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Impact of urban expansion on ecosystem service values in Debre Markos town and surrounding Peri-Urban areas, Northwestern Ethiopia, using geospatial technology and remote sensing

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Abstract. Urban expansion in peri-urban areas significantly impacts ecosystem service functions by converting land use/land cover (LULC) types to built-up areas. LULC changes resulting from urban expansion can affect ecosystem service functions. Therefore, the objective of this study was to assess the impact of urban expansion on ecosystem service values (ESV) in the town of Debre Markos and its peri-urban areas. To this end, the spatial and temporal dynamics of LULC were analysed using Landsat 7 and 8 (ETM+ and OLI) satellite images from the last 20 years. ESVs were generated for each LULC category using ERDAS IMAGINE 2015 and ArcGIS 10.6. Based on the study results, the urban settlement in the study area increased by 1360 ha (285.94%), while the area of other LULC types decreased. As a result of urban expansion in the study area over the last 20 years (2004–2024), there has been a 19.33% decline in total ESVs. This indicates that the study area has suffered a loss of USD 0.683 million/ha/year due to LULC change caused by urban expansion. The LULC changes resulting from urbanisation in the area have therefore negatively impacted ecosystem service functions over the last 20 years. Consequently, proper planning of urban expansion and conservation of natural resources (inland wetlands and forests, including plantations) are necessary for sustainable ecosystem management in the area.

Keywords: ecosystem, ESVs coefficients, LULC changes, natural resources depletion, urbanization.

1. Introduction

Urban expansion (urbanization) is a transformation of various land-use land cover types into urban settlements or built up areas (Bai et al., 2012; He et al., 2021). This process involves the concentration of which the population, economy, and other factors in urban centers, leading to the extensive consumption of natural resources and, inevitably, the substantial mass discharge of wastes (Cheng et al., 2019). Recently, urbanization is increased at unexpected rate, and globally, the urban land area coverage is projected to increase by 1.2 million km^2 by 2030 (Seto et al., 2012).

Urbanization serves as an engine for human and social development, deriving social transformation and center of innovation for improved living standards (Cheng et al., 2019). However, this rapid and unplanned urbanization comes with the growth of complex environmental trade-offs (Ricci, 2012). While urban centers promote stimulate economic and social development, they also simultaneously accelerate natural resource depletion, environmental pollution and other ecological stress (He et al., 2021). This is because urban areas often expanded with the expense of natural and semi natural ecosystems leading to biodiversity and habitat degradation. The natural and semi-natural ecosystems within the urban regions are under threat of loss and degradation (Sharma et al., 2019). The modification and transformation of natural ecosystems into semi-natural and artificial ecosystems, disrupts ecological balance reducing ecosystem functions such as carbon sequestration, hydrological regulation and habitat and biodiversity conservation (Kang et al., 2023). Moreover the expansion of urban settlements beyond their administrative boundaries (sprawl) in peri-urban ecosystems increasingly the conversion of natural environments in to impervious surfaces which intensify urban flooding risks and urban heat islands and deterioration of soil fertility (He et al., 2021). Thus urban expansion in today contributes to the reduction or degradation of ecosystem services and alteration of ecosystem processes, functions, and services (Cheng et al., 2019; Getahun, 2018; Kindu et al., 2016). This emphasizes the crucial need for urban growth strategies that complement the development of urban with the sustainability of ecosystem (Getahun, 2018; Kindu et al., 2016; Zhong et al., 2022). Hence, innovative urban planning and implanting approaches to nature-based solutions are therefore essential to offset these impacts through implementing urban green infrastructures, sustainable drainage system and development of urban green spaces to restore the lost ecosystem services.

In order to improve the ecological environment and realize sustainable development of mankind, it is necessary to carry out an assessment of the value of ecosystem services in relation of land use land cover change (LULCC) and to build bridges between the market value of ecosystem services and ecological systems (Troy & Wilson, 2006). The conversion of natural ecosystem causes reductions in many other ESs, especially those that support biodiversity. This process will cause further reductions in natural habitats and a more significant loss of ESs (Evers et al., 2018; Hasan et al., 2020). More than 60% (15 out of 24) of the ecosystem services are being removed on account of both direct (LULCC, climate change, external inputs) and indirect (science and technology, demographic, economic) factors. Among the factors, LULCC is one of the key indicators of the status of ES changes in targeted areas (Assaye et al., 2024).

To effectively assess and monitor the impacts of urban expansion on ecosystem services of the local environment, time series environmental analysis and quantification of ESVs are essential (Berihun et al., 2021). Ecosystem services (ESs) comprises the direct benefits provided from nature such as food, freshwater, climate, pest control, air quality and as well as the indirect benefits such as soil formation and nutrient cycling (Admasu et al., 2023; Msofe et al., 2020). These include all kinds of ecosystem services, such as the provisioning of food and raw materials; regulation of water and weather conditions; supporting of soil formation, biodiversity stability and cultural services such as recreation, spiritual values, and ecotourism (Assaye et al., 2024; Awoke & Debie, 2023; Costanza et al., 2014; Kindu et al., 2016). As the world population increases the demand for those ecosystem services continued drastically (Sharma et al., 2023). However, the unplanned and rapid urban expansion usually undermines the natural ecosystem capacity to support nature and sustain the provision of these services, threatening the balance of nature and human wellbeing. Therefore, evaluating and quantifying ESVs over time continuously not only provides information how urban sprawl modifies the ecosystem functions, but also provides insights sustainable land use planning and resource conservation strategies (Cheng et al., 2019; Sharma et al., 2023; Zhong et al., 2022). There are different scientific approaches, models and tools used for ecosystem services assessment. Some potential ecosystem service assessment tools and models are used worldwide, such as inVEST, ARIES, SWAT, and others like hedonic pricing method/HPM, travel cost methods/ TCM, stated performance method/SPM, Choice experimental methods/CEM, and Bao game (Gashaw et al., 2018).

Recently, Ethiopia is one of the world countries experienced a rapid urbanization rate, because of prevailing of high rate of rural to urban migration (Assefa et al., 2021). This process results for the over population and high concentration of people settled in the urban areas. The increase of urban population leads to high rate of settlement expansion. To fulfill housing demands there is a high rate of conversion of lands in to build up areas (urban settlements) and resulted for land degradation, reduction of bio-diversity and other environmental problems related with urbanization (Assefa et al., 2021). Ecosystem assessment and environmental sustainability activities in Ethiopia has a short history. After the 1992 Rio conference, the country proclaimed environmental policy and different regulations, agreements, and plans (GTP, CRGE). However, there are some challenges and drawbacks with ecosystem services and sustainable development in Ethiopia (Tamire et al., 2023). Studies have shown that population pressure, widespread agricultural expansion, expansion of settlement, rural poverty, inadequate management of common property resources, and land tenure insecurity due to institutional and policy reforms and demand for fuel wood and construction materials were recognized as the major drivers of LULCC in the country (Negese, 2021)

Recently in Ethiopia, studies have been done in different parts of the country to estimate the changes of ESVs due to LULCC. All these studies indicated that ecosystem services are more rapidly declining from time to time due to LULCC (Mekonnen, 2025). Therefore, studying and quantifying changes in ESVs is an important tool for public awareness and policy making process (Assaye et al., 2024) focusing on the development of knowledge on natural resource capital (Braat & de Groot, 2012) formulating approaches and policies and providing stabilize to conserve the ecosystems that provide the services. As a result, underlined attention in ESVs has progressed rapidly in the scientific communities, international organization and policy decision makers (Ba et al., 2023). But these studies are not enough because of the diversity of the Ethiopian landscape, its biodiversity, LULCC, and the dependency of communities on ecosystems for their livelihood (Wayesa et al., 2022).

