Implications of changes in land use for ecosystem service values of two highly eroded watersheds in Lake Abaya Chamo sub-basin, Ethiopia.

Wolde Mekuria [a], Assefa Gedle [b], Yitna Tesfaye [c], Euan Phimister [d, e]

[a] International Water management Institute, Addis Ababa, Ethiopia
[b] Arba-Minch University, Arba-Minch, Ethiopia
[c] Hawassa University, Hawassa, Ethiopia
[d] Business School, University of Aberdeen, Aberdeen, United Kingdom
[e] Business School, University of Stellenbosch, Cape Town, South Africa

Corresponding author
Wolde Mekuria
International Water Management Institute (IWMI)
e-mail: w.bori@cgiar.org

Abstract

Ecosystems provide a variety of ecosystem services and functions for mankind, and their sustainable use plays an important role in livelihoods. However, the resulting land degradation due to land use and land cover changes leads to loss of valuable ecosystems and associated ecosystem functions and services. This study takes two highly degraded watersheds, Aba-Bora and Guder, in Ethiopia and uses the value transfer valuation method to estimate changes in ecosystem service values. The study shows how loss of cropland and grazing lands can significantly affect ecosystem services even when plantations and shrubland increase. The results suggest that over a period of 41 years, the ecosystem service value of exclosures/shrublands and plantations increased, whereas that of crop and grazing lands decreased. The loss of ecosystem service values due to the decrease in cropland and grazing lands outweigh the gains due to the expansion of plantations and exclosures and resulted in a total loss of ecosystem service values of US$ 1.6 million in Aba-Bora watershed and US$ 24.4 million in Guder. In both watersheds, the greatest contributor to ecosystem service loss was a decline in supporting services, while the increase in plantation and shrublands (mainly through establishment of exclosures) meant that regulating ecosystem services suffered the smallest loss. Given their importance to livelihoods in these areas, the loss in crop and grazing lands significantly increase the vulnerability to shocks and narrow future livelihood options for many households. Given that severe gully erosion is the major contributor to the reduction in crop and grazing lands, catchment management that integrates the conservation of upstream areas using diverse sustainable land management practices, and gully rehabilitation measures in downstream areas could be an important option to reducing the expansion of big gullies, and conserving crop and grazing lands and ecosystem service values. However, the results suggest that the risks to livelihoods may be underestimated while the effectiveness of current actions to address land degradation over-estimated by communities.

Key words: Catchment management, Croplands, Ecosystem services, Grazing lands, Gully erosion, Livelihoods, spatial and temporal dynamics.

1. Introduction

Land degradation is a global challenge that affects livelihoods and ecosystems (United Nations Convention to Combat Desertification, 2022). Globally, about 25 percent of the total land area has been degraded and it is estimated that 24 billion tons of fertile soil is being lost per year (The Global Environmental Facility 2019). The problems linked to land degradation, including the loss of fertile soil and biodiversity, are particularly severe in the driest parts of the planet that cover approximately 46 percent of the global land area and are home to around three billion people (Mirzabaev et al. 2019; Dregne 2022; Ziadat et al. 2022). Most people who depend on drylands live in developing countries, where women and children are most vulnerable to the impacts of land degradation and drought (Mirzabaev et al. 2019).

Land use and land cover (LULC) changes in the driest part of the globe, particularly the reductions in forests and other natural vegetation and the expansion of croplands and grazed grasslands, are major drivers of land degradation and loss of valuable ecosystems and associated ecosystem functions and services at multiple scales (Reyers et al. 2009; Fu et al. 2021; Qiu et al. 2021). For example, land-cover change involves changes in the human management of ecosystems that alter the biogeochemical cycles, climate and hydrology of an ecosystem. It also drives biodiversity loss through habitat fragmentation and destruction. Such transformations due to LULC changes affect a range of provisioning, regulating, supporting and cultural ecosystem services (Mirzabaev et al. 2019).

As in other part of the world, LULC changes in the drylands of Sub-Saharan Africa are among the major drivers of land degradation and loss of a wide range of ecosystem goods and services (Karaya et al. 2021; Petersen et al. 2021). For example, a study in east Africa by Bullock et al. (2021) demonstrated a threat to dryland areas and ecoregions due mainly to the reduction of woodlands and forests, and Fenta et al. (2020) reported a US$60 billion year^{-1} loss of ecosystem service values (ESVs) due to the conversion of evergreen forest and shrubland in Sub-Saharan Africa. Aneseyee et al. (2020) demonstrated that the Omo-Ghibe basin of Ethiopia, one of the driest parts of Sub-Saharan Africa, is under severe pressure of degradation with significant consequences for loss of ESVs and rural livelihoods. Similar studies across the drylands of Sub-Saharan African countries, for example, Mekuria et al. (2021) in Central Rift Valley of Ethiopia, Msofe et al. (2020) in Tanzania, Rotich et al. (2022) in Kenya, reported significant losses in ESVs due to LULC changes.

Interlinked social, economic, and environmental factors are driving a significant change in LULC in Ethiopia, and these changes are causing considerable losses in ecosystem services (Tolessa et al. 2021; Biratu et al. 2022). As in other parts of Ethiopia, the current study area, the Lake Abaya-Chamo sub-basin of the Ethiopian Rift Valley is undergoing considerable LULC change (Wolde Yohannes et al. 2018; Gebeyehu et al. 2019), and these changes could result in reductions in ESVs and adversely affect livelihoods (Markos et al. 2018; Temesgen et al. 2018).

The Abaya – Chamo sub-basin is highly degraded, and so is experiencing different trends in LULC changes to many other previously studied regions. Therefore, this study aims to inform sustainable landscape management practices through mapping the spatial and temporal dynamics of LULC changes in two highly degraded watersheds, representing mid- and high-altitude land, and assessing the impacts in terms of the monetary values of key ecosystem services and livelihoods. Particularly, the study aims to determine associated changes in the four types of ecosystem services (provisioning, regulating, supporting and cultural), and to identify critical areas for conserving natural resources and reversing the decline of associated ESVs. This study focussed to answer three broad research questions (a) how have the spatial and temporal dynamics of LULC changes evolved over the last four decades in the two studied watersheds? (b) how do the changes in LULC influence the total and specific ESVs? and (c) what do these changes (i.e., LULC and ESVs) and communities' perception on land degradation and restoration efforts imply for land resources management and livelihoods. The study will provide improved understanding of the wide variation in natural resources, the drivers of LULC change and implications for ecosystem services and human wellbeing in areas from differing socio-ecological settings. The study also complements scarce data on the link between LULC changes and ESVs in Ethiopia and the region, so it will help to identify, design and plan more sustainable landscape management practices.

2. Methods

2.1. Case study design and study area

We selected two degraded watersheds (Aba-Bora and Guder), representing midlands and highlands to describe changes in ESVs due to changes in LULC. The study also combined biophysical and socio-economic datasets as well as collected data in areas from different socio-ecological settings to draw implications for land resources management and livelihood. The analyses of LULC changes and the assessment of the associated impacts on ESVs were conducted for a period of 41 years. This time framework was considered to investigate any possible connections between LULC changes, and key regime changes and community-based watershed development activities ongoing in in the country since 2010. Thus, four intervals (1980 - 1990, 1990 - 2000, 2000 - 2010 and 2010 - 2021) were set to enable detection of LULC and ESVs changes following regime and policy changes.

The study areas, Aba-Bora and Guder watersheds are in the Lake Abaya Chamo sub-basin of the Ethiopian Rift Valley Lakes basin and drains to Lake Abaya through Bilate River (Figure 1). Declining soil fertility, severe soil erosion, reduced access to surface and groundwater, and poor water quality are the main socio-economic and environmental challenges in the studied watersheds (Sinore and Umer 2021). In response to these socio-economic and environmental challenges, the regional bureaus of agriculture, district agricultural offices, and local administrative bodies mobilized farmers to help with the construction of soil and water conservation measures (Wolancho 2015). Table 1 presents some selected characteristics of the two studied watersheds.

