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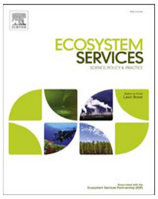

Estimating the impacts of land use/land cover changes on Ecosystem Service Values: The case of the Andassa watershed in the Upper Blue Nile basin of Ethiopia

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ABSTRACT

Estimating the impacts of land use/land cover (LULC) changes in Ecosystem Service Values (ESV) is indispensable to provide public awareness about the status of ESV, and to help in policy-making processes. This study was intended to estimate the impacts of LULC changes on ESV in the Andassa watershed of the Upper Blue Nile basin over the last three decades (1985–2015), and to predict the ESV changes in 2045. The hybrid land use classification technique for classifying Landsat images, the Cellular-Automata Markov (CA-Markov) model for LULC prediction, and the modified ecosystem service value coefficients for estimating ESV were employed. Our findings revealed that there was a continues expansions of cultivated land and built-up area, and withdrawing of forest, shrubland and grassland during the 1985–2015 periods, which are expected to continue for the next three decades. Consequently, the total ESV of the watershed has declined from US\$26.83 $\times 10^6$ in 1985 to US\$22.58 $\times 10^6$ in 2000 and to US \$21.00 $\times 10^6$ in 2015 and is expected to further reduce to US\$17.94 $\times 10^6$ in 2030 and to US\$15.25 $\times$ 10^6 in 2045. The impacts of LULC changes on the specific ecosystem services are also tremendous.

1. Introduction

Ecosystems are composed of plant, animal, and microorganism communities and the nonliving environment, interacting as a functional unit (MEA, 2003). They provide wide ranges of direct and indirect services to human wellbeing including food, fiber, raw material for industries and water supply (Costanza et al., 1997; MEA, 2003, 2005; Li et al., 2007; Braat and de Groot, 2012; de Groot et al., 2012; Costanza et al., 2014; Anaya-Romero et al., 2016; Kindu et al., 2016; Bartkowski, 2017; Costanza et al., 2017). The service depends on the type of ecosystem and their status (Tolessa et al., 2017). Each ecosystem offers a distinctive service that cannot be replaced by others. For example, forest ecosystem supplies a different service (Anaya-Romero et al., 2016) from grassland ecosystem or aquatic ecosystem. In addition, dense forests do not provide similar ecosystem services to that of degraded forest. The ecosystem services provided by a certain environment may be grouped into provisioning, regulating, supporting and cultural services (MEA, 2005; Braat and de Groot, 2012; Anaya-Romero et al., 2016; Kindu et al., 2016; Costanza et al., 2017). To produce these services, the interaction between natural, social, built, and human capital is necessary (Costanza et al., 2017). Thus, when an ecosystem is managed for providing a single service (for example, for food production) others are negatively affected (Braat and de Groot, 2012). Thus, managing ecosystems in an integrated way with the aim of providing multiple services (Braat and de Groot, 2012; Jacobs et al., 2016) is very important.

In spite of the incredible contribution of ecosystem services to the functioning of nature and sustainable human well-being and survival (Braat and de Groot, 2012; de Groot et al., 2012; Costanza et al., 2014; Bartkowski, 2017; Costanza et al., 2017; Kubiszewski et al., 2017), globally the values of ecosystem services have been significantly degraded over time and space (MEA, 2005; Costanza et al., 2014; Sutton et al., 2016). For example, the total

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global ecosystem services values in 2007 were $US145 trillion/year, however, it dropped to $US125 trillion/year in 2011 (Costanza et al., 2014). Land Use/Land Cover (LULC) changes are the main drivers which significantly altered ecosystem services (Kreuter et al., 2001; Li et al., 2007; Hu et al., 2008; Costanza et al., 2014; Anaya-Romero et al., 2016; Kindu et al., 2016; Tolessa et al., 2017; Kubiszewski et al., 2017; Wang et al., 2017). Worldwide, the magnitude of LULC changes is not uniform across the regions. For example, in temperate region forests increased at the rate of 3×10^6 ha^{-1} yr^{-1}; while in tropical regions, it decreased at the rate of 12×10^6 ha^{-1} yr^{-1} (MEA, 2005). Thus, it is believed that the extensive loss of tropical forest every year has lost a wide range of ecosystem services in the region. Obviously, the continued degradation of ecosystems comes in many countries of Africa at the expense of the livelihood of future generations (de Groot et al., 2012; Kubiszewski et al., 2017). Being a tropical country, reduction of vegetation covers for the expansion of cultivated lands were also common in Ethiopia, which is much pronounced in the highlands (Tekle and Hedlund, 2000; Zeleke and Hurni, 2001; Shiferaw, 2011; Rientjes et al., 2011; Gebrehiwot et al., 2014; Hassen and Assen, 2017). In Ethiopia, the annual rate of deforestation between 1990–2010 periods was estimated to be at a rate of 1.4×10^5 ha^{-1} yr^{-1} (FAO, 2010). Land degradation in Ethiopia, which is mainly driven by LULC changes, has lost about 17.7% of the country's total terrestrial ESV (Sutton et al., 2016).

