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Quantification of Land Use Change Impact on Ecosystem Service Value in Southern Ethiopian Rift Valley Lakes Basin at Biodiversity Hotspot Area

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Abstract

Quantification of Ecosystem Services Value (ESV) is essential to make socioeconomic activities environmentally sustainable in Ethiopia, where natural ecosystems are deteriorating, including in Protected Areas (PAs) due to increased anthropogenic pressures, Although ESV studies show progress, ESV coefficients for ecosystem services (ES) in Ethiopia have not yet been established. This study is the first to develop equivalent factors at the national level and coefficients at the district level for 23 ES types, following a unit value approach. It also quantified the total ESV and changes therein linked with land use change observed in Nech Sar National Park between 2002 and 2040. Different datasets: land use/cover, ES valuation, empirical ESV studies, per unit area price of food crops, ESV of cultivated land for food production services, various statistical formulas, geospatial tools, price standardization indices and difference adjustment indices (ecological, economic, and social) were used in different steps of the study. The results (<0.5) of the sensitivity analysis indicated that the developed coefficients are adequately reliable to estimate ESV along with the area of land types in the study area. The results showed that NNP has experienced a continued reduction in its total ESV with US$ 4.08x106 and 1.01x106 net loss in the first- and second-time intervals, respectively. Forest land and woodland are the leading resources to provide essential ES. For 67.93% reduction in total ESV was attributed to the land loss from these land types from 2002 to 2020. Apart from the magnitude, the direction of land transitions considerably affects the spatiotemporal change/gain and loss/ ESV. The study provides site-specific and long-term evidence that can help stakeholders to understand the consequences of LUC, resolve interest conflicts over land use, and implement practicable interventions.

Keywords: *ecosystem service flow, equivalent coefficient, Net gain, Nechsar*

INTRODUCTION

The ecosystem services (ES) of natural ecosystems are the essence for maintaining ecological processes (Sutton et al., 2016), socioeconomic development (Fenta et al., 2020; Jiao et al., 2022), and the survival of human beings on Earth (Kubiszewski et al., 2017). Nevertheless, over the past few decades, nearly 2/3 the world's ecosystems have significantly degraded mainly because of increased anthropogenic pressures for socioeconomic well-being (Davison et al., 2021), resulting in a critical depletion in more than 63% of ES (Sutton et al., 2016).

The existing degradation in ecosystems and ES is fundamentally attributed to the joint impacts of natural and human-induced factors (Costanza et al., 2014). However, several studies identified that anthropogenic land use change (LUC) is the major factor that increasingly threatening natural ecosystems and their multifold ES (Gashaw et al., 2018; Groot et al., 2020; Rotich et al., 2022; Sarah et al., 2020; Xie et al., 2017), including regulation of hydrological and atmospheric processes (Teferi et al., 2013), biodiversity conservation (Mekonnen, 2022) and agricultural production (Fenta et al., 2020). The problem has long been more prevalent and catastrophic in developing countries, including in Sub-Saharan Africa (SSA) region, due to massive land conversion from natural ecosystems to anthropogenic land uses: agricultural land, and urbanization, and exhaustive utilization of natural resources to meet the needs of the rapidly growing population (Fenta et al., 2020; Rotich et al., 2022; Xie et al., 2017).

In SSA, Ethiopia, where the subsistence economy of 84% of rural population depends on natural resources (Haregeweyn et al., 2017), is one of the countries experiencing a significant degradation of ecosystems and ES mainly driven by LUC and degradation (Abera et al., 2020; Gashaw et al., 2018; Tolessa et al., 2017). Due to land degradation caused by LUC, the country has experienced 17.7% of ES loss, along with the monetary value of US$397.966 billion per year (Sutton et al., 2016). Likewise, studies conducted at the watershed/local/ levels have reported a significant degradation in ES mainly due to land conversions from natural vegetation (forest, woodland and grassland) to agricultural and settlement areas (Aneseyee et al., 2019; Belay et al., 2022; Fetene et al., 2015; Temesgen et al., 2018, 2022; Tolessa et al., 2021).

Due to shortage of natural resources in non-protected areas to meet the socioeconomic needs of a rapidly growing population, PAs in Ethiopia have also been prone to the impacts of rapid anthropogenic LUC, such as cultivated land and settlements, expansion, livestock grazing, overproduction of wood, land degradation and biodiversity loss (Menbere, 2021;

Tesfaw et al., 2018). Apart from biodiversity conservation, PAs are prominently known for their multitudinous ecological and socioeconomic services from local to global levels (Mekonnen, 2022). However, due to the existing pervasive LUC and other anthropogenic activities, most of Ethiopia's PAs, including NNP (where this study was conducted) are under the critical threat of environmental degradation (Menbere, 2021; Tesfaw et al., 2018).

Thus, in a situation where anthropogenic LUC is a major cause for degradation of ecosystems and biodiversity, quantifying the value of ES in monetary units and analyzing the changes linked with the spatiotemporal dynamics of LUC is crucial for various purposes, such as to identify landscapes and natural resources that need priority for protection and restoration with reasonable cost of interventions (Kindu et al., 2016), design alternative resource management and use plans (Sutton et al., 2016), and mainstreaming environmental issues in economic development programs and policy decisions (Groot et al., 2020). Thereby, a few studies were conducted in Ethiopia (Admasu et al., 2023; Aneseyee et al., 2019; Assefa et al., 2021; Belay et al., 2022; Biratu et al., 2022; Gashaw et al., 2018; Godebo et al., 2018; Kindu et al., 2016; Mekuria et al., 2021; Mekuriaw et al., 2020; Mengist et al., 2022; Shiferaw et al., 2021a; Tolessa et al., 2017; Weldegebriel, 2021; Yohannes et al., 2018).

Researchers noted the impact of LUC on ES determined by ecosystem /land use/ type, ecological setup, LUC characteristics and people's socioeconomic activities at the local level (Kindu et al., 2016; Xie et al., 2017). Thus, to come up with pertinent results for effective policy and decision-making, location specific ESV studies with adequate consideration of ecological and socio-economic conditions are crucial, more specifically in Ethiopia, where ecosystems and landscapes are markedly heterogeneous and the magnitude and rate of LUC show great variation in both spatial and temporal scales (Ketema et al., 2020). However, the previous studies are limited in number and spatially concentrated in the northern and central highlands (Amberber et al., 2020; Gashaw et al., 2018), with little attention given to the Southern part and PAs of the country.

NNP, in Southern part of Ethiopian Rift Valley Lake Basin (RVLB), where LUC, and ecosystem degradation are drastic in-non-PAs areas due to increased socioeconomic activities and erratic-semiarid-climate conditions (Ketema et al., 2020; Kuma et al., 2022; Mekonnen, 2022), is a unique landscape by preserving the highest level; 32% of the country's biodiversity (plant, animals, birds, etc.) (Seid & Kakiso, 2018) within wide range ecosystems: evergreen forests, woodland, shrub/bushland, grassland, wetland, river and lakes at a very short range of elevation (1,086 to 1,642 m above sea level). It is also known by the provision of multiple ES from local to global levels (Mekonnen, 2022). Considering its potential of biodiversity and ecological services, the IUCN registered NNP as one of the global biodiversity hotspot areas. Apart from the ecological values, it has a long history in maintaining livelihood, job opportunities, above 98% wood demand, and sociocultural practices of subsistence rural and urban dwellers who are living inside and adjacent areas(Deribew, 2019; Fetene et al., 2015).

Nevertheless, several studies asserted that associated with population growth and other factors, an increased and intensified anthropogenic activities: expansion of agricultural and settlement areas, overproduction of charcoal and wood, etc., have made NNP one of the most vulnerable PAs in Ethiopia for rapid LUC and degradation that critically threaten its capacity for biodiversity conservation and provision of ES (Fetene et al., 2015; Muhammed et al., 2016; Tsegaye et al., 2017). Further, a recent study indicated that expansion of invasive plants, prevalent of fire, and weakened political commitments in local and regional governments, especially from the Oromia regional state side to protect the park for biodiversity and natural landscape conservation, significantly aggravate the LUC and ES degradation in the park (Mekonnen, 2022). Despite the documentation of the problems, there has not yet been a comprehensive study to quantify the impact of the past and future LUC on ESV by using remotely sensed land use data and site-specific ESV coefficients in NNP.

Moreover, even though studies on ESV are increasingly needed across the world to make socioeconomic development programs environmentally sustainable, the lack of a standardized valuation method that can be applied in different ecological setups and socioeconomic contexts is still the most critical challenge for researchers (Groot et al., 2012; Xie et al., 2017). Several studies have been conducted in different parts of the world applying different valuation methods. These methods can be grouped into two broad categories: primary data-based/functional value and unit value-based/equivalent benefit transfer approaches (Cheng et al., 2022).

However, the unit value-based methods are the most widely employed across the world because they are more suitable for estimating the values of multiple services at a time and are adaptable to any spatiotemporal scale compared to the functional approach (Gashaw et al., 2018; Rotich et al., 2022; Yang et al., 2022). They are also effective for considering various socioeconomic and biophysical conditions during quantification and for analyzing the spatiotemporal changes of ESV along with changes in land use and land cover (Niu et al., 2022). This method was primarily employed by Costanza et al. (1997), based on the equivalent coefficients developed at the global level. Despite several measures having been taken to overcome the limitations and improve the reliability (Costanza et al., 2014; Groot et al., 2012; 2020), the equivalent coefficients developed at the global level are still not effective for the valuation of ES at the national, regional, and local levels, specifically in developing countries (Groot et al., 2020), including Ethiopia (Gashaw et al., 2018). The coefficients or their input datasets lack adequate representation of ecological and socioeconomic characteristics at the lower spatial levels (Kindu et al., 2016; Xie et al., 2017).

Therefore, it is strongly recommended that developing or modifying the equivalent coefficients by taking into account the biophysical and socioeconomic factors at the study site and/or national level is necessary for credible value estimation for ES and the results to be valuable input for policy and decision-making (Ma & Zhang, 2023; Xie et al., 2017). Accordingly, the first attempt was made by (Gaodi et al., 2003) to estimate the values of China's terrestrial ecosystems using the global food production value (US$54) of cultivated land as a standard equivalent factor, given by (Costanza et al., 1997), and then further improvements were made by (Gaodi et al., 2010; Niu et al., 2022; Xie et al., 2017). However, previous studies in Ethiopia were carried out with little modification (Kindu et al., 2016) and the direct adoption of equivalent coefficients developed at the global level (Costanza et al., 1997; Groot et al., 2012, 2020). As a result, most of these studies may suffer from several limitations that can affect the credibility of their findings for policy and decision-making, as well as better resource management plans (Amberber et al., 2020).

