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RESEARCH PAPER

Land Use and Land Cover Change and Its Impacts on the Ecosystem Services in Guder River Sub-Basin, Ethiopia

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Abstract

In developing nations, land use and cover, change rates have doubled due to rapid population expansion, economic growth, and agricultural development. This study aimed to analyze the impacts of land use and cover change on ecosystem services in the Guder River sub-basin. Satellite imageries from the United States Geological Survey for 1990, 2000, and 2020 were used to detect and classify land use and cover types using Remote Sensing, ERDAS, and ArcGIS software. Ground truth data were gathered using GPS. The areas of different land use and cover types were analyzed using ArcGIS's geometric tool and the ecosystem values were calculated by multiplying the global biome coefficients by the area of each land use type. The study identified six land use types: grassland, forestland, cultivated land, settlement shrub, and barren lands. The results revealed significant changes in land use and land cover types over the study period compared to 1990. In 2020, the grassland, forestland, and shrubland areas decreased by 64.62%, 36.50%, and 15.20%, respectively. Conversely, cultivated land increased by 48.20%, settlement land by 386.66%, and barren land by 1644.1%. These changes in land use and land cover types led to a decrease in the overall ecosystem services (ESV) value between 1990 and 2020. The degradation of grassland, forestland, and shrubland significantly decreased the ESV by 64.7%, 36.47%, and 15.07%, respectively, while the expansion of cultivated land ESV increased by 48.21%. The total ESV across the study river basin decreased from $15.62 million in 1990 to $11.11 million in 2020, a 28.87% reduction. The study highlights the urgent need for land use planning and administration strategies to mitigate these impacts and promote sustainable land management in the sub-basin.

Keywords: Biome, ecosystem service values, Guder River basin, land use and cover change

Introduction

Land-use and land-cover change (LULC) is a complicated socioeconomic and environmental issue that requires a thorough understanding of how human-caused activities interact with the environment. It is a historical process relating to how people use the land. Large-scale changes in the Earth's environment are being brought on by expanding anthropogenic activities and natural phenomena in the biosphere (Lambin *et al*., 2001; Liu *et al*., 2020). Changes in land use and cover are the outcomes of socioeconomic factors and natural phenomena combined with how people have managed them over time and space (Halefom *et al.*, 2018; Lambin and Meyfroidt, 2010). Anthropogenic alterations of the natural landscape through urbanization, agriculture, and forestry have been a continuous and increasing process for the past millennium (Brown *et al*., 2012; Ellis, 2015). The rates of land use and land-cover change (LULC) have multiplied due to the late 20th and early 21st centuries' rapid and unchecked population growth and economic and industrial development, particularly in developing nations (Talukdar *et al*., 2020). The rise in the population in the highlands at the beginning of the 20th century sped up deforestation and increased land cultivation (Hurni et al., 2005). Physical factors, including topography, slope condition, soil type, and climate change, also affect land use and cover types through accelerating soil erosion (Chinzila, 2018; Megersa *et al*., 2019; Siswanto and Sule, 2019).

Ecosystem services, which are defined as the cumulative form of ecosystem goods and services that benefit human life from various ecosystem functions, have been devalued by these LULC changes (Chalchissa *et al*., 2022; Kamble *et al*., 2012). Land use and cover change modify the availability of different resources, including vegetation, soil, and water (Tewabe and Fentahun, 2020) and climate, evaporation, and runoff, particularly in small catchment areas (Babiso *et al.,* 2016; Nzunda *et al*., 2013). Its numerous ecosystem services (ESs), such as recreational opportunities, biodiversity, habitat quality, soil formation, nutrient cycling, climate regulation, erosion control, and water regulation, are threatened by the conversion of LULC to various settlements and agricultural purposes (Hu et al., 2020; Sahle *et al*., 2019; Sun *et al*., 2018; Zhao *et al*., 2019).

Even though ecosystems offer numerous services in the form of public goods, it is challenging to estimate their economic value as marketable goods present a significant challenge in quantifying ecosystem system valuation for a long time (Huq *et al*., 2019). However, to address this issue, Costanza *et al*. (1998) devised value coefficients for various land biomes and, in a ground-breaking method that has drawn significant interest from international research scholars, roughly calculated global ESVs. This method was employed in several studies to assess the effects of economic and population growth on ecosystem services (Gashaw *et al*., 2018; Ghosh and Bhunia, 2021; Kindu *et al.,* 2016; Rwanga and Ndambuki, 2017; Sahle *et al*., 2019; Tolessa *et al*., 2017).

Ethiopia is the second most populous country in Africa (Groth and May 2017; Nuñez and Murakami-Ramalho, 2012) and is experiencing one of the fastest economic growth rates in East Africa (Berhanu & Poulton, 2014). On the other hand, the country is one of the most environmentally troubled countries in the Sahel belt (Belay and Mengistu, 2021; Tschakert *et al*., 2010). The critical environmental problem in Ethiopia is land degradation in the form of soil erosion, gully formation, soil fertility and productivity loss (Benti & Balemi, 2016), and severe soil moisture stress, which is partly the result of land use land cover change (Fitsum *et al*., 2000; Gashaw *et al*., 2018). The socio-economic well-being of the people and the environment in the country are continuously and adversely changing due to degraded land resources, and subsequently give rise to various types of socio-economic challenges (Gashaw *et al*., 2018). Population pressure, urbanization, and a lack of land use planning are the main causes of LULC change in Ethiopia, which contribute to the free riding of forestland, grassland, and shrubland conversions to cultivated and settlement areas (Demissie *et al*., 2017; Megerssa & Bekere, 2019).

