Human modified landscape structure and its implication on ecosystem services at Guder watershed in Ethiopia

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Abstract We investigated the impacts of landscape structure changes on ecosystem services for Guder watershed. We first analyzed remotely sensed data of four decades (1973–2015). The raster data sets of land uses were used as an input in FRAGSTAT to analyze the magnitude of fragmentation. Furthermore, the locally modified ecosystem service values to estimate the ESVs for the watershed were used. Results indicated that grasslands, shrub land, and forest lands reduced by 83.5%, 48.5%, and 37.5%, whereas the corresponding increase was recorded for settlement and cultivated land by 572.2% and 7.1%. Fragmentation analysis showed an increase in class area (CA) for cultivated land and settlement, whereas number of patches (NP) rose for forest land, shrub land, grassland, settlement, and cultivated land signifying the extent of fragmentation. The overall ESVs of the watershed decreased due to the changes in landscape structure. We recommend the need to take in to account landscape-level watershed conservation to enhance ecosystem services.

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Introduction

The conversion and fragmentation of vegetated land uses is an ancient phenomenon and has caused a reduction in vegetated land uses with small isolated patches surrounded by human dominated landscapes (Ribeiro et al. 2009; Shrestha et al. 2012; Reddy et al. 2013; Bhagwat 2014). Such shrinking in size and increase in distance between each patch affects ecosystem service provided by individual land uses found at the landscape level (MA 2005; Yushanjiang et al. 2018; Qiu et al. 2019). Investigations of ecological phenomena at broad spatial scales often require quantifiable descriptions of landscape structure for testing relationships about the landscape and the phenomena in question. To this end, different types of measurements landscape metrics have been developed by researchers (McGarigal and Marks 1994; Rutledge 2003; Çakır et al. 2008; Wang and Yang 2012; Qi et al. 2014; Daye and Healey 2015). Among these the use of patch analysis at the landscape over spatial and temporal scales helps in drawing relationships between landscape composition and configuration to make appropriate decision with regard to resource use that determine ecosystem services.

In the past four decades, cultivated land and settlement has rapidly expanded as a result of the need for more land for crop production and establishing settlement to address the demand for more food and space in land uses that are not under human influences (Tekle and Hedlund 2000; Teketay 2001; Tolessa et al. 2016, 2017a, b). The policy frameworks designed to pursue in relation to agricultural development in the past four

decades mainly focused on extensification and small-holder farming. This land use dynamics has caused further land fragmentation and degradation that increased number of patches especially for cultivated land and settlement with diversity of usufruct rights and the conversion of other land cover to human modified land use. This landscape-scale patterns highly affect ecological roles and conditions (Harrison and Bruna 1999; Wade et al. 2003; Nagendra et al. 2004; MA 2005; Hartter and Southworth 2009; Gebreselassie et al. 2016) with significant impacts on ecosystem services which can be manifested in the form of habitat loss, reduction in land productivity (Harrison and Bruna 1999; de Groot et al. 2010; Costanza et al. 2014; Tolessa et al. 2017a, b; Yushanjiang et al. 2018; Gashaw et al. 2018). Up to now studies focused on assessing the dynamics of land uses at local, regional, and global scales. The changes at temporal and spatial scales affect the sustainability of ecosystems at landscape level and at individual land uses through altering the composition, structure, and spatial patterns of the physical and biological environments. Of the changes that affect ecosystem functions and process are the level of fragmentation. Hence, a concerted effort has been made in studying fragmentation of landscapes in space and time to support decision making processes about the sustainable use of natural resources.

Vegetated land cover conversions as well as fragmentation are most acute in rural areas of Ethiopia to feed more mouths that come both from urban and rural families (Mengistu et al. 2012; Tolessa et al. 2016). Although LULC studies were extensively studied in Ethiopia (Tekle and Hedlund 2000; Kindu et al. 2013; Gebrehiwot et al. 2014; Jacob et al. 2015, 2017) few attempted (Daye and Healey 2015; Tolessa et al. 2016) to combine LULC analysis with patch analysis to obtain a better understanding of how landscapes are changing in space and time as the use of landscape metrics is used to compare alternative landscape configuration by providing detailed quantitative information (Leitão and Ahren 2002; Moreno-Sanchez et al. 2011). Furthermore, analyzing the correlation between landscape structure and ESV would provide sufficient information for monitoring how changes in landscape structure determine the flow of services for human well-being and implementing management strategies for sustainable development, which would help determine the costs of restoration and assist in payments for ecosystem services.

In this paper, we analyze and characterize how land uses are undergoing changes at landscape level over temporal and spatial scales. We also make analysis of the spatial correlation between landscape metrics and ecosystem service values to determine which landscape metric are vital in determining the continuous flow of ecosystem services at landscape level. In addition, there is a need for a consistent evaluation of the level of land use/land cover dynamics and fragmentation of all land uses to document and provide recommendations for policy makers regarding land management practices at national level.

Study site and methodology

Study site

The detailed location, rainfall, and temperature of the watershed can be found on Kidane et al. (2018). The catchment which comprises Guder watershed drains to the Blue Nile where the Blue Nile is the major and most important river in Ethiopia with the volume of water and size of the river (Belay 2011). The major soil types of Guder catchment which is one part of the Guder sub-basin include soil Chromic Luvisols, Eutric Cambisols, Eutric Leptosols, Eutric Vertisols, Haplic Luvisols, Haplic Alisols and Haplic Nitisols (FAO 1995). Soil acidity, depth, and permeability are some of the limiting factors which reduce agricultural productivity.

The total population of the watershed is about 130,500 of which 64,881 are male and 65,619 are female (CSA 2008). The dominant economic activity is agriculture involving crop and livestock production which is mainly subsistent in its nature but here are some off-farm activities that include petty trade and forest product collection and sell. The major type of vegetation includes dry Afromontane forests that are dominantly characterized by *Podocarpus falcatus* and *Juniperus procera* species (personal observation).

Methodology

Satellite image processing and land use/land cover study

Detailed methods of image processing were described in Kidane et al. (2018). A total of 250 GCPs were collected randomly from the study area considering area

Table 1   Description of imaginary data used for land cover change study (Kidane et al. 2018)

Imaginary date	Imaginary type	Resolution	Path and raw	Source
01-02-1973	Landsat MSS	57×57 m	169/54 and 168/54	USGS
01-11-1995	Landsat TM	28.5×28.5 m	169/54	USGS
01-13-2015	Landsat OLS	28.5×28.5 m	169/54	USGS

proportion for different LULC classes (21 shrub land, 37 settlement, 12 grass, 23 forest, and 268 cultivated land) (Table 1).

Settlement land, cultivated, shrub land, grassland, and forest land are the types of land uses identified. The overall accuracy and kappa statistics were 89.6% and 0.81, respectively, which met the tolerable limit (Congalton 1991; Jessen et al. 1994; Hartter and Southworth 2009; Wondrade et al. 2014). Furthermore, these land uses were also used for estimating ecosystem service values.

Five land cover types were identified in classifying the land cover (Table 2).

Analysis of fragmentation in landscapes

Landscape metric is one of the most methods used in landscape fragmentation analysis where the raster data sets which are extracted from remotely sensed images are used as an input in FRAGSTAT software to identify and describe landscape pattern (McGarigal and Marks 1994; McGarigal et al. 2012). Landscape metrics can quantify and characterize the spatial patterns observed at a landscape based on the shape, size, number, and other spectral signatures of land parcels or patches captured in remote sensing data (Cushman and McGarigal 2002; Su et al. 2012; Daye and Healey 2015; Tolessa et al. 2016). The use of remote-sensing technologies improves the

availability of raster data sets to detect the level of fragmentation and the condition of land use/land cover dynamics (Rutledge 2003). During the study of land fragmentation the following metrics are used to evaluate the dynamics of fragmentation at class level (Table 3).

We selected landscape metrics based on four criteria (Hargis et al. 1998; Leitão and Ahren 2002; Rutledge 2003; Su et al. 2012; Wang and Yang 2012): (1) comparability with previous landscape ecological studies, (2) ability to indicate ecological conditions, (3) low redundancy among landscape metrics, and (4) ability to reflect the characteristics of landscape patterns for the study area (Table 3).