Hence, considering the gaps mentioned above, and the contribution by providing long-term and site-specific information for practitioners, decision-makers, and other stakeholders, to make decisions and interventions that can ensure the sustainability of the park's functionality for biodiversity conservation and ES, this study was conducted in NNP in the southern part of the Ethiopian Rift Valley Lakes Basin (ERVLB). Furthermore, since this study is the first in Ethiopia to quantify the ESV, particularly for PAs, based on equivalent factors developed and coefficients at the district level, the findings can motivate other researchers to do more studies using site-based coefficients and to establish the national (Ethiopian) ESV database, which is vital to environmental studies, socioeconomic decisions, and strategy formulation at different levels. The specific objectives of the study are to 1) develop equivalent factors at the national level and equivalent coefficients at the district level for ES provided by different land use types, 2) quantify the total ESV of NNP in 2002, 2020, and 2040, and 3) analyze the changes in ESV due to LUC in NNP between 2002 and 2020 (First Time Interval of the study; FTIS), and 2020 and 2040 (Second Time Interval of the study; STIS).

MATERIALS AND METHODS

Study Area

The study site is found between 5°51' and 6°05' N latitude, and 37°32' and 37°48' E longitude (Fig. 1) with a 41400ha area coverage. It is located at East of Arba Minch Town, in the upper part of Segen river catchment of ERVLB. The meteorological data collected from the Ethiopian Meteorology Agency (EMA, 2022) showed that in the study area, the total annual Rainfall is between 622 and 1177 mm, with 888.38mm average value for 33 years. The average annual minimum and maximum temperatures are between 16 and 20^{0}C, and 30 and 35^{0}C, respectively.

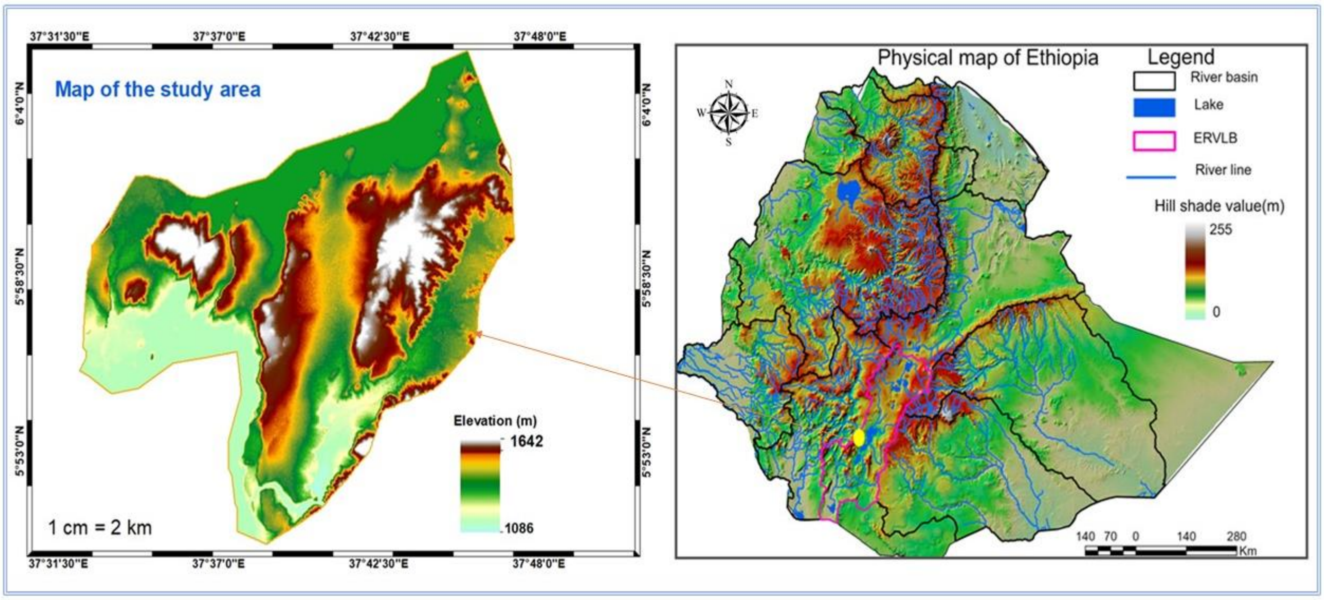

Figure 1
Map of the study area **(Note:** this study area map was adopted from (Mekonnen, 2022; Tadesse, 2020; Tsegaye et al., 2017) and used merely for research purposes)

The biological diversity and spectacular landscapes of the park offer significant opportunities for Arba Minch town and the surrounding areas to attract investments, particularly in the tourism industry. Although under different ecological problems, NNP is still continuing as one of the crucial sites for biodiversity preservation and socioeconomic development, particularly for the livelihood and job opportunities for local communities. Analyzing the impact of LUC on ES in terms of their economic value is important to address the existing environmental problems in NNP and sustain its opportunities for ecological services, including biodiversity conservation and socioeconomic development.

Dataset for Land Use Types in NNP

For land use classification and change analysis in NNP, Landsat images of 2002 and 2020 were downloaded from the new database of the United States Geological Survey (https://earthexplorer.usgs.gov). All image preprocessing activities, including radiometric and geometric corrections, were processed in ERDAS Imagine 2015. The supervised classification method (Support Vector Machine algorithm) was applied in ArcGIS 10. 8 for image classification into six land use types. These are forest land, woodland bush/shrubland, grassland, water area, and cultivated land. The classification scheme was developed based on researchers' field observation and empirical literature (Fetene et al., 2015). The area proportion and trends of changes for each land use type are summarized and presented in Table 10. In addition, the future land use patterns for 2040 were predicted by using the Cellular Automata-Markov chain model (CA-Markov) in IDRIS software, TerrSet_20. The detailed datasets for image classification processes and land use types are available in (Seid et al., 2025, 2024).

Determination of Equivalent Factors and Coefficients

The equivalent value method was applied to estimate ESV in NNP based on the equivalent coefficients developed at the local/district/ level. Formulation of equivalent factors and coefficients is the prerequisite for applying a site-based equivalent value method (Xie et al., 2017). In this study, the approaches and steps used by (Gaodi et al., 2003; X. Li et al., 2015; Xie et al., 2017) and others in China were followed to develop the equivalent factors at the national level and coefficients that adjusted for NNP and its surrounding districts/Gamo, Gelana, and Amaro/. To construct the equivalent factors and coefficients, different long-term datasets from different sources were collected. The datasets, procedures and mathematical equations applied to develop the ESV coefficients are presented and discussed in the following subheadings.

Determination of Equivalent Factors

Equivalent factor is a unit-less weight that indicates the relative contribution of each ecosystem service for the entire services provided by a given ecosystem /land use type/ (Sarah et al., 2020). There are three methods to develop reliable equivalent factors at national or any spatial scale (Xie et al., 2017). Of which we followed the most commonly used methods: the direct comparison with biomass /area/ of ecosystems (Gaodi et al., 2003), and indirect comparison with ESV obtained from empirical literature (Costanza et al., 1997; Groot et al., 2020).

More specifically, in areas where ecologically heterogeneous and constrained by scarcity of primary valuation data, following these methods is recommended by many researchers (Gaodi et al., 2003; 2010; Kindu et al., 2016; Niu et al., 2022; Shao et al., 2020; Xie et al., 2017). Accordingly, the standard equivalent factors for this study were developed based on the high-resolution (20m) land use and land cover map of Ethiopia, obtained from the national database (https://www.ethiogis_mapserver.org), and the empirical ESV studies conducted in different parts of the country.

Based on the land use and land cover (LULC) dataset, nine (9) major land types with their area coverage were identified (Table 1). Following that, twenty-three (23) ES types were specified by using the experiences from previous studies (Table 2), and based on the ecosystem service classification framework developed by (Groot et al., 2020). Then, the ESV of each ES was calculated by using the area of each LULC type and the ESV coefficient of the corresponding biome collected from primary valuation results found in the Ecosystem Service Valuation Database (ESVD) (https://www.esvd.net) (Brander et al., 2023). Among ESV databases, the current version of ESVD is the recently updated (2023) and the largest, comprising more than 9500 value records obtained from over 1100 primary valuation studies conducted in different parts of the world. Additionally, this database avoided and /or/ minimized the limitations observed in previously developed databases (Brander et.al., 2023).

Table 1
LULC's area(ha), and total ESV (2020 US$ Price level) with corresponding biome and ESV coefficients obtained from ESVD database

LULC types	**Area ($x10^6$ ha)**	**Equivalent Biome**	**Coefficients (US$ $ha^{-1}yr^{-1}$)**	**Total ESV (US$ $x10^9$)**
Forest land	19.48	Tropical forest	10080.15	196.41
Shrubland	23.33	Bush & woodland	3015.73	70.36
Grassland	33.12	Grassland	3374.59	111.77
Lenich and Mosses	1.12	Grassland	3374.59	3.77
Wetland	0.14	Inland wetland	26962.38	3.76
Water bodies	0.75	Lake & river	75906.84	57.09
Cultivated land	29.47	Intensive land*	10451.20	307.96
Barren land	6.11	Desert& Semi-desert	686.00	4.19
Built-up areas	0.12	Urban areas	65960.00	7.95
Total	113.64		199811.47	763.26

*From the intensive land biome in the ESVD database, we used only the data of Annual croplands, Perennial agroforestry, and perennial monoculture.