On the other hand, previous studies have often lacked a detailed temporal analysis of land use and land cover (LULC) changes over an extended period, particularly in the Guder River Sub-Basin. Furthermore, while many studies have focused on LULC changes, they frequently overlook the direct impacts these changes have on ecosystem services, creating a gap in understanding how shifts in land use affect ecological balance and community well-being. Additionally, there is a scarcity of research specifically targeting the Guder River Sub-Basin, leaving a gap in localized insights into LULC impacts in this ecologically and agriculturally important area. The study also addresses the need for integrating socio-economic factors with LULC changes and their effects on ecosystem services, as well as the lack of advanced remote sensing and GIS techniques in previous analyses.

This study is rooted in the urgent need to address environmental degradation and the loss of ecosystem services caused by rapid and unchecked land use changes in the Guder River Sub-Basin. The research aims to inform sustainable land management practices by providing insights into how LULC changes affects vital ecosystem services, which are essential for maintaining biodiversity, agricultural productivity, and water resources.

Therefore, generating scientific data and insights necessary for policy development, the study seeks to mitigate the negative impacts of LULC changes, aligning land use practices with environmental conservation and climate resilience goals. Furthermore, understanding these impacts is crucial for improving the livelihoods of local communities who rely on these ecosystem services. The study also aims to contribute to global research on LULC changes and their environmental impacts, offering valuable data from the Ethiopian context that can be compared with other regions facing similar challenges.

Materials and methods

Description of Study Areas

The study was carried out in the Guder River sub-basin in the West Shoa Zone, Oromia National Regional State. The study area is situated between 8°46’ 30” N and 9°1’37” N latitude and 37°37’36” E and 37°51’32.4” E longitude, with 1880 to 3194 m of elevation above sea level (Figure 1). The average annual rainfall for the area is 970 mm per year. The sub-basin receives an unimodal rainfall distribution, with the summer months receiving heavy rainfall and the autumn months receiving little. Heavy rainfalls occur from the onset of July to the end of mid-September. The temperature is between 10 and 26 °C, with an average of 18 °C throughout the year. The farmers are almost entirely devoted to rainfed agriculture, as agriculture is the principal income source of the community that lives in the sub-River basin. Cereals such as corn, wheat, barley, and teff are the main crops grown in the catchment (Benti & Balemi, 2016).

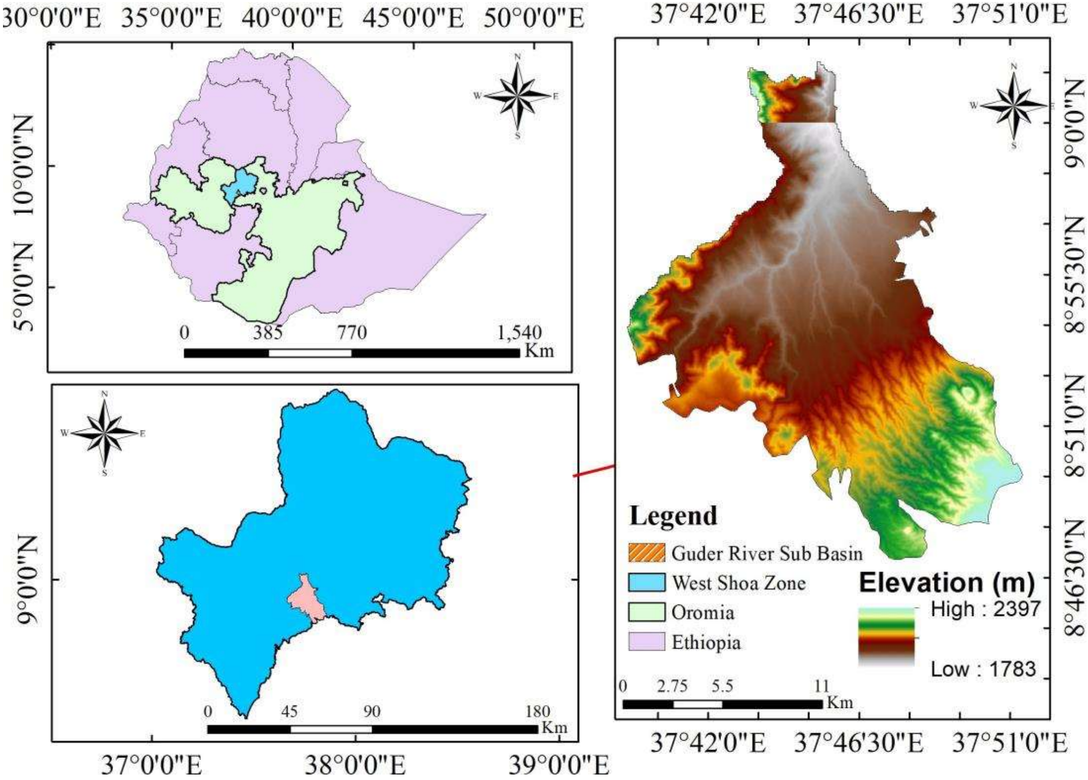

Figure 1. Location map of Guder River sub-basin

Data collection

The satellite images of global land cover change data were downloaded from the United States Geological Survey's (USGS) Earth Resource Observation and Science Center. It is freely available at the website https://www.mrlc.gov/. It is a time series of satellite images derived from remote sensing data, featuring multiple temporal and differential spatial scales with a spatial resolution of 30 x 30 meters. It includes Multi-Spectral Scanner (MSS), Enhanced Thematic Mapper (ETM+), and Operational Land Imager (OLI) Landsat images from 1990, 2005, and 2020. The USGS Earth Explorer platform was utilized to filter satellite images systematically based on cloud coverage percentages below 10%. The process ensures the provision of high-quality imagery for detailed analysis, enhancing the reliability and accuracy of research outcomes. Cloud cover is one of several constraints on the ability of sensors on Landsat to provide a continuous time series of data for glaciological studies (Marshall et al., 1994). The 240 ground control points (XY coordinates), which were selected at random from six different land use types using the handheld Garmin 72 GPS, were used to validate the accuracy of the satellite images. The total number of ground control points consists of 46, 28, 50, 44, 40, and 32 for grassland, forestland, cultivated land, settlements, shrubland, and 28 barren lands, respectively. Table 1 displays the gathered Landsat satellite images.