Though the concern of framing ecosystems in economic terms started in the 1970 s and 1980 s (Braat and de Groot, 2012), interest in ecosystem services valuation both in research and policy making processes has grown recently (Li et al., 2007; Hu et al., 2008; Braat and de Groot, 2012; Costanza et al., 2014; Wang et al., 2015; Anaya-Romero et al., 2016; Cabral et al., 2016; Costanza et al., 2017; Yirsaw et al., 2017) following the establishment of ecosystem service valuation model by Costanza et al. (1997) and the Millennium Ecosystem Assessment (MEA, 2005). Thus, the ecosystem service value coefficients established by Costanza et al. (1997) for 16 biomes were employed in various studies to determine ESV for LULC categories (e.g. Kreuter et al., 2001; Li et al., 2007; Hu et al., 2008; Tolessa et al., 2016;Tolessa et al., 2017). However, this model is criticized due to its uncertainties and limited use at the local level (Kreuter et al., 2001; Wang et al., 2006; Braat and de Groot, 2012; Kindu et al., 2016; Wang et al., 2017). Consequently, the values of ecosystem coefficients have been modified by van der Ploeg and de Groot (2010) for 11 biomes. The modification was done on the basis of the previous estimation by Costanza et al. (1997) through a benefit transfer method, which refers to the process of using existing values and other information from the original study site to estimate ESV of other similar location in the absence of site-specific valuation method. However, the modified estimates given by van der Ploeg and de Groot (2010) are very general and, because of the scale effect, it did not clearly represent the context of a certain region including Ethiopia. A further estimation of global ecosystems was carried out by de Groot et al. (2012) and Costanza et al. (2014). However, their estimates were also criticized because it overestimates some ecosystem services (Tolessa et al., 2016), and by any means, it did not actually represent a particular region. As a result, a more conservative estimation coefficients for the Ethiopian conditions was developed by Kindu et al. (2016) for 11 biomes using expert knowledge of the study landscape conditions and other studies, mainly from the Economics of Ecosystems and Biodiversity (TEEB) valuation database (van der Ploeg and de Groot, 2010; Knoke et al., 2011). Despite some local studies (e.g. Reyers et al., 2009; Egoh et al., 2012; Leh et al., 2013), such comprehensive downscaling approach is the first attempt for the African context, which often known as a data-scarce region. Previously, modifications of ecosystem coefficients were also done for China using expert knowledge based valuation methods (Xie et al., 2008).

All these efforts were made to estimate the values of ecosystem services as it is imperative to understand the multiple benefits of ecosystems through a more realistic valuation methods (Wang et al. 2006; Li et al., 2007; Hu et al., 2008; de Groot et al., 2012; Costanza et al., 2014). More specifically, quantifying the impacts of LULC changes on the amount of ESV lost/gained is important to indicate the vulnerability of each ecosystem services (Cabral et al., 2016), which provides an avenue for decision making processes and providing information about the status of ecosystem conditions (Costanza et al., 1997; Li et al., 2007; Wang et al., 2015; Anaya-Romero et al., 2016; Cabral et al., 2016; Niquisse et al., 2017). Furthermore, including the valuation of ecosystem services, broadly termed as "assigning importance" (Jacobs et al., 2016) into the land resource management and land use planning framework is vital for maintaining the health and sustainability of land resources (Cabral et al., 2016; Jacobs et al., 2016; Bartkowski, 2017). Land use changes impact studies on ecosystem services are patchy and the results are not comprehensive for assessing the trends of such changes in ecosystem services in Africa (Leh et al., 2013; Wangai et al., 2016; Niquisse and Cabral, 2017; Niquisse et al., 2017). In Ethiopia, though LULC change studies have a long history (Tekle and Hedlund, 2000; Zeleke and Hurni, 2001; Tegene, 2002; Shiferaw, 2011; Hassen and Assen, 2017), efforts in estimating the effects of LULC changes on ecosystem services are very limited, except few recent works concentrated in the central highlands of Ethiopia (Kindu et al., 2016; Tolessa et al., 2016; Tolessa et al., 2017). The Ethiopian highlands, which are located above 1500 meters a.s.l, are characterized by high human and livestock population and where agricultural production system has caused land degradation. Deforestation and the subsequent soil erosion problems are rampant in these parts of the country. For more information about these region, readers are advised to look at papers published by Hurni (1988), Zeleke and Hurni (2001), Gebrehiwot et al. (2014), Kindu et al. (2016, 2018), Tolessa et al. (2016, 2017) and Gashaw et al. (2017a,b).

The study area, Andassa watershed, is located in the northwestern highlands of Ethiopia, and it is known as one of the productive watersheds in the country (Gashaw et al., 2017b). Nevertheless, the watershed is under great pressure from agricultural land expansion. Therefore, understanding the impacts of LULC changes on ESV in the study watershed is essential to give public awareness and indicate policy directions about the lost/gain in ecosystem services. Previously, there is no study carried out in the study region with regard to the impacts of LULC changes on ESV. Hence, the objective of this study was to estimate the impacts of LULC changes on ESV in monetary values in the Andassa watershed during 1985 to 2015 periods. In addition, the study will predict the ESV in the future (2045) using the Cellular Automata-Markov (CA-Markov) model to predict the trend and spatial structure of LULC categories. We hypothesize that, due to LULC changes over spatial and temporal scales in the past and future, the total ESVs in the study watershed decrease and this will have significant impacts on human well-being.

2. Materials and methods

2.1. Study site

Andassa watershed is within the Blue Nile basin of Ethiopia (Fig. 1). It is located around 560 km northwest of Addis Ababa, the capital city and with a close proximity to the capital city of the Amhara national regional state Bahir Dar. Geographically, the

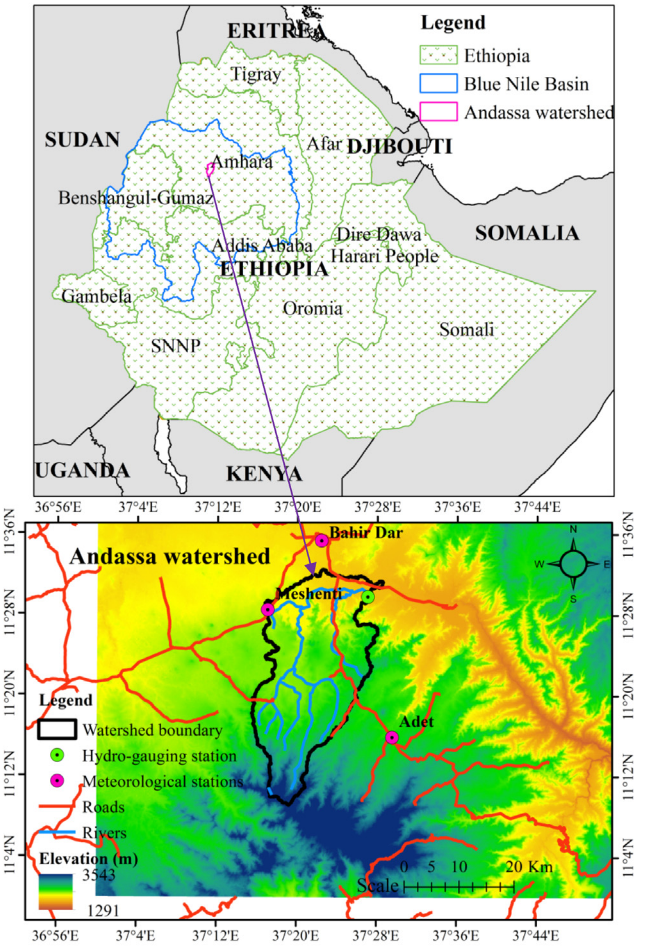

Fig. 1. Location map of the study site and meteorological stations (Adapted from Gashaw et al., 2018).

