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Research

Impacts of land use and cover change on ecosystem services in the Andit Tid watershed, Ethiopia

Ayele Desalegn Woldemariam¹ · Kebede Bekele Atlaw¹ · Getacher Kassa Mitiku¹

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Abstract

Changes in land use and land cover (LULC) significantly impact ecosystem services and biodiversity in the highlands of Ethiopia. This study was conducted in the Andit Tid watershed, the central highland of Ethiopia. It aimed to analyze historical LULC shifts and their effects on ecosystem services while predicting future changes using ArcGIS, Remote sensing, IDRISI Selva, and geospatial datasets (DEM, Landsat imagery, TEEB database). The findings revealed a major transformation from 1985 to 2023, with bushland and cultivated land declining by 36.4% and 28.2%, respectively, while forest and bare land expanded by 110.6% and 75.8%. These changes increased the ecosystem service value from USD 147,880.4 to USD 180,737, driven mainly by regulatory and provisioning services. Future projections indicate a 50.6, 5.2, and 35.2% decline in forest land, grasslands, and bare land by 2050, alongside a 34.9% and 56.8% rise in cultivated land and bushland. Consequently, the ecosystem service value is expected to decrease to USD 147,540, a net loss of USD 33,196.7. Strategic land use planning should integrate ecosystem service valuation into decision-making, strengthen regulations, and promote sustainability to mitigate these impacts. Future research should focus on continuous LULC monitoring, biodiversity impacts, climate interactions, and socioeconomic drivers. Enhancing predictive models will support policymakers in selecting sustainable land use strategies.

Keywords Remote sensing · Ecosystem service · Arc GIS · Projection · Land use · Sustainability

1 Background

Land use and land cover (LULC) changes in Ethiopia significantly impact ecosystem services, soil properties, streamflow, and soil erosion. Studies in various watersheds like Chacha, Fetam, Rib, and Zoa have highlighted the consequences of LULC changes [1–4]. These changes include shifts from natural vegetation to croplands, built-up areas, and deforested lands, resulting in alterations to ecosystem service values, soil quality, and increased risks of soil erosion. The use of advanced techniques like Cellular Automata (CA)-Markov and GIS models has enabled the assessment and prediction of LULC changes and their impacts on the environment [5].

Projected land use and land cover changes have been extensively studied using various models and scenarios in Ethiopia. Studies have utilized high-resolution data and simulation models to predict future dynamics. The CA-ANN model was utilized to evaluate past changes and predict future scenarios in the Upper Omo–Gibe River basin, highlighting significant increases in agricultural land and urban sprawl at the expense of forests and grasslands [5]. Furthermore, the Suluh River Basin study projected increases in bare, built-up, and cultivated land, emphasizing

✉ Ayele Desalegn Woldemariam, ayeledesalegn5@gmail.com | ¹Soil and Water Management Research Directorate, Debre Birhan Agricultural Research Center, P.O. Box 112, Debre Birhan, Ethiopia.



the importance of managing LULC changes sustainably to safeguard the environment [6]. The Upper Awash Basin study predicted continued urban sprawl and cultivated land expansion, necessitating effective land-use policies for ecological management [7]. Lastly, scenario modeling in Central Ethiopia indicated varying LULC changes under different scenarios, emphasizing the potential for sustainable landscape planning and management to enhance ecosystem services [8].

Land use and land cover (LULC) changes significantly affect Ecosystem Service Values (ESV) in the central highlands of Ethiopia. Studies in various watersheds like Chacha watershed (central highland of Ethiopia), Matenchose, and the central Rift Valley reveal the profound impact of LULC changes on ESV. These changes include shifts in cultivated land, forest cover, grassland, and built-up areas, leading to alterations in ESV over time [4, 9, 10]. Positive LULC changes, such as increasing forest cover, have been shown to enhance ESV, while negative changes, like the loss of forest land, result in decreased ESV [8]. Modeling future scenarios also suggests that sustainable land management practices can enhance ESV, underscoring the importance of strategic planning and conservation efforts [11]. Hence, recognizing and effectively addressing LULC changes are vital for preserving and enriching ecosystem services in Ethiopia's central highlands. In the case of the Andit Tid watershed, there was limited information on long-term LULC changes and their impact on ecosystem service values. This watershed is a key area for soil and water conservation research. However, previous studies in this watershed have primarily focused on soil erosion and hydrological dynamics, with little emphasis on how LULC changes have influenced ecosystem services over time. The lack of comprehensive studies on ESV dynamics in this watershed presents a significant research gap, limiting our understanding of how land use decisions impact critical services such as carbon sequestration, water regulation, and soil fertility.

Given the highland ecosystem's vulnerability to land degradation and climate change, investigating the long-term implications of LULC changes on ecosystem services is crucial for sustainable watershed management. This study aims to fill this knowledge gap by analyzing historical LULC trends, quantifying associated ESV changes, and modeling future scenarios. The findings will provide essential insights for policymakers and land managers to design targeted conservation strategies that enhance ecosystem resilience and sustainability in the Andit Tid watershed.