Table 1: List of Satellite image data and sources

Satellite images	Sensor	Path and row	Resolution	Date of acquisition	Sources
Landsat	MSS	169/54	30X30	11/01/1990	USGS
Landsat	ETM+	169/54	30X30	09/01/2005	USGS
Landsat	OLI	169/54	30X30	15/01/2020	USGS

Data preparation and pre-processing

In today's high-tech world, nearly all image interpretation and analysis need digital processing because most satellite images are stored in digital formats. Numerous steps were taken, including data formatting and correction, and digital enhancement for improved visual interpretation. Image preprocessing such as geometric correction and image enhancement is applied to avoid geometric distortion and unnecessary atmospheric effects. The geo-referencing process is also undertaken by ground control points (GCPs), as described by Obsa et al. (2021).

Data Analysis

Classification of land use and cover types

The classification of land use and land cover (LULC) for this study involved three key steps: image enhancement, image classification, and accuracy evaluation. To improve the visual interpretability of Landsat ETM, ETM+, and OLI/TIRS satellite images, we employed image enhancement techniques, specifically using the tasseled cap transformation. This spectral enhancement method combines multiple spectral bands to highlight vegetation and other features, thereby enhancing object distinction within the images.

The LULC classification process was conducted in two phases: unsupervised classification followed by supervised classification. Initially, unsupervised classification was performed to generate a preliminary classification map. This involved clustering algorithms that grouped pixels with similar spectral characteristics without prior knowledge of the land cover types. The unsupervised classification provided a preliminary categorization, aiding in the identification of areas requiring further investigation during the field survey. Following the field survey, supervised classification was conducted to refine and validate the LULC categories. Ground truth data collected from ten reference sites for each LULC type were used, and the satellite images were geo-referenced to the X and Y Earth coordinate system using GPS data. The Bayes' maximum likelihood method, a parametric classifier, was employed for supervised classification, as it quantitatively evaluates the variance and covariance of the spectral response patterns of different categories, ensuring a more accurate categorization of unknown pixels.

Ground truth data collected during the same season as the satellite image acquisition was essential for validating the supervised classification results. The accuracy of the classification was assessed by comparing the classified images with the reference data. To quantify changes in each land use class, the difference in area between the initial Landsat MSS data from 1990 and the final Landsat OLI data from 2020 was calculated. This involved subtracting the 1990 area values from the 2020 area values for each LULC type. The results were then compared with the most recent map of 2020 and the initial map of 1990 to identify and analyze the changes in land use and land cover over the study period. This methodology provides a comprehensive and technically robust approach to LULC classification, focusing on the specific procedures and methods used in this study to ensure accurate and reliable results

The accuracy assessment is one of the most significant last steps in the classification process. The quantitative accuracy assessment measures how well the pixels were sampled into the appropriate land cover classes. The produced image classification was made by Congalton (1991) procedures, who confirmed the accuracy of the classified images. In this technique, the reference pixels are points on the classified image for which actual data is represented. Google Earth, practical experience, and random sample points were all considered in their development. Six land use and land cover categories such as grassland, forestland, cultivated land, settlements, shrubland, and bare land were created as standards for the categorization and accuracy evaluation of GCPs. Components like overall accuracy, user accuracy, producer accuracy, and Kappa coefficient could be accurately derived after the accuracy evaluations.

The producer's accuracy level was computed by dividing the total number of correctly classified pixels by the total number of ground control points (GCP) as indicated in Equation 1

$$PA\ (\%) = \frac{\sum GCP}{\sum CCP} * 100 \qquad (1)$$

where PA represents producer accuracy in percentage, GCP is ground control points, and NC is correctly classified pixels.
The user's accuracy was also computed by the total number of correctly classified pixels divided by the total number of reference points (RP) as indicated in Equation 2.

$$UA\ (\%) = \frac{\sum RP}{\sum CCP} * 100 \qquad (2)$$

Where UA represents the user's accuracy in percentage and RP is reference points.
KAPPA analysis is a discrete multivariate technique used in accuracy evaluations (Jensen & Lulla, 1987). The Khat statistics are a metric for agreement or accuracy that comes from KAPPA analysis. It represents a Kappa estimate. Khat statistics were computed using Equation 3.

$$K = \frac{\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (X_i + Xx_{+i})}{N^2 - \sum_{i=1}^{r} (X_{ii} * Xx_{+i})} \qquad (3)$$

where K indicates Khat statistics, r is the number of rows and columns in the error matrix, N is the total number of observations, Xii is an observation in row i and column i, Xi+ is the marginal total of row i, and X+i is the marginal total of column i.

For computational purposes, equation 4 frequently takes the following form:

$$\widehat{K} = \frac{\theta_1 - \theta_2}{1 - \theta_2} \qquad (4)$$

where $\widehat{K}$ is Khat statistics, $\theta_1 = \sum_{i=1}^{r} {X_{ii}}/{N}$ and $\theta_2 = X_{i+} X_{+i}/N^2$

The Kappa statistics (K) were evaluated concerning various limits according to Landis and Landis & Koch (1977). The agreement is poor if K is less than 0, slight if K is between 0 and 0.20, fair if K is between 0.21 and 0.40, moderate if K is between 0.41 and 0.60, substantial if K is between 0.61 and 0.80, almost perfect if K is between 0.81 and 1.00 and perfect if K is equal to 1.00.

