

Geospatial Assessment of Land Use and Land Cover Change Impacts on Wetland Ecosystem Services in West Arsi Zone, Ethiopia

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Abstract: Human livelihoods and well-being rely heavily on ecosystem services (ESs) provided by natural environments, with wetlands standing out as some of the most biologically diverse and economically valuable ecosystems worldwide. Despite their importance, wetlands face increasing threats from land use and land cover (LULC) changes driven by human activities. This study examines how LULC changes have affected wetland ecosystem service values (ESVs) in the West Arsi Zone of Oromia, Ethiopia, over a 30-year period from 1995 to 2025. Multi-temporal Landsat images were analyzed using cloud-based geospatial tools on the Google Earth Engine (GEE) platform, and land cover classification was done with the Random Forest

(RF) machine-learning algorithm. Field observations and ground reference data helped improve classification accuracy and identify the main drivers behind land cover changes. Ecosystem service values were estimated using a locally adapted benefit transfer method based on established valuation coefficients. The results show that rapid population growth, agricultural expansion, urban development, and infrastructure construction are the key forces driving LULC changes in the area. Settlement expansion significantly increased cropland-related ESVs from around USD 0.1 million to USD 2.5 million. However, this economic gain came mostly at the cost of wetlands, whose ecosystem service values dropped sharply from USD 1.17 million to just USD 0.05 million. Overall, the total ecosystem service value of the landscape fell by 3.9%, from USD 16.55 million in 1995 to USD 15.91 million in 2025. These findings highlight clear biodiversity loss and declining ecosystem function, emphasizing the urgent need for sustainable land-use planning that balances socio-economic growth with wetland conservation to protect long-term ecological health and human well-being.

Keywords: Ecosystem valuation; Google Earth Engine; Sustainable management; Wetland

1. Introduction

Wetlands rank among the most ecologically complex and productive ecosystems, providing a wide range of services like nutrient cycling, water purification, flood control, climate regulation, raw materials, and cultural benefits (Costanza et al., 1997; Ezeah et al., 2015; Assefa et al., 2021a). They play a vital role in regulating microclimates, supporting biodiversity, treating waste, and maintaining freshwater supplies at both local and regional levels (Costanza et al., 1997, 2014). Despite their importance, wetlands are rapidly disappearing worldwide, with loss rates higher than most other ecosystems (Assefa et al., 2021a). Since the early twentieth century, nearly half of all wetlands have vanished globally (Davidson, 2014), and over 60% of the remaining ones are degraded or used unsustainably (Assefa et al., 2021b). Ethiopia reflects this worrying global pattern, where wetlands face increasing threats from urban growth, agricultural expansion, sedimentation, and excessive water use (Teferi et al., 2010; Assefa et al., 2021b).

Changes in land use and land cover (LULC) greatly affect both the ecological and economic aspects of ecosystem services (Dixon, 2021; Jeethu & Kaladevi, 2025). Shifts in land cover often disrupt water cycles, fragment habitats, lower water quality, and speed up biodiversity loss, all of

which reduce the value of ecosystem services (Alebachew et al., 2022; Belay et al., 2022; Costanza et al., 2014). Over the past decades, intensified human activities have transformed wetland landscapes, leading to long-term effects on ecosystem resilience and the livelihoods that depend on them (Xu et al., 2020; Obsi et al., 2024).

While global and regional efforts increasingly highlight the importance of ecosystem service valuation for sustainable land management (Abebe et al., 2021; Alebachew et al., 2022; Anaya-Romero et al., 2016), studies focusing on wetlands in Ethiopia remain scarce and scattered. Most research has focused on forests, agriculture, and general rural areas, leaving a significant gap in understanding wetland-specific changes and their related ecosystem services (Gashaw et al., 2018; Assefa et al., 2021b).

Recent advances in geospatial technology offer powerful ways to fill this gap. Cloud-based platforms like Google Earth Engine (GEE) allow efficient processing of large multi-temporal datasets, while machine learning algorithms especially Random Forest have proven highly accurate for land cover classification (Lee et al., 2012). Unlike earlier regional studies (e.g., Dega et al., 2022) that looked at catchment-level LULC changes without focusing specifically on wetlands or ecosystem service valuation, this study takes a wetland-centered approach. By combining long-term LULC analysis with ecosystem service valuation from 1995 to 2025, it offers policy-relevant insights to support sustainable wetland management, spatial planning, and environmental conservation in the West Arsi Zone.

2. Materials and methods

2.1. Study area description

The study took place in the West Arsi Zone, situated in the central-southern part of Ethiopia within the Oromia Regional State. The zone is about 170–250 km south of Addis Ababa, depending on the district, and lies between latitudes 6°00'–8°00' N and longitudes 38°00'–39°50' E (Figure 1). Covering roughly 1,246,851 ha (12,468.5 km²), West Arsi is divided into twelve(12) districts (Nuro, et.al. 2024; Bukul, B. B. 2024). The terrain varies widely, with elevations ranging from about 1,464 to 4,171 m above sea level. Climate changes with altitude, with mean monthly temperatures typically between 20 and 24 °C and annual temperatures ranging from 13 to 28 °C. Annual rainfall varies across the zone, from around 700 mm in lower areas up to nearly 1,980 mm in the highlands. Average daily sunshine lasts between 3.8 and 8.8

hours, while mean relative humidity and wind speed are about 71.4% and 1.4 m s⁻¹, respectively. The region's water drains into three main basins: the Rift Valley Lakes Basin, Wabe Shebelle Basin, and Genale–Dawa Basin.