2 Methodology

2.1 Description of the study area

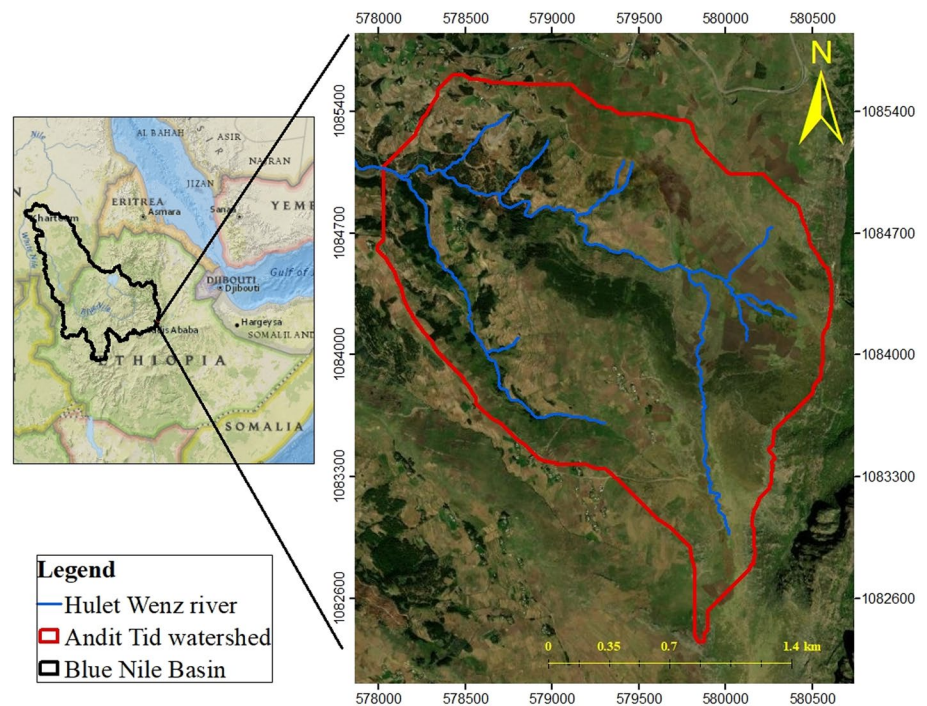
The study was conducted at Andit Tid watershed, which is situated in the central highland region of Ethiopia. The elevation of the watershed ranges from 3040 to 3550 m.a.s.l., indicating high altitude (Fig. 1). It serves as a tributary of the Upper Blue Nile basin, contributing to the larger hydrological system of the region. The watershed was established as a model watershed by the Soil Conservation Research Program (SCRIP) in 1982. This Watershed has steep slopes, high rainfall, severe soil erosion, and fast land use dynamics. Its susceptibility to LULC changes and the representativeness of Ethiopian highlands make it ideal for studying LULC impacts on ecosystem services and guiding sustainable land management and conservation strategies.

2.2 Data collection and analysis

Landsat images of 30 m resolution for 1985 (Landsat 4), 2013 (Landsat 7), and 2023 (Landsat 9) were obtained from the USGS Data Center. Band composition and supervised image classification were carried out using ArcGIS 10.5. Google Earth images were used as an ancillary during land use classification for accuracy assessments. The 2 m Digital Elevation Model (DEM) data of the watershed was obtained from the WLRC. Watershed delineation and other geospatial and hydrological analyses were conducted using the DEM.

The Economics of Ecosystems and Biodiversity (TEEB) for National and International policymakers was used as a source for assigning values of ESV for the land use types. Based on the existing land use distribution in the watershed, the study area was categorized into five LULC classes: cultivated land, forest land, bushland, bare land, and grassland.

Fig. 1 Descriptive map of the study watershed



2.3 Global ecosystem services valuation coefficient data

The data source for the ES valuation was the global Economics of Ecosystems and Biodiversity (TEEB) database (<http://www.teebweb.org>), containing coefficients of valuation ES for the representative biome [12]. The TEEB database is often used to estimate ecosystem service values across different LULC types, especially in regions where primary valuation data is unavailable [13]. More than 1310 compiled data have been found in the TEEB database, which was collected from different parts of the globe [12, 14]. However, its transferability to the Andit Tid watershed, located in Ethiopia, is limited due to differences in ecological, socio-economic, and land management conditions. The values derived from TEEB may not fully capture the local ecosystem functions, such as water regulation, soil fertility, or carbon sequestration, which can vary significantly across regions [15]. Global data like the TEEB database may lack regional specificity, reducing accuracy in local ESV assessments. However, TEEB valuation data of East Africa was applied to the study watershed since East Africa's LULC types are more related to the land use pattern of Ethiopia. In the study watershed, the nearest equivalent biome was assigned to each LULC type, suggested by TEEB [12] to get their equivalent coefficients ES (Table 1).

2.4 Ecosystem service (ES) analysis

In the ES valuation process, the value of biome coefficients was assigned to each LULC type of the watershed according to the value used in TEEB coefficients [12] and used by [16–18]. The area in hectare of each LULC type was multiplied by its corresponding value coefficients to calculate the total ES value for a particular LULC type [19]. The values of the LULC types in each reference year were summed to estimate the total ESV of the watershed for each reference year. Each ES function value obtained from TEEB multiplied by the land use cover area is ecosystem function valuation (ESV). To obtain the four major ES (provisioning, regulating, supporting, and cultural ES), one has to sum up all the individual ES function values. To map ESV to each LULC type, ArcGIS was used to assign the value for each reference year. The change in ESV between 1985 and 2023 was calculated using the formula shown in Equation [18, 19] as presented in Eq. 1.

$$ESVchange(\%) = \frac{ESV_{Recentyear} - ESV_{Initial\ year}}{ESV_{Initial\ year}} * 100 \quad (1)$$

Table 1 Ecosystem functions value coefficients of each LULC type database TEEB of [12]

No.	Ecosystem value type	Ecosystem service values (US\$ ha/year) in each land use land cover							
		FL	CL	GL	WL	SL	BL	S/B	WB
1	Water supply	178	0	114.4	4.33	114.4	0	0	1770.6
2	Food production	67	186	130	0	130	0	0	14.5
3	Raw material	475.51	103.4	19	138.2	19	0	0	1.4
4	Biomass fuel	31.34	0	79	67.28	67.28	0	0	0
5	Genetic resources	327.68	0	0.01	0	0.01	0	0	8.23
6	Water regulation	15.6	0	5	0	5	0	0	3878.4
7	Water purification	275.2	0	99.71	253.56	99.71	0	0	1348.13
8	Erosion control	360	3.45	55.89	26.76	0	0	0	0
9	Biological control	20.62	30	30	0	30	0	0	0
10	Biodiversity protection	263	24	52.68	11.44	52.68	0	0	361.4
11	Climate regulation	569	204.65	121.91	383.72	121.91	0	0	66.76
12	Gas control	22.12	0	2.41	0	2.41	0	0	0
13	C-sequestration	1229.79	96	297.39	8.16	297.39	0	0	0
14	Nutrient cycling	11.61	0	0	0	0	0	0	0
15	Pollination	48.29	20	32	0	0	0	0	0
16	Soil formation	3.26	0	7	0	0	0	0	0
17	Habitat	28.057	0	0	0	0	0	0	0
18	Recreation	810.68	0	3.11	0	0	0	0	519.47
19	Tourism	73.74	0	0	0	0	0	0	0

FL: Forest Land; CL: Cultivated Land; GL: Grass Land; WL: Wood Land; SL: Shrub Land; BL: Bare Land; S/B: Settlement/Built-up; WB: Water Body

2.5 Land use land cover projection

Future LULC dynamics of the study watershed were projected and modeled using TerrSet18.32 software using Land Change Modeler (LCM) and the IDRISI GIS analysis extension. A contiguity kernel is applied by CA-Markov to grow out a land-use map to a later period using a CA function using the anticipated amount of change that was generated by Markov chain analysis, primarily the transition probability [20]. To benefit from the advantages of combining the stochastic spatial Markov technique with the stochastic spatial CA method [21–23], the CA–Markov model was used in this study. Depending on the previous or present land cover condition, the LULC change dynamics for any region are calculated mathematically following Eq. 2 [20, 24].