Debre Markos town, which is found in Amhara region, Ethiopia. The population number and residential housing demand is rapidly increased from time to time. To solve the problem, the town administration transfers large areas for the residents for residential house construction in the last 20 years (Debere Markos town administration Annual report, 2023). This measurement results for conversion of inland wetland around the town, forest and cultivated land in to build up areas. Therefore, it is crucial to assess the potential impact of urban expansion on multiple ESVs. However, there is no any study conducted in Debre Markos town to evaluate the impacts of rapid urbanization rate on the ecosystem values. Based on the above-mentioned deficiencies, the aim of this study was to evaluate the impact of rapid urbanization on Ecosystem service values in case of in Debre Markos Rego-politant town in the last 20 years.

2. Research Materials and Methods

2.1. Description of the Stud Area

Debre Markos town is one of the Rego-politant cities which is found in Amhara region North- West Addis Ababa with 300 km distance and 265 km from Bahir Dar, the center of Amhara National Regional State. The town is located in between the coordinates of 10°16′ 05” N to 10°23′ 47” N latitude and 37°42′ 0”E to 37°47 43” E longitudes (Fig. 1). Debre Markos town has area coverage of 7829.37 ha and topographically the town lies in the high land area with some undulated with an elevation ranging from 2202 to 2514 meter above the sea

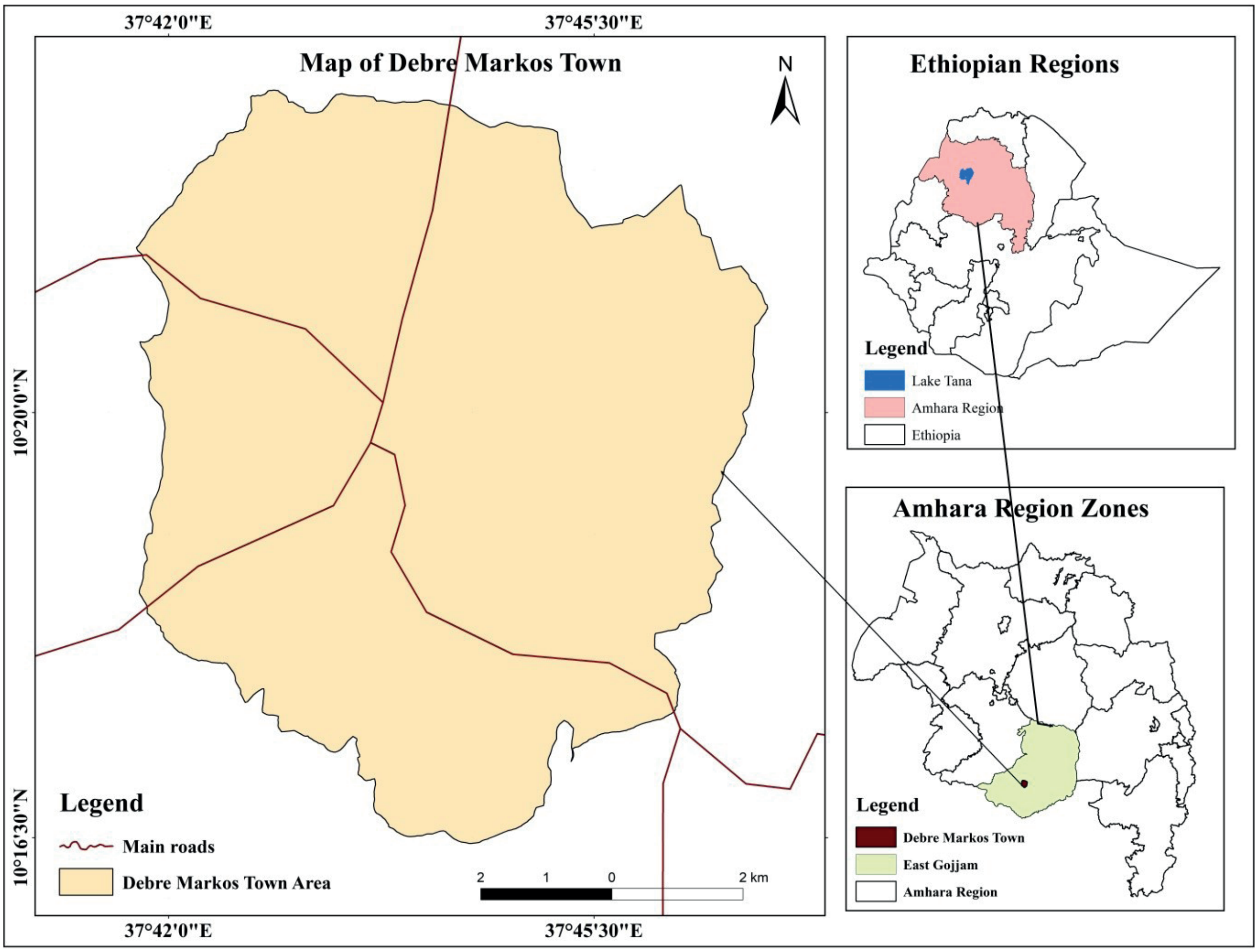

Figure 1. Study Area Map

level. Based on the traditional agro-ecological classification, the town falls in Dega agro-ecology. Its average annual temperature is 18.5°C with annual rainfall of 1380 mm (Kebede, 2019). Recently, Debre Markos town has been rapidly urbanized town, experiencing a significant horizontal expansion and population growth. This leads to the physical expansion of the town leading to conversion of surrounding agricultural land and other ecosystems into urban settlements. Since 2009, the town has expanded by including 13 rural kebeles which surround the town. These kebeles are Wonka from north, Dalgaw, Achira, and Yebo from south east, Chemoga from south, Yebragie from north, Endimata from east and Yemeka from west. From 1998 to 2017 about 5125 hectares of land was included to urban land use, residential took the lion share, indicating that the demand of land for housing was increased (Mekuriaw & Huseyin, 2019). The total population of the town is over According to the municipality's report, the town has over 123,000 from which 51% of the population are females. The main economic actives are small scale farming (peripheral area), and other service providing economic activities (Belay, 2020).

2.2. Data sources and data collection methods

To investigate the trends of urban expansion in the area, time series Landsat satellite images (2004, 2014 and 2024) were accessed and downloaded from (USGS, https://www.usgs.gov/). All the satellite images are downloaded in the dry season (January-February) (Table 1). The preprocessing and band combination of satellite images were done before the main classification using ERDAS IMAGINE 2015 software. The sample training areas for LULC classification and accuracy assessment were collected from Google Earth, field data collection using hand held GPS, interview and from formerly collected secondary data sources.

In addition, to assess the communities' perception towards urban expansion and its impact on ESVs in the study area and to support and validate the findings of image analysis, survey questionnaires was used. From the total households in the study area(4942), 385 sample households were selected by using Kothari formula (Kothari, 2004). From which 274 (71%) are males. The sample respondents were selected from kebeles in the urban expansion peripheral areas (Wonka, Dalgaw, Achira, Chemoga, Endimata, Yebragie and Yebo) based on stratified and systematic sampling techniques from the existing household list data.