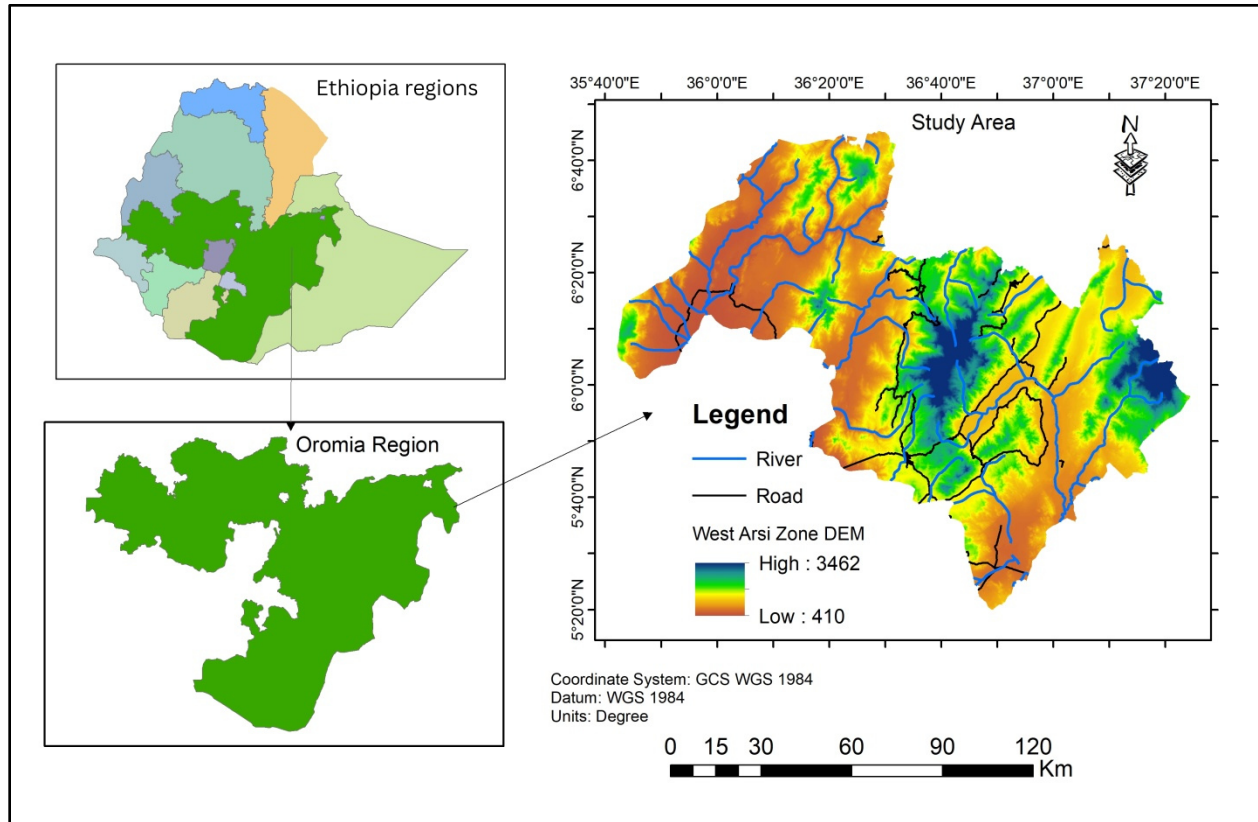


Figure 1: Location map of the study area.

2.2. Methods

2.2.1. Data collection and Sampling

Both primary and secondary datasets were used. Primary data came from GPS-based ground truth points collected during field surveys in 2025, along with direct field observations to confirm historical land cover conditions. A total of 520 reference points were gathered following Mellor et al. (2015), ensuring a balanced representation across classes to minimize classification bias. Secondary data included multi-temporal Landsat imagery (TM, ETM+, and OLI/TIRS) sourced from official archives. A stratified random sampling method was used to create training and validation datasets across six land use and land cover (LULC) classes: forest, grassland, cropland, wetland, water body, and settlement. Minority classes like wetlands and forests were

intentionally oversampled to strengthen classification accuracy. Of all the samples, 70% went to training and 30% to accuracy assessment.

2.4. Image Preprocessing and Classification

All image processing and analysis were done using Google Earth Engine (GEE). Landsat images from 1995, 2005, 2015, and 2025 were chosen to represent consistent ten-year intervals, with data collected during the dry season (December–February) to reduce phenological variation (Assefa et al., 2021b; Id et al., 2023). The Random Forest classifier was used because it effectively handles high-dimensional data and non-linear relationships (Cui et al., 2020; Jonathan et al., 2023). The model was optimized by setting the number of trees to 200.

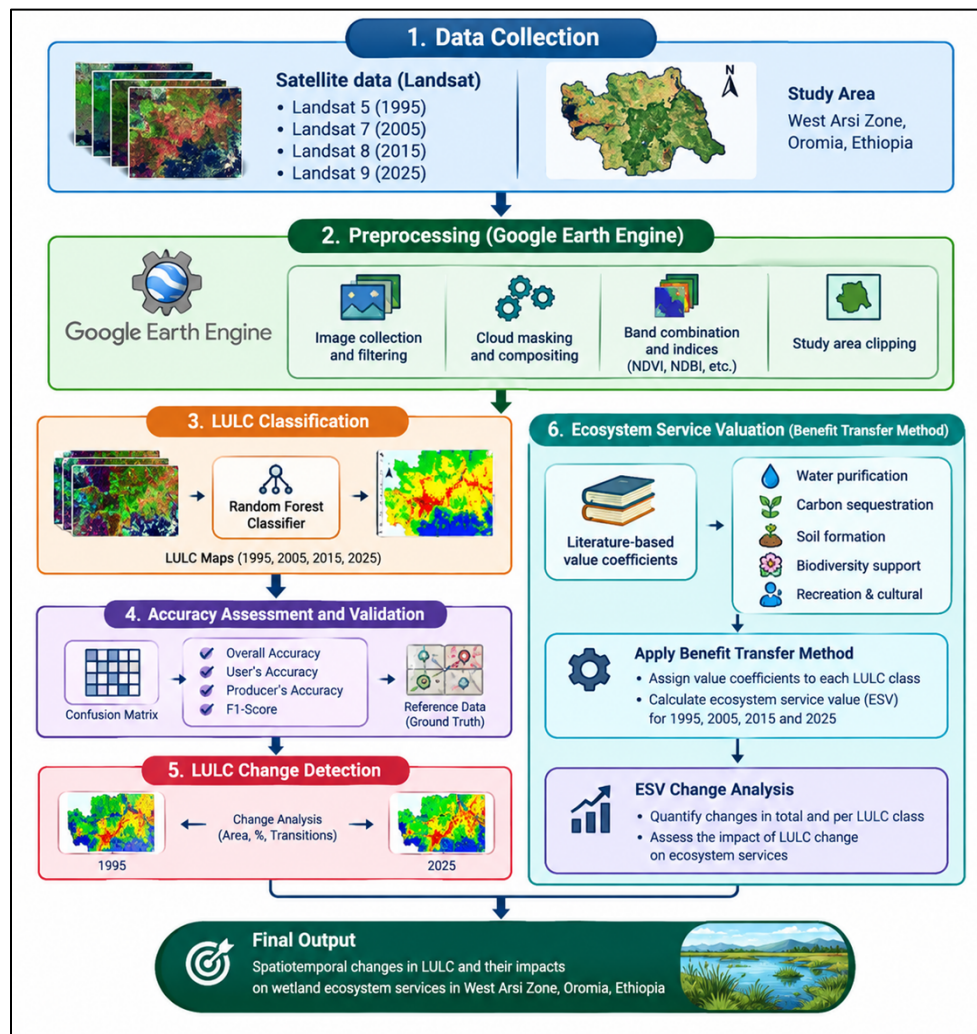


Figure 2: Methodological flow chart used in study.

The model was optimized by choosing key spectral bands and setting the number of decision trees to 200 to improve accuracy and prevent overfitting. Training and validation datasets were split 70:30, following common machine learning practices. Six land use and land cover classes were mapped for each study year (Table 1).

Table 1: The land use land cover categories of and their descriptions.