To increase the reliability and minimize the probability of errors, it has been recommended that the equivalent coefficients obtained from ESVD, should be from the records of studies carried out in areas/countries/ that have /nearly/ similar ecological setups and socioeconomic conditions with study site/country/, instead of using directly the coefficients developed at global level (Costanza et al., 1997; Groot et al., 2012, 2020). Accordingly, all the values used in this study were obtained from studies conducted in tropical and partially tropical countries, especially from countries that can be matched with Ethiopia in terms of ecological and socioeconomic conditions. The extracted values (US\$ $ha^{-1}yr^{-1}$) from the database for each ES of biomes were standardized at the 2020 price level for computational and other advantages (Costanza et al., 1997; Groot et al., 2012). After the value standardization, the average coefficient of the most representative biome was used to calculate the total ESV for each ES in LULC at the national level (Table 1). Finally, the value of food production in cultivated land (US\$$12.88 \times 10^9$) was used as a standard factor to compute the initial equivalent factors based on (Equation 1).

$$W_{ij} = \frac{\mathrm{ESV_{ij}}}{\mathrm{ESV_{fc}}} \qquad (1)$$

Where, W_{ij} is the relative weight of the i^{th} ecosystem service of the j^{th} land type, $\mathrm{ESV_{ij}}$ is the value of the i^{th} ecosystem service in the j^{th} land type, and $\mathrm{ESV_{fc}}$ is food production value of cultivated land.

Moreover, to strengthen the reliability of the equivalent factors determined based on the area of LULC types, the ESV from previously conducted studies in different parts of the country were also considered (Table 2). According to (Xie et al., 2017), the ESV obtained from the literature are important for taking into account the spatio-temporal effects of biophysical and socio-economic factors. All the empirical studies that we utilized here were conducted at the watershed /district/ levels, published only in reputable journals, and used the global or slightly modified equivalent coefficients (Table 2).

The collected empirical studies were coded, and then their calculated ESV were entered into the Microsoft Excel sheet. All estimated ESV in each study were converted from their international value (US\$) to local value (Ethiopian Birr) using the Purchasing Power Parity (PPP) exchange rate at the reference year of the coefficients used in each study and then standardized to 2020 local price level by using the GDP deflators. Again, the standardized values were converted to their international value (US\$) by using the PPP exchange rate

(11.928) of the year 2020. Finally, the equivalent factor of each ES provided by each land type in the area of each literature was calculated by using the mean value of food production in the cultivated land (Table 2) and the empirical formula given in Equation (1).

Table 2
The ESV studies in Ethiopia that used to develop the relative weight/factor for different ES based on the food production value (US$ 2020 price level) of Cultivated land

Land use/ cover types	Mean food production value (US$ x10^6) *	Reference points(years) for ESV estimation	Sources/Empirical studies
1,2,4&7	0.06	1986 & 2005	(Mekuriaw et al., 2020)
1,2&7	49.87	1972,1986, 2008& 2017	(Godebo et al., 2018)
1,2,4&7	0.81	1973, 1984, 2000 & 2014	(Tolessa et al., 2017)
1,2,4&7	1292.14	1984,1998, 2013&2021	(Debie and Anteneh, 2022)
1,2,4,6&7	4318.92	2000, 2010 &2020	(Alebachew et al., 2022)
1,2,3,4,6&7	281.53	1988,1998, 2008 & 2018	(Aneseyee et al., 2019)
1,2,4&7	532.78	1985,2000 & 2015	(Gashaw et al., 2018)
1,3,4&7	27.73	1985, 2000& 2016	(Solomon et al., 2019)
1,3,4,6&7	435.23	1973, 1986, 2000 & 2012	(Kindu et al., 2016)
1,2,4,6,7&8	1781.79	1985 & 2010	(W/yohannes et al., 2020)
1,2,4,6&7	207.65	1973, 1990, 2005 & 2020	(Mekuria et al., 2021)
1,2,4,5,6&7	2376.81	1986, 2001, 2011 & 2021	(Biratu et al., 2022)
1,2,4&7	774.13	1995,2008 & 2020	(Belay et al., 2022)
1,4,6&7	40.70	1985, 1995, 2010 & 2022	(Admasu et al., 2023)
1,4&7	1.86	1991, 2003 & 2020	(Mathewos and Aga, 2023)
1,4&7	390.68	1973, 1995&2015	(Muleta and Biru, 2019)
1,2,4&7	6.35	1973,1986,2001 &2015	(Tolessa et al., 2021)
4,5,6&7	42.86	1984,1994,2004 & 2019	(Assefa et al., 2021)
1,2,4,5,6,7&8	4953.49	1973, 1986 ,2000 &2017	(Tolessa et al., 2018)
1,4,6&7	185.64	1973,1986,2001&2016	(Negash et al., 2020)
1,2,4,5,6,7&8	201.08	1986,1994,2009 & 2019	(Mengist et al., 2022)
1,4,6&7	9.42	1985,1995, 2010 & 2022	(Admasu et al., 2023)
1,2,4,5,6&7	185.54	1986 & 2016	(Temesgen et al., 2018)
1,2,3,4,6,7&8	2615.03	1986 & 2016	(Shiferaw et al., 2021)

*Extreme values /outliers/ were removed in each step of the analysis. Note; 1 = Forest land, 2 = Bush/ shrub lands, 3= Woodland, 4 = Grassland, 5 = Wetland, 6 = Waterbody, 7 = Cultivated land, and 8= Settlement/ Built up/ Area

All the statistical calculations, including outlier detection, were performed in STATA (Version 14). Moreover, the procedures and empirical formulas applied for price standardization are available in (Brander, 2004; Groot et al., 2020). The datasets were also obtained from (https://www.imf.org/http://faostat.fao.org/), which is a reliable and commonly used database (Groot et al., 2020; Kindu et al., 2016). Ultimately, the standardized equivalent factors at the national level were developed by taking the average value of the initial equivalent factors obtained from the area of each LULC type (Table 1) and. the literature (Table 2). Table 3 displays the final equivalent factors.

Table 3

Equivalent factors for different land use and cover types in Ethiopia*

	Ecosystem/land/ types									
Ecosystem services	CL	FL	BS	WL	GL	LM	WeL	WA	BL	SA
Water supply	1.229	0.220	0.117	0.081	0.270	0.015	2.625	2.819	0.267	0.014
Food production	1.000	0.741	0.684	0.083	0.965	0.000	1.261	1.843	0.000	0.010
Raw material	1.084	1.893	0.587	4.630	0.182	0.017	1.317	0.091	0.017	0.005
Genetic resources	0.307	0.565	0.492	0.274	0.402	0.000	0.257	0.005	0.000	0.000
Water regulation	0.580	0.161	0.089	0.145	0.030	0.000	1.525	7.519	0.000	0.010
Waste treatment	2.657	0.499	1.233	0.311	0.457	0.000	3.158	3.166	0.000	0.003
Erosion control	0.533	1.215	0.919	0.498	0.179	0.002	0.251	0.194	0.000	0.000
Climateregulation	1.711	0.778	0.821	0.923	0.557	0.062	1.083	0.541	0.000	0.463
Biological control	0.857	0.118	0.073	0.015	0.149	0.000	4.793	0.242	0.000	0.000
Gas regulation	0.995	4.720	0.301	1.290	0.065	0.000	0.135	0.050	0.000	0.097
Disturbance regu	2.042	0.250	0.129	0.086	0.031	0.000	4.555	0.061	0.000	0.103
Nutrient cycling	0.148	0.437	1.938	0.390	0.169	0.000	0.271	0.000	0.000	0.000
Pollination	1.460	0.288	0.099	0.111	0.136	0.005	0.002	0.667	0.000	0.000
Soil formation	0.548	0.118	0.143	0.033	1.488	0.124	0.099	1.263	0.000	0.000
Habitat/refugia	0.000	0.129	0.756	0.864	0.672	0.010	1.383	0.237	0.000	0.000
Recreation	1.515	0.600	0.629	0.266	0.054	0.016	0.386	4.181	0.000	2.974
Cultural	2.045	0.028	0.162	0.139	0.182	0.025	0.548	0.156	0.000	0.000
Medical	0.018	1.167	0.010	0.620	0.003	0.000	0.338	0.001	0.000	0.000
Spiritual	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000
Aesthetic	0.366	0.000	0.060	0.025	0.000	0.000	0.006	0.111	0.041	0.164
Main species	0.003	0.625	0.000	0.029	0.000	0.000	0.026	0.045	0.000	0.000
Cognitive dev’t	0.004	0.029	0.277	0.011	0.378	0.013	0.075	0.007	0.000	0.021
Existence	2.203	0.011	0.007	3.528	0.082	0.003	0.001	0.200	0.000	0.000

*Note: in all steps of equivalent factor determination, outliers were checked and removed. CL= Cultivated land, FL=Forest land, BS= Bush and shrub, WL= woodland, GL= grassland, LM= Lenich and Mosses, WEL= wetland, WA=water Areas, BL= barren land and SA= settlement/ built up/ areas

Determination of Equivalent Coefficients

It has been noted that the ecological conditions, and communities’ socioeconomic status and perception of the services provided by each land type determine the monetary value of ES in a given landscape (Kindu et al., 2016; Ma & Zhang, 2023; Sarah et al., 2020). Therefore, taking into account the biophysical, socioeconomic, and cultural contexts at the local level and adjusting the differences with the national level are necessary to develop an effective equivalent coefficient (Shi et al., 2022; Xie et al., 2017). Accordingly, in this research, the Net Primary Production (NPP), demographic, social, and economic variables were included to construct the equivalent coefficients for the study area and surrounding districts.

Baseline Value

Empirical studies have confirmed that the average economic value of food grains per unit area can be taken as a good baseline value for establishing equivalent coefficients (Gaodi et al., 2003; Liu et al., 2020; Wu et al., 2013; Xie et al., 2017). This is because the value of food production is easily traceable in well-functioning markets (Xie et al., 2017). It is also assumed that the output of natural products /services/ of any ecosystem can be equivalent to the net value (excluding human input cost) of the grain output per unit area from agricultural land (Niu et al., 2022; Shao et al., 2020).