Table 1. Satellite images used for LULC change analysis

Year	Satellite (sensor)	Date acquisition	Path/ Row	Spatial resolution
2004	Landsat 7 ETM+	February 2004	169/053	30 m multispectral
2014	Landsat 8 OLI	February 2014	169/053	30 m multispectral
2024	Landsat 8 OLI	February 2024	169/053	30 m multispectral

2.3. Data Analysis Methods

2.3.1. Land use land cover classification and change detection analysis

To detect the spato-temporal dynamics of urban expansion in the last 20 years in the study area, time series satellite image analysis was performed using geospatial technologies. To detect urban change (LULC) change detection image classification was performed by doing image preprocessing, band combination, and sufficient sample training areas from each LULC categories of each year were collected. Based on the sample training areas the satellite images of each year were classified in to 5 LULC categories (built up, forest land, cultivated land, grass land and wetland) using ERDAS IMAGINE software supervised classification, maximum likelihood classification algorism. This classification type requires that researcher select training areas for use as the bases for classification Maximum likelihood classification assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class.

Accuracy assessment of LULC classification (producer, user overall accuracy and Kappa coefficient) were evaluated using reference field data. For image classification about 40-50 ground truth points were collected in the field and Google Earth-Pro images for each LULC category (Mitra et al., 2023). Similarly, for accuracy assessment, 30-40 ground truth data for each LULC type were collected based on their area coverage in the study area. An accuracy assessment of classification image confirmed that the classification image fulfilled the required accuracy with over all accuracy of 85.3%, 87.4% and 91.5% for the 2004, 2014 and 2024 respectively for evaluation and quantification of ecosystem services in the existed LULC. After LULC classification of each year, LULC change detection analysis was done for the last 20 years in the study area to investigate urban expansion and dynamics of other LULCs using the following formula used by (Deka et al., 2019):

$$K = \frac{Ai - AF}{Ai} * 100\%;\ C = \frac{K}{T} \quad (1)$$

where: K is the percentage of change in area of a land use and Ai and Af indicates the initial and final area of the land use considered. C is the land use dynamic degree of a given land use within the study period and T is the time period in years. A LULC change detection matrix were used to illustrate the direction and area of difference in LULC change in the give time (2004–2024).

2.3.2. Estimation of ecosystem service values

Different approaches were developed and used for estimation of ecosystem service valuation. Among the several approaches used for ecosystem service valuation methods are market-based valuation approach that includes market price approach, cost-based approach and production function approach, revealed preference approach that include travel cost method and hedonic pricing, and stated preference approach including contingent valuation method and choice modeling (He et al., 2021; Kindu et al., 2016; Mitra et al., 2023). Scholars have argued how to quantify ecosystem services using consistent, comparable approaches (Nemec & Raudsepp-Hearne, 2013). It has been estimated and quantified at different spatiotemporal scales, in relation to their functions (Nemec & Raudsepp-Hearne, 2013). Different scholars such as (Kindu et al., 2016), developed ecosystem values for 11 biomes. However, the ecosystem values of built-up area were assigned to zero. In this study, to assess the ESVs the area a benefit transfer approach was based on the global value coefficients or modified value coefficients for the target LULC types developed by other scholars, especially in data-deficient areas. The modification of ES value coefficients was performed based on the benefit transfer (BT) approach, which refers to the adaptation of existing values or data from one site to estimate the ESVs of other new similar sites in the absence of the site-specific valuation information (Assefa et al., 2021; Awoke & Debie, 2023; Kindu et al., 2016). The LULC datasets for each year, which are used as proxies for the measurement of the ESVs, was prepared, and the corresponding area in hectares is assessed and presented in a raster in the ArcGIS 10.6 software. In the ESV process, the value coefficients are assigned to each LULC type. The total value of ecosystem services in the study area for each year was calculated as multiplying the area of a given LULC type with the corresponding modified ecosystem service value coefficients that are extracted from weight factors of the ecosystem services per hectare of each biome, which was used by (Assaye et al., 2024; Awoke & Debie, 2023; Kindu et al., 2016; Rotich et al., 2022) as presented in the following table (Table 2) based on the following Equation (2):

$$ESV = \sum (A_{K \times V_{Ck}}) \qquad (2)$$

where ESV = the total estimated ecosystem service value, Ak = the area (ha) and VCk = the value coefficient (US\$ ha^{-1} $year^{-1}$) for LULC type 'k'.

Table 2. LULC categories, equivalent biomes and valuation coefficients used for ecosystem service values in USD/ha^{-1} $year^{-1}$

LULC categories	Biomes	*ESV coefficients in* USD/ha^{-1} year^{-1}
Vegetation	Forest	986.69
Built up	Urban	0.00
Grass land	Grass	293.25
Wetland	Inland wetlands	4204.02
Cultivated land	Crops	225.56

Note: Adopted from (Assefa et al., 2021; Awoke & Debie, 2023; Kindu et al., 2016).

Generally, ecosystem services are categorized as provision service, supporting services, regulation services and cultural services. Therefore, in addition to the above equations the ecosystem values provided by individual functions in the study area and year was calculated using the equation below (Equation 3) as used by Assaye et al. (2024), Assefa et al. (2021), Awoke & Debie (2023) and Kindu et al. (2016), and presented in Table 3.

$$ESVf = \sum (AK * VCfk) \qquad (3)$$

where ESVf is the estimated ecosystem service value of function f, A_k is the area (ha) and VC_{fk} is the value coefficient of the function (US\$ ha^{-1} $year^{-1}$) for LULC category 'k'.

Table 3. LULC categories and their corresponding ecosystem sub-service values (USD/ha^{-1} $year^{-1}$)

Ecosystem service	Biome and ESV coefficients in *USD/ ha^{-1} year^{-1}*				
	Inland wetland	Forest	Grass	Crops	Urban
Provision service					
Water supply	280.73	8.00	117.45		
Food production	171.10	32.00		187.56	
Raw materials	198.54	51.24			
Genetic resource	45.64	41.00			
Medicinal resources	33.10				
Regulating services					
Water regulation	981.84	6.00	3.00		
Waste treatment	1153.95	136.00	87.00		
Erosion control	63.14	245.00	29.00		
Climate regulation	208.36	223.00			
Biological control			23.00	24.00	
Gas regulation	67.35	13.68	7.00		
Disturbance regulation		5.00			
Supporting services					
Nutrient cycling	103.72	184.40	25.00		
Pollination		7.27	1.00	14.00	
Soil formation	48.50	10.00			
Habitat	716.51	17.30			
Cultural services					
Recreation	76.89	4.80			
Culture	54.65	2.00	0.80		
Total	4204.02	986.69	293.25	225.56	0.00

Note: Adopted from: Assefa et al. (2021), Awoke & Debie (2023), He et al. (2021) and Kindu et al., (2016).

The Change in ecosystem services in the study area in the given period was calculated or determined by calculating the differences between the estimated values for each LULC category based on the formula given (Equation 4):

$$\text{Percentage of ESV change} = \left(\frac{ESVt2 - ESVt1}{ESVt1}\right) \times 100 \qquad (4)$$

where ESVt2 (US\$ ha^{-1} $year^{-1}$) = the estimated ecosystem service value in the most recent year, and ESVt1 (US\$ ha^{-1} $year^{-1}$) = the estimated ecosystem service value in the previous year. Positive values suggest an increase in the ESVs, whereas negative values imply a decrease in the ESVs.