While it can simulate multi-directional LULC change analysis, the CA–Markov model is commonly used and successful in detecting spatiotemporal changes in LULC [24–26]. Additionally, it is a user-friendly bottom-up approach model for future LULC prediction by identification of complex system dynamics and prediction of the future spatial model by taking both physical and socioeconomic elements into account. The transition probabilities of various land cover categories from discrete time steps are quantified using it. After that, a CA model is applied to these probabilities to project spatially explicit changes over time [25].

$$S(t + 1) = P_{ij} + S(t) \quad (2)$$

where $S(t)$ and $S(t + 1)$ are the system status at the time of t or $(t + 1)$; P_{ij} is the transition probability matrix in a state which is calculated following Eq. 3:

$$P_{ij} = \begin{bmatrix} P_{11} & P_{12} & \dots & P_{1n} \\ P_{21} & P_{22} & \dots & P_{2n} \\ \dots & \dots & \dots & \dots \\ P_{n1} & P_{n2} & \dots & P_{nn} \end{bmatrix} \quad 0 \leq P_{ij} < 1 \text{ and } \sum_{j=1}^n P_{ij} = 1, (i, j = 1, 2 \dots n) \quad (3)$$

where P denotes the Markov probability matrix and P_{ij} is the likelihood that the current state i will change to state j in the upcoming period.

The Change Analysis, Transition Potentials, and Change Prediction tabs are the main functional keys of the Land Change Modeler (LCM). To simulate the future LULC in 2050 under the business-as-usual scenario, the change rates were established through the change analysis tab along with the transition potential maps. Maps of transition potential can be created based on the various sub-models and related explanatory variables by using a Multi-Layer Perceptron (MLP) neural network method in the LCM model. Thus, the MLP-NN model has been used to compute the proportionate number of transitions that the dependent variables (earlier image and later image and independent factors have on the future LULC change, as other scholars like [20, 24–28] have used.

Slope, altitude, aspect, distance from roads, distance from rivers, and population density are typically the main factors causing changes in land use [29]. These topographic variables (Slope and altitude) were produced using a DEM. The Euclidean distance function in Arc GIS was used to generate distance from road and river maps using vector data elements like maps of rivers and roads. The population density map of the watershed was clipped from the country's population density map. Finally, IDRISI selva Software used these variables as input to execute the potential transition maps.

3 Result and discussion

3.1 Land use and land cover changes analysis

As shown in Fig. 2 and Table 2, the land use and land cover (LULC) of the study watershed have undergone significant changes since 1985. Notably, there has been a substantial decrease in cultivated land (–61 ha) and bushland (–20.4 ha) within the watershed between 1985 and 2023. Conversely, forest land has shown a notable increase (52 ha), followed by bare land (25 ha). The Grassland area has experienced a slight increase over the past 38 years (between 1985 and 2023). Various studies conducted across different regions of Ethiopia have noted a transformation in the distribution of land use and land cover types. One such study highlighted that cultivated land experienced a slight increase between 1984 and 1994, followed by a gradual decline since 1994 [30].

However, the majority of these studies have consistently highlighted an increase in the coverage of cultivated land and settlements, alongside a decrease in the coverage of forest land [1, 7, 8, 11, 18, 19, 31–33]. From 2000 to 2020, there was a 15% increase in cropland and a substantial 46.95% increase in construction areas, while vegetation and grassland witnessed declines of 70.02% and 38.1%, respectively [1]. The woodland cover saw a notable increase from 20.6% to 40.2%, while grassland showed a marginal increment, rising from 35.9% to 36.9%. Conversely, barren land decreased

Fig. 2 The land use and land cover shifted over time, from 1985 to 2023

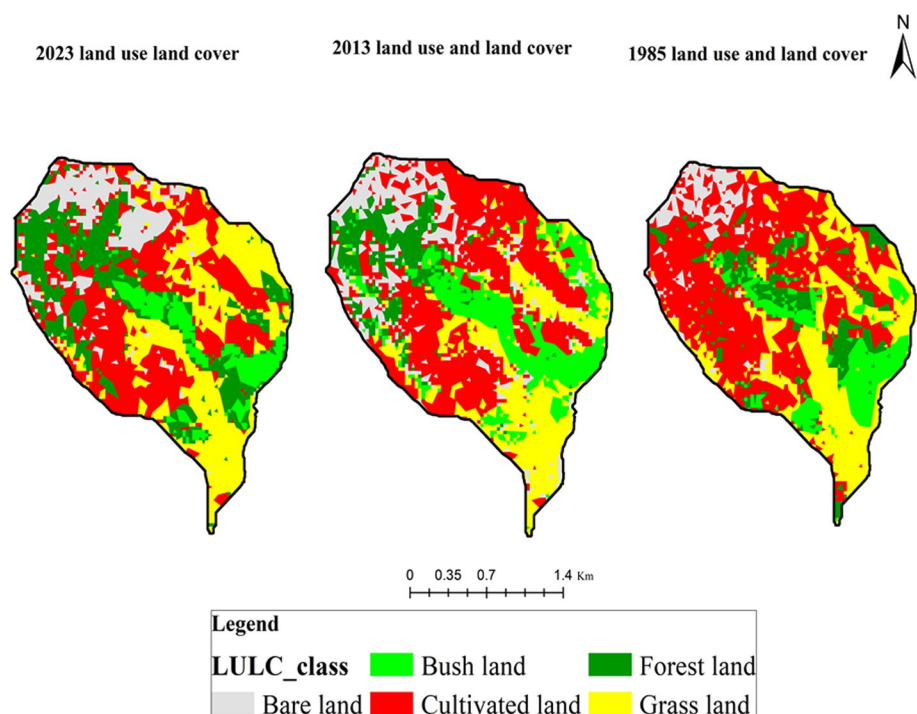


Table 2 The shift in LULC types of the study watershed from 1985 to 2023

LULC type	Area (ha) by 1985	Area (ha) by 2023	Area change (ha)
Forest land	47.0	99	52.0
Bushland	56.4	36	-20.4
Grassland	123.6	128	4.4
Bare land	33.0	58	25.0
Cultivate land	216.0	155	-61.0
Total area (ha)	476.0	476	