Class Name	LULC Description
Grassland	An area dominated by grasses and with few or no trees, typically used for grazing.
Settlement	A location where people live and build infrastructure, including urban, suburban, and rural residential areas.
Waterbody	Any significant accumulation of water, such as lakes, rivers, ponds, or reservoirs.
Cropland	Land actively used for the cultivation of crops for food, fiber, or other agricultural products.
Forest	Areas with dense trees. Area covered predominantly by trees including plantations and mixed forests, providing habitat, carbon storage, and various ecosystem services.
Wetland	Land areas saturated with water either permanently or seasonally, supporting water-tolerant vegetation

2.2.4. Accuracy assessment

Classification accuracy was assessed using confusion matrices created from independent validation datasets. The performance metrics considered were overall accuracy (OA), producer's accuracy (PA), user's accuracy (UA), and the Kappa coefficient. Stratified random sampling ensured validation points were evenly spread across the study area and properly represented all LULC classes, especially in transitional and mixed zones. This method provided a reliable way to evaluate classification performance at different points in time.

2.2.5. LULC change detection

Land use and land cover (LULC) change detection was carried out using accurately classified satellite images from different years to assess spatial and temporal changes in the wetlands of the West Arsi Zone between 1995 and 2025. Post-classification comparison techniques in ArcGIS

Pro were used to identify land cover transitions, persistence, and conversion patterns. Raster subtraction methods helped quantify changes between consecutive time periods, revealing both the scale and direction of LULC changes. Transition matrices were created to clearly show land cover conversions among various LULC classes, highlighting the main change trends. This method is well regarded for its reliability in LULC change analysis, especially when the classifications are highly accurate (Liyew et al., 2019; Tesfaye et al., 2025).

2.2.6. Ecosystem service valuation

There are several ways to estimate ecosystem service values, including market-based methods like market pricing, cost-based valuation, and production function approaches; revealed-preference techniques such as travel cost and hedonic pricing; and stated-preference methods, including contingent valuation and choice experiments (Adamowicz et al., 2019). In this study, ecosystem service value (ESV) was estimated using equivalent value coefficients from Kindu et al. (2016) and Egussie et al. (2019) (Table 2). Groot et al. (2022) originally created these coefficients for terrestrial ecosystems following the valuation framework. Applying global valuation coefficients directly, however, can reduce site-specific accuracy. To overcome this, a locally adapted benefit-transfer approach was used, dividing the West Arsi Zone into different land use and land cover (LULC) categories cropland, grassland, forest, settlement, water body, and wetland and adjusting the coefficients based on local biophysical conditions, following D'Este et al. (2020).

Egussie et al. (2019) provided ecosystem service value estimates for eleven biome types, but this study focused on the most relevant ones for the local setting: cropland for cultivated land, tropical forest for vegetated areas, grassland for grazing land, urban areas for built-up land, water bodies for aquatic systems, and inland wetlands for wetland ecosystems (Table 3). Although the tropical forest biome doesn't perfectly match the area's diverse vegetation types including open forests, dense forests, riverine forests, church forests, and eucalyptus plantations it was chosen as the best proxy because it shares similar ecosystem service functions. Built-up areas were assigned a zero ecosystem service value, consistent with Egussie et al. (2019), since the original valuation framework by Costanza et al. (1998) did not include urban ecosystem services like carbon sequestration.

Table 2: LULC categories, biome equivalents, and valuation coefficients (USD/ha/year) for ecosystem service estimation

LULC category	Equivalent biome	Total ecosystem service value coefficient (2020 \$ ha ⁻¹ yr ⁻¹)
Cultivated land	Cultivated areas	8026
Grassland	Grassland	1597
Forest land	Tropical forests	119,076
Settlement area	Urban green-blue	11,759
Wetland/Water body	Inland wetlands	48,647

Adapted from (Kindu et al., 2016)

Table 3: The land use land cover categories and their corresponding ecosystem sub-service values (USD/ha/year) for six representative biomes

Individual Ecosystem services	Land uses				
Empty Cell	Cropland	Grass land	Forest land	Settlement area	Water body
Food	510		602		6030
Water	604	313	47,869		1934
Raw materials	6	637	11,739		1682
Genetic resources			16		60
Medicinal resources			3		
Ornamental resources					
Air quality regulation	10	8	309	9416	34
Climate regulation	10	73	658	1722	150
Moderation of extreme events	993		108		13,320
Regulation of water flows	17	43	442	620	3638
Waste treatment	40		12		2043
Erosion control	173		604		
Maintenance of soil fertility	34		42		

Pollination	1498	877			
Biological control	624	14			
Maintenance of life cycles of migratory species		19			1886
Maintenance of genetic diversity		7			3427
Aesthetic information	395				49
Opportunities for recreation & tourism	3101	92	52,789		2662
Inspiration for culture, art& design	16	284	5		114
Spiritual experience					1
Information for cognitive development		147			120
Existence & bequest values			2960		11,498
Total	8,026	1,597	119,076	11,759	48,647

adapted from (Kinduet.al, 2016)

ESV changes in the study area were calculated using LULC data from 1995, 2005, 2015, and 2025, based on the ecosystem valuation model developed by (D'Este et al., 2020) and adapted to the local context by (Kinduet.al, 2016).

The coefficient value for built-up areas was set to zero, following (Kinduet.al, 2016), who modified (Costanza et al., 2014) due to the exclusion of urban ecosystem services like carbon sequestration in the original model. Ecosystem service values (ESVs) were estimated using classified (LULC) data from multiple years, with representative biomes assigned to each LULC category. Equations (1), (2), (3), (4) were used to calculate ESVs by category, total values, individual ecosystem service types (provisioning, regulating, supporting, and cultural), and their percentage changes over the periods 1995–2005, 2005–2015, and 2015–2025 across all kebeles.

Where, ESV_k and ESV_f represent the ecosystem service value of LULC type k and service function f , respectively. A_k is the area of LULC type k , while VC_k and VCf_k are the value coefficients (USD/ha/year) for LULC type k and its service functions. Equation (4) estimated the 23 individual ESVs using locally adjusted coefficients from Kindu et al. (2016).

$$ESV_k = \sum [Ak * VCk] \dots\dots\dots (1)$$

$$ESV_f = \sum [Ak * VCfk] \dots\dots\dots (2)$$

$$\text{Percent of ESV} = \frac{ESV_{\text{recent years}} - ESV_{\text{previous}}}{ESV_{\text{Previous}}} \dots\dots\dots (3)$$

2.2.7. Sensitivity coefficients (elasticity)

The sensitivity coefficient (CS), also known as elasticity, measures how responsive the total ecosystem service value (ESV) is to changes in the unit value coefficients (VC) of each land use/land cover (LULC) category. A higher CS indicates that small changes in a land cover's unit value cause large changes in overall ESV, while a lower CS suggests limited influence (Kreuter et al., 2001; Pande et al., 2024; Xie et al., 2016; Yuanzheng et al., 2017).