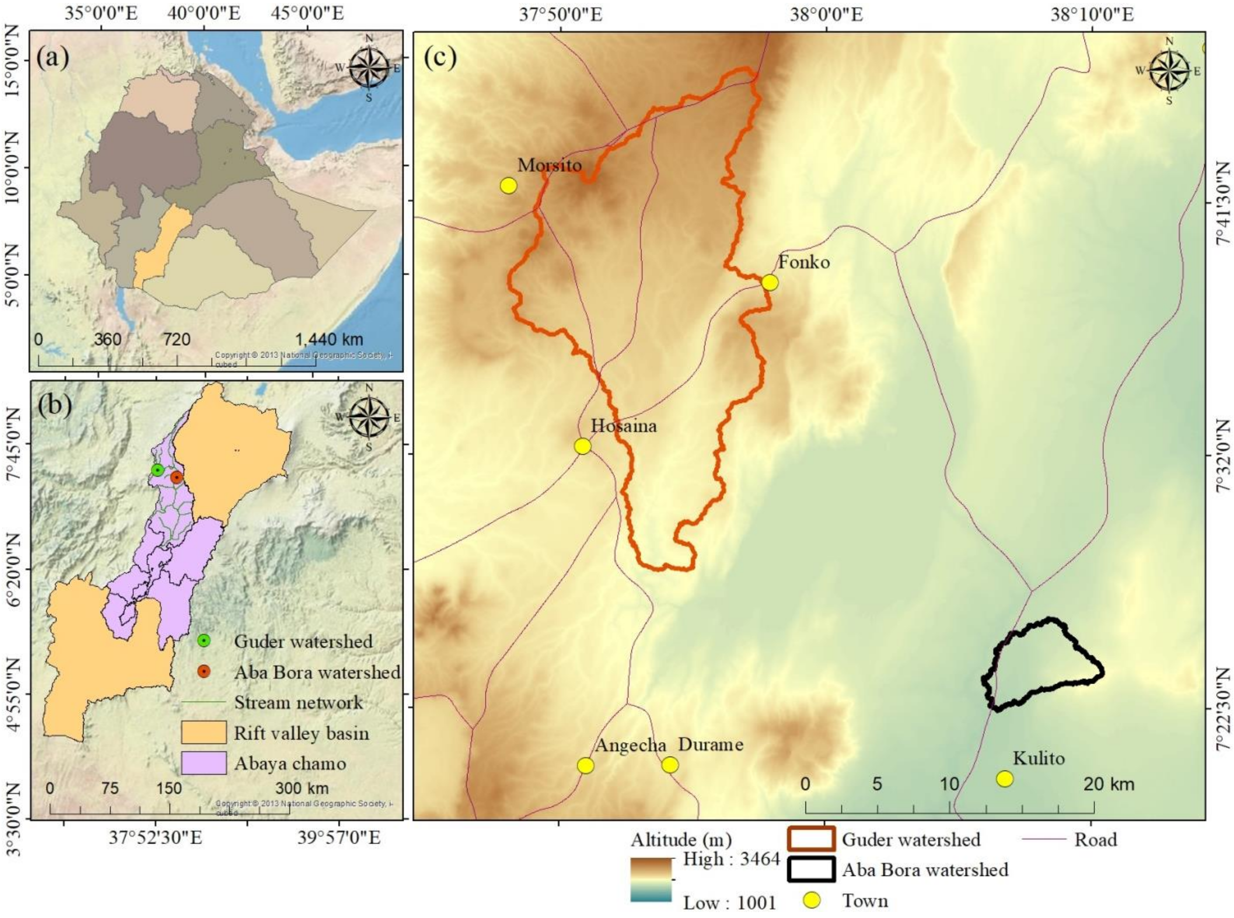


Figure 1. Location of the study area: (a) Rift Valley Lakes basin, (b) Abaya Chamo sub-basin, and (c) Aba-Bora and Guder watersheds.

Table 1. Selected characteristics of Aba-Bora and Guder watersheds.

Site characteristics	Aba-Bora watershed	Guder watershed
Area (km^2)	28.91	330.66
Elevation (m)	From 1780 to 2161	From 2011 to 2944
Dominant land use and land cover	Croplands	Croplands
Rainfall distribution	Bimodal	Bimodal
Duration of long rainy season	July – September	July – September
Duration of short rainy season	March - May	March - May
Monthly rainfall during long rainy season (mm)	Ranges from 100 to 146	Ranges from 149 to 173
Monthly rainfall during short rainy season (mm)	Ranges from 20 to 143	Ranges from 20 to 150
Annual rainfall (mm)	Ranges from 752 to 1272	Ranges from 921 to 1556
Mean annual temperature (ºC)	Ranges from 19 to 22	Ranges from 15 to 19
Average Education (years respondent) *	2.182	3.569
Average Family size	6.472	6.517
Average landholding (Timad)**	3.843	2.515
Tropical Livestock Units	2.985	3.982

Note: *the information on the annual rainfall and temperature is based on data obtained from the nearby stations, Alaba Kulito station for Aba-Bra and Hosana station for Guder watersheds for the year 1992-2012.*

* *The information on average characteristics in the two watershed was derived from survey data from approximately 500 households collected in fours kebele (two for each watershed) in 2021 as described in section 2.4.*

** *A Timad is equivalent to 0.25 hectare.*

2.2. Assessment of land use and land cover dynamics

2.2.1. Satellite image data

Landsat images used in the study of different time points were downloaded from the website of the United States Geological Survey (USGS) (Table 2). These data were acquired to characterize the LULC of 1980, 1990, 2000, 2010 and 2021, and analyse the dynamics of LULC from 1980 to 1990, 1990 to 2000, 2000 to 2010, 2010 to 2021, and 1980 to 2021. To avoid a seasonal variation and reduce the effects of cloud cover, the dry cloud-free seasons (less than 10%) were selected (Table 2).

Table 2. Characteristics of Landsat images used for the analysis of land use and land cover changes.

No	Sensor	Spatial resolution	Acquisition date
1	Landsat 8 OLI	30m	Jan-28-2021
2	Landsat 4–5 TM	30m	Jan-30-2010
3	Landsat 4–5 TM	30m	Feb-20-2000
4	Landsat 4–5 TM	30m	Dec-25-1990
5	Landsat 1 MSS	60m	April-16-1980

Note: MSS refers to Multispectral Scanner System, TM-Thematic Mapper, and OLI-Operational Land Imager. Tiles of single Landsat scene, Path/row: 169/55 level 1 was used.

2.2.2. Land use and land cover classes

A total of six LULC classes (Bare land, Built-up, Croplands, Grasslands, Exclosures/Shrublands and exclosures enriched with plantations) were identified. The description used in this study of the LULC classes are summarized in Table 3.

Table 3. Land use and land cover classes adapted and modified from IPCC

LULC classes	Description
Croplands	Represents lands currently under crop, fallow and preparation, and include both rainfed and irrigated agricultural lands.
Exclosures enriched with plantations	Exclosures dominantly covered by eucalyptus and other plantations.
Shrublands/exclosures	Protected lands covered with small trees (2-5 m high) mixed with scattered or patches of trees and bush lands.
Grasslands	Represents lands dominantly covered with grazed grasslands and bushes (0.2-2m) that also includes scattered or patches of trees.
Bare lands	A land use category that includes bare soils, bare rocks, quarry, gravel rocks and degraded lands (mainly big gullies and gorges) and are left without crops, exposed rocks and dried riverbeds.
Built-up	Refers to intensively used lands such as rural villages, towns, and roads.

2.2.3. Reference data

The collection of ground control points (GCPs) employed multiple steps. First, the LULC classes of the watersheds were analysed using unsupervised classification of Landsat and Google earth images. Second, sampling points to gather GCPs were randomly selected from each LULC class. Third, 460 GCPs, 173 from Aba-Bora and 287 from Guder watersheds, were collected using field surveys. The collection of GCPs was aided by Global Positioning System (GPS) device with a positional error of ±3 m. An additional 320 reference points, 80 from Aba-Bora and 240 from Guder watersheds, were collected from Google earth images to supplement the GCPs gathered during field surveys. Multiple stages of gathering GCPs were employed to ensure the collection of GCPs from all major LULC classes and fair representation during training and verification of image classification. The field surveys were conducted in February 2022.

The classification of the LULC classes of 1980, 1990, 2000 and 2010 were based on GCPs collected using Google earth imagery, Normalized Difference Vegetation Index (NDVI) and expert knowledge. Accordingly, the GCPs collected from the field were overlaid to Google earth images of 1980, 1990, 2000, and 2010 and permanent features or reference points were identified. This was cross validated with the unsupervised classification and NDVI. The identification of these permanent features or reference points were identified due mainly to ensure a good spatial distribution of reference data over the whole study area. In total about 680 (204 from Aba-Bora and 476 from Guder watersheds), 700 (231, 469), 850 (246, 604) and 950 (285, 665) GCPs were collected from Google earth images for the years 1980, 1990, 2000 and 2010, respectively. Of which, 75% were used for training, whereas the remaining 25% was used for accuracy assessment.

2.2.4. Image pre-processing, classification and accuracy assessment

Radiometric and atmospheric correction were conducted to reduce differences in the sun angle and to better match spectral characteristics of the different LULC classes across time as well as enhance images. The enhanced image bands were layer stacked. Following such image pre-processing, the supervised classification of LULC classes using a maximum likelihood algorithm was performed. The performance of the supervised LULC classification was assessed via three steps. First, the performance was assessed using visual inspection based on the acquired knowledge from the field surveys. Second, a confusion matrix with appropriate accuracy indices (user accuracy, producer accuracy and overall accuracy) and nonparametric Kappa coefficient were used (Jensen, 2005; Lillesand et al. 2004; Congalton and Green 2019) (Supplementary material 1). Third, the performance of the LULC classification was validated using the 25% randomly selected GCPs.

2.2.5. Change detection

Post-classification technique was used to identify and quantify LULC dynamics over a period of 41 years (1980 - 2021). The transition matrix was mapped, and losses and gains for each LULC class determined for the 1980 to 1990, 1990 to 2000, 2000 to 2010, and 2010 to 2021 periods. The results were presented in tables and maps showing the transition of each LULC class. The analysis on the change detection was done using GIS.

2.3. Assessment of changes in ecosystem service values

The classified LULC conditions and the ecosystem service valuation database (Brander et al. 2023) were used to assess the change in ESVs. The ecosystem service valuation database (ESVD) is a follow-up to “The Economics of Ecosystems and Biodiversity” (TEEB) database which currently contained over 6700 data points or values from 900 case studies on monetary values of ecosystem services across all biomes (Brander et al. 2023). For this study, we used the data updated in 2020, and this version of ESVD contains 4042 value records based on 693 studies (i.e., three times as many as the original TEEB database). This recently updated ESVD added additional variables, and information on study site location, size and condition. The values recorded in ESVD were obtained from six geographical locations (Continents); Africa (309 studies), Asia (1140), Europe (1639), North America (594), South America (109) and Oceania (223).

The database updated in 2020 (Table 4), and the value transfer valuation method were used to estimate the changes in ESVs in response to LULC changes in the studied watersheds (Johnston et al. 2015). The value transfer valuation method estimates the ecosystem service value at a "policy or study site" using existing information from different "study site (s)”. As specific ESVs for different land use and land cover in Ethiopia (i.e., the study or policy site) is lacking, we first selected the most representative biomes from the list in the ESVD. Second, we used the selected representative biome as a proxy for each LULC class identified in this study (Table 4). Third, we extracted the mean standardized values per ecosystem services per biome indicated in the database for the evaluation. Fourth, prior to use the values in ESVD, we have checked and contextualized some of the values. For example, we excluded the values of the opportunities for recreation and tourism assigned to croplands (i.e., assigned a value of zero, Table 5), as the contribution of croplands in the study watersheds to recreation and tourism is insignificant. This supports not to exaggerate the loss of ESVs due to the loss of croplands in the studied watersheds. We accepted assigning a value of zero for water for plantations (as indicated in the database, Table 5), as the plantations in the study watersheds are mainly covered by *eucalyptus trees*.