significantly from 43.4% to 22.6% [11]. In the Upper Blue Nile basin of Ethiopia, there was a continuous expansion of cultivated land and built-up areas, alongside a reduction in forest, shrubland, and grassland during the period from 1985 to 2015 [18]. Another study reported a decrease in forest cover by 46%, shrubland by 44%, and grassland by 42%, coupled with an increase in cultivated land by 23%, settlement by 137%, and water bodies by 80% during the period from 2000 to 2020 [17]. From 1991 to 2020, farmlands, towns, and bare land demonstrated increasing trends, whereas forest and grassland exhibited declining trends [10]. Furthermore, between 1985 and 2021, bare land and farmland have been expanding at the expense of other land use types [2].

The primary factors driving the shift in land use and land cover within the watershed from 1985 to 2023 were the decline in cultivated areas and the expansion of the forested regions. Additionally, there was an increase in bare land and a decrease in grassland observed in the overall changes depicted in the graph (Fig. 3). The significant players in the reduction of cultivated land, totaling around 60 ha, were the increases in bare land (approximately 29 ha), forested areas (25 ha), and grassland (12 ha), respectively. Conversely, bushland contributed positively, adding 6 ha to the net change in cultivated land area. This shift in the land use system differs from the changes in land use types observed in the Amhara region of Ethiopia, where agricultural land has expanded at the expense of forests and shrublands due to population growth [34]. This distinct pattern of land use and land cover change in the watershed is driven by the greater economic value of trees, particularly *Eucalyptus*, compared to cash crops.

3.2 Ecosystem service value shift between 1985 and 2023

Maps were utilized to depict the spatial distribution of Ecosystem Services Value (ESV) within the watershed from 1985 to 2023. The total ESV was estimated at USD 147,880.4 in 1985 and increased to USD 180,737.1 in 2023. In 1985, cultivated land held the highest ESV contribution at USD 48,721 (33%), while in 2023, forest land took the lead with USD 97,682.3 (54%) as the highest ESV-contributing land use. Between 1991 and 2020, the Economic Service Values (ESVs) experienced

Fig. 3 The contributions of different land use types for the net change on other land use types and the total net change of all land use types between 1985 and 2023 in ha

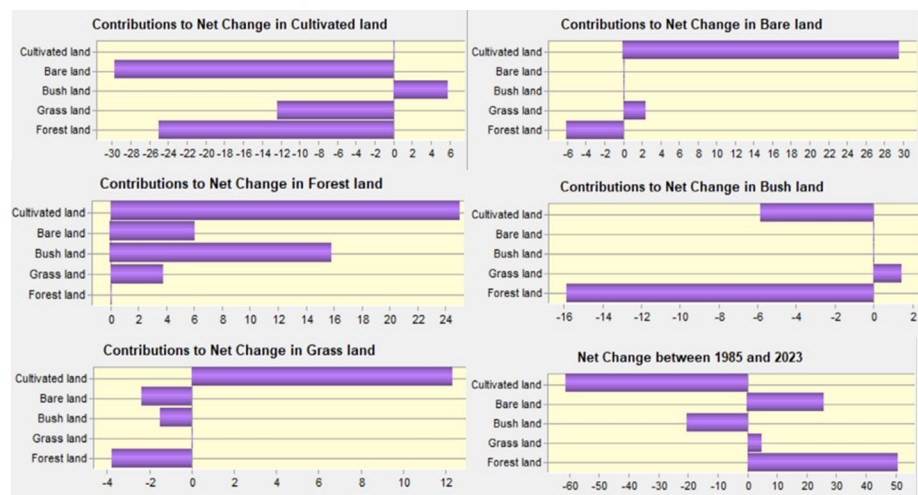


Fig. 4 The spatial map of the ecosystem services value within the watershed in 1985 and 2023

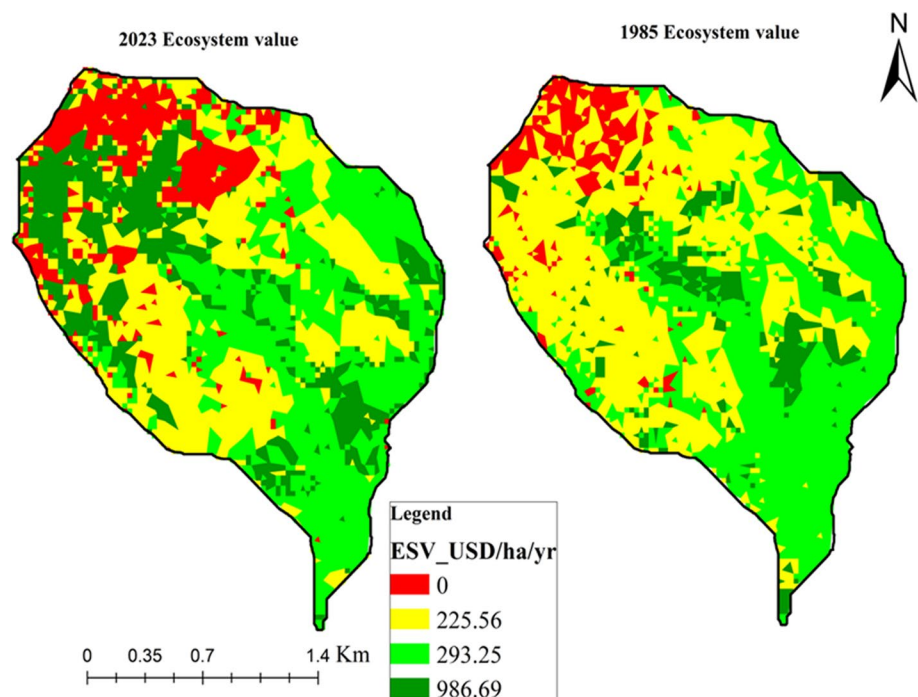


Table 3 The area coverage of land use types and their corresponding ESVs by 1985 and 2023