study site is situated between 11 °08′-11°32′N and 37°16′-37 °32′E. The watershed (58,760 ha) is dominated by hilly topography and elevation shows variations within a small distance. According to the data obtained from the Geographic Information System (GIS) department of the Ethiopian Ministry of Water and Energy (EMWE) in 2016, the major soil types of the study watershed are Haplic Alisols (49.6%), Eutric Leptosols (22.8%), Chromic Luvisols (10.8%), Haplic Nitisols (9%) and Eutric Vertisols (7.1%). With the data obtained from the same source, its geology is characterized by Alluvium, Ashangi basalts, basalts related to volcanic centre and Termaber basalts. Andassa River, the major river of the watershed, is also among the tributaries of Blue Nile River.

Agriculture is the leading economic activity in the watershed and the main sources of livelihood. The study area comprises mixed farming zones where crops are grown for food and for cash, and livestock is kept for the complementary purpose, as a means of security during a food shortage, and to meet farmers' cash needs. The dominant crops grown are Tef (*Eragrostistef* (Zucc.) Trotter.), Finger Millet (*Eleusine coracana* (L.) Gaertn.), Maize (*Zea mays* L.), Barely (*Hordiumvulgare* L.), Wheat (*Triticumaestivum* L.), Faba bean (*Viciafaba* L.), Pea (*Pisumsativum* L.), Chickpea (*Cicerarietinum* L.) and Grass pea (*Lathyrussativus* L.). Tuber crops such as Potato (*Solanumtuberosum* L.) and Sweet potato (*Ipomoea batatas* (L.) Lam.) and vegetables such as Shallot (*Allium cepa* L.) and Garlic (*Allium sativum* L.) are also produced. Sugarcane (*Saccharumofficinarum* L.) is also the highly produced plantation along the bank of the Andassa River.

The climate of the study watershed is highly sub-tropical (85.2%) with a small portion of temperate climate (14.8%). Weather record data collected from three meteorological stations for the period from 1990 to 2011 show that the mean annual rainfall (1990–2011) in the study region ranges from 1242 mm in Adet to 1398 mm in Bahir Dar localities, showing small variability between the years (Fig. 2). Similar to rainfall, the mean temperatures of the stations in those periods are less variable (Fig. 3). According to the LULC impact study, which was carried out using the flow data measured at the outlet of the study watershed (Fig. 1), the annual average surface runoff in the 2000 and 2015 periods are amounted to 233.7 mm and 242.8 mm, respectively while its Evaporation and Transpiration (ET) within the same periods are estimated to be 579 mm and 578.8 mm, respectively (Gashaw et al., 2018).

2.2. Land use/land cover dataset

The LULC datasets in this study were obtained from Gashaw et al. (2017b). As briefly mentioned in the paper, the 1985, 2000 and 2015 Landsat images were classified using the hybrid land use classification technique, which combines the unsupervised and supervised classification techniques. The result revealed that there was a significant expansions of cultivated land (36,820 to 45,108 ha) and built-up area (35 to 672 ha) at the expense of forest (2068 to 1138 ha), shrubland (15,377 to 8992 ha) and grassland (4461 to 2850 ha) during the 1985–2015 periods (Table 1; Fig. 3). Prediction of the 2030 and 2045 LULC states was carried out using the CA-Markov model.

The CA-Markov model, available in IDRISI; version 17.0, is a robust model for predicting the trend and the spatial structure of different LULC categories (Arsanjani et al., 2011; Wang et al., 2012) using basis (historical) LULC image, transition probability matrix and suitability images as a group file (Clark Labs, 2012; Eastman, 2012). Consequently, it has widely applied in LULC change modeling elsewhere (e.g. Kamusoko et al., 2009; Arsanjani et al., 2011; Sang et al., 2011; Al-sharif and Pradhan, 2013; Singh et al., 2015). In this study, the 2015 classified map was used as a basis LULC image, and the 2000 and 2015 maps were used for assembly transition probability matrix. For preparing a single suitability map for each LULC categories, CA-Markov considers factors and constraints (Clark Labs, 2012; Eastman, 2012; Omar et al., 2014; Singh et al., 2015). Factors are criterions that indicate the relative suitability of areas under consideration whereas constraints are criterions which limit the alternatives under consideration (Clark Labs, 2012; Eastman, 2012). The factors considered were the distance to river, distance to town, distance to road, proximate to the developed area, suitable areas for conversion to each class and elevation while slope was considered as a constraint (See Gashaw et al., 2017b for detail). River and road data were collected from the GIS department of the EMWE while data such as distance to town, proximate to the developed area and suitable areas for conversion to each class were derived from the classified LULC maps. Elevation and slope were generated from a 30 m ASTER Global Digital Elevation Model (ASTER GDEM). A set of relative weights for a group of factors were assigned through in-depth focus group discussions with agricultural development agents and local elders. The factors and constraint considered were integrated using a Multi-Criteria Evaluation (MCE) decision support system with Weighted Liner Combination (WLE) fuzzy membership function to produce a single suitability map for each class. Validation of CA-Markov has been done and the result (not shown here) indicates that the model is accurate to predict future LULC states. Further explanations about the procedures followed in the LULC prediction of the study watershed can be referred from Gashaw et al. (2017b). The prediction result indicates that the