2.3.3. Ecosystem service sensitivity analysis

Sometimes the LULC types and the corresponding coefficient values might be correctly matched. Therefore, to check it, making sensitivity analysis is essential to assure the change in percentage of ecosystem services over the given time in the study. The coefficient of each LULC type was adjusted by ±50%. Accordingly, the sensitivity coefficient was calculated using Equation (5):

$$CS = \frac{(ESVj - ESVi1)/\text{ESVi}}{VCjk - VCik/VCik} \quad (5)$$

where, ESV is estimated ecosystem service value, VC is the value coefficient, i and k the initial and adjusted values respectively, and k is the LULC class.

2.3.4. Socio-economic data analysis

The responses from the questionnaires were analyzed using descriptive statistics. Descriptive statistics were used to assess the community perception on the impacts of urban expansion on the ecosystem services.

3. Results and Discussion

3.1. Spatio-temporal trends of LULC change of the study area (2004-2024)

The dynamics of LULC plays a significant effect on the provision of ecosystem service (ES) influencing the function, structure and productivity of the ecosystem (Awoke & Debie, 2023; He et al., 2021; Kindu et al., 2016). Accordingly, the spatiotemporal dynamics of Debre Markos town in the last two decades revealed a remarkable shift in LULC conversion as presented in Table 4. Hence, cultivated land was the dominant LULC type throughout the study periods which constitutes 55.5%, 48.5%, and 42.2% in 2004, 2014, and 2024, respectively. However, its constant decline in the study area infers increasing land pressure due to urban expansion and infrastructure development. Urban settlements (built-up areas), on the other hand, showed a rapid and continuous increase from 475.93 ha (6.1%) in 2004 to 1,836.81 ha (23.5%) in 2024, indicating the continuing urban expansion trend in Debre Markos and its neighboring areas. Such alteration of cultivated and forest, grass and inland wetland to urban areas has significant implications for ecosystem service delivery, as it usually shifts to the decline of regulating and supporting services such as water filtration, carbon sequestration, and habitat provision (Kindu et al., 2016; Sieber & Pons, 2015).

Table 4. LULC of Debre Markos Town (2004-2024)

LULC-type	2004		2014		2024	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Cultivated land	4346.32	55.5%	3799.12	48.5%	3305.02	42.2%
Forest land	1104.93	14.1%	1305.93	16.7%	1043.09	13.3%
Grass land	1619.07	20.7%	1519.07	19.4%	1451.03	18.5%
Built Up	475.93	6.1%	932.23	11.9%	1836.81	23.5%
Inland Wetland	283.12	3.6%	273.02	3.5%	193.42	2.5%
Total	7829.37	100.0%	7829.37	100.0%	7829.37	100.0%

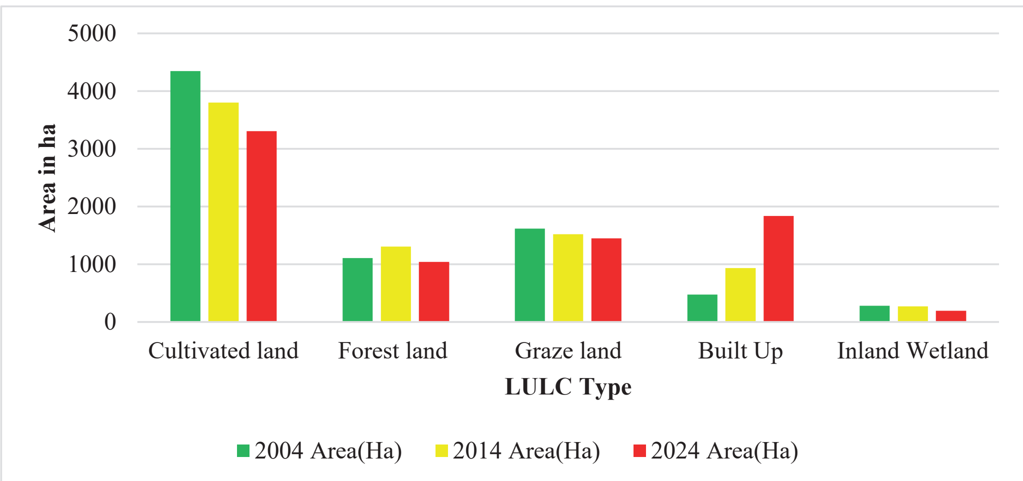

Figure 2. Dynamics of LULC

Based on the results of LULC (Land Use Land Cover) classification of time series Landsat imagery from 2004, 2014, and 2024, the dominant land use type in the study area was cultivated land, covering 55.5%, 48.5%, and 42.2%, respectively. The second-most dominant land use types have shifted over time: In 2004, cultivated land was followed by grassland and forest land (in order of their coverage). In 2024, cultivated land was followed by built-up areas and grassland (in order of their coverage). This transition highlights a major urbanization trend. Inland wetland was consistently the least dominant LULC in the study area across all years, covering only 3.6%, 3.5%, and 2.5% in 2004, 2014, and 2024, respectively. Consequently, built-up areas experienced a dramatic increase, rising from 475.93 ha (6.1%) in 2004 to 1836.81 ha (23.5%) in 2024 within Debre Markos town and its surrounding area.

Furthermore, the constant decline in inland wetland ecosystem in the study period indicates that, the inland wetland ecosystem was diminished from 3.6% in 2004 to 2.5% in 2024 that represents the decline of essential functional ecosystem functions including flood regulation, ground and surface water recharge, habitat for wild life and regulating functions of climate change in carbon sequestration (Assefa et al., 2021; Kibret, 2020; Msofe et al., 2020). The expansion of urban settlements with the expense of other natural productive ecosystems infers the need for sustainable urban planning and other development activities like urban greenery and green infrastructures to mitigate the adverse impacts of unplanned urbanization on ecosystem service values (Agnihotri, 2018; Assefa et al., 2021; Awoke & Debie, 2023; Zerga et al., 2021).

3.2. LULC change analysis

Change detection analysis was carried out simultaneously for all existed land use classes to identify and quantify the spatio-temporal conversion pattern of Debre Markos town and in the peripheral surroundings. The change detection method is a powerful approach for assessing LULC dynamics and to quantify the number of converted pixels to other land use classes (Kindu et al., 2016; Mariye et al., 2022; Mitra et al., 2023). Using this approach, the time series classified images (LULC classes) 2004 to 2024 were analyzed to detect and quantify the LULC transitions. The pattern of LULC analysis of Debre Markos town in the three consecutive years (2004-2024) was presented in the table below (Table 5). Change detection analysis is used to pattern different features such as land cover change and to analyses the rates of such changes.

The spatio- temporal pattern of LULC change in Debre Markos between 2004 and 2024 (Table 5) shows that there was a significant modification of LULC. Accordingly, the cultivated land in the study period was decreased by 1041.3 ha (23.96%), forest land by 61.84 ha (5.60%), grazing land by 168.04 ha (10.38%), and inland wetlands by 89.7 ha (31.68%) over the 20 years' period. The increase of forest land in the study area was due to the expansion of Eucalyptus plantation in the surrounding of the town in the last few years, which is related to government land compensation rate increased for plantation than cultivated land. In the contrary, built-up areas were increased dramatically by 1360 ha (285.94%), indicating the rapid expansion of urban areas with the expense of cultivated and other natural ecosystems. Such a rapid expansion of built-up areas reveals that the existence of rapid urbanization which was caused by population growth due to rural-urban migration, government-led housing initiatives, and infrastructure development within the town (Mekuriaw, 2019). Thus, the expansion of urban settlements has resulted for the alteration of cultivated land and other natural ecosystems (forest, inland wetland, and grass land) in to impervious surfaces that significantly alter the local structure and functions of the ecosystem (Assefa et al., 2021; Awoke & Debie, 2023; Gashaw et al., 2018).