LULC type	Area (ha) by 1985	ESVs (USD)	Area (ha) by 2023	ESVs (USD)	Change in ESVs
Forest	47	46,374.43	99	97,682.3	51,307.9
Bushland	56.4	16,539.3	36	10,557.0	−5982.3
Grassland	123.6	36,245.7	128	37,536.0	1290.3
Bare land	33	0	58	0.0	0.0
Cultivate land	216	48,720.96	155	34,961.8	−13,759.2
Total area (ha)	476	147,880.39	476	180,737.1	32,856.7

a total decrease of US \$157.24 million as a result of the modifications in Land Use and Land Cover (LULC) [10]. In both maps (Fig. 4), the areas shaded in red represent bare land, which was identified as having a null ecosystem service value.

3.3 Change in ecosystem services values

As presented in Table 3, between 1985 and 2023, the ESV of the forestland increased by USD 51,307.9, from USD 46,374.4 in 1985 to USD 97,682.3 per year in 2023: the largest ESV change in the watershed. The ESV of the cultivated land was decreased by USD 13,759.2, followed by bushland which was decreased by USD 5982.3. The total ESV in the watershed was increased by USD 32,856 (22.2%) from USD 147,880.39 in 1985 to USD 180,737.1 in 2023, with an increasing rate of USD 864.6 (0.58%) per year.

3.4 Ecosystem function valuation changes

The watershed has an assemblage of four major ES: provision, regulating, supporting, and cultural functions, as illustrated in Fig. 5 and described in Table 4. In 2023, the highest value was estimated at USD 435,329.5 for regulating ES, followed by USD 207,463.8 for provisioning ES. The cultural ES was estimated at USD 87,955.66 and for supporting ES was USD 17,122.5. During the study period of 1985–2023, the regulating ESV covers the largest increases, which accounted for USD 111,933.4. Provisioning, supporting, and cultural ES were also increased by US 33,242.7, USD 3694.8, and USD 46,003.5, respectively.

Fig. 5 The comparison chart of four major Ecosystem Service values over three time periods

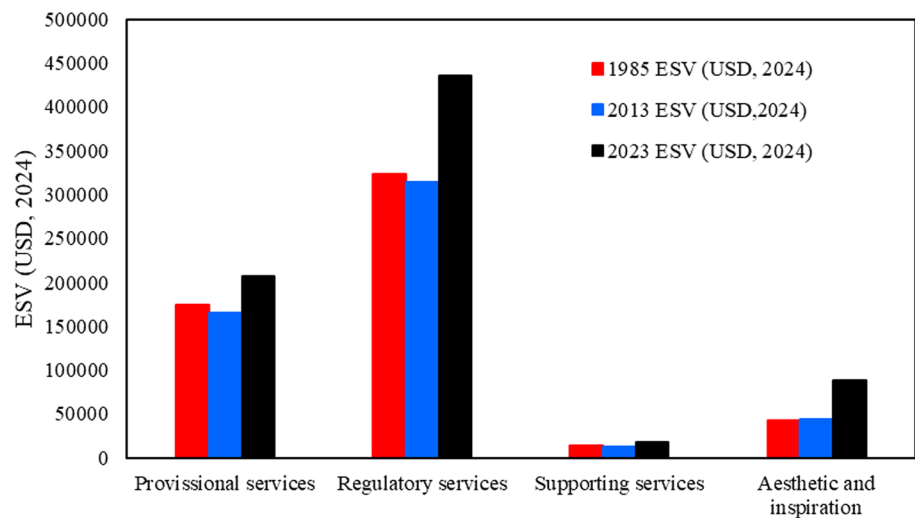


Table 4 The values of the estimated individual ecosystem function in USD ha⁻¹

Ecosystem service types		1985 ESV (USD)	2023 ESV (USD)	Deviation
Provisional services	Water supply	28,958	36,383.6	7425.6
	Food production	66,725	56,783.0	− 9942.0
	Raw material	48,103.37	66,218.5	18,115.1
	Biomass fuel	15,031.972	15,636.7	604.8
	Genetic resources	15,402.76	32,442.0	17,039.2
	Total	174,221.102	207,463.8	33,242.7
Regulatory services	Water regulation	1633.2	2364.4	731.2
	Water purification	30,882.2	43,597.2	12,715.0
	Erosion control	24,573.204	43,328.7	18,755.5
	Biological control	12,849.14	11,611.4	− 1237.8
	Biodiversity protection	27,027.4	38,396.5	11,369.1
	Climate regulation	92,891.2	108,045.0	15,153.8
	Gas control	1473.44	2585.1	1111.7
	C-sequestration	132,066.33	185,401.2	53,334.8
	Total	323,396.114	435,329.5	111,933.4
Supporting services	Nutrient cycling	545.67	1149.4	603.7
	Pollination	10,544.83	11,976.7	1431.9
	Soil formation	1018.42	1218.7	200.3
	Habitat	1318.679	2777.6	1459.0
	Total	13,427.599	17,122.5	3694.9
Aesthetic and inspiration	Recreation	38,486.356	80,655.4	42,169.0
	Tourism	3465.78	7300.3	3834.5
	Total	41,952.136	87,955.7	46,003.5

3.5 Ecosystem function valuation changes

The food production and biological control functions decreased from 1985 to 2023 due to the decreased area of cultivated land and bushland, respectively. However, most individual ES functions were increased during this study period. The highest gain of ES function value was observed in the regulatory category of C-sequestration by USD 53,334.8; the smallest gain was in the supporting category of soil formation by USD 200.3.