Accordingly, the baseline value for this study was calculated by selecting five major crops: Barley, Maize, Sorghum, Teff, and Wheat, which share more than 75% of the cultivated land and are used as staple food consumption in the surrounding areas of NNP. For the baseline value determination, the Gamo zone, Amaro and Gelana districts were used because of their geographical proximity. In addition, several studies confirmed that among the communities living the surrounding areas, the Gamo Community from Gamo Zone, Kore Community from Amaro District and Guji Community from Gelana District have strong and long-lasting economic, sociocultural, health treatment and recreational attachments with NNP (Deribew, 2019; Fetene et al., 2015; Mekonnen, 2022; Solomon & Dereje, 2015; Tsegaye et al., 2017; Wana, 2007). Thus, using the food crop production value from these administrative units is important to establish a rational baseline value. In this study, the average value of long-term recorded data (2002 to 2020) was used to offset /minimize/ the effects of different factors on yield and price of selected crops over time, as recommended by (Niu et al., 2022; Yang et al., 2022). Additionally, the calculated average price ($ha^{-1}yr^{-1}$) was also adjusted by the average producer price index (PPI) of the selected crops to control the effect of price inflation (Kindu et al., 2016; Shao et al., 2020).

Finally, the baseline value was computed by using the formula given in equation (2). (Ma and Zhang, 2023; Shao et al., 2020; Xie et al., 2017), and the result was **US$ 135.12 $ha^{-1}yr^{-1}$** (Table 4). The datasets that were used for the baseline value calculation were taken from Ethiopian Statistical Agency (www.statsethiopia.gov.et), FAOSTAT (https://www.fao.org/faostat/), and also different statistical documents produced by governmental offices at district, zonal, and regional levels.

$$E_t = \frac{1}{7}\sum_{i=1}^{n}\frac{m_i p_i q_i}{M} * PPI \qquad (2)$$

Where, E_t is the economic value of crop yield per area (US$/ha), *i* is the crop type *(i= 1, 2,3...n)*, m_i is the total area (ha) of crop *i*, p_i is the price of crop *i* in (US$/t), q_i is yield of crop *i* (t/ha) and *M* is total area covered by all selected crops.

Table 4
Economic value of crop yield per unit area (from 2002 to 2020)

Year	Total value of each crop (in x10^{6}US$)					Total value (in x10^{6}US$)	Total area (million ha)	economic value of crops (US$/ha/yr)
	Teff*	Barely	Wheat	Maize	Sorghum			
2002	5.240	2.238	1.241	3.637	2.067	14.423	0.153	94.277
2003	5.173	3.437	2.635	4.048	3.837	19.130	0.128	149.750
2004	10.394	4.070	3.599	1.592	10.097	29.752	0.139	214.726
2005	6.222	3.724	2.946	4.357	3.451	20.700	0.132	157.212
2006	8.374	3.994	4.475	5.413	3.914	26.170	0.138	190.127
2007	17.221	6.036	9.670	17.548	8.807	59.282	0.140	423.088
2008	31.799	7.595	11.807	29.055	15.279	95.535	0.142	674.251
2009	32.506	11.513	9.177	25.059	8.260	86.515	0.156	553.334
2010	24.929	12.772	6.814	17.968	6.122	68.606	0.173	396.232
2011	49.926	4.768	6.559	17.877	10.770	89.900	0.169	532.847
2012	31.183	7.259	8.624	33.953	16.950	97.969	0.162	605.564
2013	155.446	7.870	10.248	39.589	8.834	221.987	0.159	1398.518
2014	164.639	7.203	5.338	60.233	10.923	248.334	0.175	1416.231
2015	135.534	6.977	5.633	43.870	10.659	202.672	0.164	1237.076
2016	95.230	13.842	8.343	39.650	10.167	167.231	0.167	1003.193
2017	159.954	12.068	9.853	44.838	4.006	230.719	0.156	1474.439
2018	92.783	10.227	12.588	67.356	2.117	185.072	0.165	1119.499
2019	160.445	15.434	21.427	30.362	3.045	230.713	0.132	1746.135
2020	57.167	16.472	19.930	52.468	18.792	164.829	0.142	1164.522

*The prices for Teff were collected from the woreda and zonal agricultural bureaus

The change in NPP has been considered as an effective proxy to understand and analyze the impact of LUC on ES and functions in both spatial and temporal scales (Hailu et al., 2015; Niu et al., 2022). NNP contains various determinantal factors of the ES provided by an ecosystem/land type/ (Martínez et al., 2019). It is also sensitive to the changes in basic elements for ecosystems wellbeing and their capacity for providing services (Wang et al., 2022). For example, changes in vegetation types, density and distribution (Li etal.,2015), climate (temperature, precipitation and radiation) (Turner et al., 2006; L. Wang et al., 2013), soil nutrients (Fu et al., 2013; Xie, et al., 2017). Apart from these, NPP is a crucial indicator of Ecosystems' resilience to pressures posed by human activities and climate change (Hailu et al., 2015; Yan et al., 2019). Considering its strong relation with ecosystem health and services, NPP has been used as an important ecological adjustment proxy to ESV coefficients at local, regional and national levels by several researchers (Li et al., 2015; Niu et al., 2022; Sun et al., 2021; P. Wang et al., 2022; W. Zhou et al., 2023; Xie et al., 2017).

Table 5

Ecological adjustment index

Land Type	Total mean NPP (KGC/m^2)			Annual mean NPP ($KGC/m^2/yr$) (2002- 2020)			productivity index
	National level	Study area		National level	Study area		
Forest land	22.547	25.267		1.187	1.33		1.589
Shrub land	7.441	10.061		0.392	0.53		0.633
Woodland	25.628	22.097		1.349	1.163		1.39
Grassland	10.167	16.584		0.535	0.873		1.043
Cultivated land	13.711	16.891		0.722	0.889		1.062

In this study, the NPP of forest land, woodland, shrubland, grassland, and cropland was used as a proxy for computing the ecological adjustment index (Table 5). The NPP data from remote sensing databases are more preferable and reliable when field-based data are not feasible due to various reasons (Sun et al., 2021), particularly in countries like Ethiopia, where biophysical data are scarce, and field surveys are expensive. Therefore, in this study, the 0.5 km resolution NNP data with size coefficient (0.0001) from MOD17A3's global database was extracted (from 2002 to 2020) by using LULC types from the database of MCD12Q1 (https://lpdaac.usgs.gov/data access/. After the data processing was performed in ArcGIS 10.8, the ecological adjustment index was calculated using the formula given in Equation (3), following, (Gaodi et al., 2003; Liu et al., 2020).

$$E_K = \frac{NPP_k}{NPP_{mean}} \qquad (3)$$

Where, E_K is the ecological adjustment index of k^{th} land type in the study area, NPP_k is the mean NPP of the k^{th} land type in the study area, NPP_{mean} is the average of the total mean NPP of land types at the national level (for this study, Ethiopia)

Socioeconomic Adjustment Index

The ability and willingness of local people to pay for ecosystem services significantly influence their economic value (Jiang et al., 2021; Song et al., 2008). Moreover, several researchers agreed that people's ability and willingness to pay are mostly related to their economic and social development status, respectively (Kindu et al., 2016; Liu et al., 2020; Niu et al., 2022; Shi et al., 2022; Song et al., 2008; Zhao et al., 2021). In this study, the socioeconomic adjustment index (*SE*) was computed based on the empirical formula in Equation 4 (Liu et al., 2020) by using the outputs from Equations 5 to 10.

$$S_E = S_i * E_i \qquad (4)$$

The economic adjustment index **(E_i)** was computed by using the GDP per capita value of the country (Ethiopia) and the Southern regional state (where NNP and surrounding districts are located). Equation 5 was applied to calculate E_i, following (Gaodi et al., 2003; Li et al., 2015; Ma & Zhang, 2023), and the results are found in Table 6.

$$E_i = \frac{GDP_r}{GDP_n} \qquad (5)$$

Where S_E is the socioeconomic adjustment index, E_i is the economic adjustment index (ability to pay), S_i is the social development index (willingness to pay), GDP_n is the per capita at the national level, and GDP_r at the regional level.

Table 6

Economic adjustment index

GDP-per capita (US$)	Year		
	2002	2020	mean
GDP-per capita at study area's region	168.452	209.271	188.862
GDP-per capita at the national level	426.320	727.357	576.839
Ability to pay adjustment index	0.395	0.288	0.341

The social development stage index was used for social adjustment (P_t) and calculated by applying the formulas given in Equations 6 to 10. This index is more useful for social adjustment because it consists various socioeconomic variables and key coefficients that indicate the social development level and people's living standard in rural and urban areas (Li et al., 2015; Niu et al., 2022). The computed results for P_t are presented in Table 7.

$$S_i = \frac{l_{study\ area}}{l_{national}} \qquad (6)$$

$$l_{study\ area} = l_1 h_1 + l_2 h_2 \qquad (7)$$

$$l_{national} = l_3 h_3 + l_4 h_4 \quad (8)$$

$$L = \frac{1}{1 + ae^{-b(1/E_n - 2.5)}} \quad (9)$$

$$E_n = \frac{f_e}{t_e} \quad (10)$$

Where, S_i is the social development adjustment index, l_1 and l_2, and l_3 *and* l_4, are social development status related to willingness to pay in urban and rural areas, respectively, h_1 and h_2, and h_3 and h_4 are proportions of urban and rural population, respectively, 1 is the maximum value of *l*, represents the willingness to pay in the stage of rich society, E_n is the Engel coefficient, a and b are constants (equal to 1), e is the natural logarithm (2.718), f_e and t_e are food and total expenditure of people, respectively

Table 7

Social development adjustment index

Study area				National level		
Index	2002	2020		Index	2002	2020
Urban angel coefficient	0.698	0.485		Urban Agnel coefficient	0.626	0.626
Rural angel coefficient	0.593	0.522		Rural Angel coefficient	0.573	0.573
h_1	0.094	0.179		h_3	0.155	0.222
h_2	0.906	0.821		h_4	0.845	0.778
l_1	0.193	0.113		l_3	0.168	0.097
l_2	0.141	0.128		l_4	0.168	0.097
$l_{study\ area}$	0.146	0.126		$l_{national}$	0.168	0.097
Social development stage factor						1.080

The data utilized to calculate the socioeconomic adjustment index were obtained from the Ethiopian Statistical Agency (www.statsethiopia.gov.et) and FAOSTAT (https://www.fao.org /faostat/) and other statistical documents produced by the government offices and NGOs at the district, regional, and federal. Finally, the ESV equivalent coefficients (Table 8) for twenty-three individual ecosystem services (*f*) and six land use types in the study areas were calculated by using equations 11 and 12, (Li et al., 2015; Niu et al., 2022; Shao et al., 2020; Shi et al., 2022; Si et al., 2014).

