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Research Application Summary

Assessing and modeling land use/cover and ecosystem services evaluation in Central Ethiopia

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Abstract

Land degradation and ecosystem services (ES) impairment are a common phenomenon in Ethiopia due to unintended land use/cover (LULC) changes. Hence, currently millions are suffering with land conversions related socioeconomic and environmental problems. However, limited effort has been made to study the past and future impact of LULC changes on the ES values. This study aimed at estimating the values of ES in the past and future LULC changes of central Ethiopia. We assessed LULC transitions for 1973-2018 and simulated for 2050; thereby, ES values were estimated in different land covers to infer the total ecosystem value of the whole study area. The results revealed that natural forests, wetlands, and grazing lands, shrub-bush lands and water body were reduced by 16071.7, 6293.8, 35651.8, 72641.8, and 13559.2, respectively in the years between 1973 and 2018. On the contrary, cultivated lands and built-ups were increased by 225348.7 and 3331.5 ha, respectively. Similarly, in the 2050 cultivated lands and built-ups will be 678486.4 and 5050.17 ha, respectively and it shows 35.9 and 86.8% increments contrary to others land cover of the study landscape. As a result, the total value of ES of the study area reduced from US$ 1235.8 to US$ 1008.5 million (19%) in the years between 1973 and 2018. The total value of ES will be declined by US$ 263.8 million (27%) in 2050 compared to 1973. Of all estimated 17 individual ES only food production and food biological control were increased by 23 and 2.3%, respectively. For 15 individual ES reduced throughout the study periods. Therefore, it is possible to conclude that transitions of natural ecosystems in the landscape has caused immense ESs values loss and trade-offs. This implies that urgent policy measures are required that properly addresses land use related trade-offs and holistic benefits. Further studies that examine different land use management scenarios as options are paramount to indicate and encompass a mix of policy options.

Keywords: Artificial Neuron Network, Cellular Automata, Eastern African, Ecosystem Service Valuation, Ethiopia, MOLUSE, Simulation

Résumé

La dégradation des terres et la détérioration des services d'écosystèmes (SE) sont un phénomène courant en Éthiopie en raison de changements involontaires de l'utilisation/couverture des terres (UCT). Ainsi, des millions de personnes souffrent actuellement de problèmes socio-économiques et environnementaux liés à la conversion des terres. Cependant, peu d'efforts ont été faits pour étudier l'impact passé et futur des changements de l'UCT sur les valeurs des SE. Cette étude visait à estimer les valeurs des SE dans les changements passés et futurs de l'UCT dans la région centrale de l'Ethiopie. Nous avons évalué les transitions de l'UCT pour 1973-2018 et les avons simulées pour 2050; ainsi, les valeurs des SE ont été estimées dans les différentes couvertures des terres pour déduire la valeur totale de l'écosystème de toute la zone d'étude. Les résultats ont révélé que les forêts naturelles, les marais, les terres de pâturage, les terres peuplées d'arbustes et les masses d'eau ont été réduites de 16071,7; 6293,8; 35651,8; 72641,8 et 13559,2, respectivement, entre 1973 et 2018. A l'opposé, les terres cultivées et les constructions ont augmenté de 225 348,7 et 3 331,5 ha, respectivement. De même, en 2050, les terres cultivées et les constructions seront respectivement de 678 486,4 et 5 050,17 ha, ce qui représente une augmentation de 35,9 et 86,8 % par rapport aux autres types de couverture de terres du paysage étudié. En conséquence, la valeur totale des SE de la zone d'étude a diminué de 1 235,8 à 1 008,5 millions de dollars US (soit 19%) entre 1973 et 2018. La valeur totale des SE sera réduite de 263,8 millions de dollars (soit 27%) en 2050 par rapport à 1973. Sur l'ensemble des 17 SE spécifiques estimés, seules la production alimentaire et la lutte biologique alimentaire ont augmenté de 23 et 2,3 %, respectivement. Pour les autres 15 SE spécifiques, la production a diminué tout au long des périodes étudiées dans ce travail. Ainsi donc, il est possible de conclure que les transitions des écosystèmes naturels dans le paysage ont entraîné une perte de valeur considérable des SE et des compromis. Cela suppose que des mesures politiques urgentes sont nécessaires pour régler correctement les compromis liés à l'utilisation des terres et les avantages intégrés. Des études supplémentaires qui examinent différents scénarios de gestion de l'utilisation des terres comme des options sont primordiales pour guider et englober un mélange d'options politiques.