Fig. 6 The major land use land cover change driver variables used during the projection

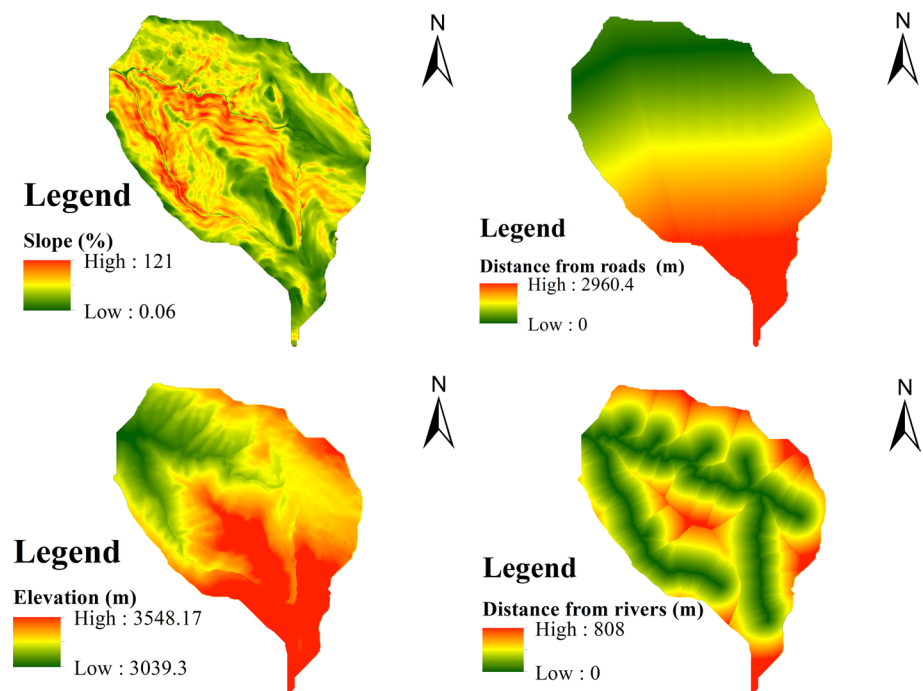


Table 5 The drivers' variables that are assumed to drive the land use change in the future

No.	Driving variables	Cramer's V	P value
1	Distance from rivers	0.1424	0
2	Elevation	0.2405	0
3	Distance from roads	0.321	0
4	Slope	0.356	0

3.6 Projection of land use and land cover by 2050

3.6.1 Land use and land cover change driver variables

The key factors considered for land cover projection included elevation, slope, distance from the roads and distance from the rivers were illustrated in Fig. 6.

Table 5 presents the results of Cramer's V and P values of the driving variables of land use and land cover change. The analysis revealed that slope was found to be the primary driving variable (Cramer's V of 0.356) influencing changes in projected land use and land cover types, while distance from rivers exhibited the least impact (Cramer's V of 0.1424). A study at the Gidabo River basin reported slope as the second most driving variable and elevation as the least influential variable [24]. Another study at Matenchose Watershed, Rift Valley Basin of Ethiopia, found slope as the least influential driving variable that impacts LULCC in the study watershed [25].

3.6.2 Result of the validation of land use and land cover projection

The agreement/disagreement components (Table 6) are validated through a validation analysis conducted by the Clark Lab's LCM module of IDRISI Selva version 17.00 software. The results are further divided into two categories: 0.087 (error due to quantity/DisagreeQuantity) and 0.0677 (error due to allocation/DisagreeGridcell). Therefore, the data table showed that rather than quantity error between the projected and actual 2023 images, allocation error was the cause of the differences between the two maps. Generally, with the AgreementGridcell (0.5647), AgreementChance (0.1667), and AgreementQuantity (0.1139) values, the actual and projected land use land covers show a perfect agreement.

Table 6 LULC classification agreement/disagreement of quantity, strata and gridcell

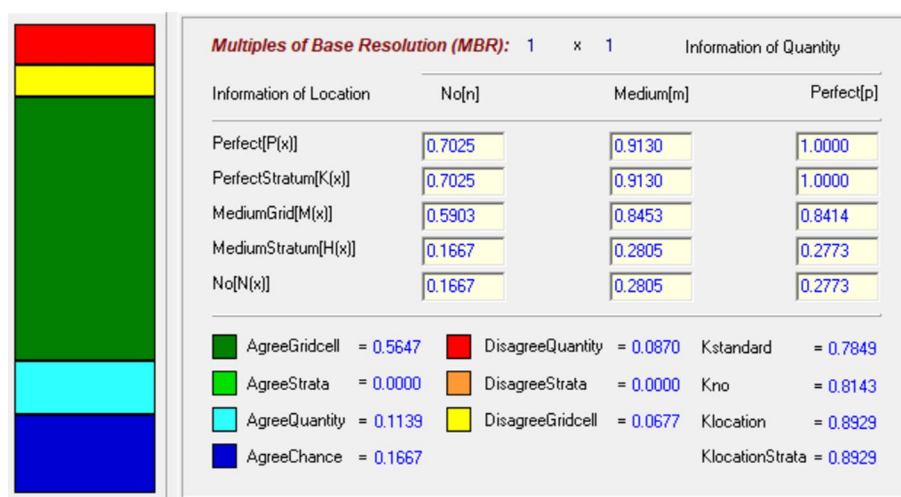
Agreement/disagreement	Value
AgreementChance	0.1667
AgreementQuantity	0.1139
AgreementStrata	0
AgreementGridcell	0.5647
DisagreeGridcell	0.0677
DisagreeStrata	0
DisagreeQuantity	0.087

As depicted in the wizard (Fig. 7), the quality measures presented alongside the land use change projection output indicate a near-perfect alignment. The metrics for AgreeGridcell (green shade), AgreeQuantity (light blue), and AgreeChance (blue shade) amounted to 0.8453, explaining to 84.35% kappa value. This indicates that the projection closely approximates perfection.

Model validation is necessary to compare the projected and actual map quality to assess the accuracy level. Several indices of agreement, notably the Kno index and the Klocation index, are employed to assess the accuracy and validity of predictions made using the CA–Markov model for land use and land cover (LULC) changes. Kappa values for quantity and location statistics show that the actual map and the projected map of 2023 were compared (Table 7). To determine how comparable the projected and real maps were, kappa statistics (K) were evaluated [35]. [36] state that the model is considered valid when the entire Kappa, or K, standard value, is above 70%.