$$VC_K = \sum_{k=1}^{n} \sum_{f=1}^{n} VC_{kf} \quad (k = 1, \ldots, n; j = 1, \ldots, n) \quad (11)$$

$$VC_{Kf} = E_{if} * Et * SE * P_k \quad (i = 1, \ldots, n; f = 1, \ldots, n) \quad (12)$$

Where, VC_K is the ESV of Kth land type (US$ ha^{-1} yr^{-1}), VC_{Kf} is the ESV of individual ecosystem service (f) in Kth land type (US$ ha^{-1} yr^{-1}), P_K is the ecological adjustment index of Kth land use type, E_{if} is equivalent factor for individual ecosystem service (f) in Kth land type at national level, E_t is baseline value, and S_E is socioeconomic adjustment index

Table 8

Equivalent coefficients (US$ha^{-1}yr^{-1}) for NNP and surrounding districts

Ecosystem Service type	FL	BS	WL	GL	CL	WA
Water supply	14.044	2.982	4.533	11.338	52.549	113.497
Food production	47.407	17.432	4.645	40.523	42.758	74.202
Raw material	121.132	14.960	259.110	7.643	46.349	3.664
Genetic resources	36.166	12.539	15.334	16.881	13.127	0.201
Water regulation	10.329	2.268	8.115	1.260	24.799	302.726
Waste treatment	31.916	31.424	17.405	19.191	113.607	127.468
Soil erosion control	77.754	23.421	27.870	7.517	22.790	7.811
Climate regulation	49.758	20.924	51.654	23.390	73.158	21.781
Biological control	7.568	1.860	0.839	6.257	36.643	9.743
Gas regulation	301.938	7.671	72.193	2.730	42.544	2.013
Disturbance regu	15.984	3.288	4.813	1.302	87.311	2.456
Nutrient cycle	27.972	49.391	21.826	7.097	6.328	0.000
Pollination	18.394	2.523	6.212	5.711	62.426	26.854
Soil formation	7.563	3.644	1.847	62.485	23.431	50.850
Habitat/refugia	8.267	19.267	48.352	28.219	0.000	9.542
Recreation	38.405	16.030	14.886	2.268	64.778	168.333
Cultural	1.782	4.129	7.779	7.643	87.439	6.281
medicine	74.651	0.255	34.697	0.126	0.770	0.040
spiritual	0.087	0.000	0.000	0.000	0.000	0.201
Aesthetic	0.000	1.529	1.399	0.000	15.649	4.469
Main species	39.992	0.000	1.623	0.000	0.128	1.812
Cognitive development	1.839	7.059	0.616	15.873	0.171	0.282
Existence	0.673	0.178	197.439	3.443	94.195	8.052

FL=Forest land, BS= Bush and shrub, WL= woodland, GL= grassland, CL=Cultivated land WA= Water areas

Assessment of Ecosystem Services Value (ESV) in NNP

Analyses the Change in Total ESV

The total ESV for the land use types and individual ecosystem services in 2002, 2020 and 2040 were calculated by Equation (13) and Equation (16), respectively. These empirical formulas were used by several researchers (Costanza et al., 1997; Gashaw et al., 2018; Kindu et al., 2016; Rotich et al., 2022; Tolessa et al., 2017). The amount of change in ESV during the study time intervals was calculated using the formula given in Equation (14).

$$ESV_t = \sum_{k=1}^{n} (A_k + Vc_{\mathrm{k}}) \quad (13)$$

Where, ESV_t represents total ecosystem service value, A_k represents area (ha) of kth land use type, and VC_k is value coefficient (US\$ ha^{-1} yr^{-1}) for kth land use type.

$$\mathbf{E}\mathrm{SVr} = \left(\frac{ESV_{fr} - ESV_{ir}}{ESV_{ir}}\right) \quad (14)$$

Where, ESV_r is the percentage of change in ESV, $\mathrm{ESV_{ir}}$ is the ESV at the initial reference year (t_1), and ESV_{fr} is the ESV at the final reference year ($\mathrm{t_2}$). Moreover, the rate of annual change (r) of ESV was analyzed through equation (15), which is derived from the compound interest law (Puyravaud, 2003).

$$r = \left(\frac{1}{t_2 - t_1}\right) * ln\left(\frac{ESV_{fr}}{ESV_{ir}}\right) \quad (15)$$

$$ESVf_t = \sum_{k=1}^{n} (A_{kft} * Vc_{f\mathrm{k}}) \quad (16)$$

Where, $\mathrm{ESV_{ft}}$ is the ESV of individual ecosystem service (f) at time t, $\mathrm{A_{kft}}$ is the area (ha) of land use type k at time t, and $\mathrm{VC_{fk}}$ is the ESV coefficient value of f (US\$ ha^{-1} yr^{-1}) for land use type k (Table 8).

ESV Flow Analysis

To examine the impact of LUC directions (transition from and to) on the ESV gain and loss, the ESV flow analysis model was applied based on equation 17. This model is effective and essential for understanding the effect of LUC dynamics on the spatiotemporal changes in ESV (Zhao et al., 2020; Zhiqian et al., 2023).

$$PL_{ij} = A_{ij}\,(VC_j - VC_i) \quad (17)$$

Where, PL_{ij} is the gain/loss of ESV after the land use type i is transferred to land type j, VC_i and VC_j are the ESV coefficients of land use type i and j, respectively, and A_{ij} is the area (ha) transferred from land type i to j.

Sensitivity Analysis

During the valuation of ecosystem services and goods, there may be uncertainties and limitations (Si et al., 2014). Undertaking sensitivity analysis, therefore, is essential to ensure the reliability of coefficients and to minimize limitations (Kindu et al., 2016; Li et al., 2010). Accordingly, in this study, the Coefficient of Sensitivity Analysis (CS) method was applied. This method is commonly used in ecosystem valuation studies (Kindu et al., 2016; Si et al., 2014; Zhang et al., 2015), based on the standard economic concept of elasticity (Kreuter et al., 2001). The formula for CS analysis is given in Equation (18).

$$CS = \frac{(ESV_j - ESV_i)/ESV_i}{(VC_{jk} - VC_{ik})/VC_{ik}} \quad (18)$$

Where, CS is the coefficient of sensitivity, VC is the coefficient, ESV is the estimated ecosystem service value, i and j are the initial and adjusted values, respectively, and K is the land use type.

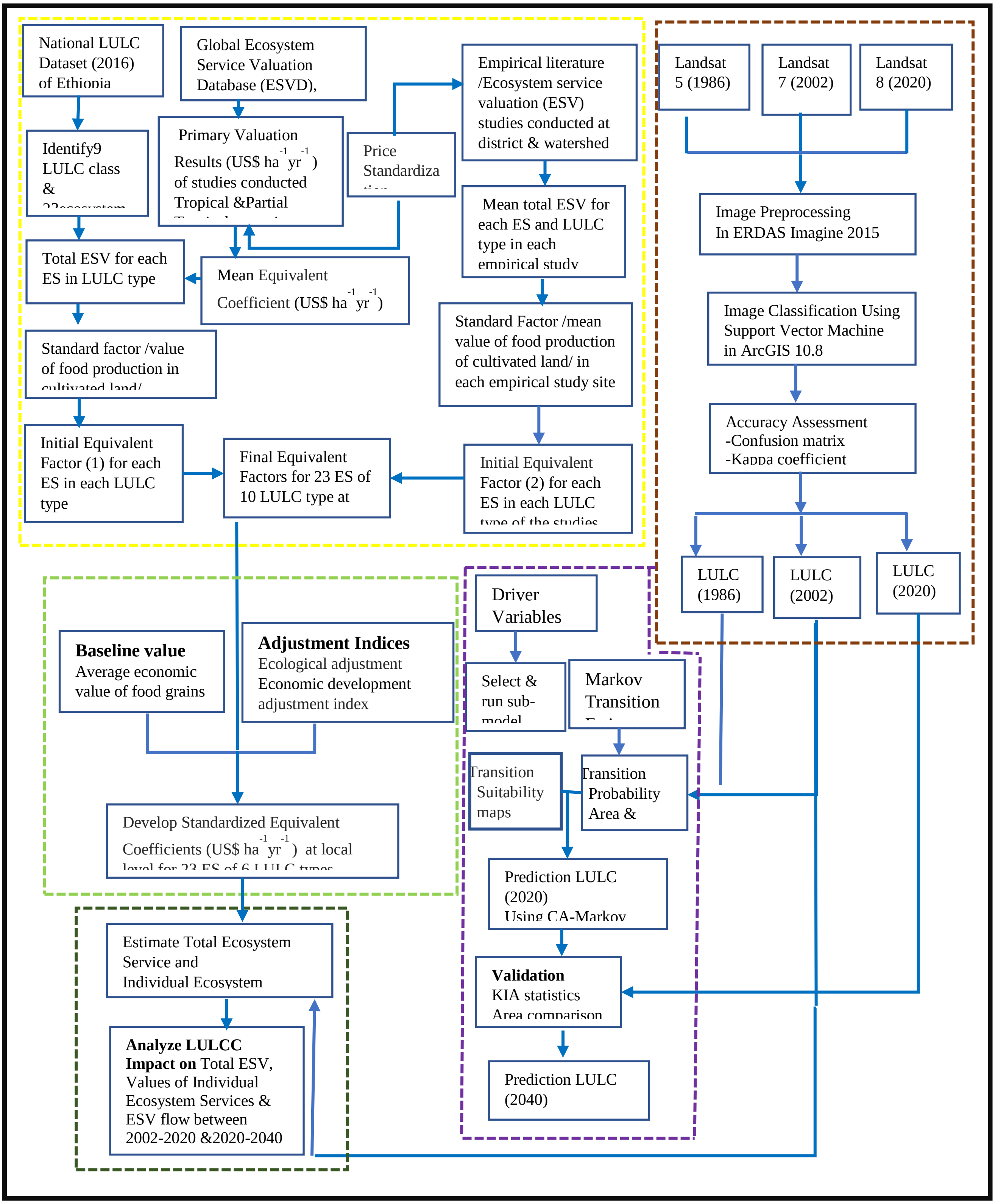

Figure 2: Flow chart showing the steps to develop equivalent coefficient at the district level and analyze the LUCC on ESV at NNP

RESULTS

Changes in Land Use Types between 2002-2040

The results of the study displayed that from 2002 to 2040, the study area has been under noticeable land transitions (gains and losses) (Table 10). At the initial reference year of the study (2002), woodland covered the largest portion (38.44%) of the study area. However, it exhibited the highest and continuous reduction (54.2%) throughout the study period, followed by forest and grassland. On the contrary, by overtaking sizable land from forest, woodland an d grassland, bush/shrubland has exhibited a continued expansion and taken the largest portion of the study area in 2020 (35%) and 2040 (43.64%)) with the highest percentage of increment (123%) and annual rate of change (2.2%) between 2002 and 2040. The expansion of bush/shrub at the expense of NNP's, key natural resources for biodiversity conservation and generation of multifold ES, has become one of the leading threats, and aggravated by the expansion of invasive species (Deribew, 2019; Fetene et al., 2015; Mekonnen, 2022; Seid et al., 2024). Despite the study area being legally protected for biodiversity preservation and protection of rare endemic species, the LUC analysis revealed agricultural land expansion by 274 ha (33.08%) in the FTIS, and 212 ha (19.26%) in the STIS, particularly by displacing the natural forest and woodland located at the Eastern edge of the park.