Landscape-level ecosystem service estimation

The modified ecosystem service value coefficients developed for the highlands of Ethiopia based on expert knowledge of the area by modifying global value data sets were adopted (Kindu et al. 2016, 2018; Gashaw et al. 2018). Then for each ecosystem service value of the area these modified coefficients were used to estimate the overall and individual ecosystem service values (Tables 4 and 5). Furthermore, since all land uses identified in our study and the modified global biome data bases are not perfect matches, we used proxies to estimate the values. In addition, to calculate the values of ES for each land

Table 2   Descriptions of land cover types in the study area (Kidane et al. 2018)

LCLU classes	Descriptions
Shrub land	Areas covered with small trees, bushes, and shrubs, usually not exceeding 3 m in height
Settlement land	Land dominated with houses and huts
Grassland	Areas are covered by both long and short grasses, annual wetlands which are used for private and communal grazing purpose with the mix up scattered trees, shrub/bushes, and also cover, mainly with classic gullies and exposed rocks, including rock outcrops, denuded land, and badlands.
Forest land	Area covered by trees where the trees cover density is greater than 10%. It includes plantation and natural forest.
Cultivated land	Areas used for crop cultivation, both annuals and perennials. This category includes areas currently under crop, fallow, and land under preparation.

Table 3 Landscape metrics used in the present study

Acronym	Metric	Description
CA	Class area	Area of patch for each with land use (ha), CA > 0
PLAND	Percentage of landscape	Proportion of the landscape occupied by certain LULC class (0 < PLAND < 100)
NP	Number of patches	Number of patches in the landscape of the same LULC class (NP ≥ 1)
PD	Patch density	Total number of patches in land use (PD > 0)
AREA_MN	Mean patch size	Mean area of patches of the same LULC class (m^2), AREA_MN > 0
EDGECON	Contrasting edge ratio	Total length of edge shared between cells with the focal land use and contrasting land use (0 ≤ EDGECON ≤ 100)
TECI	Mean dispersion	Proportion of cells of contrasting land use that are within a specified distance of cell with focal land use; 0 ≤ TECI ≤ 100
CWED	Contrast weighted edge density	Proportion of cells of contrasting land use that are within a specified distance of cell with focal land use, total number of cells with land use, CWED ≥ 0
CONTAGION	Contagion	Proportion of the landscape occupied by patch type (class); number of adjacencies (joins) between pixels of patch classes and based on the double-count method; number of patch classes present in the landscape, including the landscape border if present. 0 < CONTAG ≤ 100

Note. All the measures are computed based on raster data with 30 × 30-m cells. Metrics 1 and 2 are the area of land type and its percentage of landscape. They provide basic information about the proportion of land use changes. Metrics 3 and 4 are number of patches and patch density. They measure the fragmentation degree from the patch number aspect. Increased patch number and density generally represent an increased fragmentation. Metrics 5 and 6 are mean patch size and mean perimeter-to-area ratio, and they focus on size and shape of the patches. If the total area of a land use type keeps the same or increases, a decrease of mean patch size of this class type indicates an increase in the fragmentation. Perimeter-area ratio is a simple measure of shape complexity. An increase of the value indicates a more complex patch shape or the decrease in patch size with a constant shape

use over spatial and temporal scales the following equation was used:

$$\text{ESV} = \sum (A_K X V C_k) \qquad (1)$$

where ESV is the estimated ecosystem service value, A_K is the area (ha), and VC_k is the value coefficient (US \$ ha^{-1} yr^{-1}) for LULC category k. The change in ecosystem service value was estimated by calculating the differences between the estimated values for each LULC category in 1973, 1995, and 2015.

Table 4 LULC categories in the study watershed, the corresponding biomes, and ecosystem service coefficients based on the modified estimates (Kindu et al. 2016, 2018; Gashaw et al. 2018)

LULC categories	Equivalent biome	Ecosystem service coefficient (US \$ ha^{-1} yr^{-1})
Cultivated land	Cropland	225.56
Forest land	Tropical forest	986.69
Shrub land	Tropical forest	986.69
Grassland	Grassland/range lands	293.25
Settlement	Urban	0

In addition to estimating LULC dynamics effects on the total value of ecosystem services, we also estimated the impacts of such changes on 17 individual ecosystem services in the study landscape. The values of each 17 ecosystem services provided by LULC at the landscape level were calculated using the following equation (Hu et al. 2008) for the study period:

$$\text{ESV}_f = \sum (A_K X V C_{fK}) \qquad (2)$$

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

The use of locally modified values coefficients which were based on global value coefficients has been found to be criticized because it does not take into account local-level biophysical differences; the values are based on existing willingness to pay of individuals for ecosystem services at local-, regional-, and global-level studies which did not cover wide ecological regions and little knowledge of respondents about the value of environmental resources (Costanza et al. 1997, 2014; Van der Ploeg et al. 2010; Kindu et al. 2016, 2018; Gashaw et al. 2018). Despite these limitations, such type of studies are

Table 5 Coefficients (US $ ha^{-1} yr^{-1}) of the modified ecosystem service valuation (Kindu et al. 2016, 2018; Gashaw et al. 2018) 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

providing important information about the status of ecosystem services in monetary values that could be used as basis for decision making processes with regard to the management of natural resources (Tolessa et al. 2017a, b). We used a simple benefit transfer method as described in many studies (Costanza et al. 2014; Kindu et al. 2016; Gashaw et al. 2018).

Moreover, the correlation between nine landscape metrics and 17 ecosystem services were calculated within SPSS.17 software based on Pearson correlation coefficient (Yushanjiang et al. 2018; Qiu et al. 2019).

Results

Land use/land cover change

Rapid conversion of grassland (83.5%) to human-influenced land uses could be due to two major reasons. The first one is related to the open access nature of grasslands for communities to easily convert it. Grasslands are common property resources in rural Ethiopia partly because of the agropastoral and pastoral livelihood activities of the communities where individual ownership is not claimed. The second could be due to its relative location on flat areas where cultivation and settlement is not damaging the land. So, farmers' decision to convert grassland to either settlement or cultivated land is based on institutional, biophysical, and economic factors.

Shrub land (48.5%) was converted to settlement and cultivated land next to grassland as this land use is also considered to be partially open for communities to collect forest products, keeping livestock and are not strictly protected by government laws as compared to high forests. In Ethiopia, shrub lands are managed as community forests in each Peasant Associations (PAs) for the purpose of collecting firewood, construction material, and other for environmental services with the intention of reducing pressure from protected forests.

Forest land (37.5%) conversion was usually the results of the demand for land when options from other land uses (grassland and shrub land) are limited. Forest land conversion is made for cultivation of relatively fertile land which do not require the addition of fertilize and done with low effort for cultivation by slash and burn system. Newly established families are those who are actively engaged with the conversion of this particular land use to obtain access to land. The NDVI values corresponding to forest land use indicated the decrease in forests across elevation, that is, forest land, substantially decreased with variable magnitudes (Table 6 and Figs. 1 and 2). When we compare the conversion of forest land across elevation ranges, the highest reduction was observed in the middle watershed (2303.1–2787) by 35% than the lower (1820–2303) and upper watersheds (2787.1–3271) for the study period (Table 6 and Figs. 1 and 2).

Settlement (572.2%) increased at a much higher rate than cultivated land due to the increased number of families within the central highland areas of Ethiopia, but such rate of increase is less than the actual amount as compared to cultivated land. For instance, the percentage of cultivated land in the watershed was 66.5% in 1995 but settlement was 6.6% despite the higher rate of change. The higher percentage of change between periods explain the rapid increase in settlement but the actual area cover is low as settlement in rural Ethiopia is so small in size.