Following classification and accuracy evaluation, ArcGIS performed geometric calculations to determine the areas of each land type in the study area.

Ecosystem service valuation (ESV)

Ecosystem Service Value (ESV) was assessed using global ecosystem service values as the technique described in Ghosh and Bhunia (2021). This study used the global ecosystem service assessment table for environmental benefit consumption with the appropriate biomass costs to estimate EVS per hectare (Table 2) for different land use and land cover types in the Guder River sub-basin for 1990, 2000, and 2020.

Table 2. Lists the LULC classifications, with the equivalent biomes and the overall ESV coefficients

LULC Categories	Equivalent Biome	ESV Coefficient (USD/ha/year)
Grassland	Grass/rangeland	232
Forestland	Tropical forests	2007
Cultivated land	Crop land	92
Settlement	Urban	0
Shrubland	Forest	969
Bare land	Urban	0

Source: Costanza et al. (1998)

The area of land use and land cover type was multiplied by the coefficient ecosystem value using equation 5 to get the overall ecosystem value for each specific land use type:

$$ESV_a = A_a * VC_a \qquad (5)$$

where ESV is the ecosystem service value, A_a is the area (ha) of land use land cover types, and VC_a is the coefficient value for the land use category ‘a’ as US$ per ha per year.

$$ESV_b = \sum(A_a * VC_{ab}) \qquad (6)$$

where is the ESV of ecosystem service function 'b'; is the value coefficient of land use type "a" as US$ per ha per year with ecosystem service function type 'b'.

The total ecosystem service function of the entire sub-basin was obtained by summing the estimated ESV from each LULC category using Equation 3 t to estimate the values of 17 ecosystem services as per the methods in Hoque et al. (2020) and Tolessa et al. (2017).

$$ESV_C = \sum_{a=1}^{n} A_a * VC_a \qquad (7)$$

where $ESVc$ is the total ESV in US$

The rate of change in the ecosystem value over the research period was calculated using the formula below.

$$ESV\% = \frac{EVS_f - EVS_p}{EVs_p} * 100 \qquad (8)$$

where $ESV\%$ is the rate of change in the period from the previous year to the final year, $ESVf$ is total ESV for the year of 2020, and $ESVp$ is the total ESV for the year of 1990 or 2000.

Table 3 shows the lists of LULC classifications with the equivalent biomes and the overall ESV coefficients. The equivalent biomes for each LULC category were chosen for this study. Thus, cropland represented cultivated land, tropical forest represented forest land, shrubland represented forest land, grassland represented rangeland, and settlement and bare land represented urban land.

Table 3. The annual ESV's global coefficient of ecological service values

Major service	Ecosystem Services	The coefficient of the annual ESV model (USD/ha/year)					
		Crop land	Forest land	Shrub land	Grass land	Settlement area	Bare land
Provision service	Food Production	54	32	43	67	0	0
	Raw materials	0	315	138	0	0	0
	Genetic resources	0	41	16	0	0	0
	Water supply	0	8	3	0	0	0
Regulating services	Climate regulation	0	223	141	0	0	0
	Gas regulation	0	0	0	7	0	0
	Disturbance regulation	0	5	0	0	0	0
	Waste treatment	0	87	87	87	0	0
	Water regulation	0	6	2	3	0	0
	Biological control	24	0	2	23	0	0
	Erosion control	0	245	96	29	0	0
Supporting	Nutrient cycling	0	2	2	0	0	0
	Pollination	14	0	0	25	0	0
	Soil formation	0	112	66	2	0	0
Cultural	Cultural values	0	922	361	0	0	0
	Recreation	0	10	10	1	0	0
	Total	92	2007	969	232	0	0

Source: Costanza (1997)

Results

Evaluation of data accuracy

Table 4 presents the evaluation results of the land use and land cover accuracy-testing matrix for the Guder River sub-basin from 1990 to 2020. The accuracy assessment of land-use and land-cover categories in the provided table reveals varying levels of classification precision. Cultivation land exhibits the highest accuracy, with a classification accuracy of 92.97% to 95.97%, indicating strong reliability in identifying this category. Forestland also shows robust accuracy, ranging from 86.36% to 90.48%, while grassland achieves a perfect accuracy of 100% in one assessment and 80% in another, reflecting a generally high level of classification certainty. Conversely, bare land and shrub land categories show lower accuracy, with bare land ranging from 62.50% to 66.67% and shrub land from 83.33% to 88.24%, suggesting some challenges in distinguishing these categories accurately. Settlement areas, with an accuracy of 80.00% to 85.71%, and grassland show mixed results but still fall within acceptable accuracy ranges. Overall, the classification process demonstrates high reliability for most land-use categories, particularly cultivation and forestland, with some areas needing improved accuracy, particularly for bare land.