The LULC categories might not be identical with the representative biome. For example, the exclosures enriched by plantation are dominantly covered by eucalyptus trees, which might reduce the ecosystem services compared to the representative biome, woodlands and shrublands. Similarly, the exclosures/shrublands in this study are dominated by small and recently regenerated indigenous tree species. However, the values indicated in the ESVD for the proxy biomes (Table 4) can be used as proxies for estimating ESVs of the LULC types identified in the studied watersheds (Gashaw et al. 2018).

The equation described by Gashaw et al. (2018) was used to estimate ESVs from each LULC class and the total ESVs of the studied watersheds. The total ESVs of the entire watershed was obtained by summing the estimated ESVs from each LULC category (Eq. 1, Gashaw et al.

2018). In addition, the values of the individual ecosystem services, provisioning, regulating, supporting and cultural, were estimated using Eq. 2 (Gashaw et al. 2018). The 2020 updated coefficients that were used in this study are shown in Table 5. The percent change of ESVs in 1980 to 1990, 1990 to 2000, 2000 to 2010, and 2010 to 2021 periods was calculated using Eq. 3 (Kindu et al. 2016; Gashaw et al. 2018).

$ESV_{k=} \sum(A_k \times VC_k)$ …………………………………………………………………. Eq. 1.

$ESV_{f=} \sum(A_k \times VC_{fk})$ ………………………………………………………………… Eq. 2.

$Percent\ change\ of\ ESVs = \left(\frac{ESV_{recent\ year} - ESV_{previous\ year}}{ESV\ previous\ year}\right) \times 100$ …………………….... Eq. 3.

Where, ESV$_k$ and ESV$_f$ are ESVs 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' (IntS\$ ha^{-1} yr^{-1}, 2020 Price Levels) and VC$_{fk}$ is the value coefficient of function 'f' (Int\$ ha^{-1} yr^{-1}, 2020 Price Levels) for LULC type 'k'.

Table 4. Land use and land cover classes, the corresponding biomes and mean standardized values per ecosystem service biome based on the updated values (De Groot et al. 2020). The values are given Int$/Hectare/Year; 2020 Price Levels).

Aba-Bora watershed		Guder watershed		Mean ESVs
LULC classes	Equivalent biome	LULC classes	Equivalent biome	
Bare lands	Desert	Bare lands	Desert	0.0
Croplands	Cultivated areas	Croplands	Cultivated areas	4927
Plantations	Woodland and shrublands	Exclosures enriched with plantations	Woodland and shrubland	769
Grasslands	Grasslands	Grasslands	Grassland	1597
Exclosures/Shrublands	Woodland and shrublands			769
Build - up	Build – up areas	Built-up	Built-up areas	0.0

Table 5. Coefficients (Int$/hectare/year; 2020 price levels) of ecosystem service values for the four-land use and land cover classes.

Ecosystem services	Croplands	Plantations	Grasslands	Exclosures/ shrublands
Provisioning				
Food	510	8		8
Water	604		313	
Raw material	6	1	637	1
Genetic resources				
Medicinal resources		1		1
Ornamental resources				
Regulating				
Air quality regulation	10	7	8	7
Climate regulation	10	89	73	89
Moderation of extreme events	993			
Regulation of water flows	17	71	43	71
Waste treatment	40			
Erosion prevention	173			
Supporting				
Maintenance of soil fertility	34			
Pollination	1,498			
Biological control	621			
Maintenance of life cycles of migratory species				
Maintenance of genetic diversity				
Cultural				
Aesthetic information	395	38		38
Opportunities for recreation and tourism		124	92	124
Inspiration for culture, art, and design	16	214	284	214
Spiritual experience				
Information for cognitive development		214	147	214
Existence and bequest values		2		2
Total	4,927	769	1,597	769

2.4. Assessment of communities' perception on land degradation and restoration

Household surveys were conducted to collect data on average household and farm characteristics and perceptions within communities on land degradation and restoration efforts in both Aba-Bora and Guder. Data were gathered from 248 households in Aba-Bora and 274 in Guder (522 in total) selected from fours kebeles (two for each watershed) in February and March 2021. Random samples of households were drawn from lists provided by each kebele administration after stratification based on wealth and gender status. After pre-testing elsewhere, the data was collected during February and March 2021 using a team of enumerators employing tablets, with the questionnaires available in both English and Amharic (i.e., the local language). Then data was cleaned, and descriptive analysis undertaken.

3. Results

3.1. Land use and land cover and spatial and temporal dynamics

3.1.1. Accuracy of land use and land cover classification

In both watersheds, the results indicate a very good classification performance that satisfies overall accuracy of at least 85% and Kappa values of more than 0.80 (Table 6). Also, the producer and user accuracies show good agreement (>70%). However, in 1980, grasslands and plantation in Aba-Bora watershed were poorly classified, with user accuracies of 69.6% and 68.4%, respectively. Similarly, bare lands, built-up areas and plantations displayed relatively low user accuracies in Guder watershed (Table 6).

Table 6. Accuracy assessment of classified images for Aba-Bora and Guder watersheds

LULC classes	Accuracy (%)									
	Aba-Bora Watershed									
	1980		1990		2000		2010		2021	
	Prod.	Users	Prod	Users	Prod.	Users	Prod.	Users	Prod.	Users
Bare land	76.4	70.0	96.0	82.1	93.1	86.7	98.3	91.8	91.7	86.6
Croplands	96.4	99.4	93.5	96.9	95.6	99.1	93.5	99.2	91.9	99.5
Grasslands	90.0	69.6	69.6	74.2	76.1	73.7	97.8	72.6	96.3	70.3
Exclosures/Shrublands	-	-	95.0	73.8	96.1	68.5	95.0	75.4	91.4	79.8
Plantations	100.0	68.4	98.2	86.9	98.2	93.7	98.0	95.2	100.0	92.3
Overall accuracy (%)	87.0		88.8		89.4		90.0		92.6	
Kappa Statistics	0.78		0.83		0.85		0.87		0.88	
	Guder Watershed									
Built-up	73.2	70.0	91.2	72.7	100.0	89.8	95.3	70.0	98.6	90.4
Bare land	86.2	70.4	98.3	86.5	92.1	73.2	97.0	73.7	88.5	75.4
Grasslands	82.6	89.2	87.4	91.4	94.0	89.5	96.3	88.8	93.5	89.2
Croplands	94.8	92.7	81.7	91.4	79.5	90.6	90.8	98.4	91.5	97.4
Plantations	81.2	72.5	97.5	74.2	96.7	74.0	92.9	71.7	92.7	77.0
Overall accuracy (%)	90.0		87.0		88.4		92.0		92.2	
Kappa Statistics	0.80		0.84		0.80		0.85		0.86	

Note: Prod. Refers to producer accuracy.

3.1.2. Land use and land cover and spatial and temporal dynamics

The LULC analyses showed that croplands, grasslands and plantations were widely distributed across the watersheds (Figure 2). Of the identified LULC classes, croplands dominated the watersheds (covers 64.3 to 76.4% in Aba-Bora, and 60.3 to 80.4% in Guder watershed) (Table 7). In both watersheds, grasslands displayed negative changes throughout the investigated years while bare lands, exclosures/shrublands, plantations and built-up areas showed positive changes (Table 7). By contrast, croplands displayed a more mixed pattern.