Table 6 Land use/land cover changes of the landscape, 1973–2015 (Kidane et al. 2018)

LULC class	Absolute area coverage (ha)			Cover change between periods (%)		
	1973	1995	2015	1973–1995	1995–2015	1973–2015
Cultivated land	29,236.3	31,015.7	31,300	6.1	0.92	7.1
Shrub land	7730.44	5736.24	3983.76	− 25.8	− 30.6	− 48.5
Settlement	1017.07	3064.95	6836.31	201.4	123	572.2
Grassland	1920.38	1114.47	317.25	− 42	− 71.5	− 83.5
Forest land	6749.64	5722.44	4216.5	− 15.2	− 26.3	− 37.5

As crop production is the dominant livelihood activity in Ethiopia, the change in vegetated land to cultivated land is one of the major causes of deforestation. Although the rate of increase in percentage cover change for cultivated land (7.1%) is low the overall area of land under cultivation is large (67%) in 2015, indicating the dominance of this particular land use. Our study area is regarded as one of the potential areas for crop production in the country with cereal crops dominated farm plots supplying large quantities of grain to
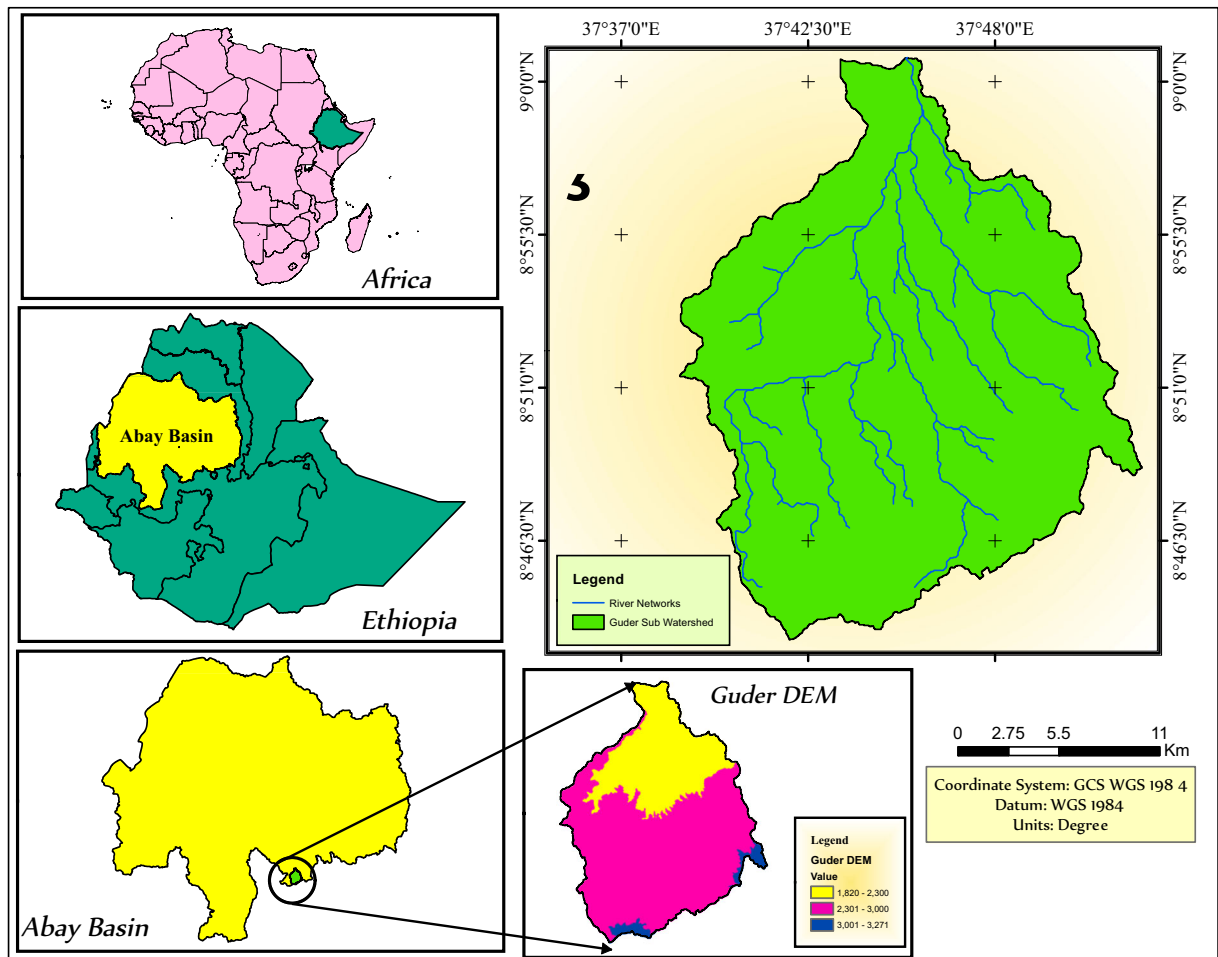
Fig. 1 Location map of the study watershed (Kidane et al. 2018)
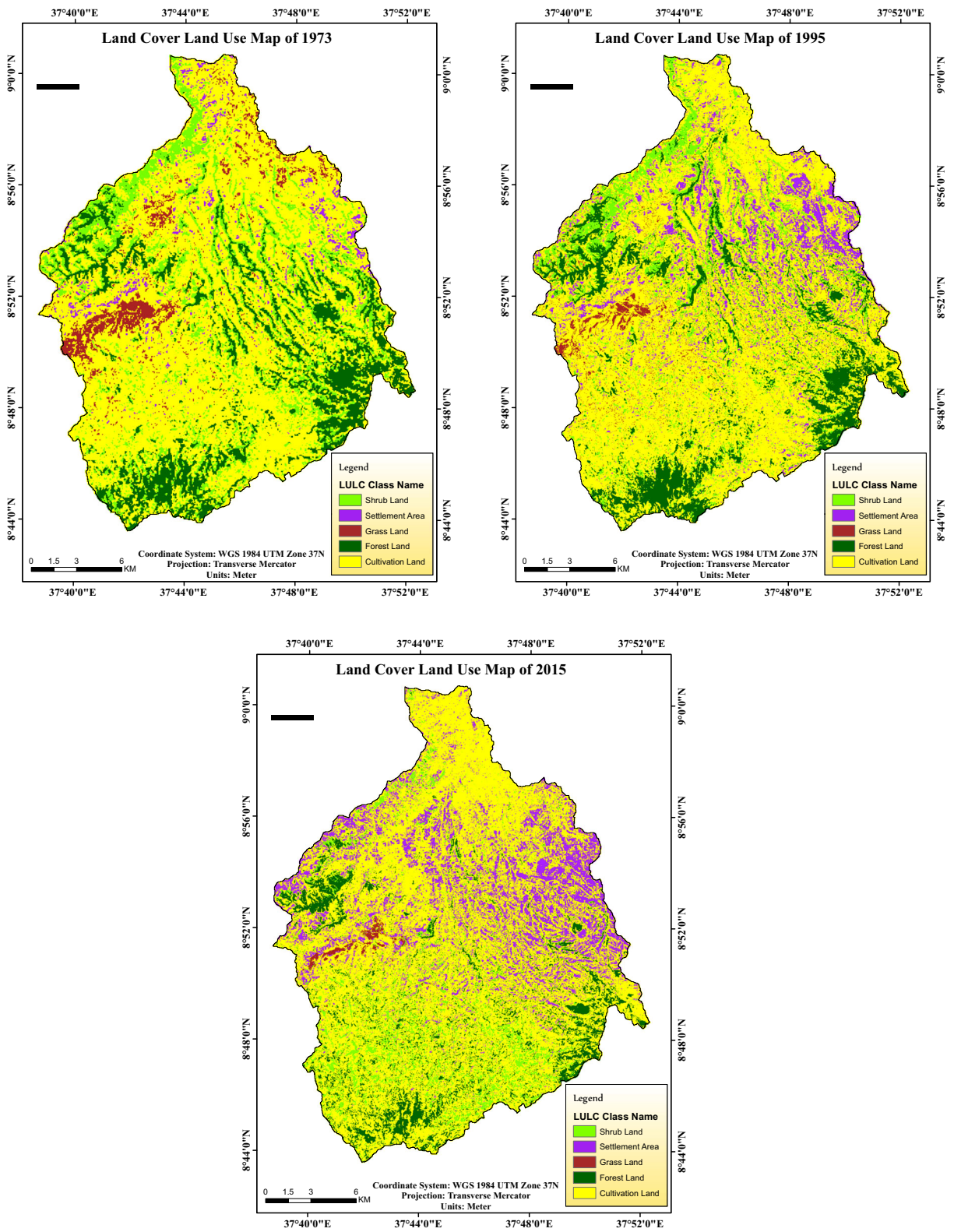
Fig. 2 Land use/land cover map of Guder watershed (1973–2015) after Kidane et al. (2018)

the central market. In general, for the two phases of the study, that is, phase I (1973–1995) and phase II (1995–2015) are characterized by similar magnitude of land use changes although the amount varies between the phases. This means that in the second phase (42.8%), the decrease in vegetated land uses are much higher than the first phase (27.7%) corresponding to an increase in the loss of these land uses by 54.5%.