Mots-clés: Réseau de neurones artificiels, automates cellulaires, Afrique de l'Est, évaluation des services écosystémiques, Éthiopie, MOLUSE, simulation

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Introduction

In Ethiopia due to land use/cover (LULC) changes that are causing land degradation and biodiversity losses, the capacity of ecosystems to provide multiple Ecosystem Services (ES) have been reduced through time (Gebreselassie *et al*., 2016). The LULC changes entail the conversion of physical entities/cover type (e.g. forest to cultivated land, or grazing land to cultivated land) and the form people utilize the land (e.g. rain-fed to irrigation agriculture) (Verburg *et al*., 2009). However, the conversions of natural ecosystems (i.e. natural forest, rangeland, wetlands) to semi-natural (i.e. agro-ecosystem, urban) are more prominent (Gebreselassie *et al*., 2016). Changes in LULC have inherent and non-linear variations in different place and time (Nelson *et al*., 2009). Thus, the extent and form of changes in each LULC types varied widely (Furst *et al*., 2010; Terefe *et al*., 2016). This is due to the variation of the drivers that changes LULC over space and time. Multidimensional connections of human induced drivers like socio-economic, institutional, and policies together with environmental factors fundamentally affect LULC of the landscapes (Hurni *et al*., 2005). Ever growing demands for tillable land and infrastructures that are commonly related with rapid population growth causes conversion of LULC. Emerging socioeconomic development activities have also been the main reasons for expansion of agricultural and urban areas (Hurni *et al*., 2005).

The LULC conversions in central Ethiopia are causes of several environmental hazards and ESs losses. Previous studies have shown the impact of LULC conversions on water and land resources degradation and ecosystem disservices in the landscape. For instance, Aga *et al*. (2018a; b) revealed that LULC conversion related soil erosion increased sediment loading and siltation into the Lakes (i.e Zeway, Abjiyata and Langano). These lakes have been acting as nutrients (phosphate, nitrate and silicate) and sediment sink, thereby lake turbidity and eutrophication have increased over the years (Ayenew and Legesse 2007). Similarly, Aga *et al*. (2018a; b) reported that lakes water level, volume, quality and biodiversity were reduced overtime due to LULC conversion in the landscape. The environmental hazards in central Ethiopia are a by-product of LULC trade-offs and policies which favor only agricultural production (Kindu *et al*., 2016; Tolossa *et al*., 2016). Often, conversion of natural ecosystems like forest, wetland and grazing land for crop production has been for short-term economic benefits but in the long-term people have been denied access to useful services (e.g water availability and quality, air quality, pollination, food, fiber, recreation, and the likes) and have exprienced food-insecurity (Kindu *et al*., 2016; Tolossa *et al*., 2016). In order to should reduce poverty and assure sustainable development, provision of ESs bundle is paramount and become compulsory (Hurni *et al*., 2005).

The LULC based ESV is paramount to disclose spatially monetary value of ESs and changes in the landscapes (Kindu *et al*., 2016; Tolossa *et al*., 2016). The ESV discloses non-marketable and neglected ESs to the attention of policy makers and informed experts for better landscape management (Costanza *et al*., 1997). It is, therefore, crucial to identify and prioritize land degradation prone areas and the information generated used to comprehend the needed resources for land conservation and sustainability (Mengiestie *et al*., 2016). As such ESV is designed to use proxy data in the area where environmental hazard is prevalent and data are scarce (Costanza *et al*., 1997; Li *et al*., 2007; Hu *et al*., 2008). Despite its merits some concerns have also been raised related to ESV study (Tolossa *et al*., 2016). Uncertainties and under estimation of the contributions of some LULC types are the concerns in ESV (Li *et al*., 2007; Hu *et al*., 2008). Nevertheless, ESV has been the widely used approach in contemporary ecosystem studies (Nelson *et al*., 2009). However, little is known and studied about marketable and non-marketable ESs bundles and problems of ecosystem disservices at landscape scale in Ethiopia. Yet LULC analysis and prediction is crucial in order to understand ecosystem disservices, biodiversity losses, ESs impairments and then prepare future management plan. The aim of this study was to assess LULC dynamics of the past and the upcoming years and associated impacts on the values of ESs. Therefore, attempts were done in this study to detect the LULC changes and associated effect on the value of ESs at wider landscape level across time. The findings of the study will hopefully contribute to policy options development for sustainable landscape ecosystems and enhance ESs provision and human livelihood.

Materials and Methods

The study area is located at latitude of 38◦ 81’ and 39◦ 8’ E, and 7◦10’ and 8◦30’ N and covers about 10073.5 km^2. The altitude ranges from 1646m above mean sea level to 4171m above sea level on the highlands areas.