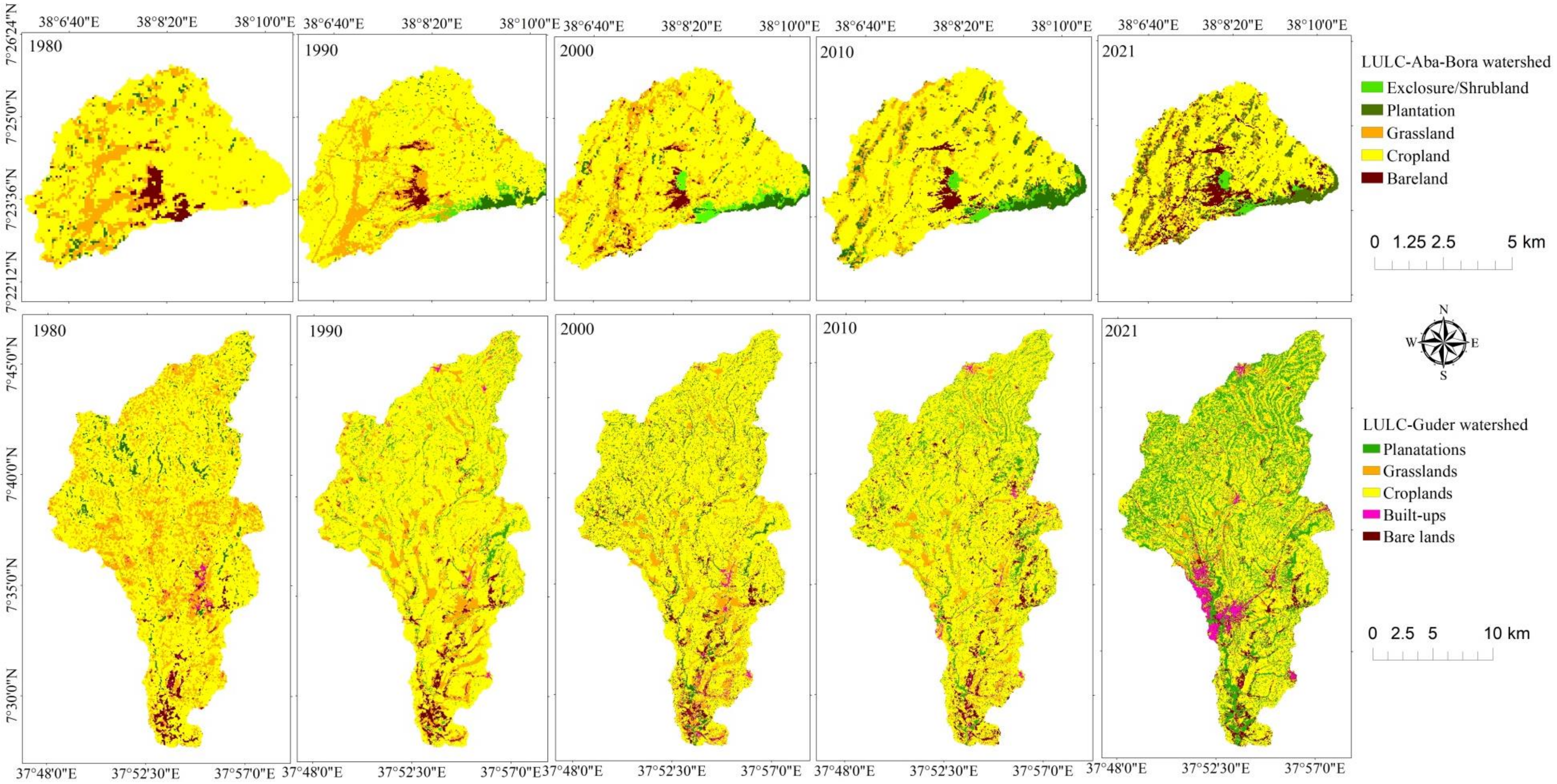


Figure 2. Land use and land covers classes of Aba-Bora and Guder watersheds

Table 7. Area (ha) of major land use and land cover classes in Aba-Bora and Guder watersheds.

Aba-Bora watershed										
LULC classes	Investigated years					LULC changes				
	1980	1990	2000	2010	2021	1980-1990	1990-2000	2000-2010	2010-2021	1980-2021
Bare lands	127	57	93	94	371	-69	36	1	277	245
Croplands	2156	2210	2160	2118	1862	53	-50	-42	-256	-295
Grasslands	545	461	422	333	230	-85	-39	-88	-103	-316
Plantations	60	103	132	260	337	43	29	128	77	277
Exclosures/shrublands	0.0	61	85	86	94	61	24	1	8	94
Total	2891	2891	2891	2891	2891					
Guder watershed										
Bare land	696	957	1459	1668	2060	262	502	209	392	1364
Built-up	314	401	460	508	984	87	59	48	476	670
Croplands	24441	26056	26570	25497	19950	1615	514	-1073	-5547	-4492
Grasslands	6409	3720	2282	1963	1336	-2689	-1439	-319	-627	-5074
Plantations	1206	1934	2293	3429	8738	728	359	1136	5308	7532
Total	33066	33066	33066	33066	33066					

The analysis of the dynamics of LULC indicates that the studied watersheds experienced various pathways in terms of LULC conversion (Figure 3). For example, in both watersheds, grasslands were converted into croplands and bare lands, croplands to bare lands and plantations, and croplands to plantations and exclosures/shrublands (Supplementary materials 2, 3). Over the period of 41 years, exclosures/shrublands, plantations, bare lands and build up areas increased, whereas croplands and grasslands decreased (Figures 4, 5). The results also indicated that bare lands increased in both watersheds, while built-up areas increased in Guder watershed at the expense of croplands and grasslands (Figure 3). Exclosures/shrublands and plantations in Aba-Bora watershed displayed gains, mainly in the central and southern part of the watershed at the expense of crop and bare lands (Figure 3).

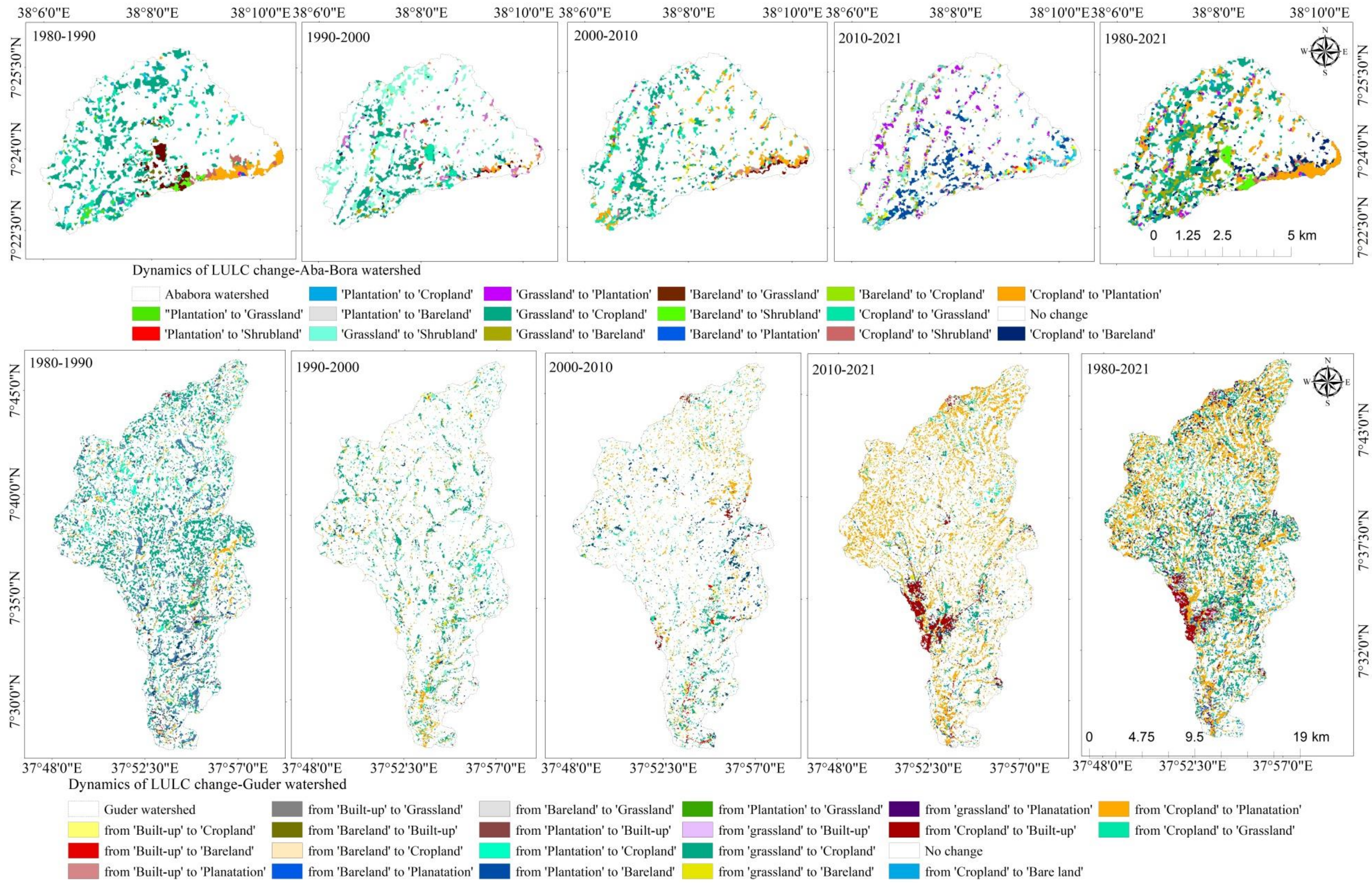


Figure 3. Dynamics of the major LULC classes in the Aba-Bora and Guder watersheds

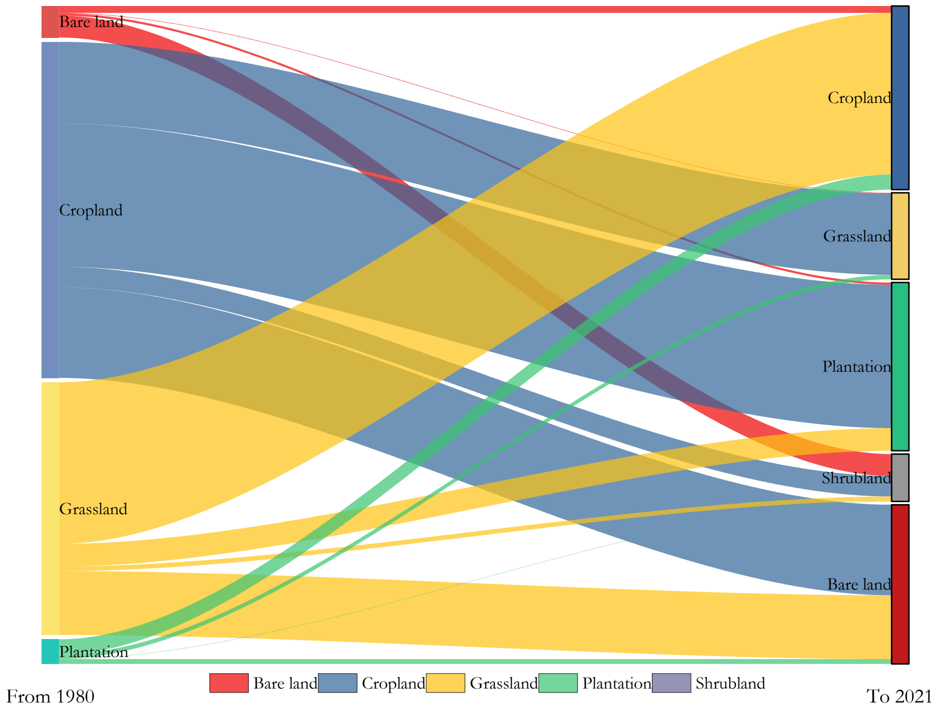


Figure 4. Sankey diagram of LULC change transfer matrix showing "from – to" changes for Aba-Bora watershed from 1980 to 2021.