Landscape scale metrics analysis

As human modified land uses are increasingly dominating the landscape in our study area, the diverse land uses especially natural environments decrease in size and the ecosystem services expected shrink linearly producing the slow level of required products obtained at the landscape level.

The results showed that different land use/land cover types had different values of landscape metrics. Class area pattern and percentage of landscape measure have shown conversion in land use/land cover types in the study period (1973–2015). Of this, the conversion of grass, shrub, and forest land to cultivated land and settlement were significant. The dominance of cultivated land and settlement land described by CA and PLAND can be taken as one way of understanding the level of human activities in to the natural environment.

AREA-MN (− 30.2%) decreased for cultivated land which indicates an increasing trends of fragmentation in the study period. The level of fragmentation indicates that there is variability with comparable differences between among the land use types identified in the study period. For example, NP increased for all land uses except for grassland which tended to be converted at much more higher rates to settlement and cultivated land after fragmentation (Table 7).

In addition to the overall reduction of forest area, we found an increase in the number and a decrease in the size of patches reflecting the ongoing fragmentation of forest habitats. The increased NP for forest land by 4800% is indications of excessive fragmentation by systematically converting the forests not only from the edge but also from the center that slowly disintegrate continuous forests as there are two mechanisms by which smallholder farmers tend to covert forests. First, farmers slowly convert forests to cultivated land at the edge when their farm land is in the close proximity of forests. Furthermore, they cut trees around their farm land to increase visibility for protecting crops from wild animal raid. Second, farmers settle and cultivate in the middle of the forest without noticeable activities for long time and they slowly expand their farm outward.

Table 7 shows the variation of fragmentation distribution patterns. Results showed that there was significant spatiotemporal variation in CONTAG. CONTAG decreased for cultivated land (− 4.4%), shrub land (− 29.7%), and forest land (− 21.7%) which indicates aggregation of patches with low level of disturbance spread and low edge density. For the rest land uses CONTAG increased over the study period implying to the increase in edge. PD increased for cultivated land, settlement, and forest land, and the most obvious increases in PD were found for shrub land which shows the spatial heterogeneity of the land uses. Considered together, NP increased over the study period except grassland suggesting land use fragmentation which resulted in reduced area (AREA-MN) for all patches.

Ecosystem service values of Guder watershed

The ecosystem service values of Guder watershed estimated based on the modified local value estimate through the use of proxies for each land use indicated that the overall ESVs were reduced by 28.9% (Table 8). The sum of ESV for each LULC types consistently decreased from 1973 to 2015, and the most important decrease was observed for shrub land, grassland, and forest land. The largest losses of ESVs were recorded for 1973–2015(US $6.2 million), 1995–2015 (US $3.4 million), and 1973–1995 (US $2.82 million). When we see individual ESVs for the study period (1973–2915), food production contributed the highest value across the 17 ecosystem services and provisioning services. Climate regulation, erosion control, and nutrient cycling are the three services reduced much more than others although others were negatively affected due to land use changes (Tables 8 and 9).

Landscape-scale metrics and ecosystem services

There were significant relationships among landscape-scale metrics values and ecosystem services values (Table 10). Among these relationships, CA, PLAND, AREA-MN, CWED, and CONTAG were significantly and positively correlated with food production, biological control, and pollination. In addition, NP and PD were significantly and positively correlated with soil formation,

Table 7 Representation of spatial pattern at class level for five land uses in three periods of study (1973, 1995, and 2015), based on 11 landscape metrics for the watershed

Landscape metrics	Values			Change between periods (%)		
	1973	1995	2015	1973–1995	1995–2015	1973–2015
Cultivated land						
CA	29,157.12	31,139.82	32,565.96	6.8	4.6	11.7
PLAND	62.81	67.07	70.15	6.8	4.6	11.7
NP	629	1181	1006	87.8	− 14.8	59.9
PD	1.35	2.54	2.16	88.1	− 14.9	60
AREA-MN	46.35	26.37	32.37	− 43.1	22.8	− 30.2
EDGECON	66.06	67.74	62.13	2.5	− 8.3	− 5.9
TECI	71.71	68.37	63.68	− 4.7	− 6.7	− 11.2
CWED	49.98	69.93	76.72	39.9	9.7	53.5
CONTAG	0.9	0.88	0.86	− 2.2	− 2.3	− 4.4
Shrub land						
CA	7745.85	5387.76	3430.71	− 30.4	− 36.3	− 55.7
PLAND	16.68	11.6	7.39	− 30.5	36.3	− 55.7
NP	2351	5582	6147	137.4	10.1	161.5
PD	5.06	12.02	13.24	137.5	10.1	161.7
AREA-MN	3.29	0.97	0.56	− 70.5	− 42.3	− 82.9
EDGECON	73.82	69.11	71.40	− 5.6	3.3	− 3.3
TECI	74.37	68.77	71.56	− 7.5	4.1	− 3.8
CWED	36.72	38.78	31.52	5.6	− 18.7	− 14.2
CONTAG	0.74	0.6	0.52	− 18.9	− 13.3	− 29.7
Settlement land						
CA	949.68	3558.42	6299.55	274.7	77	563.3
PLAND	2.05	7.66	13.57	273.7	77.2	561.9
NP	661	2998	4348	353.6	45	557.8
PD	1.42	6.46	9.37	354.9	45	559.9
AREA-MN	1.44	1.19	1.45	− 17.36	21.85	0.69
EDGECON	72.56	51.17	51.68	− 29.5	0.99	− 28.8
TECI	72.91	50.79	51.06	− 30.3	0.53	− 29.9
CWED	5.74	16.13	27.34	181	69.5	376.3
CONTAG	0.67	0.66	0.68	− 1.5	3	1.5
Grassland						
CA	1848.33	712.08	292.14	− 61.5	− 58.9	− 84.2
PLAND	3.98	1.53	0.63	− 61.6	− 58.8	− 84.2
NP	834	2449	403	193.6	− 83.5	− 51.7
PD	1.79	5.27	0.87	194.4	− 83.5	− 51.4
AREA-MN	2.22	0.29	0.72	− 86.9	148.3	− 67.6
EDGECON	98.66	92.08	89.76	− 6.7	− 2.5	− 9
TECI	98.76	93.95	91.81	− 4.8	− 2.3	− 7
CWED	11.09	9.68	2.37	− 12.7	− 75.5	− 78.6
CONTAG	0.76	0.48	0.67	− 36.8	39.5	− 11.8
Forest land						
CA	6723.27	5631.93	3832.38	− 16.2	− 31.9	− 42.9

Table 7 (continued)

Landscape metrics	Values			Change between periods (%)		
	1973	1995	2015	1973–1995	1995–2015	1973–2015
PLAND	14.48	12.13	8.26	− 16.2	− 31.9	− 42.9
NP	82	2267	4018	2664.6	77.2	4800
PD	1.77	4.88	8.66	175.7	77.5	389.3
AREA-MN	8.19	2.48	0.95	− 69.7	− 61.7	− 88.4
EDGECON	62.23	65.53	70.3	5.3	7.3	12.9
TECI	64.5	64.83	70.88	0.51	9.3	9.9
CWED	17.7	21.18	25.38	19.7	19.8	43.3
CONTAG	0.83	0.78	0.65	− 6	− 16.7	− 21.7

habitat/refugia, and recreation. By contrast, there were negative correlations between a number of landscape metrics and ecosystem services indicating landscape-level configuration of the various land use types are affecting the ecosystem services. We also found few significant relationships between landscape metrics and ecosystem services which are described above. Generally, landscape metrics were not significantly correlated with regulating and supporting services of ecosystems which could be related to the continuous reduction of vegetated land uses in the area (Table 10).