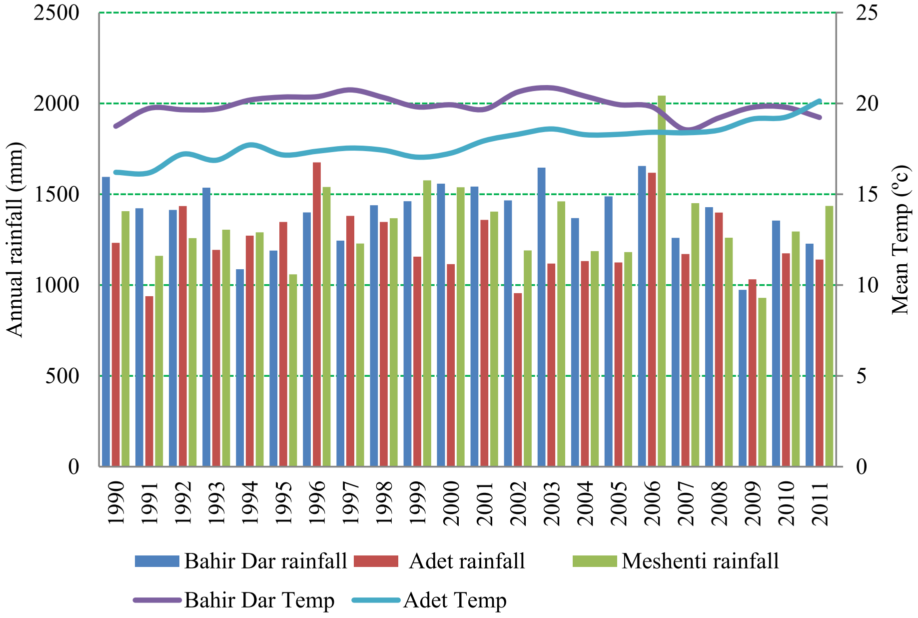

Fig. 2. Annual rainfall and mean temperature of the study region from 1990 to 2011 periods.

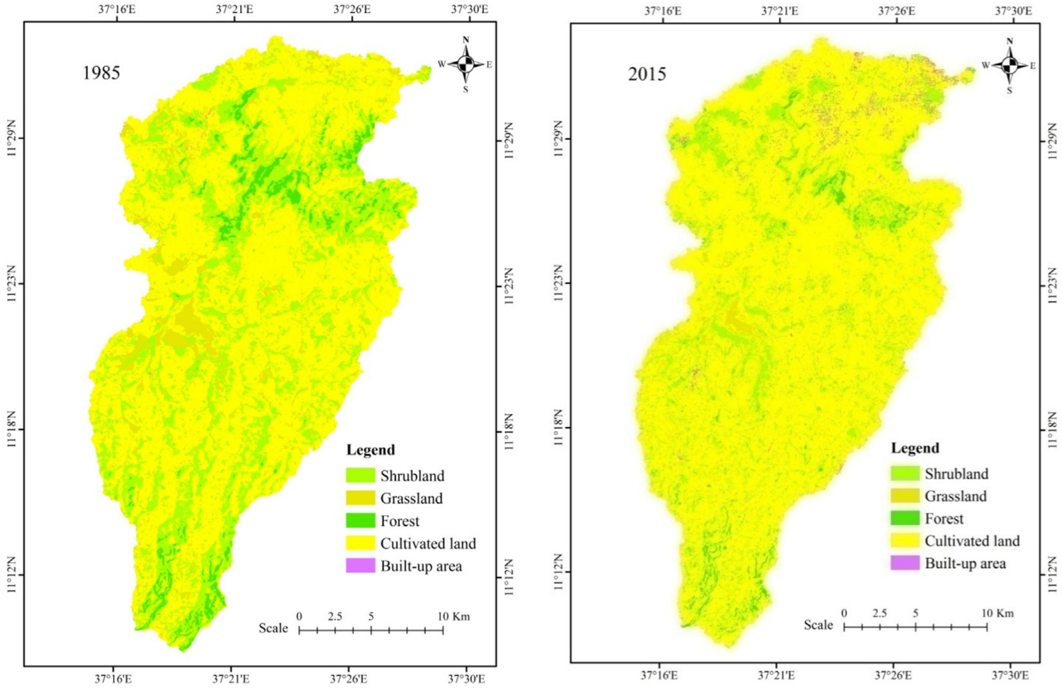

Fig. 3. The 1985 and 2015 LULC of the study watershed (Gashaw et al. 2017b).

Table 1
LULC types from 1985 to 2045 periods in the Andassa watershed (Gashaw et al., 2017b).

Study periods	LULC classes (ha)				
	Cultivated land	Forest	Shrubland	Grassland	Built-up area
1985	36,820	2068	15,377	4461	35
2000	42,925	1504	10,447	3783	101
2015	45,108	1138	8992	2850	672
2030	48,932	898	5391	2342	1197
2045	50,425	763	2780	1344	3448

expansion of cultivated land and built-up area at the expense of vegetative LULC types are expected to continue in the 2030 and 2045 periods (Table 1).

2.3. Estimation of ecosystem service values

We assessed the change in ESV using the classified (1985, 2000 and 2015) and the predicted (2030 and 2045) LULC conditions. The modified ecosystem service value coefficients (Kindu et al., 2016, 2018) developed for 11 biomes for Ethiopian condition were employed in this study to determine ESV from the five LULC categories. Thereafter, the LULC types of the study watershed were associated to the corresponding representative biomes (Table 2). The most representative biomes used as a proxy for each LULC category are: 1) cropland for cultivated land, 2) tropical forest for forest and shrubland, 3) grassland/rangeland for grassland, and 4) urban for the built-up area.

The LULC categories are not exactly identical with the representative biomes. For example, cultivated land in this study accounts areas used for perennial and annual crops, irrigated areas and the scattered rural settlements. The inclusion of rural settlements in this category, even though they are scattered, may not exactly represent the ESV assigned to cropland biome. Forest in the study area is also areas covered with dense trees, which include both *eucalyptus* and coniferous species. In addition, shrubland was also represented with tropical forest biome. However, shrubland in the study area are areas less dense than forests, and it only represents areas covered with small trees, bushes and shrubs, and in some areas, grasses are found within them. Thus, the composition and structure of the represented forest and shrubland categories are somehow different from that of tropical forest biome but they provide similar ecosystem services. In the same way, built-up area was represented with urban biome. In the study area, the built-up area did not represent very urbanized area rather it represents only areas used for construction sites and towns. So the functions and characteristics of the built-up area are also a little bit different from urban biome, and built-up areas are expected to provide better ecosystem service than the represented biome. However, the represented grassland biome is very much related; which are areas covered by grasses usually used for grazing and those remain some months in a year. Thus, though the represented biomes are not exactly similar in their characteristics and functions with the LULC in our context, they can be used as surrogates for estimating ESV of the LULC types for our study watershed. Such use of proxies for LULC types with the corresponding biomes were common in many ESV studies (e.g. Kreuter et al., 2001; Wang et al., 2006; Li et al., 2007; Hu et al., 2008; Tianhong et al., 2010; Kindu et al., 2016; Tolessa et al., 2016, 2017).