Results of Sensitivity Analysis

When the Coefficient of Sensitivity value (CS) is greater than 1, it indicates the estimated ESV is elastic /highly sensitive/ with respect to changes in equivalent coefficients and the opposite is true if the CS value is less than 1(Si et al., 2014). Like previous studies, the CS analysis was undertaken with ± 50% adjustment of the values equivalent coefficients that were developed for the study site and surrounding districts. As displayed in Table 9, the CS value of all land use types was less than 1. Woodland (0.47 - 0.025) and water body (0.29 - 0.41) had the higher CS values, which were mainly attributed to their larger area and higher value of coefficients. Overall, the results of CS analysis demonstrated that the estimated ESV were inelastic (i.e. low sensitive) with respect to changes in equivalent coefficients, indicating the reliability of the developed coefficients for the study area.

Table 9
Percentage change in total ESV and coefficient sensitivity (CS) after 50% adjustment of ESV coefficients (VC)

Change in value coefficients	2002			2020			2040	
	%	CS		%	CS		%	CS
Forest VC ± 50%	4.34	0.09		3.45	0.07		3.06	0.06
Bush/Shrub VC ± 50%	3.64	0.07		7.29	0.15		9.46	0.19
Woodland VC ± 50%	23.30	0.47		15.40	0.31		12.65	0.25
Grassland VC ± 50%	2.76	0.06		3.03	0.06		1.86	0.04
Cultivated land VC ± 50%	1.38	0.03		2.09	0.04		2.58	0.05
Water body VC ± 50%	14.57	0.29		18.74	0.37		20.40	0.41

Status of Total Ecosystem Service Value (ESV)

The total ESV for the study area and each land use type in the year 2002, 2020 and 2040 were estimated based on the ESV coefficients developed to study area and the area (ha) of the land use types (Table 10 and Fig. 4). The results of the analysis revealed that the total ESV was US\$ 33.71x10^6 in 2002, 29.64x10^6 in 2020 and also expected to be US\$28,62x10^6 in 2040. In all reference years, the amount ESV contributed to the total ESV had a significant difference among the land use types, which was linked with the capability of each land use type in the provision of the specified ES and change in its size due to LUC being observed in the study area. For example, in 2002, woodland was the highest contributor to total ESV with US\$ 15.71x10^6 (47.01%), followed by water, forest, and bush/shrubland with the value of US\$9.83x10^6 (29.15%), 2.93x10^6 (8.69%) and 2.46x10^6 (7.28%), respectively.

Water body shared the largest contribution in 2020 and 2040 with its ESV of US\$11.11 x10^6 (37.48%) and 11.68x10^6 (40.79%), respectively. Similarly, the value of bush/shrubland i ncreased to US\$ 4.32x10^6 (14.59%) in 2020, and it is also expected to be US\$5.41x10^6 (18.92%) in 2040, which is mainly due to its larger proportionate size at the initial time and expansion at the expense of forest, woodland and grassland. It has also been expected that the contribution of woodland and forest will decrease to 25.61% and 6.12% in 2040 from its contribution of 31.16% and 6.89% in 2020 for the total ESV. In general, the results confirmed that during the study time, the contribution to total ESV by the vegetation land use types declined from 68% in 2002 to 58% in 2020 and then to 54% in 2040, while the contribution by water and cultivated land increased.

Table 10

Land cover (ha) (adopted from Seid et al. (2024 & 2025), and total ESV of land use types in 2002, 2020 & 2040

Land use type		Area(ha)				ESV (x10^6 US$ yr^{-1})				ESV (%)		
		2002	2020	2040		2002	2020	2040		2002	2020	2040
Forest		2540.43	1771.92	1518.12		2.93	2.04	1.75		8.69	6.89	6.12
Bush/Shrub		8188.29	14417.55	18058.14		2.46	4.32	5.41		7.28	14.59	18.92
Woodland		15835.68	9203.76	7301.88		15.71	9.13	7.24		47.01	31.15	25.61
Grassland		5565.60	5362.11	3175.47		1.86	1.79	1.06		5.52	6.05	3.71
Cultivated		827.10	1100.70	1312.74		0.93	1.24	1.48		2.76	4.18	5.16
Waterbody		8443.35	9544.41	10034.10		9.83	11.11	11.68		29.15	37.48	40.79
Total		41400				33.71	29.64	28.62				

Changes in Total ESV

The changes in total ESV and each land use type of ESV were calculated in terms of amount (US$), percentage of proportion and rate of annual change during the FTIS, STIS, and the entire time interval of the study(2002 -2040) (Table 11 and Fig.4). The total ESV has shown a continuous reduction throughout the study time, even though positive changes observed in some land use types' ESV. The amount of change during the FTIS was US$ 4.08x10^6 with a 0.72% rate of annual change, which accounted for 12.09% of the total ESV in 2002. Similarly, in STIS, there will be a loss of about US$ 1.01x10^6 of ESV by 0. 17% of the annual loss rate, which is 3.41% of the total ESV recorded in 2020. Similarly, between 2002 and 2040, the total ESV has declined by US$ 5.09x10^6 (15.09 %) with the annual decreasing rate of 0.43%.

As the results of the analyses shown in (Table 11), among the land use types that exhibited a reduction in ESV, the total amount change, i.e., about US$ 8.47x10^6 of woodland, which is more than half of (53.89%) its value in 2002, has been the highest, followed by forest and grassland between 2002 and 2040. At the FTIS, the ESV of forest, grassland and woodland revealed a sizable reduction by the amount of US$ 0.89x10^6 (30.25%), 6.58x10^6 (41.88%) and 0.07 x10^6 (3.66%) with annual decreasing rate of 2.00%, 3.14% and 0.21%, respectively, even though these land use types are vital to ecosystem services provision and jointly shared above 61% of total ESV of the study area in 2002. In contrast, during the entire period of study, due to vast areal expansion, bush/shrubland is the only vegetation land use type that showed a continuous increment in ESV with the amount of US$2.96x$10^6$ (120.54%), although its ESV coefficient is the lowest (see Table 8). In the FTIS, its value also increased by 76.08% of the value it had in 2002, with the highest rate of change (3.14%), followed by cultivated land and water. Moreover, the results of the study indicated that during the STIS, there will be rising of ESV in water and cultivated lands while dropping is expected in grassland (40.78%), woodland (20.66%) and forest (14.32%), although the amount of change/loss/ in ESV will show a declining trend in forest and woodland.

Table 11

Changes in total ESV and each land use type (2002 – 2040)

Land use type		Change in Total ESV										
		2002 - 2020				2020 - 2040				2002 - 2040		
		x10^6 US$	Proportion (%)	Annual rate(%)		x10^6 US$	Proportion (%)	Annual rate(%)		x10^6 US$	Proportion (%)	Annual rate(%)
Forest		-0.89	-30.25	-2.00		- 0.29	-14.32	-0.77		-1.18	-40.24	-1.35
Bush/shrub		1.87	76.08	3.14		1.09	25.25	1.13		2.96	120.54	2.08
Woodland		-6.58	-41.88	-3.01		- 1.89	-20.66	-1.16		-8.47	-53.89	-2.04
Grassland		-0.07	-3.66	-0.21		- 0.73	-40.78	-2.62		-0.80	-42.94	-1.48
Cultivated		0.31	33.08	1.59		0.24	19.26	0.88		0.55	58.72	1.22
Water		1.28	13.04	0.68		0.57	5.13	0.25		1.85	18.84	0.45
Total ESV		-4.08	-12.09	-0.72		- 1.01	-3.41	-0.17		-5.09	-15.09	-0.43

ESV of Individual Ecosystem Services

The aggregated value (ESV_f) of individual ecosystem services provided by land use types at three reference years and changes during all time intervals of the study presented in (Table 12 and Fig. 3). Concerning the contribution to the total ESV, there has been a deviation among individual ecosystem services with the range of the highest mean contribution of US$ 4.14x10^6 (13.5%) by provision of raw materials to the lowest contribution of US$ 0.0025x10^6 (0.01%) that contributed by spiritual value service. Of the total ESV, individual services which disjoin tedly accounted above 5% in all reference years of the study; material provision, recreation, water regulation, existence value, waste treatment, climate and air quality regulations, and food production services jointly contributed US$ 25.31x10^6 in 2002, 21.72x10^6 in 2020 and US$ 2 0.90x10^6 in 2040, which indicating these services are the major ecosystem services provided by land use types and the leading contributors to the total ESV in the study area comparing with the rest twelve individual ecosystem services (Table 12). Nevertheless, the loss of ESV from the former ecosystem services, i.e., US$3.59x10^6 (14,19%) and 0.82x10^6 (3.78%) was hi gher than the loss of US$ 0.48x10^6 (5.77%) and 0.19x10^6 (2.40%) from the later ecosystem services during the FTIS and STIS, respectively.