The overall observed results of the this study aligns with urbanization trends are rapidly increased in developing countries like Ethiopia where the expansion of urbans are often unplanned and intrudes upon area where ecologically valuable and sensitive (Assimamaw Assefa, 2021; Kindu et al., 2016; Rotich et al., 2022). The changes in LULC are showed in Figures 2 and 3, which shows the quantity and

Table 5. LULC change (gain or loss)

LULC- type	2004-2014		2014-2024		2004-2024	
	Change in ha(gvl)*	%	Change in ha(gvl)*	%	Change in ha(gvl)*	%
Cultivated land	-547.2	-12.59%	-494.10	-13.01%	-1041.30	-23.96%
Forest land	201.0	18.19%	-262.84	-20.13%	-61.84	-5.60%
Grass land	-100.0	-6.18%	-68.04	-4.48%	-168.04	-10.38%
Built Up	456.3	95.88%	904.58	97.03%	1360.88	285.94%
Inland Wetland	-10.1	-3.57%	-79.60	-29.16%	-89.70	-31.68%

*Note: (gvl) means (gain versus loss -)

spatial extent of land transformation in Debre Markos town and in the peripheries. The LULC transitions ecologically valuable ecosystems to built-up areas indicates a major LULC modification that likely exerts significant negative pressure on the existence and sustainability of local biodiversity and ecosystem functionality (Assefa et al., 2021; Sieber & Pons, 2015; Yoshida et al., 2010).

3.3. Ecosystem service valuation and Change in ecosystem service values

The total ESVs were derived from LULC pattern of the study area using benefit transfer approach, utilizing global or locally modified value coefficients for the relevant LULC types, especially in regions where primary valuation data are lacking. This method involves adapting existing ESV data from one location to estimate values for similar areas without site-specific information (Aligas et al., 2023; Kindu et al., 2016; Rotich et al., 2022). LULC datasets for each study year served as proxies for ESV estimation, with the corresponding area in hectares calculated and mapped using GIS in raster format. During the valuation process, each LULC category was assigned a specific value coefficient. This study primarily applied value coefficients from (Costanza et al., 2014) and the adopted local modified ecosystem services coefficients followed those of (Gashaw et al., 2018) and (Kindu et al., 2016).

Change in ESVs across the study period in the study area reflects the impact of LULC change(dynamics) on the capacity of the ecosystem of each biome to provide natural goods and services from nature (Assaye et al., 2024; Assefa et al., 2021; Kindu et al., 2016; Mekonnen, 2025). As presented in (Table 6), the total estimated ESVs of the study area in the given time period were USD 3.736 million in 2004, USD 3.739 million in 2014, and USD 3.013 million in 2024. Although a slight increase (USD 0.003 million) was observed between 2004 and 2014, the total ESV declined sharply by USD 0.740 million between 2014 and 2024, resulting in an overall reduction of approximately USD 0.693 million over the past 20-years period in the study area. This finding has similarity with other findings of Assaye et al. (2024), Assefa et al. (2021) and Gashaw et al. (2018). This negatively changed

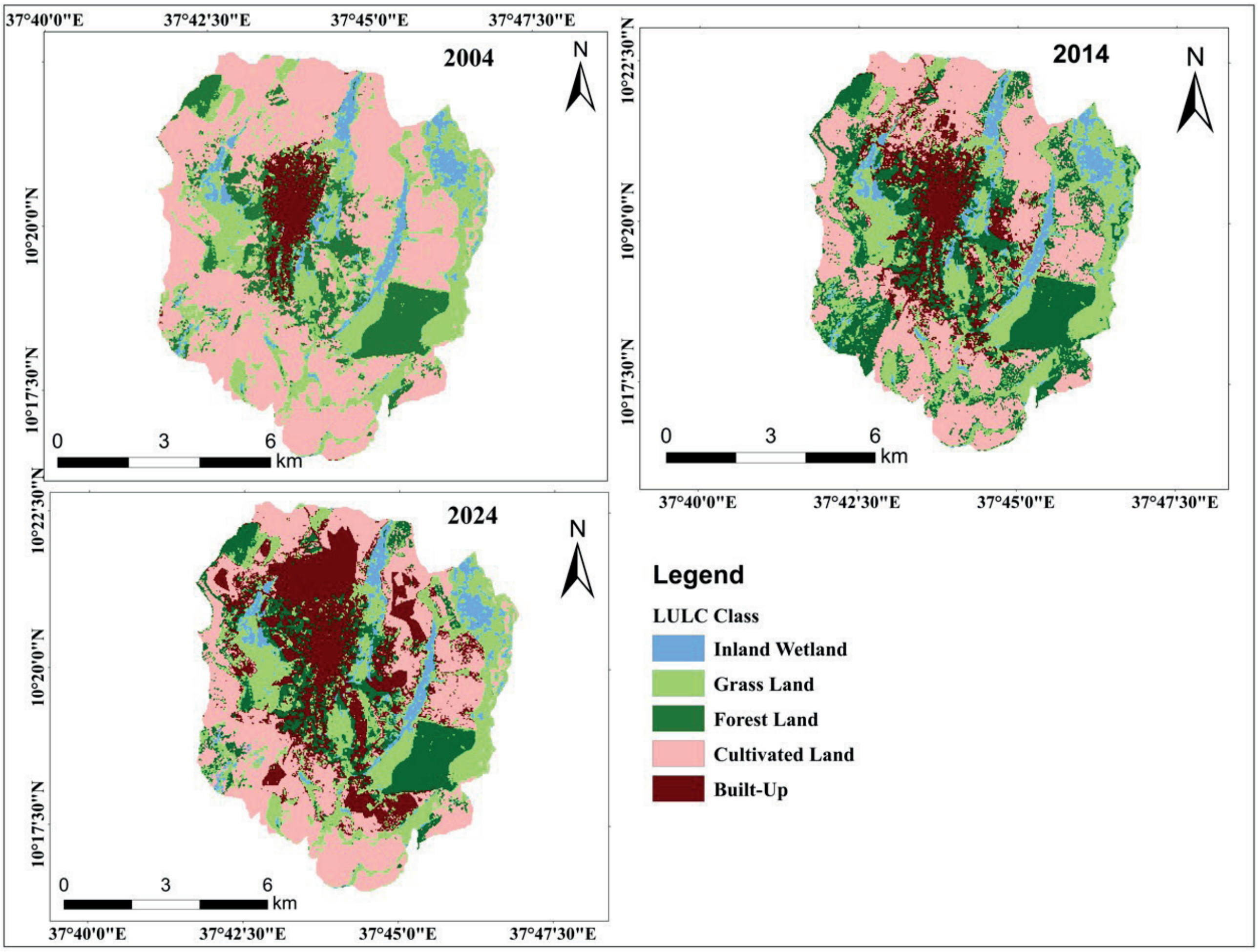

Figure 3. LULC change of Debre Markos town (2004–2024)

in total ESVs shows that urban expansion and associated land use changes have led to a decline of essential regulating, providing and supporting ecosystem services, such as carbon sequestration, water purification, and habitat provision (Assaye et al., 2024; Gashaw et al., 2018; Kindu et al., 2016; Rotich et al., 2022). The conversion of cultivated, forested, and wetland areas which are major contributors of ecosystem services has had undergone a predominantly substantial consequence on the total ESVs. Thus, these results of the study aligned with similar studies in other parts of Ethiopia that stated similar conclusions, where expansion of built-up land areas corresponds with reduction in overall ESVs (Assaye et al., 2024; Yoshida et al., 2010).

