction in ESVs for forest, shrubland, and grassland was primarily attributed to the increase in farmland, which rose from US\$29.17 $\times 10^6$ in 1984 to US \$84.3 $\times 10^6$ in 2022, representing a significant increase of 188.95%. The findings underscore the need for proactive measures to mitigate further loss of ES and promote sustainable land management practices. By prioritizing the conservation and restoration of forest, shrubland, and grassland habitats, it is possible to safeguard the ES provided by the watershed and ensure its long-term ecological integrity and resilience.

CRediT authorship contribution statement

Getahun Sisay: Writing – review & editing, Writing – original draft, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Berhan Gessesse:** Writing – review & editing, Visualization, Validation, Supervision, Project administration. **Christine Fürst:** Writing – review & editing, Visualization, Validation, Project administration. **Meseret Kassie:** Writing – review & editing, Visualization, Validation, Supervision, Project administration. **Belaynesh Kebede:** Writing – review & editing, Visualization, Validation, Supervision, Project administration. **Woubet G Alemu:** Writing – review & editing, Visualization, Validation, Project administration, Investigation.

Declaration of competing interest

The authors declare no competing interests.

Data availability

Data will be made available on request.

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Supplementary materials

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