Table 2
LULC categories in the study watershed, the corresponding biomes, and ecosystem service coefficients based on the modified estimates (Kindu et al., 2016).

LULC categories	Equivalent Biome	Ecosystem service Coefficient (US $ ha^{-1} yr^{-1})
Cultivated land	Cropland	225.56
Forest	Tropical Forest	986.69
Shrubland	Tropical Forest	986.69
Grassland	Grassland	293.25
Built-up area	Urban	0

Estimation of ESV from each LULC category were undertaken using Eq. (1), following the method employed in the previous studies (Kreuter et al., 2001; Wang et al., 2006; Li et al., 2007; Hu et al., 2008; Tianhong et al., 2010; Kindu et al., 2016; Tolessa et al., 2016; Tolessa et al., 2017). The total ESV of the entire watershed was obtained by summing the estimated ESV from each LULC category. In addition to the computation of total ESV, the values of the 17 individual ecosystem services were also estimated using Eq. (2) (Hu et al., 2008; Tianhong et al., 2010; Kindu et al., 2016; Tolessa et al., 2016; Tolessa et al., 2017). The modified coefficients that were used in this study are shown in Table 3. The percent change of ESV across different periods (1985–2000, 2000–2015, 1985–2015, 2015–2030, 2030–2045 and 2015–2045) were computed using the formula shown in Eq. (3) (Cabral et al., 2016; Kindu et al., 2016).

$$ESV_k = \sum (A_k * VC_k) \tag{1}$$

$$ESV_f = \sum (A_k * VC_{fk}) \tag{2}$$

$$Percent\ of\ ESV\ change = \left(\frac{ESV_{recent\ year} - ESV_{previous\ year}}{ESV_{previous\ year}} \right) * 100 \tag{3}$$

where, ESV_k and ESV_f are ESV of LULC type '*k*' and ESV service function '*f*', respectively; A_k is area (ha) of LULC type '*k*'; VC_k is the value coefficient of LULC type '*k*' (US $ ha^{-1} yr^{-1}) and VC_{fk} is the value coefficient of function '*f*' (US$ ha^{-1} yr^{-1}) for LULC type '*k*'.

Table 3
Coefficients (US $ ha^{-1} yr^{-1}) of the modified ecosystem service valuation (Kindu et al., 2016) for the four represented biomes.

Ecosystem Services	Biome			
	Cropland	Tropical forest	Grassland	Urban
Water supply		8		
Food production	187.56	32	117.45	
Raw materials		51.24		
Genetic resources		41		
Water regulation		6	3	
Climate regulation		223		
Disturbance regulation		5		
Gas regulation		13.68	7	
Biological control	24		23	
Erosion control		245	29	
Waste treatment		136	87	
Nutrient cycling		184.4		
Pollination	14	7.27	25	
Soil formation		10	1	
Habitat/refuge		17.3		
Recreation		4.8	0.8	
Cultural		2		
Sum	225.56	986.69	293.25	0

Note: The equivalent LULC categories for each biome are available in Table 2.

After we obtained the total ESV, the average ESV of the land (US$ ha^{-1} yr^{-1}) in our study watershed was also estimated for the previous (i.e. 1985, 2000 and 2015) and the predicted LULC periods, following the formula established in Eq. (4).

$$ESV_{av} = ESV_t/W_a \tag{4}$$

where, ESV_{av} is the average ESV of the land (US$ ha^{-1} yr^{-1}) during a specific year, ESV_t is the total ESV in that year, and W_a is the area of the watershed in ha.

3. Results

3.1. Changes in the total ecosystem service values

The changes in ESV from 1985 to 2015 periods, and its predicted amount in the year 2030 and 2045 for each LULC type and total ESV were evaluated and presented in Table 4. In the study watershed, the ESV of cultivated land increased between 1985 and 2015 periods. Conversely, the ESV of forest, shrubland and grassland over these periods has been reduced (Table 4). The increase of ESV for cultivated land and its reduction for vegetated LULC categories are expected to continue in 2030 and 2045 periods (Table 4). Consequently, the total ESV has reduced from US$ 26.83 × 10^6 in 1985 to US$ 22.58 × 10^6 in 2000 and to US$ 21.00 × 10^6 in 2015 and is expected to further decrease to US$ 17.94 × 10^6 in 2030 and to US$ 15.25 × 10^6 in 2045. It was found that the major contributor to these changes is the change in shrubland. The next major contributor to the reduction of total ESV across the study periods was the reduction of forest cover (Table 4; Fig. 4). It is also observed that the LULC occurred over 1985 to 2015 periods has lost US$ 5.83 × 10^6 ESV, and the expected changes in LULC during 2015 to 2045 periods will drop about US$ 5.75 × 10^6 ESV if the existing condition is not improved in terms of land management practices (Table 5).

Table 4
Effects of LULC changes on the total ESV (US$ in millions) in the Andassa watershed.