Different spatial attributed data were used from numerous sources for LULC change analysis. Four landsat satelite images for study periods of 1973, 1986, 2010 and 2018 were used to assess and simulate LULC of the study area. These images were cloud free and collected from United States Geological Survey (USGS). A topographic map and aerial photo were used to support image classification processes. A total of 110 random Ground Control Points (GCPs) collection were done for classification and accuracy assessment. Overall, the ancillary data were used to enhance image classification, accuracy assessment and change analysis.

Image classification and accuracy assessment. Model Builder in ArcGIS 10.3 software was used to composite bands and make mosaicked images of 1973, 1986, 2001 and 2018. Geo-referencing and rectification were done to adjust distortion using ground points and roads network using ArcGIS. Following to geo-correction atmospheric correction were performed to remove the haze and noze from images using ERDAS Imagine 15 software. Images were then resampled using study area boundary and image enhancement was done. Then, supervised classification procedure was conducted for image classification. Accordingly, the training points that proportionally distributed to each cover types were taken based on GPS ground points and Google earth. Maximum Likelihood Classifier was used in supervised classification procedures to classify the images independently in ERDAS Imagine 15 software. During post-classification the pattern and differences of LULC over studied years were determined and detected. The percentage of LULC change was calculated as follows.

% of LULC change =((area of final year-area of initial year)∕(area of initial year)*100)

The accuracy of image classification was evaluated using a non-parametric Kappa test.

Modelling to predict LULC of 2050. Cellular Automata-Artificial Neuron Network (CA-ANN) model that integrated the module for Land Use Change Evaluation (MOLUSE) was used to predict the 2040 and 2050 LULC using QGIS version 2.18.15 software. The CA-ANN model has three processes (Artificial Neuron Network, Cellular Automata, and validation) that made the model convenient and suitable for LULC prediction. LULC of 1986, 2011 and 2018 were used for model calibration and validation. We used 2018 LULC as observed map to validate the model which predicted 2018 LULC based on Kappa index statistics. Population density, DEM, altitude, slope and distance from river, settlements, and roads were used as input variables. These variables were prepared as raster data with equal row and column as well as zero nodata. The variables were identified based on previous studies used variables for LULC prediction. In this LULC projection process three major stages were considered. Accordingly, transition probability was computed using quantitative analysis to classify LULC maps. Then, the transition maps were computed. At the end, CA spatial filter to the transition probabilities and the transition potential maps were used for simulation. Therefore, the transition probabilities matrix and area changes were computed based on Markovian approach.

Approaches for ecosystem services valuation (ESV). Benefit transfer method was used to estimate the values of ES. The classified LULC maps of the study periods were used as a proxy for representative biomes to estimate values of ES for each land cover of the study area. Thereafter, the total ES values for the whole study area were estimated based on the values coefficients modified by Mengistie *et al*. (2016) in Ethiopia for 11 biomes.

The total value of ES for study periods of 1986, 2010, 2018 and 2050 were computed as per the following formula:

$$ESV_{kt} = \sum (A_k * VC_k) \ldots\ldots (1)$$

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

The total ESV for reference year 't' were computed by adding the ESV of each LULC class as follows

$$ESVT_t = \sum (ESV_{kt}) \ldots\ldots (2)$$

The change in ESV over time was assessed using the following formula:

$$\text{Percentage ESV change} = [(ESV_{t2}\text{-}ESV_{t1}) / ESV_{t1} \text{ X } 100] \ldots\ldots (3)$$

Similarly, individual ecosystem functions of the study area were also estimated based on the modified coefficients from Mengistu *et al*. (2016) and computed as follows.

$$ESV_f = \sum (A_{kx} VC_{fk}) \ldots\ldots (4)$$

where; ESVf = calculated ES value of function 'f', Ak = the area (ha) and VC_{fk} = value coefficient of function 'f' (US\$ ha^{-1} yr^{-1}) for LULC type 'k'.

Results and Discussion

Land use/cover (LULC) dynamics in the study area. The LULC transitions were analyzed for the study periods 1973, 1986, 2011, 2018 and 2050 (Table 1). The results show that the LULC of the study landscape were natural forests, plantation forests, shrub-bush lands, bare-lands, grazing lands, wetlands, built-ups, cultivated lands and water body (Table 1). The overall classification accuracy of the study periods was more than 85%. In the first study period (1973) cultivated land, Shrub-bush land and grass lands had higher coverage with 43.1, 21.3, and 15%, respectively. Whereas water, forests, wetland, bare and built-up areas had the least area coverage.