The high consistency between the simulated and actual images indicates the model's efficacy in capturing and replicating the complex dynamics of land use and cover transitions over time. The average value of these indices, standing at 0.846, signifies that 84.6% of the LULC categories between the two images are equivalent. This level of agreement suggests that the CA–Markov model demonstrates almost perfect ability in predicting LULC changes within the study area.

The following table (Table 8) presents the probabilities of transitioning between different land use types, as well as the likelihood of remaining in the current land use. Analysis confirms that grassland (with a stability rate of 70.2%) and bare land (with a stability rate of 64%) exhibit greater relative stability compared to other land use types. Conversely,

Fig. 7 Visually summarizes the validation metrics of the projected and actual LULC of 2023**Table 7** Accuracy assessment of the simulated land use image of 2023

Index	Value
Kno	0.8143
Klocation	0.8929
KlocationStrata	0.8929
Kstandard	0.7849

Table 8 Probability of change in land use types between 2023 and 2050

2023–2050 LULC change probability	Forest land	Grassland	Bushland	Bare land	Cultivated land
Forest land	0.3617	0.1338	0.1451	0	0.3594
Grassland	0.0737	0.7021	0.0304	0.0131	0.1807
Bushland	0.4208	0.0218	0.5036	0	0.0538
Bare land	0.1812	0.004	0	0.6398	0.175
Cultivated land	0.1886	0.1494	0	0.1608	0.5012

forest land, with a stability rate of 36.2%, is the primary land use type showing a high probability of transitioning towards cultivated land, accounting for 35.9% of the total area.

As depicted in Fig. 8, the primary drivers of the net change in projected land use and land cover were cultivated land and forest land, with bare and bushlands also playing significant roles. Cultivated land saw a net increase, largely influenced by forest land contributing approximately 36 ha, grassland around 9 ha, and bare land approximately 13 ha from their respective coverage areas. In the context of decreased forest land coverage, cultivated land, bushland, and grassland had negative contributions of 36 ha, 13 ha, and 5 ha, respectively. Notably, grassland was the only category with a positive contribution of 5 ha.

Overall, in the projected land use and land cover shift of the study watershed by 2050, forest land and cultivated land emerged as the predominant land use types experiencing significant changes in their coverage. As reported by [36], between 2035 and 2055, the predictions for Land Use and Land Cover (LULC) indicate an increase in agricultural land, grassland, settlement areas, and woodlands by 44.02, 30.35, 69.2, and 55.05%, respectively. Conversely, forest and scrub/bushlands are expected to decrease by 21.53% and 11.08%, respectively [37].

3.6.3 Projected land use and land cover of the watershed by 2050

As presented in Table 9 and illustrated in Fig. 9, by the year 2050, the distribution of land use types in terms of the area will be as follows: Cultivated land (44.18%), Grassland (25.63%), Bushland (11.92%), Forest land (10.32%), and Bare land (7.94%).

3.6.4 Shifts in LULC from 1985 to 2050

Table 10 presents the land use and land cover (LULC) changes from 1985 to 2050, specifically from 2023 to 2050. Significant shifts were noted across all LULC categories during the latter period. Cultivated land, in particular, exhibited a notable increase of 54.2 ha, while forest area declined by 50.1 ha. Additionally, bushland expanded by 20.44 ha, whereas bare land decreased by 20.4 ha. Among these changes, the least alteration occurred in grassland, which is projected to diminish by 6.6 ha by 2050 compared to its current coverage.

Fig. 8 The contributions of different land use types for the net change on other land use types and the total net change of all land use types between 2023 and 2050 in ha

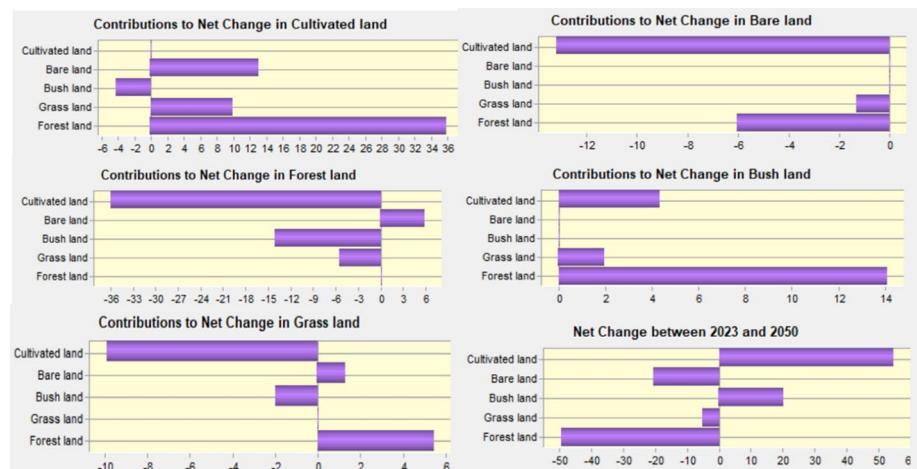
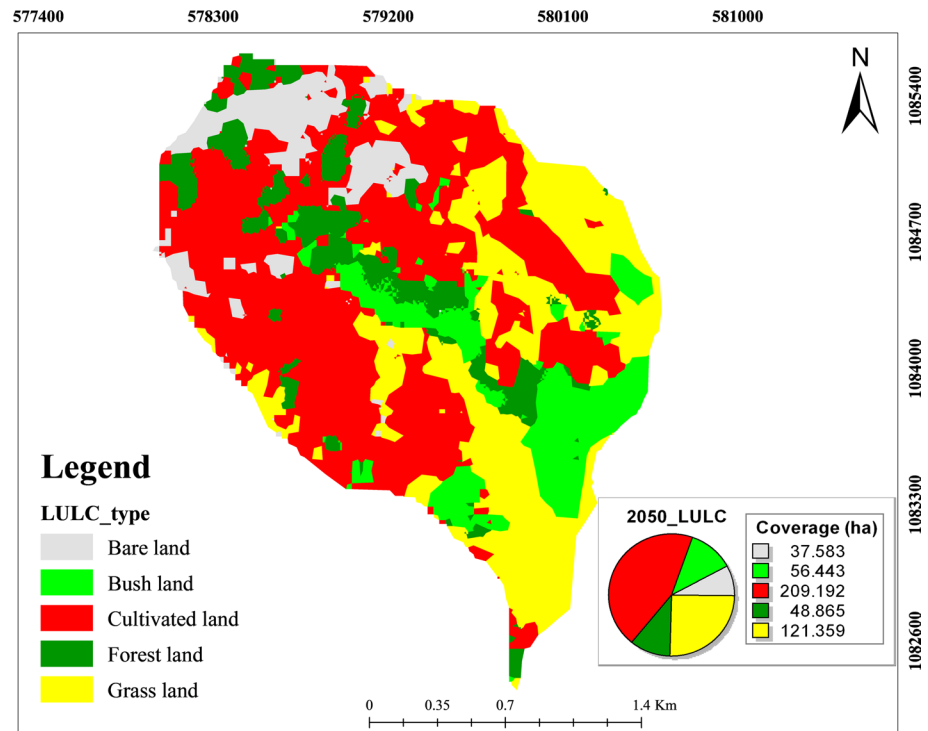