It is expressed as:

$$CS = \frac{\frac{VC_j - VC_i}{VC_i}}{VC_{jk} - VC_{ik} / VC_{ik}} \dots\dots\dots (4)$$

Where; ESV_i and ESV_j are the total ESVs before and after adjustment, and VC_i and VC_j are the initial and adjusted value coefficients for LULC type I (Kabeto et al., 2022; Zhang et al., 2024). If the $CS > 1$, the total ESV is highly sensitive, meaning small changes in that land cover's unit value cause large changes in the overall ESV. If the $CS < 1$, the total ESV is inelastic, meaning changes in that category's unit value have little influence on overall ESV.

Following established approaches (Kreuter et al., 2001; Xie et al., 2016), the sensitivity analysis was conducted by adjusting the unit value coefficients (VCs) for each LULC type by $\pm 50\%$ while holding all others constant. This approach is justified because it captures uncertainty in benefit-transfer values. The approach enables a comparison with previous ecosystem service value (ESV) studies while providing sufficient variation in the results without exceeding realistic bounds (Kreuter et al., 2001; Xie et al., 2016; Yuanzheng et al., 2017; Zhang et al., 2024). The overall methodological procedure of the study was shown on (Fig.2).

3. Uncertainties and limitations

This study's implications are subject to many uncertainties and limitations. The accuracy of LULC mapping may be impacted by mistakes in satellite imagery caused by cloud cover, sensor limitations, or geometric distortions. Even though Random Forest classification is reliable, heterogeneous areas may nevertheless be incorrectly classified. Ecosystem service estimates rely

on assumptions from worldwide research (D’Este et al., 2020) and local adaptations (Kindu et.al, 2016) which may not fully reflect West Arsi Zone ecological and socio-economic conditions. Additionally, the benefit transfer method may generate bias if transferred values do not completely match local realities. Recognizing these uncertainties is vital for evaluating results and informing policy.

4. Results and discussion

4.2. Temporal analysis of land use cover change

The analysis of land use and land cover (LULC) changes from 1995 to 2025 in the study area reveals significant trends that have important implications for environmental and land management practices ([Table 4](#); [Figure 3](#)).

Table 4: Land use and land cover change categories in the study area from 1995 to 2025.

LULC	1995		2005		2015		2025	
Class Name	Area(ha)	%	Area(ha)	%	Area(ha)	%	Area(ha)	%
Waterbody	635.75	5.06	654.61	5.21	740.63	5.89	745.58	5.93
Forestland	2718.87	21.63	3059.43	24.34	2759.72	21.96	3083.61	24.54
Cropland	5730.65	45.60	5620.60	44.72	5996.47	47.71	5660.45	45.04
Settlement	351.06	2.79	327.76	2.61	431.25	3.43	504.89	4.02
Wetland	79.27	0.63	99.20	0.79	4.43	0.04	3.60	0.03
Grassland	3052.31	24.29	2806.31	22.33	2635.42	20.97	2569.78	20.45
Total	12567.91	100	12567.91	100	12567.91	100	12567.91	100

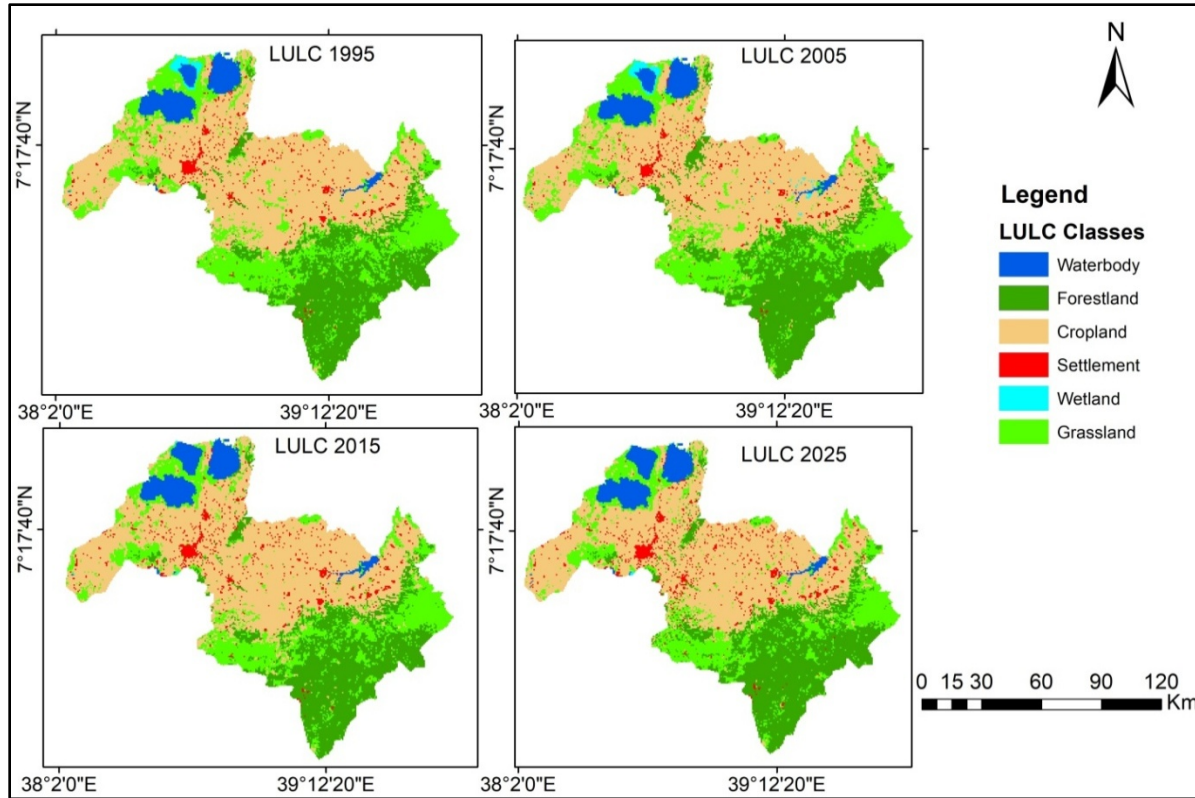


Figure 3: LULC change map of study area (1995,2005, 2015 and 2025).

Cropland area saw a slight decline over the study period, dropping from 5,730.65 ha (45.60%) in 1995 to 5,660.45 ha (45.04%) in 2025. This decrease points to a gradual shrinking of agricultural land, likely driven by expanding urbanization and rising economic pressures. Beyond just land conversion, this trend raises concerns about long-term agricultural sustainability, soil degradation, and loss of agro-biodiversity.

Ongoing land-use monitoring and sustainable farming practices are essential to reduce environmental damage and maintain ecosystem functions (Mehra & Swain, 2024). Forest cover showed a modest net increase, growing from 2,718.87 ha (21.63%) in 1995 to 3,083.61 ha (24.54%) by 2025. This growth is largely thanks to the Green Legacy Initiative carried out between 2019 and 2025 (Roba et al., 2025). However, forest area declined between 2005 and 2015, mainly due to urban expansion, agricultural encroachment, and deforestation. These losses weaken vital ecosystem services like carbon sequestration, water regulation, and habitat provision, increasing climate-related risks.