Discussion

Land use/land cover change

The dominant land use type identified in Guder watershed is cultivated land. The increase in cultivated land use is related to the agriculture based nature of the economic activity of the country where 85% of the labor

is engaged in farming activities and 45% of the GDP is accounted for and is highly susceptible to land degradation (CSA 2008; Wondrade et al. 2014; Gebreselassie et al. 2016; Kidane et al. 2018). The Agricultural Development Led Industrialization (ADLI) policy designed by the Ethiopian government to promote economic growth through increasing production and productivity with the available land and labor is one of the policy directions influencing such land use changes. PSDEP I and PASDEP II were implemented to improve agricultural sector performance through capacity-building program and enhancement of the transfer of technologies to improve production. Although much effort was made to increase production at the cost grassland, shrub land, and forest land, the program was constrained by sustainable production of the desired amount of production due to land degradation and the economic capacity of farmers to adopt improved agricultural technologies. These plans led to 41.6% contribution of agriculture to GDP (FDRE 2010). The land ownership proclamation of Ethiopia which abolished

Table 8 Changes in ESV (US $ in millions) in the study watershed (1973–2015)

LULC categories	1973–1995		1995–2015		1973–2015	
	ESVs	Change (%)	ESVs	Change (%)	ESVs	Change (%)
Cultivated land	0.4	1.9	0.07	0.38	0.47	2.2
Shrub land	− 1.97	− 9.2	− 1.73	− 9.3	− 3.7	− 17.3
Settlement	0	0	0	0	0	0
Grassland	− 0.24	− 1.1	− 0.23	− 1.2	− 0.47	− 2.3
Forest land	− 1.01	− 4.7	− 1.49	− 8	− 2.5	− 11.7
Sum	− 2.82	− 13.2	− 3.4	− 18.2	− 6.2	− 28.9

Table 9 Effects of LULC changes on the annual ecosystem service in the Guder watershed

No.	Ecosystem services	ESV across periods (US$ in millions)			Overall change
		ESV$_f$ 1973	ESV$_f$ 1995	ESV$_f$ 2015	1973–2015
1	Provisioning services				
	Water supply	0.11	0.10	0.06	− 0.05
	Food production	6.18	6.13	9.04	2.86
	Raw materials	0.75	0.58	0.42	− 0.33
	Genetic resources	0.60	0.47	0.33	− 0.27
2	Regulating services				
	Water regulation	0.10	0.06	0.06	− 0.04
	Climate regulation	3.23	2.56	1.83	− 1.40
	Disturbance regulation	0.07	0.06	0.04	− 0.03
	Gas regulation	0.22	0.17	0.11	− 0.11
	Biological control	0.74	0.77	0.76	0.02
	Erosion control	3.60	2.84	2.02	− 1.54
	Waste treatment	2.14	1.66	1.14	− 1.00
3	Supporting services				
	Nutrient cycling	2.67	2.12	1.51	− 1.16
	Pollination	0.57	0.54	0.51	− 0.06
	Soil formation	0.15	0.12	0.08	− 0.07
	Habitat/refugia	0.25	0.19	0.14	− 0.11
4	Cultural services				
	Recreation	0.07	0.06	0.22	− 0.15
	Cultural	0.03	0.02	0.02	− 0.01
	Sum	21.44	18.62	15.24	− 6.2

private ownership of rural land by the feudal system to public also played major role in the distribution of land to tenant farmers and subsequent policies to improve production of agricultural commodities contributed to the horizontal expansion of cultivated land during the Derg period (Ottaway 1977; Crewett et al. 2008).

Furthermore, the agricultural growth plan (AGP) of the growth and transformation plan (GTP) I which was envisaged in 2010/2011 for 5-year period resulted in the growth of the agricultural sector by 6.6% per annum with the share of the sector from the GDP to be 38.5% (FDRE 2016) that resulted in low structural transformation where the country still engaged dominantly on agriculture activities carried out by small-scale farmers. Although the overall production of agriculture sector was recorded for both PSDEP I, PSDEP II, and GTPI, these increases in production were attributed mainly to the increase in cultivated land over the years (FDRE 2010, 2016). Such development policy of the

government is influencing land use practices which corroborated with other studies in tropical countries (Abdullah and Hezri 2008; Oestreicher et al. 2014; Arowolo et al. 2018; Qiu et al. 2019; Zhang et al. 2019).

In addition, the overall reduction in the important environmental benefits of forested land uses resulted in further encroachment for more production. In our specific study area, the presence of large rivers such as Debis and Guder provided better opportunities for irrigation of horticultural crops which provided farmers to intensify production. Furthermore, informal institutions operating within the rural communities in relation to common property rights are still active influencing the allocation of land resources to different stakeholders and land uses can be an integral part of the land use conversion.

In general, agricultural expansion through cultivation of major food crops is the proximate causes of shift in vegetated landscapes which is similar to

Table 10 Relationships between landscape metrics and ESV of the watershed for the study period

ESV	Landscape metrics								
	CA	PLAND	NP	PD	AREA-MN	EDGECON	TECI	CWED	CONTAG
Food production	0.98**	0.98**	− 0.44	− 0.47	0.94**	− 0.19	− 0.12	0.85**	0.69**
Raw material	− 0.25	− 0.25	0.31	0.36	− 0.31	− 0.14	− 0.16	− 0.03	− 0.05
Water supply	− 0.24	− 0.24	0.33	0.38	− 0.31	− 0.14	− 0.16	− 0.02	− 0.05
Genetic resources	− 0.24	− 0.24	0.31	0.36	− 0.31	− 0.14	− 0.16	− 0.02	− 0.05
Water regulation	− 0.29	− 0.29	0.25	0.29	− 0.34	− 0.02	− 0.05	− 0.08	− 0.04
Climate regulation	− 0.25	− 0.25	0.31	0.36	− 0.31	− 0.14	− 0.16	− 0.03	− 0.05
Disturbance regulation	− 0.25	− 0.25	0.34	0.39	− 0.31	− 0.13	− 0.15	− 0.01	− 0.07
Gas regulation	− 0.27	− 0.27	0.29	0.33	− 0.33	− 0.07	− 0.09	− 0.05	− 0.06
Biological control	0.98**	0.98**	− 0.38	− 0.41	0.94**	− 0.19	− 0.12	0.84**	0.69**
Erosion control	− 0.26	− 0.26	0.31	0.36	− 0.32	− 0.12	− 0.14	− 0.03	− 0.06
Waste treatment	− 0.29	− 0.29	0.29	0.35	− 0.35	− 0.05	− 0.07	− 0.07	− 0.07
Nutrient cycling	− 0.25	− 0.25	0.31	0.36	− 0.31	− 0.14	− 0.16	− 0.02	− 0.05
Pollination	0.89**	0.89**	− 0.26	− 0.28	0.86**	− 0.18	− 0.12	0.82**	0.63**
Soil formation	− 0.24	− 0.24	0.59**	0.61**	− 0.27	− 0.03	− 0.05	− 0.02	− 0.38
Habitat/refugia	− 0.24	− 0.24	0.59**	0.61**	− 0.27	− 0.03	− 0.05	− 0.02	− 0.38
Recreation	− 0.24	− 0.24	0.60**	0.61**	− 0.28	− 0.03	− 0.05	− 0.02	− 0.39
Cultural	− 0.24	− 0.24	0.38	0.41	− 0.31	− 0.09	− 0.11	0.01	− 0.11

**Correlation is significant at the 0.01 level (two-tailed)

other findings elsewhere in the tropics (Zak et al. 2008; Ribeiro et al. 2009; Hartter and Southworth 2009; de Freitas et al. 2013; Wondrade et al. 2014; Tapia-Armijos et al. 2015; Tegegne et al. 2016). Similar studies in Ethiopia found the dominance of agricultural land use (Tefera and Sterk 2008; Mengistu et al. 2012; Daye and Healey 2015). Variation in deforestation along elevation was also documented elsewhere in the tropics (Tapia-Armijos et al. 2015). In our study area the conversion of forest land to settlement and cultivated land in the middle could be due favorable environmental condition to grow crops widely used for consumption in addition to its benefits for low level of health-related risks for human and livestock.