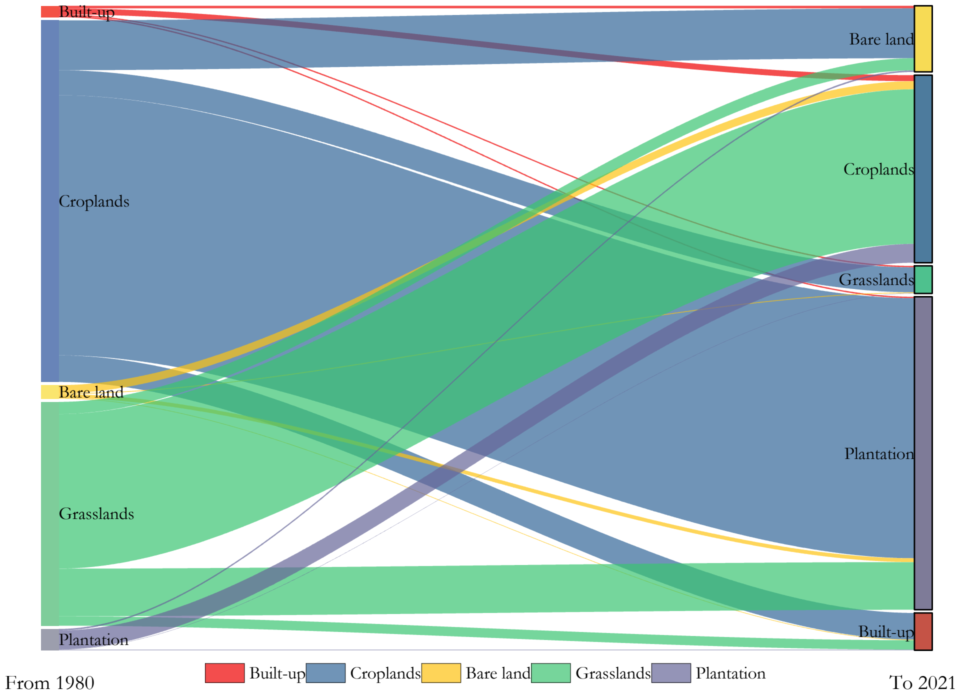


Figure 5. Sankey diagram of LULC change transfer matrix showing "from – to" changes for Guder watershed from 1980 to 2021.

3.2. Changes in the total and specific ecosystem service values

The total ESVs in both watersheds decreased over the period of 41 years (Table 8). The total ESVs in Aba-Bora watershed fell from US $ 11.5 million in 1980 to US $ 9.9 million in 2021, whereas the ESVs in Guder watershed fell from US$ 131.6 to 107.2 million. The changes in LULC over the period resulted in a total loss of ESVs of US $ 1.6 million in Aba-Bora and US$ 24.4 million in Guder watershed (Table 8).

Table 8. Effects of LULC changes on the total ecosystem service values and changes in ecosystem service values (in millions of US $; 2020 price levels).

LULC types	Total Ecosystem Service Values					Changes in Ecosystem Service Values				
	1980	1990	2000	2010	2021	1980 – 1990	1990 – 2000	2000 – 2010	2010 - 2021	1980 - 2021
Aba-Bora Watershed										
Croplands	10.6	10.9	10.6	10.4	9.2	0.3	-0.3	-0.2	-1.2	-1.4
Plantations	0.0	0.1	0.1	0.2	0.3	0.0	0.0	0.1	0.1	0.2
Grasslands	0.9	0.7	0.7	0.5	0.4	-0.1	-0.1	-0.1	-0.2	-0.5
Shrublands	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.1
Sum	11.5	11.8	11.4	11.2	9.9	0.2	-0.3	-0.2	-1.3	-1.6
Guder Watershed										
Cropland	120.4	128.4	130.9	125.6	98.3	8.0	2.5	-5.3	-27.3	-22.1
Grassland	10.2	5.9	3.6	3.1	2.1	-4.3	-2.3	-0.5	-1.0	-8.1
Plantations	0.9	1.5	1.8	2.6	6.7	0.6	0.3	0.9	4.1	5.8
Sum	131.6	135.8	136.3	131.4	107.2	4.3	0.5	-4.9	-24.2	-24.4

In both watersheds, the values of ESVs of most of the individual underlying ecosystem services fell (Table 9). Over the period (1980–2021), the greatest ecosystem service loss in both watersheds was related to pollination (US$ 0.4 million in Aba-bora and US$ 6.7 million in Guder), followed by moderation of extreme events (US$ 0.3 million in Aba-Bora and US$ 4.5 million in Guder) and water supply (US$ 0.3 million in Aba-Bora and US$ 4.3 million in Guder). In terms of the classification of ESS into provisioning, regulating etc, services, the greatest losses of ESVs in the 1980 to 2021 period were of broadly the same type. In Aba-Bora watershed, supporting services experienced the largest loss (US $ 0.63 million), followed by provisioning services (US$ 0.62 million), regulating services (US$ 0.34 million) and finally cultural services (US$ 0.1 million). In Guder watershed, the comparable losses were supporting services (US$ 9.7 million), provisioning services (US$ 9.8 million), regulating services (US$ 5.0 million) and with no overall changes in cultural services.

Table 9. Effects of land use and land cover changes on individual ecosystem services or functions in the studied watersheds over a period of 40 years.

Ecosystem services	Ecosystem Service Value (ESV) Across Periods (in Millions of US $)											
	Aba-Bora Watershed						Guder watershed					
	ESV_f 1980	ESV_f 1990	ESV_f 2000	ESV_f 2010	ESV_f 2021	Overall change	ESV_f 1980	ESV_f 1990	ESV_f 2000	ESV_f 2010	ESV_f 2021	Overall changes
Food	1.1	1.1	1.1	1.1	1.0	-0.1	12.5	13.3	13.6	13.0	10.2	-2.2
Water	1.5	1.5	1.4	1.4	1.2	-0.3	16.8	16.9	16.8	16.0	12.5	-4.3
Raw material	0.4	0.3	0.3	0.2	0.2	-0.2	4.2	2.5	1.6	1.4	1.0	-3.3
Genetic resources	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Medicinal resources	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ornamental resources	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Air quality regulation	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.3	0.3	0.0
Climate regulation	0.1	0.1	0.1	0.1	0.1	0.0	0.8	0.7	0.6	0.7	1.1	0.3
Moderation of extreme events	2.1	2.2	2.1	2.1	1.8	-0.3	24.3	25.9	26.4	25.3	19.8	-4.5
Regulation of water flows	0.1	0.1	0.1	0.1	0.1	0.0	0.8	0.7	0.7	0.8	1.0	0.2
Waste treatment	0.1	0.1	0.1	0.1	0.1	0.0	1.0	1.0	1.1	1.0	0.8	-0.2
Erosion prevention	0.4	0.4	0.4	0.4	0.3	-0.1	4.2	4.5	4.6	4.4	3.5	-0.8
Maintenance of soil fertility	0.1	0.1	0.1	0.1	0.1	0.0	0.8	0.9	0.9	0.9	0.7	-0.2
Pollination	3.2	3.3	3.2	3.2	2.8	-0.4	36.6	39.0	39.8	38.2	29.9	-6.7
Biological control	1.3	1.4	1.3	1.3	1.2	-0.2	15.2	16.2	16.5	15.8	12.4	-2.8
Maintenance of life cycles of migratory species	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Maintenance of genetic diversity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aesthetic information	0.9	0.9	0.9	0.8	0.8	-0.1	9.7	10.4	10.6	10.2	8.2	-1.5
Opportunities for recreation and tourism	0.1	0.1	0.1	0.1	0.1	0.0	0.7	0.6	0.5	0.6	1.2	0.5
Inspiration for culture, art and design	0.2	0.2	0.2	0.2	0.2	0.0	2.5	1.9	1.6	1.7	2.6	0.1
Spiritual experience	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Information for cognitive development	0.1	0.1	0.1	0.1	0.1	0.0	1.2	1.0	0.8	1.0	2.1	0.9
Existence and bequest values	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sum	**11.5**	**11.8**	**11.5**	**11.2**	**9.9**	**-1.6**	**131.6**	**135.8**	**136.3**	**131.4**	**107.1**	**-24.4**

3.3. Perceptions within communities on land degradation and restoration efforts

Households in the two watersheds make their livelihood mainly from a subsistence mixed crop-livestock farming system. In addition to practicing mixed crop–livestock farming, a considerable number of households engage in off-farm and non-farm activities. Figure 6 illustrates the proportion of households receiving income of different types. This shows that agriculture and particularly crop sales income, which over 80% of households receive remain the main source of external income for households (Figure 6).