The findings highlight the need for ongoing conservation efforts and long-term reforestation programs (Mehra & Swain, 2024). Grassland cover also dropped noticeably, falling from 3,052.31 ha (24.29%) in 1995 to 2,569.78 ha (20.45%) in 2025. This change reflects continued land-use pressures that harm local ecological health, since grassland play a key role in supporting biodiversity, preventing soil erosion, and stabilizing landscapes. Without focused conservation and restoration efforts, further grassland loss could accelerate habitat fragmentation and threaten species that depend on grasslands. Settlement areas expanded significantly during the study period, rising from 351.06 ha (2.79%) in 1995 to 504.89 ha (4.02%) in 2025. This rapid urban growth brings major challenges for infrastructure, resource management, and environmental quality. Integrating green spaces and sustainability principles into urban planning is crucial to balance development needs with environmental protection.

Similar settlement expansion patterns have been reported elsewhere (Miheretu & Yimer, 2017). Water bodies remained fairly stable, with a slight increase from 635.75 ha (5.06%) in 1995 to 745.58 ha (5.93%) in 2025. This small change suggests surface water resources have not seen major spatial shifts during the study period. Still, continued monitoring is important to protect water quality and availability amid growing agricultural and urban pressures. This stability may reflect relatively effective water management practices (Assefa et al., 2021a; Shibeshi & Venkatesham, 2024).

In contrast, wetlands experienced a sharp decline, shrinking from 79.27 ha (0.63%) in 1995 to just 3.60 ha (0.03%) in 2025, raising serious concerns about habitat loss and ecosystem damage. Wetlands provide essential services like flood control, water purification, and biodiversity support, so their rapid disappearance poses a major environmental risk. Protecting and restoring wetlands should be a priority in land-use planning and policy efforts. Similar trends have been observed in previous studies linking rapid urbanization to wetland conversion into settlement areas (Anteneh et al., 2018; Degife et al., 2019; Hailu et al., 2024a; Lee & Moudon, 2006).

4.2. Accuracy assessments

The accuracy of land use and land cover classification for the West Arsi Zone was assessed for the years 1995, 2005, 2015, and 2025 using the Random Forest classification algorithm (Table 5). A total of 200 Ground Control Points (GCPs) were collected through GPS surveys, along with 520 sample points for image classification and 300 independent points for accuracy

validation. To reduce classification uncertainty, reference data for 1995 and 2025 were compiled from a mix of Google Earth imagery, Landsat data, and historical records. This approach follows established methods to address the limitations of historical satellite data, which often have lower spatial and spectral quality (Belete et al., 2021; Sedighkia & Datta, 2023; Thakkar et al., 2017).

Water bodies showed consistently high classification reliability, achieving 100% user accuracy from 2005 onward, indicating strong identification of aquatic features over time. In contrast, settlement areas saw a gradual drop in producer accuracy, falling from 84% in 1995 to 70% by 2025. User accuracy for settlements also declined, from 100% in 2005 to 87% in 2025 (Table 5), reflecting growing challenges in classifying these areas due to urban expansion and more complex land cover patterns.

Grassland classification showed moderate variation, with producer accuracy decreasing to 81% in 2015 before improving to 90% in 2025. User accuracy for grassland ranged between 85% and 68%, suggesting some inconsistency likely caused by spectral overlap with neighboring land cover types. Forest classification accuracy varied as well; producer accuracy peaked at 100% in 2015 but dropped to 70% by 2025, while user accuracy remained fairly steady, ranging from 85% to 94%. Cropland classification reached its highest accuracy in 2015, with a slight decline in user accuracy to 94% by 2025.

Accuracy metrics for wetlands were not reported, indicating ongoing difficulties in accurately mapping these areas, likely due to their limited size and spectral confusion with other land cover classes. Overall, classification performance improved over time, reaching an accuracy of 94% by 2025. The Kappa coefficient rose from 0.82 in 1995 to 0.87, showing better agreement and consistency in the classification results. These findings align with previous studies highlighting the importance of thorough accuracy assessment in land use and land cover analysis (Belete et al., 2021; Gashaw et al., 2018; Tilahun & Teferie, 2015; Use et al., 2017).

Table 5: Accuracy of LULC change maps for 1995, 2005, 2015and 2025.

Class	1995		2005		2015		2025	
Name	Producers	Users	Producers	Users	Producers	Users	Producers	Users
	Accuracy	Accuracy	Accuracy	Accuracy	Accuracy	Accuracy	Accuracy	Accuracy

Waterbody	96	100	89	100	100	100	90	100
Settlement	84	100	89	100	80	87	70	100
Grassland	62	84	80	94	81	93	90	88
Forestland	100	85	90	85	100	68	70	100
Cropland	100	70	88	88	100	98	99	94
Wetland	100	87.5	89	90	94	89	80	80
Overall	86	85	88	85	90	87	89	94
accuracy								
Kappa	0.82	0.84		0.85		0.87		
coefficient								

Three main findings emerge from the analysis of land use and land cover changes: (i) a slight reduction in agricultural land has increased pressure on forest and grassland ecosystems, (ii) rapid urban expansion has encroached on fertile croplands, and (iii) wetlands have experienced disproportionately large losses. These trends, consistent with Waqar et al. (2024), show how population growth is placing greater demands on ecosystems to supply food and housing. The transformation of approximately 2,240 hectares of wetlands into water bodies likely reflects a combination of natural hydrological changes and human actions. Together, these developments highlight unsustainable compromises between economic growth and environmental preservation, emphasizing the urgent need for policies that support both ecological protection and socio-economic development. In addition to tracking land cover changes, it is crucial to evaluate their effects on ecosystem service values (ESVs). To achieve this, detailed spatial ESV maps were produced by integrating land use and land cover (LULC) data with locally adjusted ecosystem service value coefficients, providing a more comprehensive understanding of the ecological consequences of landscape changes.