Landscape-scale metrics analysis

Class area (CA) and percentage of land (PLAND) are one of the indicators of the level of change in the area of certain land uses. In our case the reduction in CA and PLAND of shrub land, grassland, and forest land on one hand and the increase in these indices for settlement and cultivated land provide a firsthand information as to how conversion of land use through human activities are reducing the coverage of the natural environment (Table 7). This finding corroborates other studies elsewhere (Moreno-Sanchez et al. 2011).

The decrease in CONTAG of individual land use types such as cultivated land, shrub land, and forest land is the result of the interspersion of different patch types, as well as aggregation within a patch type (Hargis et al. 1998; Haddad et al. 2015; Estoque and Murayam 2016). The decrease in CA and increase in NP of forest land use is an indication of the scale of fragmentation (Guo 2006; Ribeiro et al. 2009; Moreno-Sanchez et al. 2011; Shrestha et al. 2012; Bonilla-Bedoy et al. 2014; Qi et al. 2014; Tapia-Armijos et al. 2015; Daye and Healey 2015; Sharma et al. 2016; Shifaw et al. 2019). The increased NP for all land uses can be considered to be the increase in level of fragmentation (Çakır et al. 2008; Reddy et al. 2013; Liu et al. 2014). The increase in PLAND in the study period for cultivated land and settlement on one hand and decrease in PLAND of vegetated land uses (grassland, shrub land, and forest land) is similar to other

studies (Pinto-Ledezma and Rivero-Mamani 2014; Estoque and Murayam 2016) where the ecosystem services are diminishing in quality and quantity.

Land redistribution during the derge period by the government from the landlords with farm size > 10 ha (Ottaway 1977; Mohammed and Inoue 2014) and voluntary transfer of families for new couples resulted in further fragmentation of cultivated land. In addition, the increasing number of new families through marriage and migration from other parts of the country contributed to dividing of grasslands, shrub lands, and forest lands on a competitive basis. This is evident in developing countries of the world where population growth triggers a more demand for land for settlement and cultivation in addition to the development of infrastructure which paves the way for more resource utilization (Sheng-yan et al. 2003; Reddy et al. 2013; Elagouz et al. 2019).

As multifunctional landscapes provide multiple ecosystem services, it is important to maintain mosaics of patches in human-modified landscapes as different land uses within the landscape provide different level of ecosystem service (Di Giulio et al. 2009; Haddad et al. 2015; Verhagen et al. 2016).The increased levels of fragmentation for land uses are similar to other findings (Hartter and Southworth 2009; Moreno-Sanchez et al. 2011; Su et al. 2012; Daye and Healey 2015; Qiu et al. 2019) which are conditioned by anthropogenic activities although the impacts vary across land uses (Guo 2006). Moreover, continuous fragmentation of land uses as manifested in our study area has significant impacts on multiple ecosystem services but has more significant impacts on regulating services in the watershed (Zhang and Gao 2016; Qiu et al. 2019).

Ecosystem service values of Guder watershed

The reduction in the overall ESVs within the study period are consistent with other studies in Ethiopia (Kindu et al. 2016, 2018; Tolessa et al. 2017a, b; Gashaw et al. 2018; Tolessa et al. 2018), Mozambique (Niquisse et al. 2017), China (Li et al. 2007; Hu et al. 2008; Wang et al. 2017; Yushanjiang et al. 2018; Zhang et al. 2019), and Nigeria (Arowolo et al. 2018). The individual ecosystem service values have been affected with varying degrees due to land use changes for all the study years (Xu et al. 2019). The overall provisioning services increased and had positive value (US $2.21 million) over four decades, but each service within the provisioning services decreased except food production.

Biological control (US $0.02 million) is one of the positive values attained from regulating services but other services had negative values (Gashaw et al. 2018; Zhang et al. 2019).

Landscape-scale metrics and ecosystem services

Landscape composition and configuration have found to be significantly affecting the overall and individual ecosystem services provided at the landscape level. There is a significant correlation between landscape metrics and ecosystem services such as food production with CA, PLAND, AREA-MN, CWED, and CONTAG. The correlation between certain landscape metrics and ecosystem services has been reported (Yushanjiang et al. 2018; Shifaw et al. 2019; Qiu et al. 2019). Our results have shown that the negative correlation between landscape metrics such as genetic resource with CA indicates the level of reduction in ecosystem services at the landscape which corroborates other studies elsewhere (Qiu et al. 2019). The high level of fragmentation shown through increasing number of patches indicated the lowering of ecosystem services for all land use types identified at a parcel level and landscape scale.

Conclusion

We found that human-influenced land uses are most important cover types increased at unprecedented pace. Settlement and cultivated land increased by 572.2% and 7.1%, respectively, for 1973–2015. But, other cover types such as grassland, shrub land, and forest land decreased by a magnitude of −83.5%, −48.5%, and −37.5%, respectively.

The increased level of fragmentation at landscape scale and the dominance of human-dominated land uses impair the provision of optimal ecosystem services because of the homogenization activities toward few land use classes. Since landscape changes are associated with the provision of ecosystem services, while conversion of landscapes in to homogenous land uses, it is expected that the sustainability of the services delivered will be at loss.

We also found that ESVs reduced for the watershed due to changes in the landscape structure for the study period. In addition, there is a relationship between landscape metrics and ESVs. CA, PLAND, AREA-MN, CWED, and CONTAG are significantly and positively correlated with food production. Therefore, in order to

maximize ecosystem services at landscape scale, managing land uses in accordance with the productive potential is crucial. We recommend the protection of fragmented forests, shrubs, and grasslands within human-modified landscapes for sustained production and biodiversity conservation.

References

Abdullah, S. A., & Hezri, A. A. (2008). From forest landscape to agricultural landscape in the developing tropical country of Malaysia: pattern, process, and their significance on policy. *Environmental Management, 42*, 907–917.

Arowolo, A. O., Deng, X., Olatunji, O. A., & Obayelu, A. E. (2018). Assessing changes in the value of ecosystem services in response to land-use/land-cover dynamics in Nigeria. *Science of the Total Environment, 636*, 597–609.

Belay, H. (2011). *Evaluation of climate change impacts on hydrology on selected catchments of Abbay Basin* (pp. 97). MSc thesis, Addis Ababa University.

Bhagwat, S. (2014). In C. J. Kettle & L. P. Koh (Eds.), *The history of deforestation and forest fragmentation: a global perspective, in: Global forest fragmentation* (p. 190). Wallingford: CABI International.

Bonilla-Bedoy, S., Molina, J. R., Macedo-Pezzopane, J. E., & Herrera-Machuca, M. A. (2014). Fragmentation patterns and systematic transitions of the forested landscape in the upper Amazon region, Ecuador 1990–2008. *Journal of Forestry Research, 25*(2), 301–309.

Çakır, G., Sivrikaya, F., & Keleş, S. (2008). Forest cover change and fragmentation using Landsat data in Maçka State Forest Enterprise in Turkey. *Environmental Monitoring and Assessment, 137*, 51–66.

Congalton, R. G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment, 37*, 35–46.

Costanza, R., d'Arge, R., de Groot, R., Farberk, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Suttonkk, P., & van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature, 387*, 253–260.

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., Farber, S., & Turner, R. K. (2014). Changes in the global value of ecosystem services. *Global Environmental Change, 26*, 152–158.

Crewett, W., Bogale, A., & Korf, B. (2008). *Land tenure in Ethiopia: continuity and change, shifting rulers, and the quest for state control, CAPRi Working Paper 91*. Washington, DC: International Food Policy Research Institute. https://doi.org/10.2499/CAPRiWP91.

CSA. (2008). *Summary and statistical report of the 2007 population and housing census: Population size by age and sex*. Ethiopia: Addis Ababa.

Cushman, S. A., & McGarigal, K. (2002). Hierarchical, multi-scale decomposition of species-environment relationships. *Landscape Ecology, 17*, 637–646.

Daye, D. D., & Healey, J. R. (2015). Impacts of land-use change on sacred forests at the landscape scale. *Global Ecology and Conservation, 3*, 349–358.

de Freitas, M. W. D., dos Santos, J. R., & Alves, D. S. (2013). Land-use and land-cover change processes in the upper Uruguay Basin: Linking environmental and socioeconomic variables. *Landscape Ecology, 28*, 311–327.

de Groot, R. S., Alkemade, R., Braat, L., Hein, L., & Willemen, L. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity, 7*, 260–272.