Table 9 The projected land use, land cover type, and its coverage and proportion by 2050

No.	LULC type	Area (ha)	Proportion (%)
1	Forest land	48.86	10.32
2	Grassland	121.36	25.63
3	Bushland	56.44	11.92
4	Bare land	37.58	7.94
5	Cultivated land	209.19	44.18

Fig. 9 The projected land use and land cover of the study watershed by 2050**Table 10** The shifts in LULC areas from 1985 to 2050 (65 years) and from 2023 to 2050

No.	LULC type	1985 area (ha)	2023 area (ha)	2050 area (ha)	1985 to 2023	2023 to 2050	1985 to 2050
1	Forest land	47	99	48.86	52	- 50.14	1.86
2	Grassland	123.6	128	121.36	4.4	- 6.64	- 2.24
3	Bushland	56.4	36	56.44	- 20.4	20.44	0.04
4	Bare land	33	58	37.58	25	- 20.42	4.58
5	Cultivated land	216	155	209.19	- 61	54.19	- 6.81

Table 11 presents the anticipated shift in ecosystem values resulting from changes in land use and land cover types. According to the findings, it is evident that the ecosystem service value of the surveyed watershed is projected to decrease by USD 33,196.7 (18.4%) by the year 2050 compared to 2023. This is estimated that there will be a 0.68% decrease in ecosystem values of the watershed per annum up to 2050. The most significant decline in ecosystem value was noted in forested areas, with a decrease of USD 49,467.8 attributed to a substantial reduction in forest coverage. While there was a projected increase in cultivated land coverage, the corresponding rise in ecosystem service value from this land use type was considerably lower than the value lost by the watershed due to the decrease in forest coverage. Similar research findings indicate that the total value of services derived from natural ecosystems is projected to decrease by 36.24% between 1985 and 2050 [38].

The projected decline in ecosystem service value (ESV) by 2050 has serious implications for local communities in Andit Tid, where livelihoods heavily depend on agriculture, water resources for livestock rearing, and forest ecosystems.

Table 11 The area coverage of different land use types by different years and their corresponding ecosystem service values

LULC type	Area (ha) by 1985	1985 ESVs (USD)	Area (ha) by 2023	2023 ESVs (USD)	Area (ha) by 2050	2050 ESVs (USD)	Projected change of ESV (USD) from 2023 to 2050
Forest	47	46,374.43	99	97,682.3	48.86	48,214.5	− 49,467.8
Bushland	56.4	16,539.3	36	10,557	56.44	16,551.9	5994.9
Grassland	123.6	36,245.7	128	37,536	121.36	35,588.6	− 1947.4
Bare land	33	0	58	0	37.58	0.0	0.0
Cultivate land	216	48,720.96	155	34,961.8	209.19	47,185.4	12,223.6
Total area (ha)	476	147,880.39	476	180,737.1		147,540.4	− 33,196.7

Studies indicate that land use and land cover changes, driven by deforestation, agricultural expansion, and population growth, are key factors contributing to the decline in ESV [39]. This decline threatens essential ecosystem services such as soil fertility, water regulation, and carbon sequestration, which are crucial for sustainable agricultural productivity and climate resilience. Reduced soil fertility and increased erosion, as documented in the Upper Blue Nile Basin, are expected to lower crop yields, exacerbating food insecurity and economic hardship for farming communities [40, 41]. The decline in forest cover also diminishes the availability of non-timber forest products, such as firewood and medicinal plants, which many households rely on for income and subsistence [42]. The worsening environmental conditions not only increase rural poverty but also accelerate land degradation, pushing vulnerable communities into unsustainable land-use practices that further exacerbate ecosystem decline [42]. Immediate solutions, including afforestation, sustainable land management, and integrated watershed protection strategies, are needed to increase ESV and safeguard the biodiversity and environmental sustainability of Ethiopia's highland ecosystems.

4 Conclusion

This study investigates the effects of changes in land use and land cover from 1985 to 2050 on ecosystem services in the Andit Tid watershed. The study employed ArcGIS, Landsat images, DEM, IDRSI Selva, and the TEEB database tailored for Sub-Saharan Africa for mapping, land use and land cover classification, land change projection, and assigning ecosystem service values to different land use types, respectively. The research confirmed a significant change in land use and land cover within the watershed.

Correspondingly, it identified fluctuations in ecosystem services due to these changes, spanning 1985–2050. The findings indicated a notable shift in the watershed's landscape, accompanied by changes in the provision of ecosystem services. Specifically, there was a substantial increase in the watershed's ecosystem service value, amounting to USD 32,856 from 1985 to 2023. However, projections suggest a potential decrease in ecosystem services worth USD − 33,196.7 (a decrease of 18.4%) by 2050, attributed to ongoing land use and cover changes, particularly in forest land coverage. Consequently, the study underscores the importance of proactive land planning and implementing land use policies within the watershed. It emphasizes the need for concerted efforts from land managers to prioritize biodiversity conservation and ensure sustainable management practices for the benefit of future generations. Additionally, it is important to acknowledge that other factors, such as climate change, population growth, and socio-economic development, could also significantly influence ecosystem service values alongside the observed land use and land cover changes. These factors may exacerbate or mitigate the impact of LULC changes, further highlighting the complexity of managing ecosystem services in the watershed.

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Data availability Datasets generated during the current study are available from the corresponding author on a reasonable request.

Declarations

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Competing interests The authors declare no competing interests.

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