Table 4. Land use and cover test accuracy matrix for the Guder River sub-basin (1990–2020)

LULC categories	LULC2020	%	GCP	Reference total	Clarified total	No of Correct	Producer accuracy (%)	Users' accuracy (%)
Grass Land	2074.66	7.90	15	12	15	12	100	80
Forest Land	3229.84	12.31	22	21	22	19	90.48	86.36
Cultivation land	18119.26	69.03	124	128	124	119	93	96
Settlement area	140.793	0.54	15	14	15	12	85.71	80
Shrub land	2575.25	9.81	18	17	18	15	88.24	83.33
Bare land	107.96	0.41	15	16	15	10	63	67
Total	26247.76	100	209	209	209	187		

Land use and cover classification and changes over decades

The findings indicate that the asymmetrical changes of the six land use types continued over the last three decades, while some expanded while others shrank (Figure 2). Land use and cover analysis results reveal six land use types: cultivated land, forestland, grassland, shrubland, settlements, and barren land. The results also show that the study river basin's land use and cover types changed significantly over time. In the 1990s, these land use types varied across grassland, forestland, cultivated land, settlements, shrubland, and bare land, covering 5,863.81, 12,226, 28.93, and 3,036.75 ha, respectively. From 1990 to 2000, grassland areas declined sharply by 56.07% with a continued decrease of 19.46% from 2000 to 2020, totaling a 64.62% reduction over 30 years. This reflects a significant shift from grasslands to other uses, particularly cultivated land. Forestland also saw a notable decline, decreasing by 23.02% from 1990 to 2000 and by 17.50% from 2000 to 2020, resulting in a 36.50% decrease over the same period, indicating ongoing deforestation.

Conversely, cultivated land increased significantly, with a 41.99% rise from 1990 to 2000 and a more modest 4.38% increase from 2000 to 2020, culminating in a 48.2% growth over 30 years. Settlement areas expanded dramatically, rising by 103.53% from 1990 to 2000 and by 139.11% from 2000 to 2020, highlighting rapid urbanization. Shrub land experienced a 23.57% decline from 1990 to 2000 but saw a slight recovery with a 10.96% increase from 2000 to 2020, resulting in a 15.20% overall decrease. Bare land saw the most dramatic change, with a 180.94% increase from 1990 to 2000 and a staggering 520.82% rise from 2000 to 2020, indicating severe land degradation or conversion. The data shows a clear trend of increasing agricultural and settlement areas, significant reductions in grassland and forestland, and a dramatic rise in bare land, underscoring the need for effective land management and conservation to address environmental impacts.

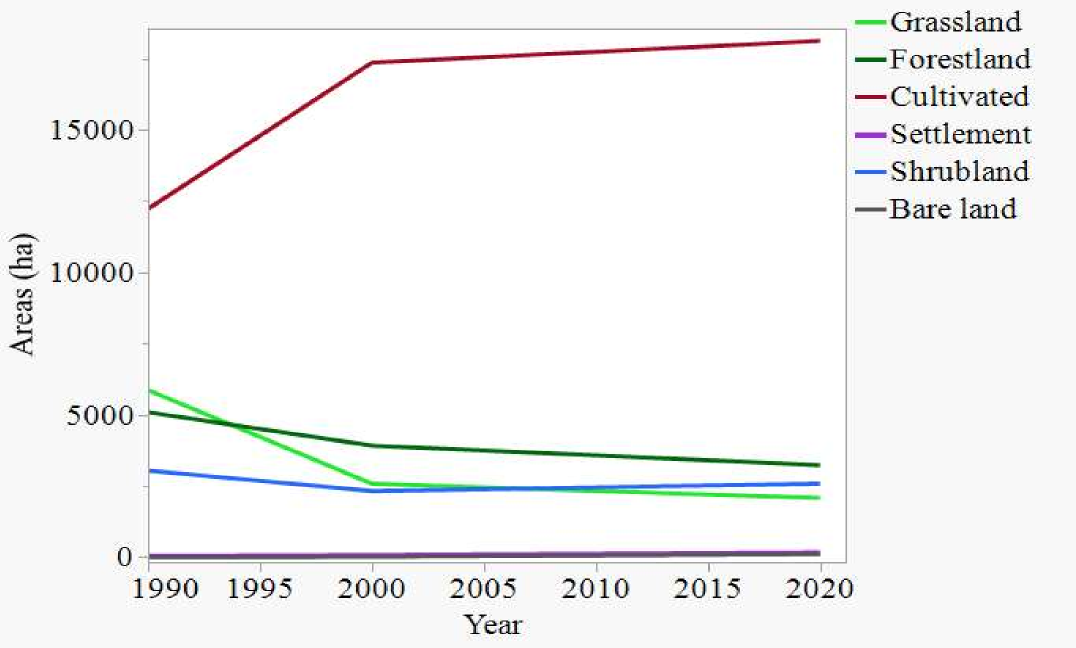

Figure 2. Land use and cover test accuracy matrix for the Guder River sub-basin (1990–2020)

Figure 3 shows spatial distribution patterns of six land use land and cover types over the period from 1990-to-2020. The distribution of each land use type has varied over the last three decades. As shown in Figure 2a, the sub-basin was primarily covered by cultivated land (46.58%), followed by grassland (22.34%), with barren land being the smallest at 0.02%. The spatial distribution of the cultivated land is widely extended in the central and northern parts of the sun-basin, where it has continued to expand in all directions by replacing forests, grasslands, and shrublands. The forestland is widely occupied in the western and southern portions of the sub-basins (Figure 3a).