LULC categories	1985 ESV	%	2000 ESV	%	2015 ESV	%	2030 ESV	%	2045 ESV	%
Cultivated land	8.31	31.0	9.68	42.9	10.17	48.4	11.04	61.5	11.37	74.5
Forest	2.04	7.6	1.48	6.5	1.12	5.3	0.89	5.0	0.75	4.9
Shrubland	15.17	56.5	10.31	45.7	8.87	42.2	5.32	29.7	2.74	18.0
Grassland	1.31	4.9	1.11	4.9	0.84	4.0	0.69	3.8	0.39	2.6
Built-up area	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Sum	26.83		22.58		21.00		17.94		15.25	

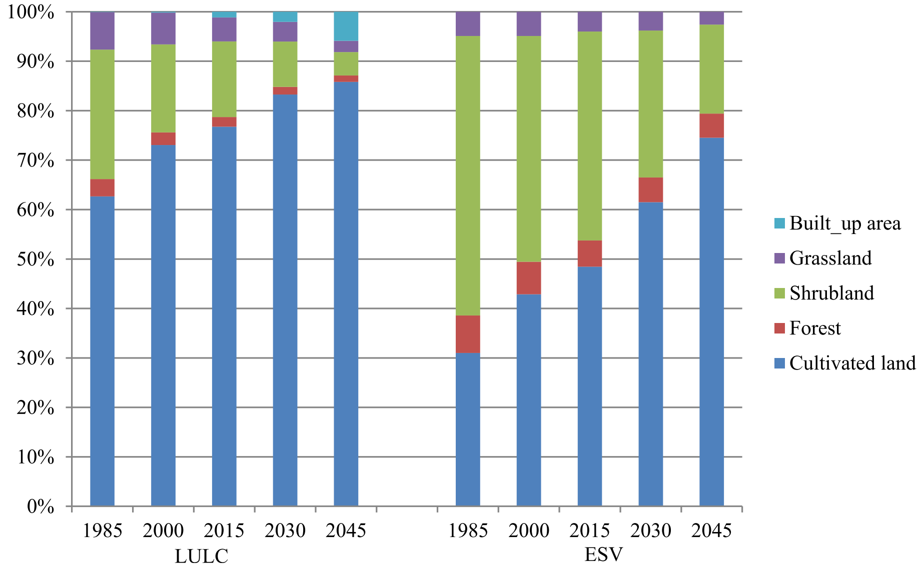

Fig. 4. Proportions of LULC (%) and ESV (%) for the periods from 1985 to 2045 in the Andassa watershed.

Table 5
Changes in ESV (US$ in millions) in the study watershed.

LULC categories	1985–2000		2000–2015		1985–2015		2015–2030		2030–2045		2015–2045	
	US $ in millions	Change in%	US $ in millions	Change in%	US $ in millions	Change in%	US $ in millions	Change in%	US $ in millions	Change in%	US $ in millions	Change in%
Cultivated land	1.37	16.5	0.49	5.1	1.86	22.4	0.87	8.6	0.33	3.0	1.2	11.8
Forest	−0.56	−27.5	−0.36	−24.3	−0.92	−45.1	−0.23	−20.5	−0.14	−15.7	−0.37	−33.0
Shrubland	−4.86	−32.0	−1.44	−14.0	−6.3	−41.5	−3.55	−40.0	−2.58	−48.5	−6.13	−69.1
Grassland	−0.2	−15.3	−0.27	−24.3	−0.47	−35.9	−0.15	−17.9	−0.3	−43.5	−0.45	−53.6
Built-up area	0		0		0		0		0		0	
Sum	−4.25		−1.58		−5.83		−3.06		−2.69		−5.75	

The LULC changes in our study watershed have also reduced the average ESV of the land from 457 US\$ ha^{-1} yr^{-1} in 1985 to 384 US\$ ha^{-1} yr^{-1} in 2000 and to 358 US\$ ha^{-1} yr^{-1} in 2015 and is expected to continue to reduce in the 2030 and 2045 periods (Fig. 5).

3.2. Impact of land use/land cover changes on the specific ecosystem service values

The impacts of LULC changes on the specific ecosystem services are presented in Table 6. The result revealed that there exist diverse effects of LULC changes on the various ecosystem services; it increased some ecosystem service while others were reduced. For example, during 1985–2015 periods, only food production, biological control and pollination increased corresponding to the LULC changes. Conversely, most of the ecosystem services were reduced (Table 6). From the periods 2015 to 2045, merely food production and biological control are expected to increase while 15 ecosystem services are expected to reduce (Table 6).

In the observed (1985–2015) and predicted (2015–2045) periods, the greatest ecosystem service loss was from erosion control (US\$ 1.84 $\times$ 10^6 and US\$ 1.65 $\times$ 10^6), climate regulation (US\$ 1.63 $\times$ 10^6 and US\$ 1.47 $\times$ 10^6), nutrient cycling (US\$ 1.35 $\times$ 10^6 and US\$ 1.22 $\times$ 10^6) and waste treatment (US\$ 1.14 $\times$ 10^6 and US\$ 1.02 $\times$ 10^6). In a broader category, the greatest contributors for the loss of ESV between 1985-2015 and 2015–2045 periods, in a decreasing order, are regulating services, supporting services, provisioning services and cultural services (Table 6).

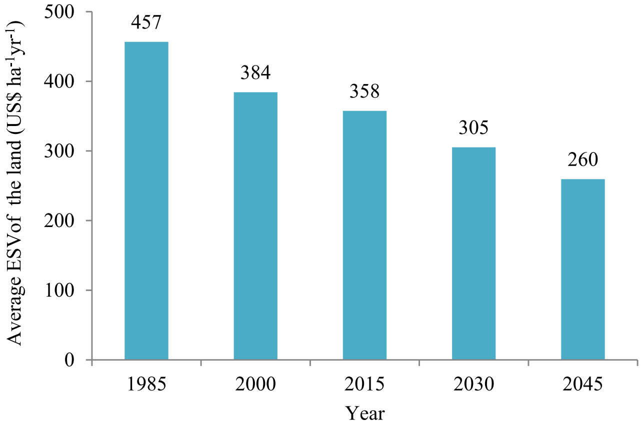

Fig. 5. The average ESV of the land from 1985 to 2045 periods in the study watershed.

4. Discussions

4.1. Changes in the total ecosystem service values

The loss of ESV in the study watershed mainly due to the loss of shrubland and forest land use categories is very similar to the findings of various studies in Ethiopia and elsewhere. For example, the predominant contributor for the reduction of ESV in Munessa-Shashemene landscape of Ethiopia (Kindu et al., 2016, 2018), Toke Kutaye district, Ethiopia (Tolessa et al., 2016) and Chillimo forest, Ethiopia (Tolessa et al., 2017) during 1973–2012, 1973–2014 and 1973–2015 periods, respectively, were reductions in natural forests and woodlands, forest land and shrub/bushland, and forest land, respectively. Moreover, the loss of ESV during 1973–2004 periods in Pingbian County, China was also due to the loss of forest and shrubland (Li et al., 2007). A study by Hu et al. (2008) in Menglun, Southwest China also illustrates the major contribution of forest cover loss for the deterioration of ESV over 1988 to 2006 periods.