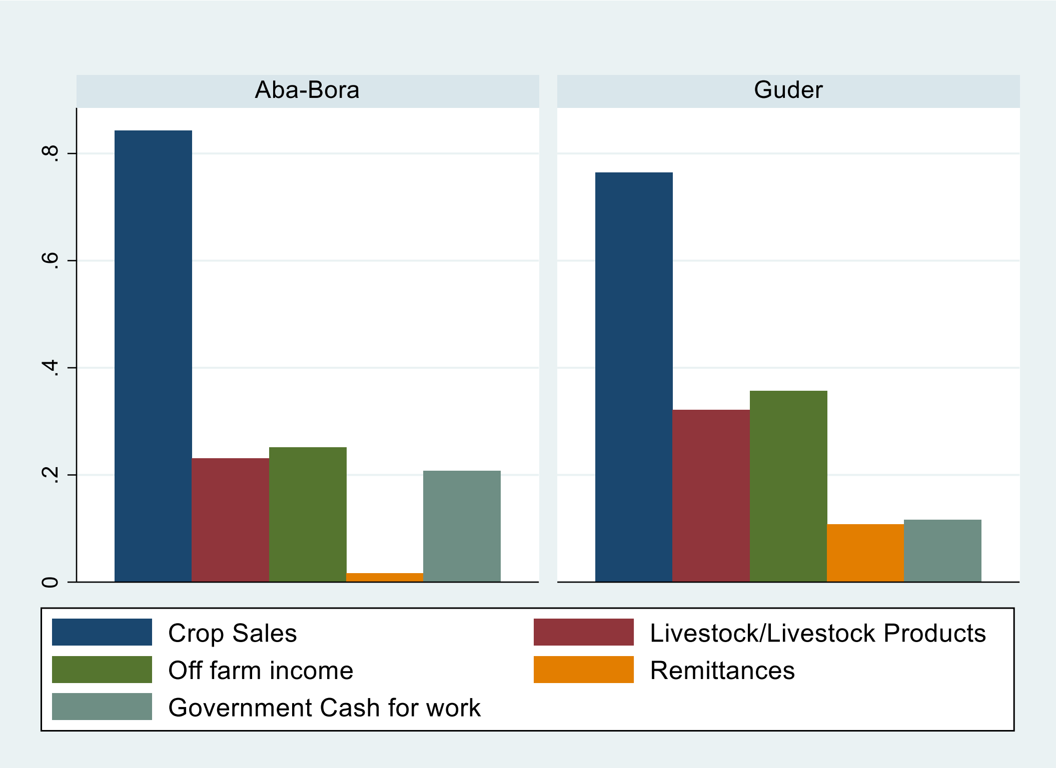
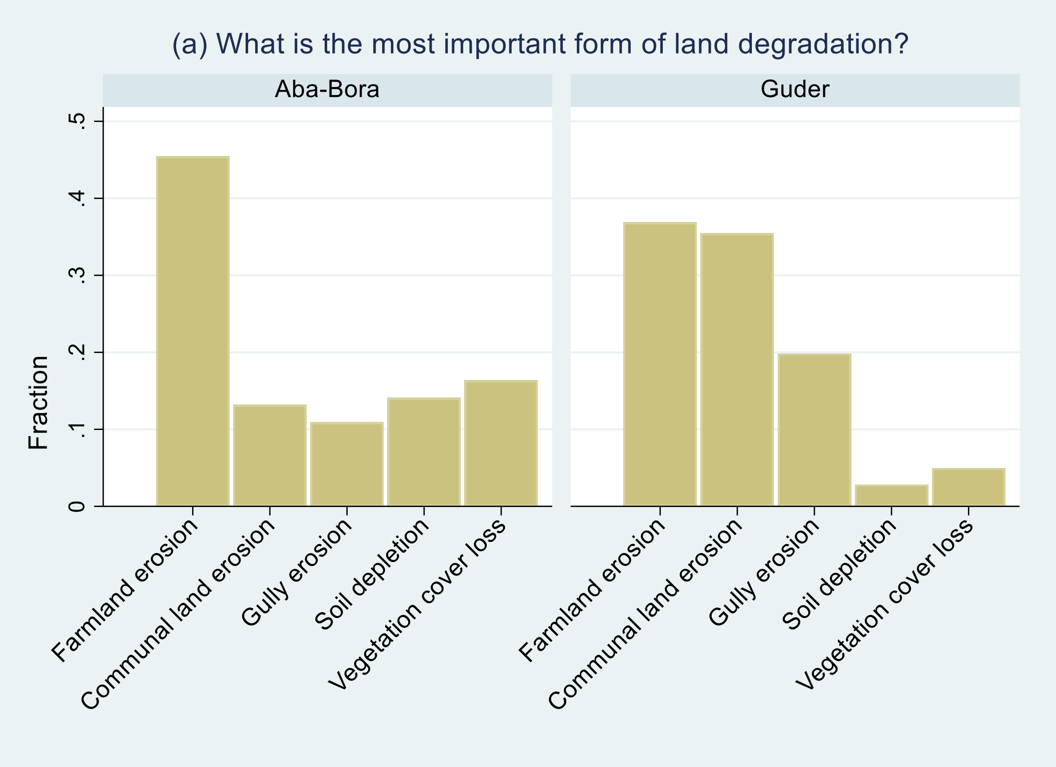
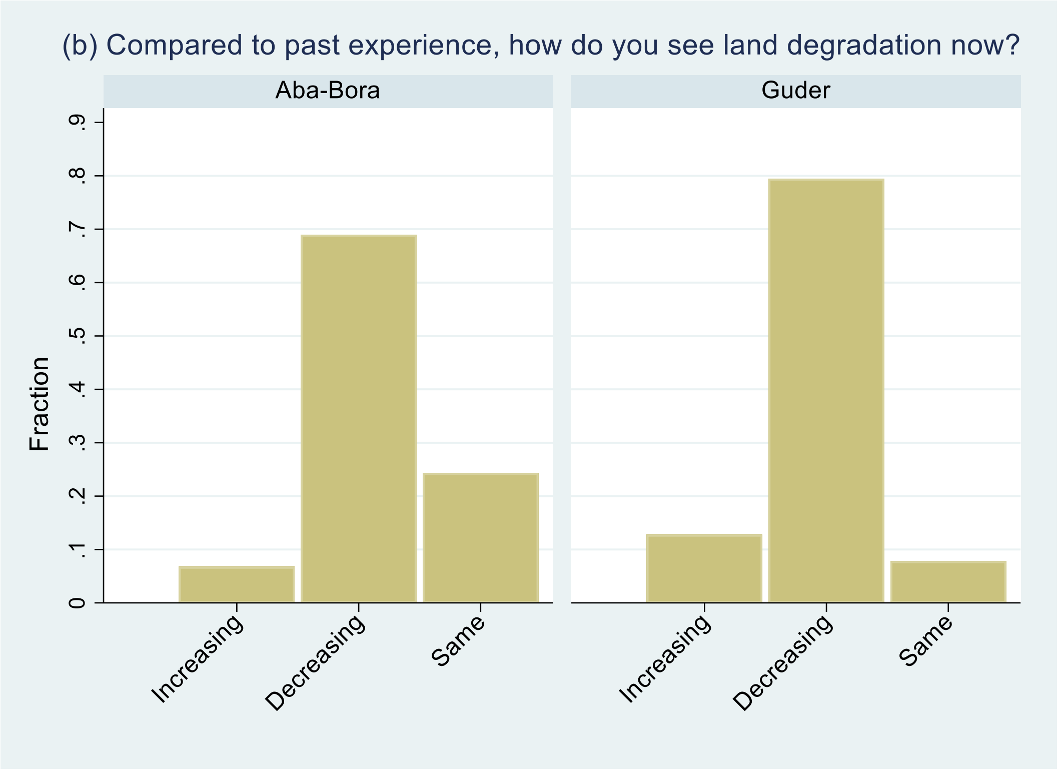


Figure 6. Household Income Sources: Proportion receiving income from each source.

The household survey data collected does suggest that the land degradation challenges are acknowledged by people living in these communities, but the scale of the challenge and risks appear less well-known. Almost 90% of the respondents in Aba-Bora think land degradation is an important problem with over 50% agreeing in Guder. The role of gully formation in land degradation appears well recognized particularly in Aba-Bora (Figure 7). In contrast to the evidence from the land use change analysis both watersheds most thinks the problem is getting better, and they are also extremely positive (and possibly over-optimistic) about the ability of current community-based watershed activities to address the degradation problems. Similarly for the ecosystem services provided by exclosures, there appears to be somewhat a disconnect between the importance of such measures for the community and the benefits which accrue to individual households.


(a) What is the most important form of land degradation?



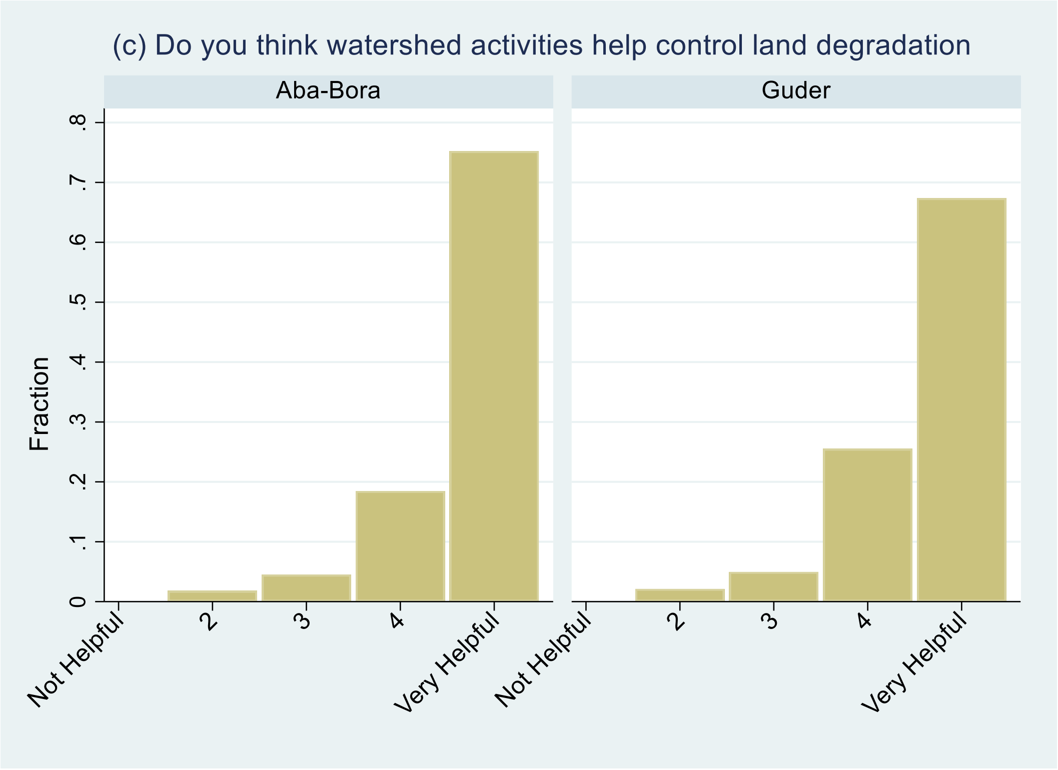


Figure 7. Perceptions around land degradation a) Most important types of land degradation b) Extent of the problem now c) Usefulness of watershed development activities

4. Discussion

4.1. Changes in LULC and ESVs and implications for land resources management and livelihood

The overall accuracy of at least 85% and kapa coefficient of more than 0.8 in both watersheds can be rated as substantial and hence the classified image was found to be fit for further use and analysis. The relatively lower user accuracies of grasslands (69.6%) and plantation (68.4%) in Aba-Bora watershed for the year 1980 could arise from that grasslands were often confused with croplands and bare land. Also, the overlap of croplands with plantations contributed to the confusion, so reducing the performance of the classification. Exclosures or shrublands showed low user accuracy for the year 2000, which could be attributed to their spectral similarity with grasslands and croplands. Similarly, bare lands, built-up areas and plantations displayed relatively low user accuracies in Guder watershed, which could be caused by the fact that many croplands (dominated by perennial crops such as Enset) are confused with plantations whose spectral profiles are similar. The relatively low user accuracy of bare lands could be related to the spectral similarity of bare lands with built-up areas.