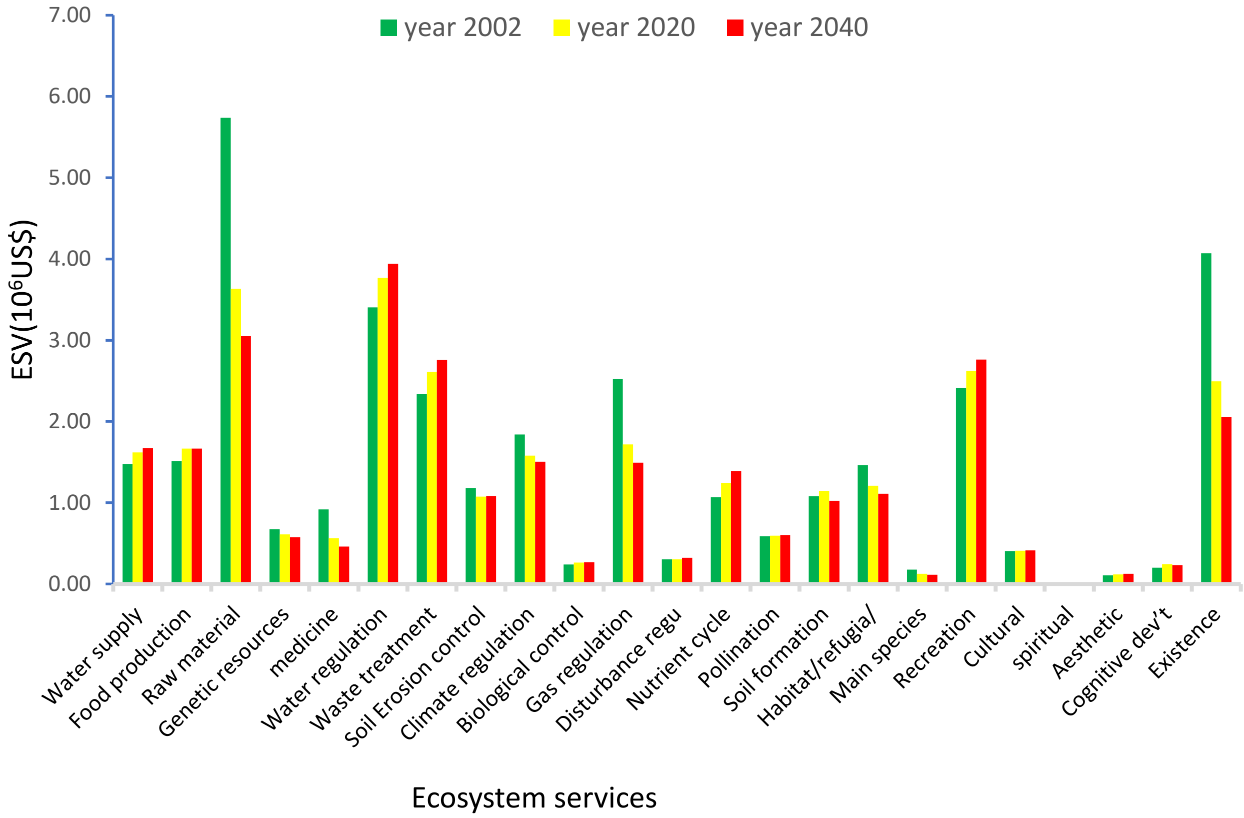

Figure 3 Values of individual ecosystem services

Moreover, the contribution of the four subgroups of ecosystem services to total ESV also had notable differences. As shown in Table 12, among the subgroups, the regulation sup group has been the principal contributor, accounting for 43.20%, 48.28% and 50.26% of the total ESV in 2002, 2020, and 2040, respectively, with the average value of US$14.42x10^6 between 2002 and 2040. Subsequently, the 2nd and 3rd contributors were the provisioning and cultural, followed by the habitat sup-group with the average value of US$8.61x10^6, 6.23x10^6, and 1.40x10^6, respectively (Table 12).

Moreover, the study's results displayed that ESV changes have been detected in all individual ecosystem services over the study period. However, the total net change i.e., US$ 5.56x10^6 (2 9.94%) and 1.57x10^6 (12.08%) in individual ecosystem services that experienced decreasing t rend was higher as compared with the total net change of US$1.49x10^6 (9.81%) and US$0.56 x10^6 (3.39%) in individual services exhibited increasing trend during the FTIS and STIS, respectively. Among the individual ecosystem services, the highest amount of ESV loss was observed in raw material provision by the value of US$2.10x10^6 (36.69%) with 2.54% of the annual rate of loss, followed by existence value, air quality regulation, and medicinal services during the FTIS, which significantly attributed to forest and woodland degradation. On the contrary, among the individual services that show an increasing trend in ESV during both timeintervals, the highest amount (US$0.36x$10^6$) was observed in water regulation, followed by US$0.28x$10^6$, 0.22x$10^6$, and 0.14x$10^6$ in waste treatment, recreation, and water supply, respectively.

Table 12

Total ESV of individual ecosystem service (ESV_f in x10^6 US$ yr^{-1}) and the changes between 2002 and 2020 and 2020 and 2040

Ecosystem service		Total ESV_f				Changes in total ESV_f						
		2002	2020	2040		2002 - 2020				2020 - 2040		
						x10^6 US$	Proportion (%)	Annual Rate(%)		x10^6 US$	Proportion (%)	Annual rate(%)
Provisioning services	Water supply	1.48	1.62	1.67		0.14	9.59	0.51		0.05	3.10	0.15
	Food production	1.51	1.67	1.67		0.16	10.33	0.55		0.00	-0.04	0.00
	Raw material	5.74	3.63	3.05		-2.10	-36.67	-2.54		-0.59	-16.11	-0.88
	Genetic resources	0.67	0.61	0.58		-0.06	-9.38	-0.55		-0.03	-5.42	-0.28
	Medicine	0.92	0.56	0.46		-0.35	-38.46	-2.70		-0.10	-18.39	-1.02
	Subtotal	**10.32**	**8.09**	**7.42**		**-2.22**	**-21.54**	**-1.35**		**-0.67**	**-8.31**	**-0.43**
Regulating services	Water regulation	3.40	3.77	3.94		0.36	10.60	0.56		0.17	4.62	0.23
	Waste treatment	2.34	2.61	2.76		0.28	11.81	0.62		0.15	5.57	0.27
	Soil Erosion	1.18	1.08	1.08		-0.11	-8.92	-0.52		0.01	0.55	0.03
	Climate regulation	1.84	1.58	1.51		-0.26	-14.18	-0.85		-0.07	-4.66	-0.24
	Biological control	0.24	0.27	0.27		0.02	10.09	0.53		0.00	0.98	0.05
	Gas regulation	2.52	1.72	1.49		-0.80	-31.85	-2.13		-0.22	-13.08	-0.70
	Disturbance regu.	0.30	0.30	0.32		0.00	1.07	0.06		0.02	6.34	0.31
	Nutrient cycle	1.07	1.24	1.39		0.17	16.37	0.84		0.14	11.62	0.55
	Pollination	0.59	0.60	0.60		0.01	1.23	0.07		0.01	1.37	0.07
	Soil formation	1.08	1.15	1.03		0.07	6.21	0.33		-0.12	-10.65	-0.56
Habitat services	**Subtotal**	**14.56**	**14.31**	**14.39**		**-0.26**	**-1.75**	**-0.10**		**0.08**	**0.56**	**0.03**
	Habitat refugia	1.46	1.21	1.11		-0.25	-17.11	-1.04		-0.10	-8.26	-0.43
	Main species	0.18	0.13	0.11		-0.05	-27.66	-1.80		-0.02	-11.94	-0.64
	Subtotal	**1.64**	**1.34**	**1.22**		**-0.30**	**-18.25**	**-1.12**		**-0.12**	**-8.61**	**-0.45**

Ecosystem service		Total ESV_f			Changes in total ESV_f					
		2002	2020	2040	2002 - 2020			2020 - 2040		
					$x10^6$ US$	Proportion (%)	Annual Rate(%)	$x10^6$ US$	Proportion (%)	Annual rate(%)
Cultural services	Recreation	2.41	2.63	2.76	0.22	8.92	0.47	0.14	5.24	0.26
	Cultural	0.41	0.41	0.42	0.00	0.62	0.03	0.01	1.42	0.07
	spiritual	0.00	0.00	0.00	0.00	8.07	0.43	0.00	3.69	0.18
	Aesthetic	0.11	0.12	0.13	0.01	11.07	0.58	0.01	8.88	0.43
	Cognitive dev’t	0.20	0.25	0.23	0.04	21.83	1.10	-0.01	-5.27	-0.27
	Existence	4.07	2.49	2.05	-1.57	-38.70	-2.72	-0.44	-17.75	-0.98
	Subtotal	**7.20**	**5.89**	**5.59**	**-1.30**	**-18.08**	**-1.11**	**-0.30**	**-5.12**	**-0.26**
	Total	**33.77**	**29.63**	**28.62**	**-4.14**	**-12.26**	**-0.73**	**-1.01**	**-3.41**	**-0.17**

Implications of Land Use Change on ESV

The gain-loss flow matrix in Table 13 and spatial distribution maps of ESV in Fig.4 show that both the magnitude and direction of land transitions in the study area have a considerable effect on the amount and spatial distribution of the total ESV. For example, the land transitions from forest and woodland to other land types have a negative impact on the amount of total ESV. In other words, the land losses for these land types have contributed to the loss of ESV, and the opposite is true for the gain transitions from other types. On the contrary, the conversions from bush/shrub and grassland to other land use types have a positive contribution to the total ESV. For instance, the land transitions from bush/shrubland to all others resulted in an increase of total ESV with the value of US$ 1067.46x10^3 and 1750.10 x10^3 at FTIS and STIS, respectively.