Accordingly, the existing trend indicates there is the trade-off between urban development and ecological sustainability in fast-growing towns like Debre Markos. Thus, if failed to manage the rapid LULC conversion due to rapid urban expansion in the study area and similar environments, could compromise the resilience of urban ecosystems and the well-being of local communities who depend on natural systems for resources and climate regulation. Therefore, integrating ecosystem-based planning and green infrastructure in urban policy frameworks is essential to sustain ecological balance while accommodating future urban growth. The temporal variations of ESVs across different land cover types are further depicted in Figure 4, which illustrates the proportional decline in ecosystem values corresponding to reductions in forest, cultivated, and inland wetland areas. The change in ESVs across time from different LULCs (biomes) was presented in the graph below (Fig. 4).

3.4. Effects/ impacts of urban expansion on ecosystem service values in the last 20 years

The impacts of LULC change on ecosystem service values (ESVs) in Debre Markos town over the past two decades (2004-2024) are presented in Table 7. Based on the results of ESVs there was a slight increment of ES (0.004 million USD) in between 2004 and 2014 due to increase of forest cover as a result of plantation practice in the surrounding area (*Eucalyptus Forest*) and there was a reduction of ESVs (0.767 million USD) in between 2014 and 2024 due to rapid urbanization in the surrounding area largely attributed to rapid urbanization and the consequent loss of ecologically valuable land covers. These findings suggest that changes in LULC directly influence the magnitude and distribution of ecosystem services within the study area.

Table 6. LULC change and ESVs of Debre Markos town (in Million USD) (2004–2024)

LULC- type	2004			2014			2024		
	Area (ha)	ESV	%	Area (ha)	ESV	%	Area (ha)	ESV	%
Cultivated	4346.32	0.980	26.2	3799.12	0.857	22.9	3305.02	0.745	24.7
Forest	1104.93	1.090	29.2	1305.93	1.289	34.5	1043.09	1.029	34.2
Grass	1619.07	0.475	12.7	1519.07	0.445	11.9	1451.03	0.426	14.1
Built Up	475.93	0.000	0.0	932.23	0.000	0.0	1836.81	0.000	0.0
Inland Wetland	283.12	1.190	31.9	273.02	1.148	30.7	193.42	0.813	27.0
Total	**7829.37**	**3.735**	**100.0**	**7829.37**	**3.739**	**100.0**	**7829.37**	**3.013**	**100.0**

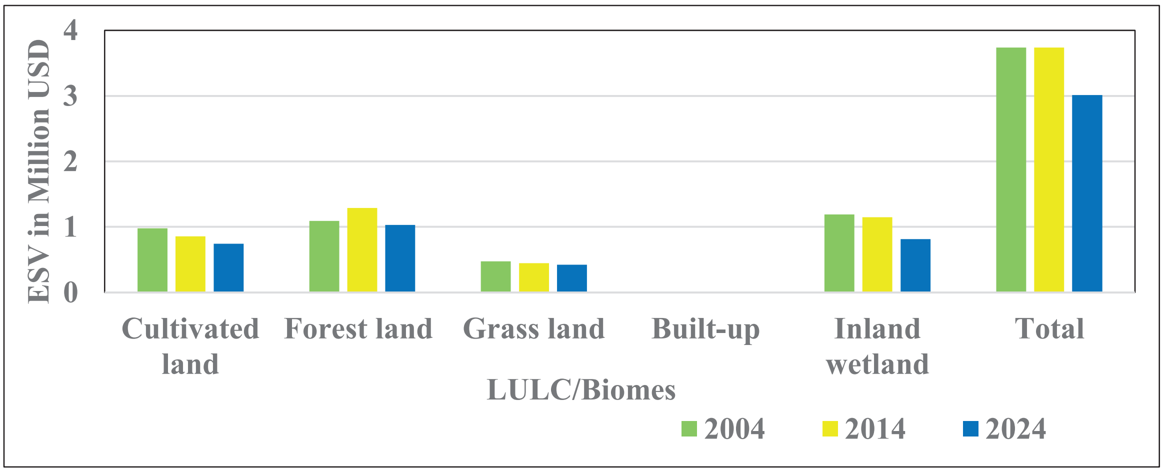

Figure 4. Change in ESVs across time (2004–2024)

Table 7. Ecosystem service changes

LULC- type	2004–2014		2014–2024		2004–2024	
	Change of ESVs in million USD	%	Change of ESVs in million USD	%	Change of ESVs in million USD	%
Cultivated land	-0.123	-12.59	-0.111	-13.01	-0.235	-23.96
Forest land	0.198	18.19	-0.259	-20.13	-0.061	-5.60
Grass land	-0.029	-6.18	-0.020	-4.48	-0.020	-4.20
Built Up						
Inland Wetland	-0.042	-3.57	-0.377	-32.85	-0.377	-31.68
Total	0.004		-0.767		-0.693	

Specifically, the conversion of inland wet land and decline of cultivated land due to urbanization plays a significant role in change in ESVs (negatively) in the study area. The change in ESVs of LULC categories indicate that the ESVs of inland wet land, cultivated land, forest land and grass land were declined by 31.68%, 23.96%, 5.6% and 4.2% respectively from 2004 to 2024. This reduction aligns with other studies conducted in Ethiopian cities, such as Bahir Dar, where total ESVs declined by USD 8.92 million between 1984 and 2019 due to urban expansion and the conversion of forest and wetland ecosystems (Assefa et al., 2021). Similar studies confirmed that expansion of cultivated land and expansion of human settlement highly affected the ecosystem services (Mariye et al., 2022; Mekonnen, 2025). Another study held in Nepal also confirmed that conversion of cultivated, forest and wetland result for reduction of ecosystem service in their study area (Shrestha & Acharya, 2021). Therefore, the declining trend of the cultivated land, wetland and forest vegetation in Debre Markos town due to built-up areas expansion have significantly contributed to the loss of ecosystem services in the town. The ESVs of the town in last three consecutive years are shown in the map below (Fig. 5).