However, significant changes in land use areas occurred over ten years. By 2000, grassland decreased from 22.34% to 9.81%, forestland from 19.38% to 12.92%, and shrub land from 11.57% to 8.84% In contrast, cultivated land increased from 46.58% to 66.17%, settlement land from 0.11% to 0.22%, and bare land from 0.02% to 0.07% (Figure 3b). The decline of forest and shrub land is predominant in the northwestern and northern parts of the water basin, while cultivated land is increasing in these regions and settlement land is expanding in the northeastern part of the basin, it signals a significant transformation from natural landscapes to agriculture and urban areas. This shift may lead to increased soil erosion, loss of biodiversity, and disruption of the natural water cycle, potentially causing long-term environmental degradation (Bare land) and challenging the sustainability of both agriculture and settlements in the region

By 2020, these trends continued, with grassland, forestland, and shrubland further decreasing to 7.9%, 12.31%, and 9.81%, respectively, while cultivated land rose to 69.03%, settlement land to 0.54%, and bare land to 0.41% (Figure 3c). These shifts indicate a significant expansion of cultivated and settlement land, likely driven by agricultural and urban development, at the expense of natural landscapes like grasslands, forests, and shrublands. This trend may lead to reduced biodiversity, altered ecosystems, and increased environmental degradation in the area. The shrubland area in the 2020s unexpectedly increased as compared to its area in 2000. Even though more research will be needed, the increment of shrubland may be related to the national green legacy program for the rehabilitation of the land use type over the past two years. The plantations established during the national Green Legacy program may be considered shrubs due to their current growth stage and characteristics. Initially, these planted areas consist primarily of young plants and saplings, which have not yet developed into mature forests. They exhibit the features typical of shrubland, including a predominance of smaller, bushy vegetation (West, 2006).

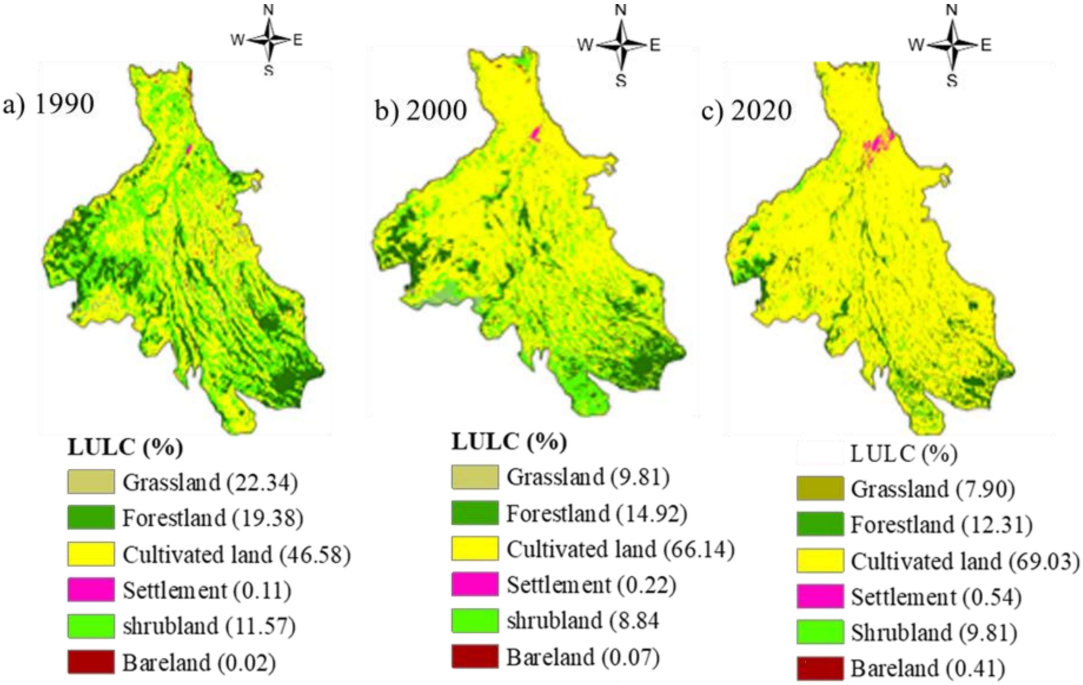

Figure 3. Land use and cover change map of the Guder River sub-basin (1990-2020)

Land Use and Cover Transition Matrix

From 1990 to 2000, the Guder River Sub-Basin experienced notable land use and land cover changes. Grassland saw a significant reduction of 3,287.91 hectares, transitioning primarily to cultivated land, which expanded by 5,134 hectares. This shift indicates a substantial conversion of grassland to agricultural use. Forestland also decreased by 1,170.88 hectares, with a portion of this area likely being converted to cultivated land as well. Settlement areas increased modestly by 29.95 hectares, reflecting urbanization trends. Shrubland experienced a decrease of 715.75 hectares, contributing to the expansion of cultivated areas. Bare land increased slightly by 11.20 hectares, indicating a minimal change in this category during this period.

Table 5. Land use land cover transition Matrix 1990-2000

LULC	Grassland	Forestland	Cultivated	Settlement	Scrubland	Bare land	Total changes
Grassland	2575.90	-1470.88	4563.00	29.95	-715.75	11.20	-3287.91
Forestland	-1170.88	3915.20	-2170.88	29.95	1074.20	11.20	-1170.88
Cultivated	4563.00	-1170.88	17360.00	29.95	1074.20	11.20	5134.00
Settlement	29.95	29.95	29.95	29.95	29.95	11.20	29.95
Scrubland	-715.75	1074.20	1074.20	29.95	2321.00	11.20	-715.75
Bare land	11.20	11.20	11.20	-11.20	11.20	17.39	11.20

Between 2000 and 2020, the trends observed in the previous decade continued, though with some variations. Grassland further decreased by 501.24 hectares, transitioning into cultivated land, which saw a notable increase of 759.30 hectares. Forestland continued to decline by 685.36 hectares, with areas being converted to other land uses, particularly cultivated land. Settlement areas experienced a more substantial increase of 81.91 hectares, indicating ongoing urbanization. Shrub land, after a decrease in the previous decade, saw a slight increase of 254.25 hectares, suggesting some reforestation or natural shrubland regrowth. Bare land expanded by 90.57 hectares, reflecting continued degradation or clearing of other land cover types.