Unlike other LULC types, the spatial and temporal dynamics of croplands displayed both increasing and decreasing trends in different time periods. For example, the expansion of croplands between 1980 and 1990 in Aba-Bora watershed and between 1980 and 2000 in Guder watershed could be attributed to the growing pressures on land from increasing human population. The loss of croplands after 1990 in Aba-Bora was due mainly to gully erosion transforming productive lands to bad land (bare lands) (Figure 8) and expansion of plantations at the expense of croplands (Figures 4, 5). The key driver for the formation of gullies in the Aba-Bora watersheds is the runoff generated from the untreated upper catchment areas. The soils in the watershed are loose, dominated by sandy texture and having poor vegetation cover, which all makes susceptible to water erosion (Yakob et al. 2022). The lack of low-cost gully rehabilitation technologies and local communities' awareness on the possibility of addressing gullies at the early stage of gully initiation and formation also contributed the expansion of gullies (Addisie et al. 2017). The loss of croplands in Guder watershed after 2000 could be attributed to the expansion of urbanization and plantations of eucalyptus trees, again at the expense of croplands (Table 7). Smallholders are mainly motivated to plant and convert their productive farm plots into eucalyptus due to the growing demand for wood and wood products as well as the associated increase in the price of its products (Alemayehu and Melka 2022). The expansion of urbanization in Guder watershed can partly be explained by the improvement in income of the local communities due to remittance (Figure 6).

Figure 8. Croplands converted to bare lands due to severe gully erosion in Aba-bora watershed (photo credit: Wolde Mekuria). The picture is taken in 2021 showing untreated upper catchment and big gullies formed in the mid-slope positions.

The analysis of the dynamics of LULC indicates that the studied watersheds experienced various pathways in terms of LULC conversion and have changed significantly since 1980. In line with the observed changes, land degradation caused by gully erosion and expansion of bare lands are a major concern in the studied watersheds resulting in declining crop and grasslands and reducing agricultural productivity. It is also found that the major contributor to the reductions in total ESVs due to LULC changes in both watersheds was the loss of croplands, with the loss of grasslands being the next most important contributor. These changes in LULC and associated loss of ESVs are expected to increase in the near future if the current increasing trend of land degradation and expansion of bare lands at the expense of croplands increases.

The results of this study differ from most previous studies, which indicate that loss of forestlands and shrublands are the major contributors of the loss of ecosystem services (e.g., Hu et al. 2008; Kindu et al. 2016; Tolessa et al. 2017; Gashaw et al. 2018; Kindu et al. 2018). By contrast, the results of this study demonstrated that loss of croplands could significantly affect ecosystem services even though plantations and shrubland increased over the period. This, in turn indicates that addressing degradation of croplands and the consequent expansion of bare lands due to gully erosion is crucial to maintain ecosystem services and support the livelihood of local communities.

The larger fall in supporting services compared to other ecosystem services can be attributed to the reduction in coverage of croplands, which particularly affecting pollination, and expansion of bare lands at the expense of productive farmlands. The relatively lower reduction in regulating services in both Aba-bora and Guder watersheds was due to the increase in plantation and shrublands (mainly through establishing exclosures).

The unique findings of this study in the spatial and temporal dynamics of LULC compared to most of the studies (e.g., Reyers et al. 2009; Agidew and Singh 2017; Msofe et al. 2020; Petersen et al. 2021; Bullock et al. 2021; Karaya et al. 2021; Biratu et al. 2022; Rotich et al. 2022) conducted in Ethiopia and elsewhere in the world demonstrated a quite different result with the change in croplands negative. The analyses of the changes in ESVs also demonstrated that conserving or decreasing the rate of the loss of croplands and grazing lands is key to minimizing the total ESVs losses in the studied watersheds. The evidence presented here suggests that crop and grazing lands are not being managed in a way that recognizes their constraints and vulnerabilities.

Rural communities in the studied watersheds, derive their livelihoods primarily from their crop-livestock mixed farming system (Figure 6). There has been a resulting decline in ecosystem services due to changes in croplands and grazing lands over the past few decades, leading to an increase in unemployment and vulnerability to shocks, and narrow future options. Addressing this through planning, designing and implementation of adaptation strategies requires site specific evidence on LULC changes and the underlying drivers (Abera et al. 2021). Considering that severe gully erosion is the major contributor to the reductions in croplands and grazing lands, catchment management that integrates the conservation of upstream areas through the implementation of diverse sustainable land management practices and gully rehabilitation measures in downstream areas could be an important option to reducing the expansion of large gullies and conserving croplands. In line with this, Esmail and Geneletti (2017) argue that the proper design of watershed investments support to address stakeholder concerns, facilitate negotiation of objectives (e.g., upstream – downstream interactions) and contribute to implementing an adaptive watershed management. Incentives, for example, in the form of payment for ecosystem services (Goldman-Benner et al. 2012) are also required to better engage both the upstream and downstream communities in watershed development activities and ensure collaboration for a common goal.

While suggesting integrated catchment management, we emphasize the need to include local actors in the development of adaptation strategies and management guidelines for the studied watersheds. In line with this, understanding the role of individual and community behaviour in the observed changes, for example, the socio-economic and socio-political processes that help explain the expansion of gullies at the expense of croplands and grazing lands is clearly important. As it is a likely key factor in local communities' participation in catchment management to address land degradation, one crucial component is the extent to which local communities are aware of the changes in LULC and associated changes and risks to ESVs and livelihoods.

Here there is mixed evidence that the issues and future risks for communities and individual livelihoods are widely understood and recognized. The household survey data collected does suggest that the land degradation challenges are acknowledged by people living in these communities, but the scale of the challenge, the risks, and the evidence that the land degradation losses are not less than in the past appear less well-known. Similarly for the ecosystem services provided by exclosures, one of the watershed development activities, there appears to be somewhat a disconnect between the importance of such measures for the community and the benefits which accrue to individual households, which suggests the role of ecosystem services and continuing and potentially increasing threat to individual livelihoods posed by land degradation may be less well understood than required for effective action.

This, in turn, suggest that understanding the distribution of the benefits and costs associated with the creation and maintenance of exclosures and the ecosystem services they create is important to ensure that, in so far as is possible, such measures are perceived as equitable and just by the community (Schreckenberg et al. 2016; Kato-Huerta and Geneletti 2022). This is important for broader economic development, but also because if the benefits and costs are seen to be unfairly distributed, then this may undermine the sustainability of exclosures reducing their usefulness in addressing land degradation.

In summary, the results suggest that more capacity building and knowledge sharing activities are needed to raise communities' awareness on the potential impacts of LULC changes on the ecosystems and livelihood. On the other hand, the optimistic view of communities on the current community-based watershed development activities could be seen as an opportunity to upscale and out scale best-practices in landscape management.

4.2. Limitations and way forward

The ESVs coefficients provided by the ecosystem service valuation database (ESVD) have been modified several times, for example the values were modified in 2010 (Van der Ploeg et al. 2010), 2012 (De Groot et al. 2012), in 2014 (Costanza et al. 2014), and in 2020 (De Groot et al. 2020). All these modifications and updates on the ESVD were made to address the criticism of the lack of representation of the context of certain regions, including Ethiopia (Gashaw et al. 2018), and over- or under-estimation of some ecosystem services (Tolessa et al. 2017). The modifications also reflect the recognition of the importance of having information on spatial ESVs to support decision making in land degradation and restoration.

Although the ecosystem service value coefficients of different LULC types included in the ESVD are not specific to the LULC classes considered in this study, it supports at least to indicate the degree and direction of the impacts of LULC changes on total and specific ecosystem service values. Particularly, conducting such studies using the available global data helps to generate empirical evidence, demonstrate the long-term dynamics of LULC changes and associated changes in ESVs, draw broader implication for sustainable landscape management and influence policy and decision-makers and facilitate actions. In addition, this kind of studies contribute to address the scarcity of evidence on ESVs estimation in the country and in the highly heterogeneous landscapes of the East African Highlands (Luedeling et al. 2011). However, efforts are needed to develop country specific data and build a database on the ecosystem service value coefficients. This would help improve the estimation of the changes in ESVs due to LULC changes and better generate reliable empirical evidence and influence policy and decision- makers. This, in turn, contributes to better planning, designing, and implementing landscape management practices and addressing the vulnerability of local communities due to landscape degradation.