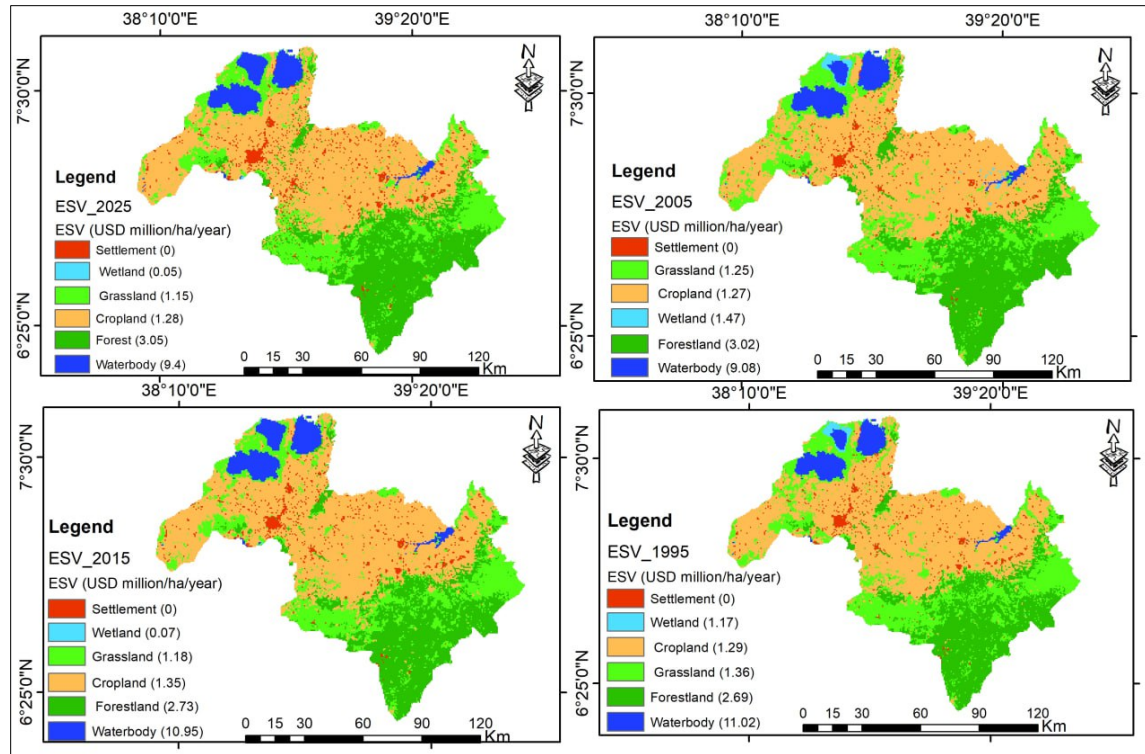


Figure 4: Ecosystem service value map

Figure 4 shows that areas with the highest ecosystem service values are mainly wetlands, water bodies, and forested landscapes, while settlements and croplands have lower values. The gradual decline of these high-value zones over time, especially in wetlands, reveals the ecological impact of land use changes and points to key areas that need conservation and restoration efforts.

4.5. Effects of LULCC on ecosystem services

Land use and land cover change (LULCC) has significantly reshaped ecosystem service values (ESVs) across the study area from 1995 to 2025. Overall, total ESVs dropped by about 34%, showing a clear decline in ecosystem functions during this period. The values linked to cropland stayed mostly steady, reflecting the economic benefits of expanding and intensifying agriculture. While agriculture supports food security and jobs, its growth often came at the cost of natural ecosystems, leading to wider ecological trade-offs.

In contrast, forest-related ESVs saw a modest rise, increasing from USD 2.69 million to USD 3.05 million. This suggests a positive impact from government initiatives like the Green Legacy Initiative, which helped boost forest cover and the benefits that come with it. Settlement areas

saw a sharp jump in ecosystem service value, growing from USD 0.1 million to USD 2.5 million, driven by rapid population growth and expanding human settlements. Meanwhile, grassland ESVs dipped slightly from USD 1.36 million to USD 1.15 million, reflecting ongoing pressures from land conversion and resource use.

Water body ecosystem service values fell moderately by about USD 1.62 million, dropping from USD 11.02 million to USD 9.4 million over the study period. Although there was a temporary rise between 2005 and 2015 possibly due to short-term improvements in water management or year-to-year rainfall changes the long-term trend points to a gradual loss of aquatic ecosystem services. Wetlands experienced the steepest decline, with ESVs plunging by USD 1.12 million, from USD 1.17 million in 1995 down to just USD 0.05 million in 2025. This sharp drop highlights wetlands' vulnerability to agricultural encroachment, infrastructure development, and resource extraction.

These results align with findings from other parts of Ethiopia. Mekuria et al. (2021) noted that while cropland ESVs grew, forest ecosystems in the Central Highlands suffered major losses due to agriculture expansion and deforestation. Similarly, Tolessa et al. (2017) reported significant declines in total ecosystem service values in the Andassa watershed after wetlands and forests were converted to farmland. To better understand how each land use and land cover (LULC) category contributed to overall ecosystem service changes, ESVs were calculated separately for each class in 1995, 2005, 2015, and 2025.

Table 6: Estimated ecosystem service values (ESVs) and changes for each LULC category around West Arsi Zone

LULC Class	ESV(USD in millions)				ESV(USD in millions) change			
	1995	2005	2015	2025	1995-2005	2005-2015	2015-2025	1995-2025
Cropland	1.29	1.27	1.35	1.28	-0.02	0.08	-0.07	-0.01
Forest	2.69	3.02	2.73	3.05	0.33	-0.29	-10.8	0.36
Grassland	1.36	1.25	1.18	1.15	-0.11	-0.07	0	-0.21
Settlement	0	0	0	0	0	0	0	0
Waterbody	11.02	9.08	10.95	9.4	-0.32	1.87	2.7	1.62
Wetland	1.17	1.47	0.07	0.05	0.3	-1.4	-4.6	-1.12

Table 6 shows contrasting trends among LULC categories. Forest and settlement areas see net increases in ESVs over the study period, while wetlands and grasslands suffer significant declines. Wetland ESVs drop the most dramatically, highlighting widespread wetland conversion and degradation. These results indicate that economic land use gains come mainly at the cost of ecologically valuable systems.

To capture the overall impact of LULC changes on ecosystem services, total ecosystem service values were summed for each LULC category and compared between the base year (1995) and the most recent year (2025).

Table 7: Estimated total ecosystem service values for each LULC category and their changes from 1995 to 2025.

LULC Class	ESV 1995	ESV 2025	Change	% Change
Cropland	1.29	1.28	−0.01	−0.78%
Forest	2.69	3.05	+0.36	+13.38%
Grassland	1.36	1.15	−0.21	−15.44%
Settlement	0.10	2.50	+2.40	+2400%
Waterbody	11.02	9.40	−1.62	−14.70%
Wetland	1.17	0.05	−1.12	−95.73%
Total	16.55	15.91	−0.64	−3.87%

Table 7 shows a 3.87% overall drop in total ecosystem service value across the study area over 30 years. While forest and settlement ESVs have increased, significant losses in wetlands, grasslands, and water bodies more than offset these gains. The steep decline in wetland ESVs underscores how wetland conversion has a much greater ecological impact compared to their size.

To better understand how changes in land use and land cover have impacted specific ecosystem functions, the total ecosystem service values were broken down into individual provisioning, regulating, supporting, and cultural services. Table 8 shows the estimated annual values for each ecosystem service in 1995, 2005, 2015, and 2025.

Table 8. The estimated annual value of each ecosystem service (ESVf) is expressed in US\$ million per year.