The reduction of the average ESV of the land throughout the study periods is attributed to the reductions of vegetation types of land covers and expansions of the non-vegetation LULC. The estimated average ESV of the land use in our study area is lower than other findings such as in Chillimo forest (Tolessa et al., 2017) and Munessa-Shashemene landscape (Kindu et al., 2016) (Table 7). This could be attributed to a number of reasons, such as the dominance of cultivated land in the study watershed, which covers above 62% of the watershed in the whole study periods and the selected ecosystem service coefficients have contributed to the estimated average ESV of the land in our study watershed. For example, if this study used the coefficients developed by Costanza et al. (1997) for similar biomes (i.e. 92 for cropland biome, 2008 for tropical forest biome, 244 for grassland biome), the total ESV in the study watershed will be US\$39.51 $\times$ 10^6 in 1985, US\$28.87 $\times$ 10^6 in 2000, US\$25.19 $\times$ 10^6 in 2015,

Table 6
Effects of LULC changes on the annual ecosystem service in the Andassa watershed.

No.	Ecosystem Services	ESV across periods (US\$ in millions)					Overall change	
		ESV$_f$ 1985	ESV$_f$ 2000	ESV$_f$ 2015	ESV$_f$ 2030	ESV$_f$ 2045	1985–2015	2015–2045
1	Provisioning services							
	Water supply	0.14	0.10	0.08	0.05	0.03	−0.06	−0.05
	Food production	7.99	8.88	9.12	9.65	9.73	1.13	0.61
	Raw materials	0.89	0.61	0.52	0.32	0.18	−0.37	−0.34
	Genetic resources	0.72	0.49	0.41	0.26	0.14	−0.31	−0.27
2	Regulating services							
	Water regulation	0.12	0.08	0.07	0.04	0.02	−0.05	−0.05
	Climate regulation	3.89	2.67	2.26	1.40	0.79	−1.63	−1.47
	Disturbance regulation	0.09	0.06	0.05	0.03	0.02	−0.04	−0.03
	Gas regulation	0.27	0.19	0.16	0.10	0.06	−0.11	−0.10
	Biological control	0.99	1.12	1.15	1.23	1.24	0.16	0.09
	Erosion control	4.40	3.04	2.56	1.61	0.91	−1.84	−1.65
	Waste treatment	2.76	1.95	1.62	1.06	0.60	−1.14	−1.02
3	Supporting services							
	Nutrient cycling	3.22	2.20	1.87	1.16	0.65	−1.35	−1.22
	Pollination	0.75	0.78	0.78	0.8	0.76	0.03	−0.02
	Soil formation	0.18	0.12	0.10	0.07	0.03	−0.08	−0.07
	Habitat/refugia	0.30	0.21	0.18	0.11	0.06	−0.12	−0.12
4	Cultural services							
	Recreation	0.09	0.06	0.05	0.03	0.02	−0.04	−0.03
	Cultural	0.03	0.02	0.02	0.01	0.01	−0.01	−0.01
	Sum	26.83	22.58	21.00	17.94	15.25	−5.83	−5.75

Table 7
The average ESV of the land in selected studies, which was computed following Eq. (4) using the available data from the studies.

Study area	Area (ha)	Year	ESV (US$ in millions)	Average ESV of the land (US$ ha^{-1} yr^{-1})	Reference
Chillimo Forest, Dendi district of Oromia National Regional State, Central highlands of Ethiopia	7687.26	1986	7.66	996	Tolessa et al. (2017)
		2001	6.40	833	
		2015	5.37	699	
Toke Kutaye district, West Shewa zone of Oromia National Regional State, Centeral highlands of Ethiopia	72,697.2	1984	33.93	467	Tolessa et al. (2016)
		2000	28.22	388	
		2014	16.71	230	
[b]Munessa–Shashemene landscape, Munessa and Arsi-Negele Districts, Centeral highlands of Ethiopia	103,675	1986	118.5	1143	Kindu et al. (2016)
		2000	114.8	1107	
		2012	111.1	1072	
Nenjiang River Basin, Heilongjiang Province, Northeast China	29,420,000	1980	99,940	3397	Wang et al. (2015)
		2005	97,510	3314	
Menglun, Xishuangbanna, Southwest China	33,488.34	1988	41.200	1230	Hu et al. (2008)
		2006	29.773	889	
Sanjiang Plain, Heilongjiang Province, China	10,882,948	1980	37, 629.323	3458	Wang et al. (2006)
		2000	22,001.018	2022	

Note: b = is the ESV estimated using the own modified coefficients.

US$17.70 × 10^6 in 2030 and US$12.08 × 10^6 in 2045. Consequently, the average ESV of the land will be a little bit increased to 672 US$ ha^{-1} yr^{-1} in 1985, 491 US$ ha^{-1} yr^{-1} in 2000 and 429 US$ ha^{-1} yr^{-1} in 2015. Conversely, if the coefficients developed by Costanza et al. (1997) was used, the average ESV of the land in the 2030 and 2045 periods will be reduced to 301 US$ ha^{-1} yr^{-1} and 206 US$ ha^{-1} yr^{-1}, respectively. Studies conducted elsewhere such as by Wang et al. (2006), Hu et al. (2008) and Wang et al. (2015) in China (Table 7) have also shown highest ESV of the land as compared to our findings. However, the ESV of the land in our study watershed is related to the Toke Kutaye district particularly in the 1984 and 2000 periods (Table 7) (Tolessa et al., 2016).