Di Giulio, M., Holderegger, R., & Tobias, S. (2009). Effects of habitat and landscape fragmentation on humans and biodiversity in densely populated landscapes. *Journal of Environmental Management, 90*, 2959–2968.

Elagouz, M. H., Abou-Shleel, S. M., Belal, A. A., & El-Mohandes, M. A. O. (2019). Detection of land use/cover change in Egyptian Nile Delta using remote sensing. *The Egyptian Journal of Remote Sensing and Space Sciences.* https://doi.org/10.1016/j.ejrs.2018.10.004.

Estoque, R. C., & Murayam, Y. (2016). Quantifying landscape pattern and ecosystem service value changes in four rapidly urbanizing hill stations of Southeast Asia. *Landscape Ecology, 31*, 1481–1507.

FAO. (1995). *Soils of EAST Africa, SEA, Food and Agriculture Organization of the United Nations*. Rome: ACD-Rom Data.

Federal Democratic Republic of Ethiopia (FDRE). (2010). *Growth and transformation plan I (GTP I) (2010/11–2014/15)* (p. 135). Ethiopia: Addis Ababa.

Federal Democratic Republic of Ethiopia (FDRE). (2016). *Growth and transformation plan II (GTP II) (2015/16–2019/20)* (p. 236). Ethiopia: Addis Ababa.

Gashaw, T., Tulu, T., Argaw, M., Worqlul, A. W., Tolessa, T., & Kindu, M. (2018). 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. *Ecosystem Services, 31*, 219–228.

Gebrehiwot, S. G., Bewket, W., G̈rdens, A. I., & Bishop, K. (2014). Forest cover change over four decades in the Blue Nile Basin, Ethiopia: comparison of three watersheds. *Regional Environmental Change, 14*, 253–266.

Gebreselassie, S., Kirui, O. K., & Mirzabaev, A. (2016). Economics of land degradation and improvement in Ethiopia, in: Economics of land degradation and improvement—a global assessment for sustainable development. In E. Nkonya, et al. (Eds.). https://doi.org/10.1007/978-3-319-19168-3_14.

Guo, L. (2006). Analysis of spatio-temporal changes in the landscape pattern of the Taishan. Mountain. *Journal of Mountain Ecology, 8*, 1–6.

Haddad, N. M., Brudvig, L. A., Clobert, J., Davies, K. F., Gonzalez, A., Holt, R. D., Lovejoy, T. E., Sexton, J. O., Austin, M. P., Collins, C. D., Cook, W. M., Damschen, E. I., Ewers, R. M., Foster, B. L., Jenkins, C. N., King, A. J., Laurance, W. F., Levey, D. J., Margules, C. R., Melbourne, B. A., Nicholls, A. O., Orrock, J. L., Song, D.-X., &

Townshend, J. R. (2015). Habitat fragmentation and its lasting impact on Earth's ecosystems. *Science Advances, 1*, e1500052.

Hargis, C. D., Bissonette, J. A., & David, J. L. (1998). The behavior of landscape metrics commonly used in the study of habitat fragmentation. *Landscape Ecology, 13*, 167–186.

Harrison, S., & Bruna, E. (1999). Habitat fragmentation and large-scale conservation: what do we know for sure? *Ecography, 22*, 225–232.

Hartter, J., & Southworth, J. (2009). Dwindling resources and fragmentation of landscapes around parks: wetlands and forest patches around Kibale National Park, Uganda. *Landscape Ecology, 24*, 643–656.

Hu, H., Liu, W., & Cao, M. (2008). Impact of land use and land cover changes on ecosystem services in Menglun, Xishuangbanna, Southwest China. *Environmental Monitoring and Assessment, 146*, 147–156.

Jacob, M., Romeyns, L., Frankl, A., Asfaha, T., Beeckman, H., & Nyssen, J. (2015). Land use and cover dynamics since 1964 in the Afro-alpine vegetation belt: Lib Amba mountain in North Ethiopia. *Land Degradation and Development, 27*(3), 641–653.

Jacob, M., Frankl, A., Hurni, H., Lanckriet, S., De Ridder, M., Guyassa, E., Beeckman, H., & Nyssen, J. (2017). Land cover dynamics in the Simien Mountains (Ethiopia), half a century after establishment of the National Park. *Regional Environmental Change, 17*, 777–787.

Jessen, L. I. F., Frans, J. M., & Wel, V. D. (1994). Accuracy assessment of satellite derived land cover data: a review. *Photogrammetric Engineering and Remote Sensing, 60*, 410–432.

Kidane, M., Tolessa, T., Bezie, A., Kessete, N., & Endrias, M. (2018). Evaluating the impacts of climate and land use/land cover (LU/LC) dynamics on the hydrological responses of the Upper Blue Nile in the central highlands of Ethiopia. *Spatial Information Research*. https://doi.org/10.1007/s41324-018-0222-y.

Kindu, M., Schneider, T., Teketay, D., & Knoke, T. (2013). Land use/land cover change analysis using object-based classification approach in Munessa-Shashemene landscape of the Ethiopian highlands. *Remote Sensing, 5*, 2411–2435.

Kindu, M., Schneider, T., Teketay, D., & Knoke, T. (2016). Changes of ecosystem service values in response to land use/land cover dynamics in Munessa-Shashemene landscape of the Ethiopian highlands. *The Science of the Total Environment, 547*, 137–147.

Kindu, M., Schneider, T., Döllerer, M., Teketay, D., & Knoke, T. (2018). Scenario modeling of land use/land covers changes in Munessa-Shashemene landscape of the Ethiopian highlands. *The Science of the Total Environment, 622–623*, 534–546.

Leitão, A. B., & Ahren, J. (2002). Applying landscape ecological concepts and metrics in sustainable landscape planning. *Landscape and Urban Planning, 59*, 65–93.

Li, R., Dong, M., Cui, J., Zhang, L., Cui, Q., & He, W. (2007). Quantification of the impact of land-use changes on ecosystem services: a case study in Pingbian County, China. *Environmental Monitoring and Assessment, 128*, 503–510.

Liu, S., Dong, Y., Deng, L., Liu, Q., Zhao, H., & Dong, S. (2014). Forest fragmentation and landscape connectivity change associated with road network extension and city expansion: a case study in the Lancang River Valley. *Ecological Indicators, 36*, 160–168.

McGarigal, K., & Marks, B. J. (1994). *FRAGSTATS: Spatial pattern analysis program for quantifying landscape structure* (p. 141). Corvallis: Oregon State University.

McGarigal, K, Cushman, S. A., & Ene, E. (2012). FRAGSTATS v42.1: spatial pattern analysis program for categorical and continuous maps, Computer software program produced by the authors at the University of Massachusetts, Amherst. http://www.umass.edu/landeco/research/fragstats/fragstats.html. Accessed 5 Aug 2018.

Mengistu, D. A., Waktola, D. K., & Woldetsadik, M. (2012). Detection and analysis of land-use and land-cover changes in the Midwest escarpment of the Ethiopian Rift Valley. *Journal of Land Use Science, 7*(3), 239–260.

Millennium Ecosystem Assessment (MA). (2005). *Ecosystems and human well-being: a framework for assessment*. Washington: Island Press.

Mohammed, A. J., & Inoue, M. (2014). Land tenure reform and its implication for the forest: case study from Oromia regional state of Ethiopia. *Journal of Forest and Environmental Science, 30*(4), 393–404.

Moreno-Sanchez, R., Moreno-Sanchez, F., & Torres-Rojo, J. M. (2011). National assessment of the evolution of forest fragmentation in Mexico. *Journal of Forestry Research, 22*(2), 167–174.

Nagendra, H., Munroe, D. K., & Southworth, J. (2004). From pattern to process: landscape fragmentation and the analysis of land use/land cover change. *Agriculture, Ecosystems and Environment, 101*, 111–115.

Niquisse, S., Cabral, P., Rodrigues, Â., & Augusto, G. (2017). Ecosystem services and biodiversity trends in Mozambique as a consequence of land cover change. *International Journal of Biodiversity Science, Ecosystem Services & Management, 13*(1), 297–311.