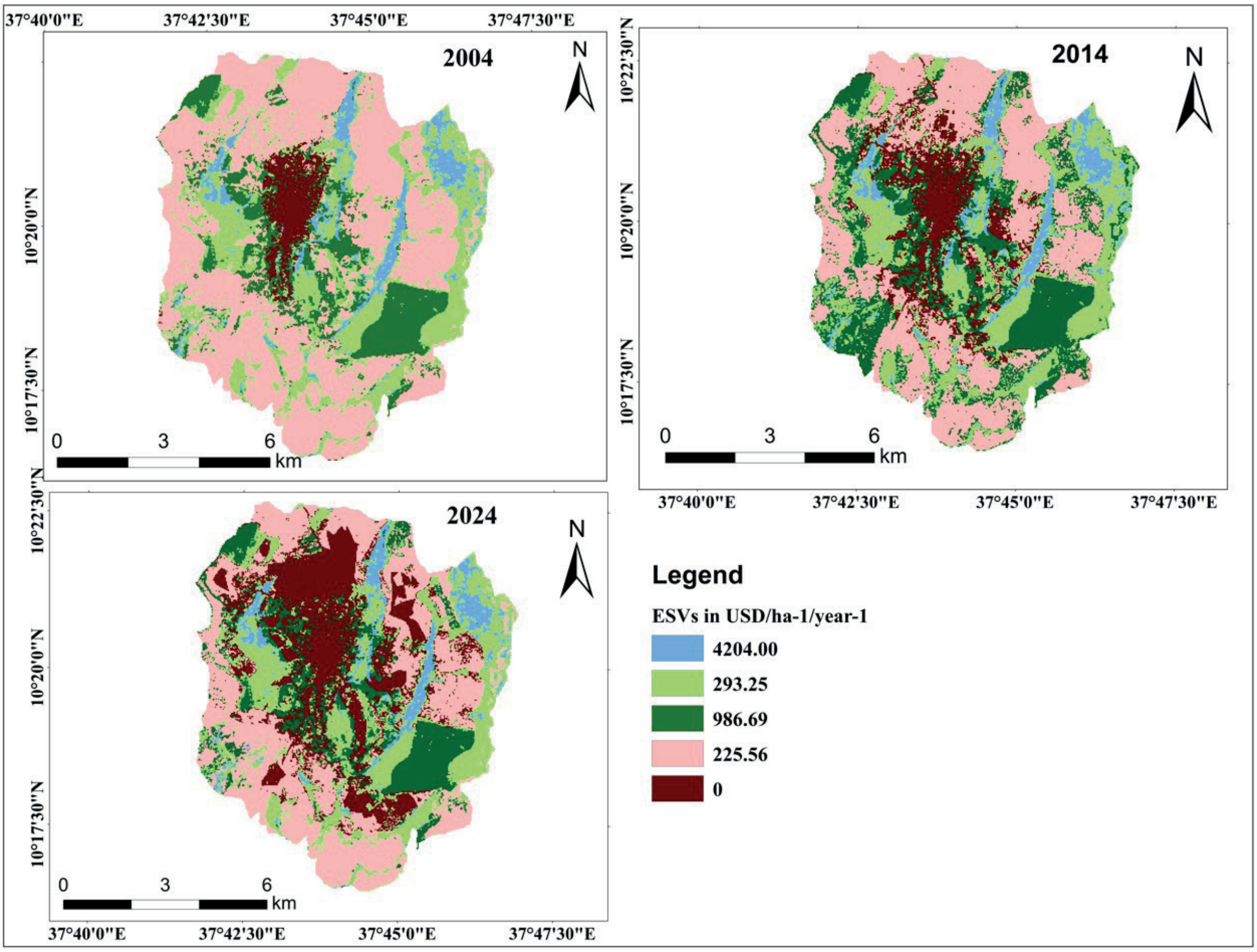

Figure 5. ESVs of Debre Markos Town (USD/ha $^{-1}$/yr^{-1}) (2004–2024)

The declining trend of cultivated land, wetland, and forest vegetation in Debre Markos town due to urban encroachment has thus contributed to a marked loss of ecosystem services, particularly in peri-urban areas. As shown on the map the Southern and Eastern parts of the town was highly affected by urban expansion. This was due to the establishment of Debre Markos university and Woseta market center (East) and expansion of residential house construction by housing cooperatives (South). Such dynamics underscore the strong link between land transformation and ecosystem degradation, highlighting how rapid urbanization alters ecosystem structure and function by disrupting ecological processes

The change in LULC in the study period not only reduce total ESVs but also alter individual ecosystem service functions (provision, supporting, regulation and cultural values). Different researchers confirmed that, the change in ecosystem service values was a result of LULCC. Decline of water body, wetland, and forest ecosystem has resulted to the decline of individual ecosystem eservice values (Assefa et al., 2021; Kindu et al., 2016). Accordingly, the impacts of LULCC in Debre Markos town in the last 20 years on individual ecosystem service functions were presented in the table (Table 8).

Table 8. The Impacts of LULCC on individual ESV functions

ES functions	ESV Functions Across Periods(2004–2024)				
	2004	2014	2024	Over all change in Million USD	Change in %
Provision service	**1.358**	**1.263**	**1.069**	-0.289	**-21.26%**
Water supply	0.278	0.266	0.233	-0.045	-16.31%
Food production	0.899	0.801	0.686	-0.213	-23.65%
Raw materials	0.113	0.121	0.092	-0.021	-18.59%
Genetic resource	0.058	0.066	0.052	-0.007	-11.39%
Medicinal resources	0.009	0.009	0.006	-0.003	-31.68%
Regulating services	**1.741**	**1.814**	**1.430**	-0.311	**-17.86%**
Water regulation	0.289	0.280	0.201	-0.089	-30.73%
Waste treatment	0.618	0.625	0.491	-0.127	-20.48%
Erosion control	0.336	0.381	0.310	-0.026	-7.66%
Climate regulation	0.305	0.348	0.273	-0.032	-10.64%
Biological control	0.142	0.126	0.113	-0.029	-20.39%
Gas regulation	0.046	0.047	0.037	-0.008	-17.72%
Disturbance regulation	0.006	0.007	0.005	0.000	-5.60%
Supporting services	**0.591**	**0.616**	**0.480**	-0.110	**-18.69%**
Nutrient cycling	0.274	0.307	0.249	-0.025	-9.10%
Pollination	0.071	0.064	0.055	-0.015	-21.55%
Soil formation	0.025	0.026	0.020	-0.005	-20.05%
Habitat	0.222	0.218	0.157	-0.065	-29.44%
Cultural services	**0.046**	**0.046**	**0.034**	-0.012	**-26.83%**
Recreation	0.027	0.027	0.020	-0.007	-26.57%
Culture	0.019	0.019	0.014	-0.005	-27.19%
Total	**3.736**	**3.739**	**3.013**	**-0.722**	**-19.33%**

According to Table 8, the total ecosystem service values of Debre Markos town declined by 19.33% between 2004 and 2024. Provisioning services decreased by 21.26%, regulating services by 17.86%, supporting services by 18.69%, and cultural services by 26.83%. Notably, several individual ecosystem functions experienced reductions exceeding 20% from their 2004 baseline values, including food production (−23.65%), medicinal resources (−31.68%), water regulation (−30.73%), waste treatment (−20.48%), biological control (−20.39%), pollination (−21.55%), soil formation (−20.05%), habitat provision (−29.44%), recreation (−26.57%), and cultural value (−27.19%). The pronounced loss in these services reflects the direct and indirect consequences of urban expansion, particularly the conversion of wetlands, forest, and grazing lands into built-up areas (Assaye et al., 2024; Assefa et al., 2021; Rotich et al., 2022). This declination in ecosystem service was associated to urban expansion and decline of inland wetland, forest and grass land in Debre Markos town and its periphery areas.