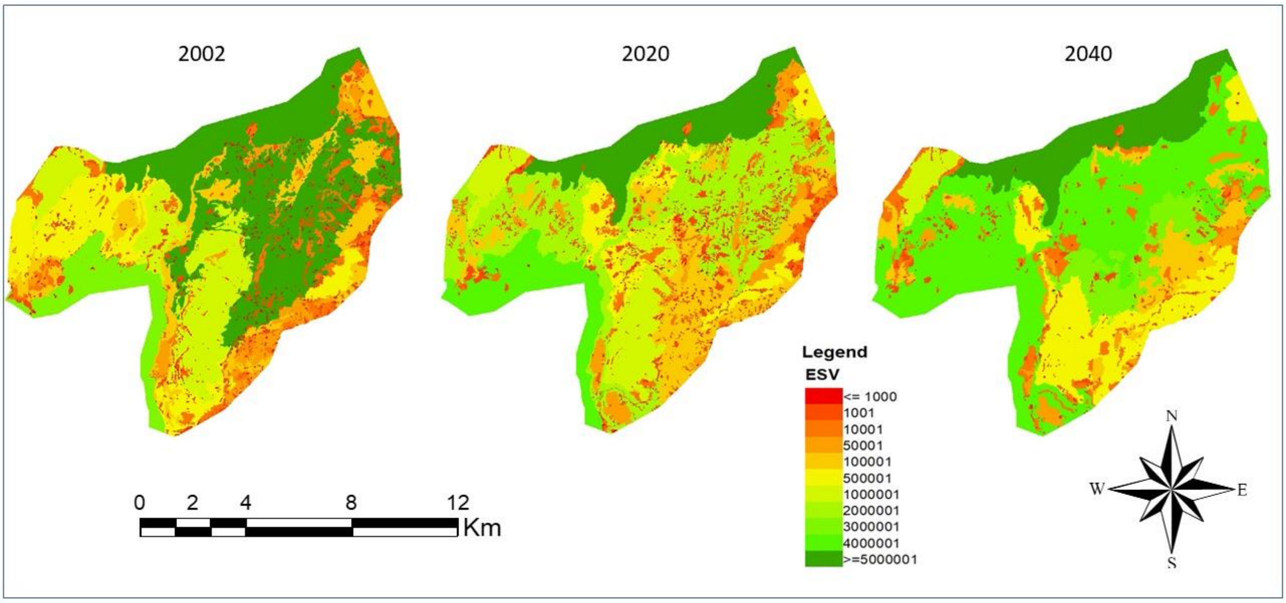

Figure 4
Spatial distribution of ESV (US$) in 2002, 2020 and 2040

The results of the flow analysis in Table 13 revealed that, except towards water bodies, the land transitions from forest to all types and from woodland to grassland and bush/shrubland caused for loss in total ESV in both time intervals of the study. The same is true from grassland to bush/shrubland, from cultivated to bush/shrub, woodland and grassland, and from water to all other types. The land transition from woodland to bush/shrubland accounted for the highest ESV loss (US$4663.31 x 10^3 and US$2785.59x 10^3) during the FTIS and STIS, respectively. In terms of gain, the conversion to woodland from bush/shrub shared the highest net gain (US$637.30x$10^3$ and 1105.04 x10^3), followed by grassland (US$560.47x$10^3$ and 510.48x10^3) at the FTIS and STIS, respectively.

Table 13

The gain and loss flow of ESV (x10^3 US$) between 2002 and 2020, 2020 and 2040 (*in Italic*)

Land use type			Final year of the time interval						
			Forest	Bush/shrub	Woodland	Grassland	Water	Cultivated	Total value
Initial year of the time interval	Forest		*	-267.53	-36.10	-68.65	3.48	-5.38	-374.19
			*	*-216.31*	*-29.40*	*-64.90*	*0.07*	*-1.70*	*-312.24*
	Bush/shrub		126.93	*	637.30	5.86	281.77	15.60	1067.46
			212.86	*	*1105.04*	*5.29*	*391.71*	*35.20*	*1750.10*
	Woodland		25.98	-4663.41	*	-814.59	58.86	27.45	-5365.71
			5.25	*-2785.59*	*	*-214.59*	*5.01*	*8.83*	*-2981.10*
	Grassland		35.80	-25.70	560.47	*	87.76	37.28	695.61
			36.32	*-63.40*	*510.48*	*	*23.21*	*66.09*	*572.70*
	Water		-0.15	-6.06	-0.11	-0.22	*	0.00	-6.54
			-0.03	*-11.27*	*-1.45*	*-3.36*	*	*-0.41*	*-16.53*
	Cultivated		0.09	-11.81	-7.61	-74.06	0.88	*	-92.51
			0.00	*-15.08*	*-1.76*	*-7.33*	*0.43*	*	*-23.73*
	Total		188.65	-4974.52	1153.96	-951.66	432.75	74.95	-4075.87
			254.40	*-3091.65*	*1582.90*	*-284.89*	*420.43*	*108.01*	*-1010.79*

*The amounts of ESV transformed between the same land use type are not included

DISCUSSIONS

In Ethiopia, there has been an increasing trend of studies on ecosystem services valuation (ESV) linked with land use change (LUC). However, there is a lack of attempts to develop site-specific valuation coefficients. This study is the first attempt in Ethiopia to quantify the impact of LUC on ESV at Nech Sar National Park (NNP) by using equivalent coefficients developed for 23 ecosystem services (ES) at the district level based on equivalent factors that were constructed at the national level, baseline vale/per unit area value of food crops/ and four difference adjustment indices.

The result of the study revealed that the LUC being observed (2002 to 2040) in NNP, particularly the continued loss in forest and woodland and expansion in shrub and cultivated lands, has negative effects on its capacity to biodiversity conservation and provision of ES. Several studies found similar findings regarding LUC dynamics in PAs of Ethiopia (Debebe et al., 2023; Fetene et al., 2015; Menbere, 2021; Temesgen et al., 2022). During the FTIS, associated with LUC, the total ESV was declined by 12.09 % from its value of US$33.71x$10^6$ in 2002. Similarly, during the STIS, a loss of US$ 1.01x10^6 is expected from its total value of US$29.64 x$10^6$ in 2020. In line with the findings of this study, previous studies (Alebachew et al., 2022; Gashaw et al., 2018; Kindu et al., 2016; Mekuria, 2013; Mekuriaw et al., 2020; Mengist et al., 2022) in Ethiopia found a significant ESV degradation due to land use and cover changes. Moreover, studies that were carried out elsewhere in Sub-Saharan Africa (Fenta et al., 2020), Bangladesh (Hoque et al., 2022), and Kenya (Rotich et al., 2022) revealed results congruent with the current study.

During the study time, the joint contribution of vegetation land use types to total ESV has declined from 68% in 2002 to 58% in 2020 and then to 54% in 2040, while the contribution of water and cultivated land has increased. In the study area, among the vegetation land use types, forest and woodlands are essential to provision of ES and contribution to ESV per unit area (Table 8), which is supported by the findings of (Kindu et al., 2016; Krause et al., 2017; Xie et al., 2017). However, the continuous transitions of land from these land types, particularly towards bush/shrubland, has been identified as the main cause to the continuous decline of ESV.

For instance, from 2002 to 2040, the total ESV declined by 15.09%, following a 42% and 53%, reduction of ESV in forest and woodland, although a 120.54% and 58.2% increment has been observed in bush/shrubland and cultivated land, respectively. Several empirical studies in Ethiopia and elsewhere reported findings that were consistent with the findings of this study. For example, a study by (Tolessa et al., 2017) documented a 68% of ESV loss was mainly because of the land conversion from forest to cultivated land and other classes. Similarly, a study carried out by (Kindu et al., 2016) was revealed the loss of US$ 19.3 million of ESV at Munessa-Shashemene landscape, Ethiopia, which was strongly linked with massive conversion of forests (natural forest and woodland) to other land categories. Conversely, studies conducted in areas where natural forests exhibited increasing trends have found improvement in ES and

ESV (Chen et al., 2013; Zhang et al., 2015; Zhao et al., 2021). Furthermore, this study also revealed a reduction in values in individual ecosystem services that have relatively high contributions to the total ESV (Table 12).

Moreover, many empirical studies have documented similar findings (Gashaw et al., 2018; Hoque et al., 2022; Jha et al., 2022; Kindu et al., 2016; Mengist et al., 2022; Si et al., 2014; Tolessa et al., 2017). Moreover, this study revealed that apart from the magnitude, the direction of land transitions also has significant implications for the changes/gain and loss of flow/ in ESV. Overall, the existing LUC, specifically the substantial land loss from forest and woodland, has resulted in degradation of important ecosystem services of NNP, such as material production, medicinal value, climate regulation, erosion control, genetic resources, species maintenance, habitat services, and existence value.

This study can help stakeholders by providing long-term evidence to understand the impact of LUC on ES, make informed decisions, and implement better management strategies. In addition, since almost all protected areas in Ethiopia have been under the threat of ecological degradation due to increased human interventions and management problems (Menbere, 2021; Tesfaw et al., 2018), such detailed analysis on ESV associated with LUC (past and future) is considerably useful to create common understanding regarding the problem and resolve the conflicts of land use interests through the active involvement of government officials and local communities.

In this study, the equivalent value transfer was applied to estimate ESV. This approach is more effective and commonly used in different parts of the world, particularly to quantify and understand the impact of LUC on ecosystem services (Gashaw et al., 2018; Jha et al., 2022; Sutton et al., 2016; Xie et al., 2017). The sensitivity analysis (Table 9) has resulted in a value less than 0.5 for all land use types. The findings were consistent with the findings of previous studies (Kindu et al., 2016; Si et al., 2014). This result indicates that the established coefficients are reliable and useful to estimate ESV in the study area and in other places in Ethiopia that have similar socioeconomic and ecological characteristics to the study area. Additional studies considering spatial heterogeneity are needed for robustness in diverse agroecological systems across the country.

CONCLUSIONS AND RECOMMENDATIONS

The NNP is globally known for its richness in biodiversity and multitudinous ecosystem services. Nevertheless, our study confirmed that NNP has been subjected to substantial LUC, affecting its capacity for biodiversity conservation and ecosystem services. The total ESV has declined by US$4.08x10^6 and 1.01x10^6 during the FTIS and STIS, respectively. It has been significantly associated with a reduction in the area of forest and woodland, which accounted for 67.93% of the total change of ESV between 2002 and 2020. Moreover, the values of the major individual ecosystem services have been declining trend associated with the land loss in these land types. Apart from the spatial extent, the direction of land transitions among the land use types has been a good factor for the gain and loss flow of ESV. Overall, the study confirmed that interventions are needed to monitor the ongoing LUC processes and improve the NNP's capacity to generate and provide ecosystem services, including biodiversity preservation and conservation. In addition, the study provides site-specific and long-term information for stakeholders to /re/design targeted and sustainable strategies, although further studies, includi ng field experiments, are required to improve the reliability of the equivalent coefficients.

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