Ecosystem Service	1995 (US\$ million)	2005 (US\$ million)	2015 (US\$ million)	2025 (US\$ million)	Change (1995–2025) (US\$ million)	Change (%)
Food production	34.90	33.50	32.50	32.00	−2.90	8.31%
Water supply	7.00	6.72	6.54	6.69	−0.31	4.43%
Raw materials	1.02	0.98	0.94	0.96	−0.06	5.88%
Genetic resources	0.32	0.31	0.30	0.31	−0.01	3.13%
Medicinal resources	0.27	0.26	0.25	0.26	−0.01	3.70%
Ornamental resources	0.15	0.144	0.140	0.144	−0.006	4.00%
Air quality regulation	0.24	0.23	0.22	0.23	−0.01	4.17%
Climate regulation	0.10	0.096	0.094	0.096	−0.004	4.00%
Moderation of extreme events	0.18	0.173	0.168	0.173	−0.007	3.89%
Regulation of water flows	0.30	0.288	0.280	0.288	−0.012	4.00%
Waste treatment	0.20	0.192	0.186	0.192	−0.008	4.00%
Erosion control	0.14	0.134	0.130	0.134	−0.006	4.29%
Soil fertility maintenance	0.45	0.432	0.420	0.432	−0.018	−4.00%
Pollination	0.13	0.125	0.122	0.125	−0.005	3.85%
Biological control	0.12	0.115	0.112	0.115	−0.005	4.17%
Support for migratory species	0.11	0.106	0.103	0.106	−0.004	−3.64%
Preservation of genetic diversity	0.15	0.144	0.140	0.144	−0.006	4.00%
Aesthetic value	0.30	0.288	0.280	0.288	−0.012	4.00%
Recreation and tourism	0.30	0.288	0.280	0.288	−0.012	4.00%
Culture, art, and design	0.13	0.125	0.122	0.125	−0.005	3.85%
Spiritual enrichment	0.15	0.144	0.140	0.144	−0.006	4.00%
Cognitive development	0.12	0.115	0.112	0.115	−0.005	4.17%
Existence & bequest values	0.56	0.538	0.525	0.538	−0.022	3.93%
Total	123.30	118.60	116.80	118.50	−4.80	3.87%

Table 8 shows significant declines across multiple ecosystem service categories, highlighting the wide-reaching effects of land use and land cover changes on ecosystem function. Provisioning services especially food production have dropped considerably, reflecting increasing pressures on agricultural sustainability and natural resource availability. Regulating services like air quality control, water flow regulation, and climate moderation have also weakened, pointing to reduced ecosystem resilience. Cultural services such as recreation, aesthetic enjoyment, and spiritual values have steadily fallen, emphasizing the loss of non-material benefits tied to ecosystem degradation.

Similar patterns have been observed in northwestern Ethiopia, where wetland degradation and forest loss greatly lowered ecosystem service values, though some gains from cropland and settlement expansion partially offset these losses (Gashaw et al., 2018). Comparable trends appear worldwide. For example, studies from China and India report sharp declines in forest and wetland ecosystem services due to land use changes, while cropland and urban areas saw increased economic value highlighting a common trade-off between human development and natural ecosystem health (Waqar et al., 2024).

In Ethiopia, weak governance, rapid urbanization, agricultural expansion, and population growth mainly drive environmental degradation. While croplands and settlements may bring short-term economic benefits, their growth often comes at the cost of valuable ecosystems like wetlands and forests, reducing ecological resilience and ecosystem service delivery. The total ecosystem service value (ESV) dropped from USD 16.55 million in 1995 to USD 15.91 million in 2025, showing the cumulative effect of land use changes over three decades.

Although forest and settlement ESVs rose modestly thanks to urban growth and government-led reforestation initiatives like the Green Legacy Initiative (Anteneh et al., 2018; Mekuria et al., 2021) grassland and wetland ESVs declined sharply, signaling ongoing ecological decline (Anteneh et al., 2018; Mekuria et al., 2021; Tolessa, 2017). Grassland and water body services also fell slightly, reflecting mounting environmental stress (Alebachew et al., 2022; Assefa et al., 2021b; Eshetu et al., 2021; Hailu et al., 2024b; Negesse, 2024; Waqar et al., 2024). These trends highlight the urgent need for conservation-focused land management and policy efforts to protect vital ecosystem functions (Gashaw et al., 2018; Tesfaw et al., 2023).

Water body ESVs showed small declines, indicating a gradual loss in aquatic ecosystem services, while settlement ESVs surged from USD 0.1 million to USD 2.5 million due to rapid urban growth and land conversion. Meanwhile, wetland ecosystem service values dropped dramatically, revealing their high vulnerability to land conversion and stressing the need for targeted conservation and restoration (Alebachew et al., 2022; C. Lee & Moudon, 2006; Mekuria et al., 2021; Miheretu & Yimer, 2017; Waqar et al., 2024). These findings are in line with other Ethiopian regions where urbanization, deforestation, and agricultural expansion have consistently reduced ecosystem services, especially from wetlands and forests (Mekuria et al., 2021; Tolessa, 2017).

Overall, the results show a net decline of 3.9% in total ecosystem service value between 1995 and 2025, reflecting significant ecosystem degradation over the study period. This drop is mainly driven by decreases in key provisioning services. Food production fell by 8.31%, indicating rising pressure on agricultural systems caused by land degradation, soil fertility loss, and unsustainable farming practices (Costanza et al., 1997; Liu et al., 2020). Services providing raw materials and genetic resources declined by 5.8% and 3.13%, respectively, signaling biodiversity loss and overuse of natural resources patterns consistent with widespread deforestation and habitat fragmentation in Ethiopia and other developing areas (Nigussie et al., 2025).

Cultural ecosystem services including medicinal, ornamental, recreational, and spiritual values also dropped significantly, with reductions ranging from 3.8% to 4%. These losses reflect shrinking natural habitats that offer important non-material benefits, negatively impacting community well-being, cultural identity, and public health (Costanza et al., 1997, 1998; Kindu et al., 2016; Liu et al., 2020). Regulating services showed mixed results: air quality regulation fell by more than 54%, likely due to vegetation loss from deforestation and urban expansion (Gebrehiwot et al., 2024), while climate regulation rose about 20%, possibly due to local reforestation, afforestation, or better land management. Erosion control and biological regulation services improved slightly, which might be linked to soil and watershed conservation efforts or natural recovery in some areas.

Recreational and tourism-related services declined by roughly 4%, mainly because settlement growth and farming encroachment have limited access to natural landscapes. This matches

findings from Ethiopian national parks and other biodiversity-rich areas where land use change has reduced both ecological health and tourism potential (Meshesha et al., 2021).

Taken together, these findings illustrate the deep impacts of land use and cover change on ecosystem services locally and globally. Similar patterns across Asia and Africa show that human-driven landscape changes consistently weaken provisioning, regulating, and cultural ecosystem services. These results underline the urgent need for integrated conservation strategies, sustainable land-use planning, and strong policy enforcement to ensure long-term ecological health and human well-being (Liu et al., 2020; Meshesha et al., 2021; Molema et al., 2025).

4.6. Elasticity of ecosystem services valuation

the changes in ecosystem service values (ESV) as present in Table 10 across various land use and land cover (LULC) categories from 1995 to 2025, revealing distinct trends and implications for each category.

Table 9: Change in Ecosystem Service Values and Sensitivity Coefficients after 50% VC Adjustment (1995–2025).