Moreover, the conversion of wetlands in to settlements and expansion of urban settlements over cultivated land plays a significant effect for the decline of ecosystem service in the area in the last 20 years in line with other studies (Assaye et al., 2024; Assefa et al., 2021; He et al., 2021; Kindu et al., 2016; Koulov et al., 2017; Maes et al., 2015). Thus, inland wet land ecosystem service values were declined by 31.68% and ESVs of cultivated land was declined by 23.69% in the area. The observed changes are consistent with findings from other regions of Ethiopia and beyond, where the conversion of wetland and agricultural areas for urban development resulted in reduced ecosystem services, such as flood control, water purification, and carbon storage This finding is lined with other findings such as (Assefa et al., 2021; Mariye et al., 2022; R. Sharma et al., 2019). In their respective study area all are confirmed that there was a decline of ecosystem service functions as a result of land use land cover change. On the other hand, another study investigated by (Awoke & Debie, 2023), confirmed that ecosystem service functions can be improved through appropriate soil and water conservation practices in their respective study area. Hence, integrating ecosystem-based management and nature-based solutions into urban planning could mitigate the adverse impacts of LULC change and promote more sustainable urban development in Debre Markos and similar urban centers.

3.5. Ecosystem service sensitivity analysis

The variation (change) in ecosystem services and its dependency on ecosystem service index was evaluated based on the elasticity of the coefficients. The Coefficient of Sensitivity (CS) is a crucial diagnostic tool used in Ecosystem Service Value (ESV) assessments, particularly when the Benefit Transfer Method (BTM) is employed. It serves to check the robustness and reliability of the estimated total ESV. The coefficient of sensitivity (CS) analysis was conducted to evaluate how changes in the value coefficients of different land-use/land-cover (LULC) types influence the total ecosystem service values (ESVs). Therefore, based on the elasticity of coefficients calculated based on adjustment of coefficients of each land use values by ±50% from the initial values were presented in the table (Table 9). Cultivated land shows moderate sensitivity, with increasing importance in 2024, suggesting growing influence on ecosystem service values (ESVs). While, forest land also consistently exhibits high sensitivity, indicating it is a key driver of ESV changes across all years. Despite lower values in 2014, grazing land also shows high CS in 2024**,** implying increasing sensitivity of ESVs to changes in grazing land. While inland wetlands maintain consistently high sensitivity, reinforcing their critical ecological role despite area changes. The sensitivity analysis reveals that forest land and inland wetlands consistently exhibit high coefficient of sensitivity (CS > 1) across all study years, indicating their dominant contribution to ecosystem service values, while cultivated and grazing lands show increasing sensitivity in recent years, particularly in 2024 (Assefa et al., 2021; Awoke & Debie, 2023).

Table 9. Coefficient of sensitivity of LULC types in respective years

LULC- type	2004		2014		2024	
	± %	CS	± %	CS	± %	CS
Cultivated land ±50%	1.47	0.94	1.29	0.57	1.12	1.24
Forest land ±50%	1.64	1.27	1.93	1.87	1.54	1.88
Grass land ±50%	0.71	1.58	0.67	0.66	0.64	1.72
Inland Wetland ±50%	1.79	1.57	1.72	1.44	1.22	1.44

3.6. Communities Perception to the Impacts of Urbanization on ESVs

In addition to time series satellite image analysis to detect urban expansion and its impact on ESVs, the community's perception was collected and analyzed to support and validate the findings. The demographic characteristics of the respondents are presented in Table 10. Based on the demographic characteristics' of respondents' 32% respondents' were young, 47.5 % were adult and 20.5% were elders. Similarly, 70.4 % the respondents are males and 40.8% respondents are farmers and the remaining were urban dwellers who are engaged in other economic activities. Accordingly, based on the analysis of survey data collected from 385 respondents more than 85% of the households agreed that unplanned expansion resulted for decline of ecosystem services in the last years. Similarly, more than 62% the respondents confirmed that the expansion of urban settlements in the peripheral parts of the town caused for the reduction of cultivated land and other natural ecosystems (forest, wetland, and grass land) which resulted for the dramatic decline of wild life and overall biodiversity in the study area. In addition, the communities also perceived and confirmed that, problem of flooding, water pollution, and modification local climate were occurred following the expansion urban settlements in peripheral parts of the town. Similarly, more than 87% of the respondents were also confirmed economic development and socioeconomic changes have led to shifts in land use patterns, affecting the environment. Data from KII (Key Informant Interview) also confirmed that the urban expansion in Debre Markos town resulted for the decline of inland wetland ecosystem around the town. They confirmed that most inland wetlands in the past were converted in to built-up areas. The findings of the study were agreed with different research findings as urban development, which can alter the natural drainage patterns, increase surface runoff, and reduce groundwater recharge. This can lead to changes in the water table, water quality, and the overall functioning of the swamp ecosystem (Assimamaw Assefa, 2021; Baral et al., 2017; Zerga et al., 2021). As described by Assefa et al. (2021) the effects of these land use and land cover changes can loss biodiversity, reduced water storage and flood regulation capacity, decreased water purification, and the disruption of important ecosystem services that the swamp provides to the local community.

Table 10. Demographic characteristics of the respondents

Demographic characteristics	Frequency	Percentage
Age		
<29	123	32.0
35-64	183	47.5
>65	79	20.5
Total	385	100.0
Sex of Respondents		
Male	271	70.4
Female	114	29.6
Total	385	100.0
Occupation of Respondents		
Farmer	157	40.8
Government employee	45	11.7
Merchant	75	19.5
Others	108	28.0
Total	**385**	**100.0**

4. Conclusion

Quantifying and estimating ESVs and their changes over time as a result of LULC changes is essential and provides important information for assessing the impact of LULCC. It also provides information for decision-making on intervention measures. This study therefore focused on assessing the impact of urban expansion on ESVs over the last 20 years (from 2004–2024). The results of the study revealed that built-up areas in the town of Debre Markos and its surrounding area increased in 2024 from 475.93 ha (6.1%) to 1,836.81 ha (23.5%), while in other areas it decreased. Thus, over the last 20 years, the area of built-up land in the study area increased by 1,360 ha (285.94%). Based on this, it can be concluded that urban development in the study area increased by 1,360 ha (285.94%). The change in LULC in the area has a significant impact on the ecosystem service values. Based on ESV estimates in this area for respective periods, the total ESVs for the town of Debre Markos was USD 3.736 million in 2004, USD 3.739 million in 2014 and USD 3.013 million in 2024. This result indicates that total economic values (TEVs) of the town increased by USD 0.003 million from 2004 to 2014, decreased by USD 0.740 million between 2014 and 2024, and the ecosystem value decreased on average by USD 0.693 million over the last 20 years (2004-2024), i.e. by 19.33%. This reduction was the result of urban expansion relative to other LULC categories. In addition, changes in LULC in this area in different time periods also affect individual ecosystem service functions. As a result, some individual ecosystem service functions have declined by more than 20% from their initial ecosystem service values (2004), e.g. food production, medicinal resources, water regulation, waste treatment, biological control, pollination, soil formation, habitat, recreation and culture. This decline in ecosystem services was linked to urban expansion and disappearance of inland wetlands, forest and grass land in the town of Debre Markos and its peripheral areas. Therefore, based on the results of this study, the authors recommended that stake holders should manage and properly direct horizontal urban expansion to minimise its impact on the environment. In addition, ecosystem services should be continuously monitored to mitigate the effects of ecosystem service disruption. In order to better assess ecosystem services, the authors advise other researchers to evaluate them by using other economic valuation methods for verification purposes.

Declarations

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Authors' contributions

The authors' collected, analyzed, interpreted the data and prepared the manuscript. The authors' read and approved the final manuscript.

Competing interests

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