Oestreicher, J. S., Farella, N., Paquet, S., Davidson, R., Lucotte, M., Mertens, F., & Saint-Charles, J. (2014). Livelihood activities and land-use at a riparian frontier of the Brazilian Amazon: quantitative characterization and qualitative insights into the influence of knowledge, values, and beliefs. *Human Ecology, 42*, 521–540.

Ottaway, M. (1977). Land reform in Ethiopia 1974–1977. *African Studies Review, 20*(3), 79–90.

Pinto-Ledezma, J. N., & Rivero-Mamani, M. L. (2014). Temporal patterns of deforestation and fragmentation in lowland Bolivia: implications for climate change. *Climatic Change, 127*(1), 43–54.

Qi, Z.-F., Ye, X.-Y., Zhang, H., & Yu, Z.-L. (2014). Land fragmentation and variation of ecosystem services in the context of rapid urbanization: the case of Taizhou City, China. *Stochastic Environmental Research and Risk Assessment, 28*, 843–855.

Qiu, L., Pan, Y., Zhu, J., Amable, G. S., & Xu, B. (2019). Integrated analysis of urbanization-triggered land use change trajectory and implications for ecological land management: a case study in Fuyang, China. *Science of the Total Environment, 660*, 209–217.

Reddy, C. S., Jha, C. S., & Dadhwal, V. K. (2013). Assessment and monitoring of long-term forest cover changes in Odisha, India using remote sensing and GIS. *Environmental Monitoring and Assessment, 185*, 4399–4415.

Ribeiro, M. C., Metzger, J. P., Martensen, A. C., Ponzoni, F. J., & Hirota, M. M. (2009). The Brazilian Atlantic Forest: how much is left, and how is the remaining forest distributed? Implications for conservation. *Biological Conservation, 142*, 1141–1153.

Rutledge, D. (2003). *Landscape indices as measures of the effects of fragmentation: can pattern reflect process? Doc science internal series 98* (pp. 26). Department of Conservation Wellington, New Zealand. http://www.doc.govt.nz. Accessed 5 Aug 2018.

Sharma, M., Areendran, G., Raj, K., Sharma, A., & Joshi, P. K. (2016). Multitemporal analysis of forest fragmentation in Hindu Kush Himalaya—a case studies from Khangchendzonga Biosphere Reserve, Sikkim, India. *Environmental Monitoring and Assessment, 188*, 596. https://doi.org/10.1007/s10661-016-5577-8.

Sheng-yan, D., Le-xiang, Q., Xin-xiang, C., Shuang, L., & Hao-min, L. (2003). Forest landscape pattern dynamics of Luoning County in Henan Province and its driving forces. *Chinese Geographical Science, 13*(3), 247–253.

Shifaw, E., Sha, J., Li, X., Bao, Z., & Zhou, Z. (2019). An insight into land-cover changes and their impacts on ecosystem services before and after the implementation of a comprehensive experimental zone plan in Pingtan Island, China. *Land Use Policy, 82*, 631–642.

Shrestha, M. K., York, A. M., Boone, C. G., & Zhang, S. (2012). Land fragmentation due to rapid urbanization in the Phoenix metropolitan area: analyzing the spatiotemporal patterns and drivers. *Applied Geography, 32*, 522–531.

Su, S., Xiao, R., Jiang, Z., & Zhang, Y. (2012). Characterizing landscape pattern and ecosystem service value changes for urbanization impacts at an eco-regional scale. *Applied Geography, 34*, 295–305.

Tapia-Armijos, M. F., Homeier, J., Espinosa, C. I., Leuschner, C., & de la Cruz, M. (2015). Deforestation and forest fragmentation in South Ecuador since the 1970s—losing a hotspot of biodiversity. *PLoS One, 10*(9), e0133701. https://doi.org/10.1371/journal.pone.0133701.

Tefera, B., & Sterk, G. (2008). Hydropower-induced land use change in Fincha'a watershed, Western Ethiopia: analysis and impacts. *Mountain Research and Development, 28*(1), 72–80.

Tegegne, Y. T., Lindner, M., Fobissie, K., & Kanninen, M. (2016). Evolution of drivers of deforestation and forest degradation in the Congo Basin forests: exploring possible policy options to address forest loss. *Land Use Policy, 51*, 312–324.

Teketay, D. (2001). Deforestation, wood famine, and environmental degradation in Ethiopia's Highland ecosystems: urgent need for action. *Northeast African Studies, 8*(1), 53–76.

Tekle, K., & Hedlund, L. (2000). Land cover changes between 1958 and 1986 in Kalu district, southern Wello, Ethiopia. *Mountain Research and Development, 20*(1), 42–51.

Tolessa, T., Senbeta, F., & Kidane, M. (2016). Landscape composition and configuration in the central highlands of Ethiopia. *Ecology and Evolution, 6*, 7409–7421.

Tolessa, T., Senbeta, F., & Kidane, M. (2017a). The impact of land use/land cover change on ecosystem services in the central highlands of Ethiopia. *Ecosystem Services, 23*, 47–54.

Tolessa, T., Senbeta, F., & Abebe, T. (2017b). Land use/land cover analysis and ecosystem services valuation in the central highlands of Ethiopia. *Forests, Trees and Livelihoods, 26*(2), 111–123.

Tolessa, T., Gessese, H., Tolera, M., & Kidane, M. (2018). Changes in ecosystem service values in response to changes in landscape composition in the central highlands of Ethiopia. *Environmental Processes, 5*(3), 483–501.

Van der Ploeg, S., De Groot, R. S., & Wang, Y. (2010). The TEEB valuation database: overview of structure, data and results. Wageningen: Foundation for Sustainable Development.

Verhagen, W., Van Teeffelen, A. J. A., Compagnucci, A. B., Poggio, L., Gimona, A., & Verburg, P. H. (2016). Effects of landscape configuration on mapping ecosystem service capacity: a review of evidence and a case study in Scotland. *Landscape Ecology, 31*, 1457–1479. https://doi.org/10.1007/s10980-016-0345-2.

Wade, T. G., Riitters, K. H., Wickham, J. D., & Jones, K. B. (2003). Distribution and causes of global forest fragmentation. *Conservation Ecology, 7*(2), 7 http://www.consecol.org/vol7/iss2/art7. Accessed 5 Aug 2018.

Wang, J., & Yang, X. (2012). A hierarchical approach to forest landscape pattern characterization. *Environmental Management, 49*, 64–81.

Wang, X., Dong, X., Liu, H., Wei, H., Fan, W., Lu, N., Xu, Z., Ren, J., & Xing, K. (2017). Linking land use change, ecosystem services and human well-being: a case study of the Manas River basin of Xinjiang, China. *Ecosystem Services, 27*, 113–123.

Wondrade, N., Dick, Ø. B., & Tveite, H. (2014). GIS based mapping of land cover changes utilizing multi-temporal remotely sensed image data in Lake Hawassa watershed, Ethiopia. *Environmental Monitoring and Assessment, 186*(3), 1765–1780.

Xu, Z., Fan, W., Wei, H., Zhang, P., Ren, J., Gao, Z., Ulgiati, S., Kong, W., & Dong, X. (2019). Evaluation and simulation of the impact of land use change on ecosystem services based on a carbon flow model: a case study of the Manas River basin of Xinjiang, China. *Science of the Total Environment, 652*, 117–133.

Yushanjiang, A., Zhang, F., Yu, H., & Kung, H. (2018). Quantifying the spatial correlations between landscape pattern and ecosystem service value: a case study in Ebinur Lake Basin, Xinjiang, China. *Ecological Engineering, 113*, 94–104.

Zak, M. R., Cabido, M., Cáceres, D., & Díaz, S. (2008). What drives accelerated land cover change in central Argentina? Synergistic consequences of climatic, socioeconomic, and technological factors. *Environmental Management, 42*, 181–189.

Zhang, Z., & Gao, J. (2016). Linking landscape structures and ecosystem service value using multivariate regression analysis: a case study of the Chaohu Lake Basin, China. *Environment and Earth Science, 75*, 3. https://doi.org/10.1007/s12665-015-4862-0.

Zhang, F., Yushanjiang, A., & Jing, Y. (2019). Assessing and predicting changes of the ecosystem service values based on land use/cover change in Ebinur Lake Wetland National Nature Reserve, Xinjiang, China. *Science of the Total Environment, 656*, 1133–1144.