The state of most LULC at the end of study period 2018 were not similar to 1973 except cultivated lands. Cultivated lands and shrub-bush lands were found with higher area coverage in 2018 by 65.6, and 18.4%, respectively. Wetlands and built-ups were with least area coverage from total area in 2018. On the other hand, increments of area coverage for cultivated lands (226191 ha), plantation forest (10462.2 ha) and built-up (5102.2 ha) were exhibited in the past 40 years (1973-2018). However, natural forests, shrub-bush lands, grazing lands, water body, and wetlands were decreased by 59149.3, 28694, 135647, 13559.2 and 6293.8 ha, respectively. Cultivated land and built-ups were increased dominantly compared to other land cover in the years between 1973 and 2018. Contrastingly, Grass land, marshy area and water body showed decreasing trends in the three study periods (from 1973 to 1986, 1986 to 2011, and 2000 to 2018). However, shrub-bush lands, plantation forests and bare-lands were not persistently decreased. This finding is

Table 1. The total LULC area coverage and changes in the study periods

LULC class	1973 (ha)	1986 (ha)	2011 (ha)	2018 (ha)	1973-2018 (ha)	2050 (ha)	1973-2050 (ha)
Cultivated lands	434331	563884.29	619939.53	659679.75	225348.75	678486.42	244155.42
Plantation forests	0	3855.69	15282.36	10267.20	10267.2	9304.20	9304.2
Natural forests	27609.12	19218.42	21257.10	11537.37	-16071.75	11314.89	-16294.23
Water body	85231.44	82488.87	78826.14	71672.22	-13559.22	68967.36	-16264.08
Grazing lands	150770.16	26219.97	25465.68	15118.29	-35651.87	15030.00	-135740.16
Wetlands	15033.24	10663.92	8614.80	8739.36	-6293.88	7310.43	-7722.81
Built-ups	665.28	585.00	3304.35	5896.08	5230.8	5050.17	4384.89
Bare-lands	36457.56	70934.94	39558.06	39789.09	3331.53	33432.75	-3024.81
Shrub-bush lands	257293.44	229150.17	195102.90	184651.56	-72641.88	178454.7	-78838.74

similar to those of other studies conducted in Ethiopia (e.g. Kindu *et al*., 2016; Terefe *et al*., 2017; Woldeyohannes *et al*., 2020). Cultivated land and built-up areas have dominantly increased in the study area. This finding is in line with several studies conducted in the country (Gebrehiwot *et al*., 2014; Kindu *et al*., 2016; Terefe *et al*., 2017; Woldeyohannes *et al*., 2020). Numerous reasons were reported to be associated with cultivated land and built-up expansion. For instance, Getinet *et al*. (2014) and Degene *et al*. (2018) indicated that population growth, economic growth, land tenure policies and regime change as possible reasons. Expansion of cultivated land may not be continued afterward to a similar extent and pattern of previous years. This is due to limited cultivated land and other land uses. However, built-up areas expansion will likely continue in similar or twofold than in previous time.

Predicted LULC of the study landscape in 2050. The LULC prediction of the study area was done for 2050 and the results are presented in Table 2 and Figure 1. The calibration of the model was with 100 iterations, 3X3 (9 pixels) neighborhood value, 0.001 learning rate, 10 hidden layer, and 0.050 momentum values. The min validation Overall Error was 0.09408 and with 76.4% efficiency of Current validation Kappa to simulate and produce LULC map of 2050. With exception of cultivated land, all simulated LULC classes will decline by 2050. Radical changes of LULC were observed between 1973 and 2050. With exception of cultivated land and built-ups all LULC classes were immensely reduced. Accordingly, grazing land, natural forest and marshy areas were decreased by 90, 83 and 41%, respectively.

Estimated ES values of the study landscape . The total ES values of the whole study area reduced from US\$ 1235.8 to US\$ 1008.6 million in the years between 1973 and 2018 (Table 2). This result is similar to several findings in the country (Tolossa *et al*., 2016, Kindu *et al*., 2016). Similarly, the results revealed that about US$ 36.6 million total ES values would be reduced in the next 30 years. The total ES value persistently declined and will continue to decline. Therefore, if the LULC changes scenario continued considerable amount of ES values would be lost from the study landscape. It is therefore essential to develop landscape management options in different scenarios.