Table 6. LULC transition Matrix: 2000 to 2020

LULC	Grassland	Forestland	Cultivated	Settlement	Scrubland	Bare land	Total changes
Grassland	2074.66	-685.36	759.30	81.91	81.91	90.57	-501.24
Forestland	-685.36	3229.84	-2170.88	81.91	81.91	90.57	-685.36
Cultivated	759.30	-2170.88	18119.30	81.91	81.91	90.57	759.30
Settlement	81.91	81.91	81.91	140.79	81.91	140.79	81.91
Scrubland	254.25	254.25	254.25	81.91	81.91	90.57	254.25
Bare land	90.57	90.57	90.57	90.57	90.57	107.96	90.57

Overall, from 1990 to 2000 and 2000 to 2020, there has been a consistent trend of decreasing grassland and forestland areas, with a corresponding increase in cultivated land. This indicates a significant shift towards agricultural land use, likely driven by population growth and the need for increased food production. The minimal changes in settlement and bare land areas suggest that the primary land use changes are occurring in natural and semi-natural landscapes, influencing the ecosystem services provided by these areas.

Impacts of land use and land cover change on ecosystems service

Figure 3 shows the overall estimated value of ecosystem service change between the 1990 and 2020 timeframes. The ecosystem service value of grassland experienced a significant decline from $1.36 million in 1990 to $0.48 million in 2020, representing a decrease of 64.70%. Similarly, forestland also showed a notable decrease in ESV, dropping from $10.20 million in 1990 to $6.48 million in 2020, which corresponds to a 36.47% decline. The ecosystem service value of shrubland experienced a moderate decline from $2.94 million in 1990 to $2.49 million in 2020, a reduction of 15.30%. In contrast to grassland, forestland, and shrubland, the ESV of cultivated land increased from $1.12 million in 1990 to $1.66 million in 2020, marking a 48.21% rise. The total ecosystem service value across all land use and land cover types decreased from $15.62 million in 1990 to $11.11 million in 2020, a reduction of 28.87%. This overall decline highlights a significant loss in ecosystem services over the three decades, primarily driven by the reductions in forestland and grassland values.

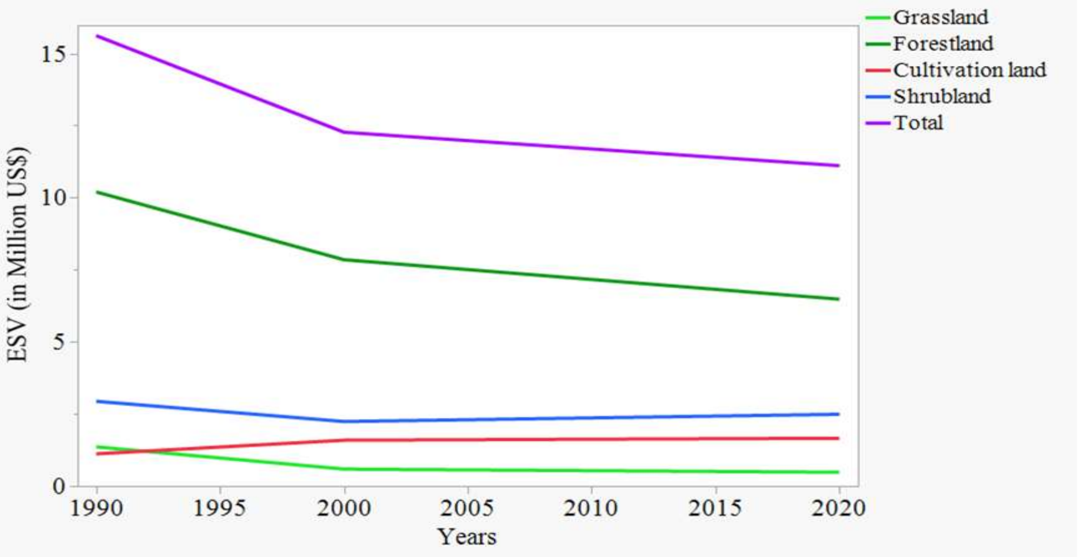

Figure 4. Trends of land use and cover types ecosystem service value (ESV) from 1990 to 2020

Specific ecosystem service changes

The impacts of land use and cover changes on each ecosystem service are presented in Table 6. In 1990, specific ecosystem service values in US dollars ranged from $2.0 x 104 to 5.79 x 106, with the highest recorded for nutrient cycling and the lowest for cultural services. In 2000, the ecosystem service value in US dollars varied between $2.0 x 104 and $4.45 x 106, with the highest recorded in nutrient cycling and the lowest in cultural services. The highest and the lowest values of ecosystem service value ranged from $10 x 103 to $3.91 x 106 million US dollars were recorded in nutrient cycling and cultural services, respectively. Except for food production and biological control, the specific values of all ecosystem services have decreased over the last three decades. The values of ecosystem service in food production and biological control in the US dollar increased by $3.5 x 104 and $5.4 x 104, respectively. This rise in ecosystem service values of food production may be related to the expansion of cultivated land use types over the study period. The highest ecosystem service loss was observed in raw materials ($6.50 x 105), erosion control ($6.01 x 105), waste treatment ($5.51 x 105), and climate regulation ($4.80 x 105) (Table 7). The Guder River sub-basin lost approximately $4.51 million of total ecosystem service value throughout the study period. The decrease in grassland, forestland, and shrubland in the study area may have contributed to the decline in total ecosystem service values.