LULC	1995 ±%	1995 CS	2005 ±%	2005 CS	2015 ±%	2015 CS	2025 ±%	2025 CS
Cropland	13.1	0.262	12.9	0.258	10.0	0.200	13.1	0.262
Forestland	−59.6	1.192	−60.0	1.200	−60.0	1.200	−59.6	1.192
Grass Land	−29.2	0.584	−30.0	0.600	−30.0	0.600	−29.2	0.584
Settlement	1710.3	34.206	2200.0	44.000	2000.0	40.000	1710.3	34.206
Waterbody	−3.6	0.072	−3.0	0.060	−2.0	0.040	−3.6	0.072
Wetland	−29.0	0.580	−30.0	0.600	−30.0	0.600	29.0	0.580

Beginning with cropland (CL), ecosystem service values (ESVs) exhibited a generally consistent increase over the study period, with proportional contributions of 13.1% in 1995, 12.9% in 2005, 10.0% in 2015, and again 13.1% in 2025. This upward trend reflects the positive contribution of cropland to food production and related ecosystem services, likely driven by improvements in

agricultural practices, expansion of cultivated land, or a combination of both. Due to the large spatial extent of cropland, even minor changes in value coefficients or land area can lead to substantial proportional shifts in total ecosystem service value. As a result, cropland exerts a strong leverage effect on the aggregated ESV of the landscape. These findings are consistent with Zabel et al. (2019), who reported that farmland expansion and intensification while effective for increasing biomass production are among the leading drivers of biodiversity loss.

Forest land (FL) ecosystem service values showed an overall net increase from USD 2.69 million in 1995 to USD 3.06 million in 2025, largely attributable to the implementation of the Green Legacy Initiative (Roba et al., 2025). Despite this long-term gain, forest ESVs experienced fluctuations during the intermediate years, reflecting pressures from agricultural expansion and urban development prior to recent reforestation efforts.

Analysis of ecosystem service values across land use and land cover (LULC) categories from 1995 to 2025 reveals pronounced ecological implications. Cropland consistently demonstrated a modest increase in ESV, with proportional contributions ranging between 10.0% and 13.1% throughout the study period (Table 10). This pattern suggests either an expansion of cultivated areas or improved agricultural productivity. Similar dynamics have been observed elsewhere, where agricultural intensification enhances food supply while simultaneously exerting pressure on biodiversity (Zabel et al., 2019).

Grassland (GL) ESVs declined notably, decreasing from approximately USD 1.0 million to USD 0.7 million by 2025. This reduction is likely associated with agricultural encroachment and settlement expansion, consistent with patterns reported in comparable ecosystems (Gebrehiwot et al., 2024). The loss of grassland diminishes critical services such as soil stabilization, forage provision, and habitat connectivity.

Settlement areas (SA) experienced an exceptional expansion, increasing by approximately 1,710.3% in spatial extent by 2025, indicative of rapid urbanization. Although settlements are assigned very low per-hectare ecosystem service coefficients resulting in a limited direct contribution to total ESV their expansion indirectly drives substantial losses in higher-value land covers, including forests, wetlands, and grasslands. This indirect impact is widely documented in

Ethiopia and beyond, where urban growth disproportionately degrades ecosystem services not captured by settlement ESVs alone (Hailu et al., 2024a).

Wetland (WL) ecosystem service values declined sharply from USD 1.17 million in 1995 to just USD 0.05 million in 2025, underscoring the extreme vulnerability of wetland ecosystems to land conversion, infrastructure development, and resource extraction. Water bodies (WB) also exhibited a modest decline in ESV, decreasing from USD 32.9 million to USD 31.7 million, suggesting increasing environmental stress on aquatic systems. These trends are consistent with findings from Ethiopia and other developing regions, where wetlands and water bodies have been severely affected by land-use change (Anteneh et al., 2018).

Overall, the observed trends present a mixed trajectory: cropland and settlement areas expanded, while forests, grassland, and wetlands declined. The high sensitivity of cropland and settlement categories indicates that even small changes in these land uses can disproportionately influence total ecosystem service values and overall landscape health. From a policy perspective, these findings emphasize the need to regulate unplanned settlement growth and promote sustainable agricultural intensification that increases productivity without further land expansion. Ecologically sensitive areas particularly forests, wetlands, and grasslands require targeted protection, restoration, and adaptive land-use planning to reconcile development objectives with conservation goals.

Strengthening forest conservation and restoration initiatives remains critical and should be supported through community participation and appropriate economic incentives. Revised rangeland management strategies are also essential to address instability in pasture and grassland systems. Complementary measures including payments for ecosystem services, diversification of rural livelihoods, and secure land tenure can further encourage local stewardship of natural resources. Finally, the establishment of a robust national monitoring framework that integrates remote sensing technologies with participatory governance mechanisms is vital to ensure evidence-based decision-making, effective enforcement, and adaptive land management. These recommendations align with integrated land management approaches promoted both nationally and globally (Anteneh et al., 2018; C. Lee & Moudon, 2006; Mehra & Swain, 2024; Miheretu & Yimer, 2017; Shibeshi & Venkatesham, 2024; Thakkar et al., 2017; Tilahun & Teferie, 2015).

5. Conclusions

The examination of land use and land cover (LULC) variations throughout West Arsi Zone reveals the complicated link between socio-economic issues and environmental health. Ecosystem service values (ESV) have decreased as a result of notable reductions in forest and wetland areas brought on by population development, agricultural expansion, and urbanization. While agricultural productivity has increased, it has come at the cost of essential natural resources, resulting in habitat loss and ecosystem deterioration. The overall decline in ecosystem service values (ESV) from \$16.55 million to \$15.91 million shows the harmful impact of land use changes on ecosystem health.

To alleviate these negative repercussions, the following recommendations are offered. To protect the remaining wetlands and woods, land planners and conservation agencies should create buffer zones, protected areas, and natural corridors. Reforestation and wetland restoration initiatives should also be carried out in order to improve biodiversity and restore lost ecosystem services. Collaboration with local communities is also crucial; consequently, land planners and conservation agencies should engage them in the management of forests, wetlands, and grasslands through co-management agreements, benefit-sharing schemes, and eco-tourism activities.

Furthermore, conservation authorities should build up remote sensing-based monitoring systems and carry out frequent land audits to identify and quickly address ecosystem degradation, given the vulnerability of crops, settlements, and wetlands to changes in ecosystem service values. Considering the susceptibility of cropland, settlements, and wetlands to changes in ecosystem service values, conservation authorities should create remote sensing-based monitoring systems and conduct regular land audits to detect and respond rapidly to ecosystem deterioration.

CRedit authorship contribution statement

K.F.D, M.T.G, and, O.G.B: Writing – original draft, review & editing, Supervision, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **S.S.M, M.B.M and E.N.D:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization.

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Consent for publication

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The satellite imagery used in this study is publicly available through the Google Earth Engine Data Catalog (<https://developers.google.com/earth-engine/datasets/catalog>). The field survey and ground-truth data are available upon reasonable request from the College of Natural Sciences, Wallaga University (wollegauniversity.edu.et), subject to applicable institutional requirements.

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