4.2. Impact of land use/land cover changes on the specific ecosystem service values

The continued increase of food production and biological control across the entire study periods is certainly attributed to the expansion of cultivated land over these periods. On the other hand, the decline of most ecosystem service across the study periods is highly associated with the reduction of shrubland (Table 7). Similar to this finding, a decrease in grasslands, woodlands and aquatic regions between 2003 and 2013 periods in Manas River Basin, China has resulted in a decrease in the value of climate regulation, gas regulation and various types of ecosystem services (Wang et al., 2017). In the same way, the reduction of natural forests and woodlands in the Munessa-Shashemene landscape, Ethiopia (Kindu et al., 2016) and forest land and shrub/bush land in Chillimo forest, Ethiopia (Tolessa et al., 2017) have also resulted in the reductions of several ecosystem services values. The predicted reduction in ESV in our study watershed for 2015–2045 is also similar to the findings of Kindu et al. (2018) where business as usual case scenario reduced the ESV as compared to other assumptions. Our findings are also consistent with others elsewhere (e.g. Niquisse et al., 2017). Hence, it is very clear that the impacts of LULC changes in the Andassa watershed are significant both on the specific ecosystem services and the overall ESV. Therefore, changing the widely employed cereal productions with fruit productions would improve the land cover and thereby enhancing ecosystem services. In addition, managing the study area through an integrated watershed approach could enhance the continuous supply of ecosystem services. Designing and implementing Payment for Ecosystem Services (PES) at micro-level as a conservation strategy could also improve the vegetation cover. The use of vegetated land use for ecotourism purposes is also the other dimension that helps local communities to generate income from the watershed and thereby to maintain ESV.

Quantitative evaluation of the changes in ESVs, such as this, can easily create a common understanding of the ongoing land use dynamics and is important to indicate the vulnerability of each ecosystem services (Cabral et al., 2016). This can provides an avenue for decision-making processes (Costanza et al., 1997; Anaya-Romero et al., 2016; Niquisse et al., 2017), and help to develop land use planning framework vital for maintaining the health and sustainability of land resources (Cabral et al., 2016; Jacobs et al., 2016; Bartkowski, 2017).

4.3. Limitations of the study

The evaluation of LULC changes in ESV for the period 1985–2015 and towards the future 2030 and 2045 incorporates various sources of uncertainty. The primary limitation of this study is associated with the accuracy of the land use classification. The land use classification of 1985, 2000 and 2015 was achieved with a total accuracy of 86.9, 85.8 and 88.8%, and a kappa coefficient of 0.83, 0.81 and 0.85, respectively (Gashaw et al., 2017b). Even though the classification performance with above the required standard (i.e. kappa coefficient above 70%) (Monserud, 1990) to be considered as valuable there are still some uncertainty associated with that. The prediction of land use with the assertion that the past trends will continue in the future considering only proximity factors is also a source of uncertainty. The socio-economic factors such as willingness to convert a land, and change in the land-use policies during the period will have a significant effect.

Additionally, to account the uncertainty of the model and the represented biomes, several studies computed Coefficient of Sensitivity (CS) using the standard economic concept of elasticity (e.g. Kreuter et al., 2001; Wang et al., 2006; Hu et al., 2008; Wang et al., 2015; Kindu et al., 2016; Tolessa et al., 2017) and in most cases, the Value Coefficients (VC) were adjusted by ±50% (e.g. Wang et al., 2006; Li et al., 2007; Hu et al., 2008; Kindu et al., 2016; Yirsaw et al., 2017; Tolessa et al., 2017). In this method, CS values greater than 1 and less than 1 represents the estimated ecosystem value is elastic and inelastic (i.e. the data is reliable), respectively, with respect to that coefficient (Kreuter et al., 2001; Hu et al., 2008; Tianhong et al., 2010; Kindu et al., 2016; Yirsaw et al., 2017; Tolessa et al., 2017). However, adjusting VC to ±25% also gives the same result. Hence, this method is not adequately addressing the reliability of the estimation because it is independent from the ±50% change of VC and it always gives values less than 1, indicating erroneously that the coefficients are robust

(Aschonitis et al., 2016). Due to this reason, applying CS method to understand the trustworthiness of the model in ecosystem services are criticized (Aschonitis et al., 2016). Accordingly, we did not employ CS analysis in our study. On the other hand, we did not check the reliability of the model by any other methods. Hence, this is the other limitations of this study. Therefore, the study highlights the importance of another robust method that accounts the uncertainty of the model and the represented biomes.

4.4. Contributions of the study

With its limitations, however, the study added a new dimension of local level estimation in ESV based on expert knowledge of the country than based on global data sets which could otherwise underestimate or overestimate the values. Studies of this kind are scarce in Africa that resulted in absence of local level estimation for decision-making processes in resource conservation and sustainable utilization. Hence, the output of the study will provide additional local level information to be included in global values for decision-making processes. It also helps to be used in data scarce areas as a substitute for similar conditions. The study has also gave an insight into the future changes in ESV, which are not the case in other studies in Ethiopia, such as Tolessa et al. (2016), Kindu et al. (2016), Tolessa et al. (2017), given the existing land use changes are unfolding due to the various proximate and underlying causes (Kindu et al., 2018). This particular piece of work will also help others to conduct research of similar types to investigate how ESVs are changing in the context of existing land degradation and climate change.

5. Conclusions

This study indicated the reductions in the total and individual ecosystem services in response to LULC changes. It was found that the significant expansion of cultivated land and built-up area and lessening of forest, shrubland and grassland cover during 1985–2015 periods, and the expected changes in 2030 and 2045 periods has reduced the total ESV from US$ 26.83 $\times 10^6$ in 1985 to US $22.58 $\times 10^6$ in 2000 and to US$21.00 $\times 10^6$ in 2015, and expected to further reduce to US$17.94 $\times 10^6$ in 2030 and to US$15.25 $\times 10^6$ in 2045. The reduction of shrubland throughout these periods is the major contributor to the reduction of ESV. Hence, the effects of the observed and predicted LULC states on the loss ecosystem services are higher than the gains. The LULC changes have also reduced the average ESV of the land during the 1985–2015 periods, and are expected to continue to reduce in the coming three decades. Therefore, curbing the expected LULC states towards increasing forest, shrubland and grassland cover are important to prevent the expected loss of ESV in the watershed. To this effect, a wide range of changing the widely implemented cereal production with fruits is imperative to improve vegetation cover of the study watershed, and then to increase ESV. Furthermore, the government should facilitate Payment for Ecosystem Services (PES) at micro-level as a conservation strategy and the other hand designing eco-tourism in the Andassa watershed will help to improve the income of local communities for conservation.

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