5. Conclusion

The study aimed to inform sustainable landscape management practices through mapping the spatial and temporal dynamics of LULC changes in two highly degraded watersheds, representing mid- and high-altitude land, and assessing the impacts in terms of the monetary values of key ecosystem services and livelihoods. The study also aimed to identify critical areas for conserving natural resources and reversing the decline of ESVs due to LULC changes. The study combined multiple dataset and methods to model these changes and draws implications for sustainable landscape management. The analyses of the changes in ESVs demonstrated that conserving or decreasing the rate of the loss of croplands and grazing lands in addition to expanding or implementing tree-based forest landscape restoration measures such as plantations and exclosures, is key to minimizing the total ESVs losses in the studied watersheds. Considering that severe gully erosion is the major contributor to the reductions in croplands and grazing lands, catchment management that integrates the conservation of upstream areas through the implementation of diverse sustainable land management practices and gully rehabilitation measures in downstream areas could be an important option to reducing the expansion of large gullies and conserving croplands. Also, understanding the role of individual and community behaviour in the observed changes, for example, the socio-economic and socio-political processes that help explain the expansion of gullies at the expense of croplands and grazing lands is clearly important. Further, the results indicated that raising the local communities' awareness on the potential impacts of LULC changes on ESVs and livelihood through capacity building and knowledge sharing activities is needed. The optimistic view of communities on the current community-based watershed development activities could be seen as an opportunity to upscale and out scale best-practices in landscape management. Further studies are required to identify the success and failure factors of the ongoing community-based watershed development activities, and why the communities failed to stop the expansion of gullies and croplands degradation in the watersheds.

References

Abera, W., Tamene, L., Kassawmar, T., Mulatu, K., Kassa, H., Verchot, L., & Quintero, M. (2021). Impacts of land use and land cover dynamics on ecosystem services in the Yayo coffee forest biosphere reserve, southwestern Ethiopia. Ecosystem Services, 50, 101338.

Addisie, M. B., Ayele, G. K., Gessess, A. A., Tilahun, S. A., Zegeye, A. D., Moges, M. M., ... & Steenhuis, T. S. (2017). Gully head retreat in the sub-humid Ethiopian highlands: the Ene-Chilala catchment. Land Degradation & Development, 28(5), 1579-1588.

Agidew, A. M. A., & Singh, K. N. (2017). The implications of land use and land cover changes for rural household food insecurity in the Northeastern highlands of Ethiopia: the case of the Teleyayen sub-watershed. Agriculture & Food Security, 6(1), 1-14.

Alemayehu, A., & Melka, Y. (2022). Small scale eucalyptus cultivation and its socio-economic impacts in Ethiopia: a review of practices and conditions. Trees, forests and people, 100269.

Aneseyee, A. B., Soromessa, T., & Elias, E. (2020). The effect of land use/land cover changes on ecosystem services valuation of Winike watershed, Omo Gibe basin, Ethiopia. *Human and Ecological Risk Assessment: An International Journal*, *26*(10), 2608-2627.

Biratu, A. A., Bedadi, B., Gebrehiwot, S. G., Melesse, A. M., Nebi, T. H., Abera, W., ... & Egeru, A. (2022). Ecosystem Service Valuation along Landscape Transformation in Central Ethiopia. Land, 11(4), 500.

Bullock, E. L., Healey, S. P., Yang, Z., Oduor, P., Gorelick, N., Omondi, S., ... & Cohen, W. B. (2021). Three decades of land cover change in East Africa. Land, 10(2), 150.

Congalton, R. G., & Green, K. (2019). Assessing the accuracy of remotely sensed data: principles and practices. CRC press.

Costanza, R., De Groot, R., Sutton, P., Van der Ploeg, S., Anderson, S. J., Kubiszewski, I., ... & Turner, R. K. (2014). Changes in the global value of ecosystem services. Global environmental change, 26, 152-158.

De Groot, R., Brander, L., Van Der Ploeg, S., Costanza, R., Bernard, F., Braat, L., ... & van Beukering, P. (2012). Global estimates of the value of ecosystems and their services in monetary units. Ecosystem services, 1(1), 50-61.

De Groot, R., Brander, L., & Solomonides, S. (2020). Ecosystem Services Valuation Database (ESVD)-Update of global ecosystem service valuation data. Department for Environment, Food and Rural Affairs (Defra, UK).

Dregne, H. E. (2002). Land degradation in the drylands. Arid land research and management, 16(2), 99-132.

Esmail, B. A., & Geneletti, D. (2017). Design and impact assessment of watershed investments: An approach based on ecosystem services and boundary work. Environmental Impact Assessment Review, 62, 1-13.

Fenta, A. A., Tsunekawa, A., Haregeweyn, N., Tsubo, M., Yasuda, H., Shimizu, K., ... & Sun, J. (2020). Cropland expansion outweighs the monetary effect of declining natural vegetation on ecosystem services in sub-Saharan Africa. Ecosystem Services, 45, 101154.

Fu, C., Chen, Z., Wang, G., Yu, X., & Yu, G. (2021). A comprehensive framework for evaluating the impact of land use change and management on soil organic carbon stocks in global drylands. Current Opinion in Environmental Sustainability, 48, 103-109.

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.

Gebeyehu, A. E., Chunju, Z., & Yihong, Z. (2019). Assessment and mapping of land use change by remote sensing and GIS: A case study of Abaya Chamo Sub-basin, Ethiopia. Nature Environment and Pollution Technology, 18(2), 549-554.

Goldman-Benner, R. L., Benitez, S., Boucher, T., Calvache, A., Daily, G., Kareiva, P., ... & Ramos, A. (2012). Water funds and payments for ecosystem services: practice learns from theory and theory can learn from practice. Oryx, 46(1), 55-63.

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(1), 147-156.

Jensen, J. (2005). Thematic map accuracy assessment in Introductory Digital Image Processing–A Remote Sensing Perspective 3rd ed (USA: Prentice Hall) pp 495–515.

Johnston, R. J., Rolfe, J., Rosenberger, R. S., & Brouwer, R. (2015). Benefit transfer of environmental and resource values. The economics of non-market goods and resources, 14.

Karaya, R. N., Onyango, C. A., & Ogendi, G. M. (2021). A community-GIS supported dryland use and cover change assessment: The case of the Njemps flats in Kenya. Cogent Food & Agriculture, 7(1), 1872852.

Kato-Huerta, J & D Geneletti (2022). Environmental justice implications of nature-based solutions in urban areas: A systematic review of approaches, indicators, and outcomes, Environmental Science & Policy, 138, 122-133, 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. Science of the Total Environment, 547, 137-147.

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

Lillesand, T. M., Kiefer, R. W., & Chipman, J. W. (2004). Remote Sensing and Image Interpretation. (I. John Wiley & Sons, Ed.) (Fifth, Vol. 53). United States of America: UG I GGS Information Services.

Luedeling, E., Sileshi, G., Beedy, T., & Dietz, J. (2011). Carbon sequestration potential of agroforestry systems in Africa. *Carbon sequestration potential of agroforestry systems: Opportunities and challenges*, 61-83.

Markos, M. G., Mihret, D. U., Teklu, E. J., & Getachew, M. G. (2018). Influence of land use and land cover changes on ecosystem services in the Bilate Alaba Sub-watershed, Southern Ethiopia. Journal of Ecology and the Natural Environment, 10(9), 228-238.

Mekuria, W., Diyasa, M., Tengberg, A., & Haileslassie, A. (2021). Effects of long-term land use and land cover changes on ecosystem service values: An example from the central rift valley, Ethiopia. Land, 10(12), 1373.

Mirzabaev, A., Wu, J., Evans, J., Garcia-Oliva, F., Hussein, I. A. G., Iqbal, M. H., ... & Weltz, M. (2019). Desertification, Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. https://www.ipcc.ch/srccl.

Msofe, N. K., Sheng, L., Li, Z., & Lyimo, J. (2020). Impact of land use/cover change on ecosystem service values in the kilombero valley floodplain, southeastern tanzania. Forests, 11(1), 109.

Petersen, M., Bergmann, C., Roden, P., & Nüsser, M. (2021). Contextualizing land-use and land-cover change with local knowledge: A case study from Pokot Central, Kenya. Land Degradation & Development, 32(10), 2992-3007.

Qiu, H., Hu, B., & Zhang, Z. (2021). Impacts of land use change on ecosystem service value based on SDGs report--Taking Guangxi as an example. Ecological Indicators, 133, 108366.

Reyers, B., O'Farrell, P. J., Cowling, R. M., Egoh, B. N., Le Maitre, D. C., & Vlok, J. H. (2009). Ecosystem services, land-cover change, and stakeholders: finding a sustainable foothold for a semiarid biodiversity hotspot. Ecology and Society, 14(1).

Rotich, B., Kindu, M., Kipkulei, H., Kibet, S., & Ojwang, D. (2022). Impact of land use/land cover changes on ecosystem service values in the cherangany hills water tower, Kenya. Environmental Challenges, 8, 100576.

Schreckenberg, K., Franks, P., Martin, A., & Lang, B. (2016). Unpacking equity for protected area conservation. Parks, 22(2), 11-26.

Sinore, T., & Umer, S. (2021). Effect of Exclosure on Soil Properties in Comparison with Grazing Land in Guder sub-Watershed, Southern Ethiopia. Journal of Mountain Research, 16(3), 1-10.

Temesgen, H., Wu, W., Shi, X., Yirsaw, E., Bekele, B., & Kindu, M. (2018). Variation in ecosystem service values in an agroforestry dominated landscape in Ethiopia: Implications for land use and conservation policy. Sustainability, 10(4), 1126.

The Global Environmental Facility (2019). Land degradation. GEF secretariate. ISBN 978-1-948690-69-0. https://www.thegef.org/publications/land-degradation.

Tolessa, T., Senbeta, F., & Abebe, T. (2017). 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., Kidane, M., & Bezie, A. (2021). Assessment of the linkages between ecosystem service provision and land use/land cover change in Fincha watershed, North-Western Ethiopia. Heliyon, 7(7), e07673.

United Nations Convention to Combat Desertification (2022). The Global Land Outlook, second edition. UNCCD, Bonn.

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

Wolancho, K. W. (2015). Evaluating watershed management activities of campaign work in Southern nations, nationalities and peoples' regional state of Ethiopia. Environmental Systems Research, 4, 1-13.

Wolde Yohannes et al. 2018; Ziadat, F. M., Zdruli, P., Christiansen, S., Caon, L., Monem, M. A., & Fetsi, T. (2022). An Overview of Land Degradation and Sustainable Land Management in the Near East and North Africa. Sustainable Agriculture Research, 11(1), 1-11.