Of all study landscapes LULC water related loss of ES values (US$ 110 million $ha^{-1}yr^{-1}$) was much prominent compared to other land covers in the years between 1973 and 2018. It is also anticipated to lose the highest ES values in the next 30 years compared to other ecosystems. Aquatic ecosystems of the study landscape needs urgent attention to prevent further loss, conserve, preserve, and restore loss over the long term. Wetlands and shrub-bush lands accounted for US$ 51 and US$ 71.7 million ES values reduction, respectively, in the period between 1973 and 2018. In the years to come ES values losses in relation to conversions of wetlands and shrub-bush lands are estimated to be US$ 11.6 and US$ 6.1 million, respectively. Expansion of cultivated land in slope gradient from gentle to steep and very steep slopes was observed (Kindu *et al*., 2016). In general, considerable expansion of cultivated land was reported all over the country. Likewise, losses of ecosystem services values were also reported in response to LULC dynamics in Ethiopia (Kindu *et* *al*., 2016; Tolossa *et al*., 2017; Gashaw *et al*., 2018; Temesgen *et al*., 2018; Hailu *et al.,* 2019). Protection, restoration and preservation of lakes and wetlands ecosystems from further damage could address about 61% of ES values losses (US$ 161 millions) in the study landscape. The conversions of shrub-bush lands and grazing lands were responsible for loss of ES values of US$ 71.7 million and US$ 39.8 million, respectively in the year between 1973 and 2018. Future land management plan of the study landscape needs to consider shrub-bush lands and lakes and wetlands ecosystems. The overall trends of the ESV of the study landscape across all natural ecosystems persistently decreased in the study periods.

Table 2. ESV (US$ million $ha^{-1}yr^{-1}$) of LULC classes and its change over study periods (1973 to 2018)

LULC class	ESV US$ million $ha^{-1}yr^{-1}$					Change of ESV US$ million $ha^{-1}yr^{-1}$		
	1973	1986	2011	2018	2050	1973-2018	2018-2050	1973-2050
Cultivated lands	98.0	127.2	139.8	148.8	153.0	50.8 (52)	4.2 (3)	55.1 (56.2)
Plantation forests	0.0	3.8	15.1	10.1	9.2	10.1	-1.0 (-9.4)	9.2
Natural forests	27.2	19.0	21.0	11.4	11.2	-15.9 (-58.2)	-0.2(-2)	-16.1(-59)
Water body	690.7	668.4	638.8	580.8	558.9	-109.9 (-16)	-21.9(-3.8)	-131.8(-19)
Grazing lands	44.2	7.7	7.5	4.4	4.4	-39.8 (-90)	0.0(-0.6)	-39.8(-90)
Wetlands	121.8	86.4	69.8	70.8	59.2	-51.0 (-42)	-11.6(-16.4)	-62.6(-51.4)
Built-ups	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bare lands	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Shrub-bush lands	253.9	226.1	192.5	182.2	176.1	-71.7 (-28)	-6.1(-3.4)	-77.8(-30.6)
Total	1235.8	1138.6	1084.4	1008.6	972.0	-227.2	-36.6	-263.8

Figures in parentheses indicates change of ESV in percent (%)

Of all estimated 17 individual ES only food production and food biological control were increased by 23 and 2.3%, respectively. The combined values of 17 ES were reduced from US$ 1235.8 to US$ 1008.6 million ha^{-1} yr^{-1} in the years between 1973 and 2018. Among the estimated ES water regulation, water supply, water treatment, erosion control, and nutrient cycling were reduced by 109, 42.7, 28.9, 23.2 and 14.5 million US$, respectively in the years between 1973 and 2018. The combined values of 17 ES would be reduced by US$ 36.6 million $ha^{-1}yr^{-1}$ in the period between 2018 and 2050. In general the result revealed that water related ES values were highly affected in LULC transitions of the study area. Therefore, strategies and policies need to give high attention for lakes and wetlands restoration and water based landscape restoration.

Conclusion

This study set-out to analyze landscape transformations and estimate the values of ESs in the study area. Four key trends are revealed; (i) A coupling of land transformations into agricultural land, and built-ups area in the study area is experiencing an upward trend over time resulting into observed reduction in natural ecosystems; (ii) Threefold decrease in ESs in the period of analysis; (iii) Lakes and wetlands related ES values reduction is about half loss from the whole study area. Therefore, wetlands and aquatic ecosystems need special attention; (iv) if the land management and existing land use policy persist, fivefold ESs values would be lost in the coming three decades. (v) trade-offs were exhibited while ES values of food production and biological control increased while for the other 15 individuals ES reduced throughout the study periods. This implies that prompt decisions and land-use policy options are required to address ES trade-offs in the study landscape. Entire landscape restoration is crucial with due emphasis to aquatic and wetlands ecosystem prevention from further damage and loss.

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