Table 7. The estimated annual value of each ecosystem service (ESV) (in millions of US$)

Major services	Ecosystem services	ESV_c1990	ESV_c2000	ESV_c2020	Change 1990-2020
Provisioning service	Food Production	1.26	1.28	1.29	0.03
	Raw materials	2.02	1.55	1.37	-0.65
	Genetic resources	0.26	0.2	0.17	-0.09
	Water supply	0.05	0.04	0.03	-0.02
Regulating service	Climate regulation	1.56	1.20	1.08	-0.48
	Gas regulation	0.04	0.02	0.02	-0.02
	Disturbance regulation	0.03	0.02	0.02	-0.01
	Waste treatment	1.22	0.77	0.69	-0.53
	Erosion control	1.70	1.18	1.10	-0.60
	Biological control	0.32	0.31	0.31	-0.01
	Pollination	0.05	0.05	0.03	-0.02
	Water regulation	0.43	0.48	0.49	0.06
Supporting services	Nutrient cycling	0.02	0.05	0.01	-0.01
	Soil formation	0.78	0.6	0.54	-0.24
	Habitat/refuge	5.79	4.45	3.90	-1.89
Cultural service	Cultural	0.09	0.07	0.06	-0.03
	Recreation	-	-	-	-
	Total	15.62	12.27	11.11	-4.51

Conclusion

The current study examined the significant land-use and land-cover changes in the Guder River Sub-Basin from 1990 to 2020 and their impacts on ecosystem service values. The land classification analysis, based on classification of satellite imagery, revealed a substantial reduction in grassland, forestland, and shrubland, while areas of cultivated, settlement, and barren lands expanded. This expansion is largely attributed to continuous agricultural activities and overgrazing, which have contributed to land degradation and the spread of barren areas. The dominance of cultivated land throughout the study period underscores the heavy reliance of the local population on agriculture, leading to the displacement of grassland, forest, and shrubland to accommodate growing agricultural demands. The findings suggest that the decline in these natural land covers is driven by the need to expand agricultural and residential areas, fueled by population growth. Historical evidence indicates that Ethiopia experienced rapid population growth from the mid-19th to early 20th century, which accelerated deforestation and increased cultivation in the highlands, a trend that is reflected in the land-use changes observed in the Guder River Sub-Basin (Hurni et al., 2005).

The current findings align with numerous national and international studies reporting similar trends (Bhat, 2022; Deng et al., 2019; H. Hu et al., 2008; Rwanga and Ndambuki, 2017; Tolessa et al., 2017). Specifically, the present results are consistent with those of Gashaw et al. (2018) and Tolessa et al. (2017), who observed the expansion of cultivated, built-up, and barren lands as well as the withdrawal of grass, forest, and shrublands in Ethiopia's central highlands and the upper Blue Nile basin, respectively. Furthermore, our findings resonate with the assessments of land use and land cover change by Hassan et al. (2016) and Obsa et al. (2021), which noted the decline and loss of forest and shrub land due to the continuous expansion of cultivated and settlement lands in Islamabad, Pakistan and central highlands of Ethiopia, respectively. The findings also concur with those of Miheretu and Yimer (2018) and Chalchissa and Kuris (2024), who found that the degradation of environmental resources was caused by a rapid decline in shrubland and other natural resources and an increase in the arable land of the northern highlands of Ethiopia. Mikias (2015) also stated that the expansion of cropland is at the expense of grassland, bushland, and forestland in the Jijiga watershed of eastern Ethiopia. Assefa and Bork (2014) and Chalchissa et al (2022)also reported that forest tree cover had decreased at the highest rates in southern Ethiopia due to the growing population pressure and its associated problems, such as the need for land resources for agricultural production and settlement areas.

The analysis of ecosystem service values revealed that the reduction in areas of key land use types, such as forestland, grassland, and shrubland, led to a significant decline in the overall value of ecosystem services. While cultivated land showed an increase in ecosystem service value, this increase was considerably lower than the losses associated with the degradation of natural landscapes like forests, grasslands, and shrublands. The data indicates that the conversion of these natural ecosystems to agricultural and residential land has diminished the ecosystem's ability to provide essential services, including provisioning, regulating, and supporting functions. This decline is particularly concerning given the critical roles that forests and grasslands play in carbon sequestration, water regulation, soil conservation, and biodiversity support. The results suggest that the long-term sustainability of the Guder River Sub-Basin's ecosystem is at risk if the current trends in land use change continue, emphasizing the need for strategies that balance agricultural expansion with the preservation of natural ecosystems to maintain essential ecosystem services.

The current findings are consistent with several studies on how land use and cover have changed over time and affect the ecosystem service functions (Bhat, 2022; Halefom et al., 2018; Kindu et al., 2016; Sewnet & Abebe, 2018). It coincides with the findings of Gashaw et al.(2018) , who found the slight increase of ecosystem service in cultivated land while continuous decline in forests, shrubland, and grassland decreased in the upper Blue Nile basin of Ethiopia, ensuring that for the next thirty years, these trends will persist. Our findings also highly support those of Tolessa et al. (2017), who reported the significant impacts of LULC change on the ecosystem service values from 1973 to 2015 in the central highland of Ethiopia.

Conclusions

The most widely used methods were employed in this study, notably remote sensing and GIS, which are powerful tools for identifying and classifying land use and cover types. Our findings revealed that six major LULC types were detected such as grassland, forestland, cultivated land, building-up areas, shrubland, and barren lands. In the last three decades, the cultivated land and built-up land use types continually expanded, causing severe destruction to the grassland, forestland, and shrubland at the highest rates. Following the land use and cover changes, there was a sharp decline in total ecosystem service values of grassland, forestland, and shrubland and a rise in cultivated land, which is nevertheless less valuable than the former or less valuable than each land use category that was transformed into cultivated land. All ecosystem service values of the biomes in the study area decreased except in crop production, with the highest values declining in habits. Therefore, we suggest that it is critical to establish awareness-building for local government bodies, stakeholders, and the community on the importance of ecological services, forest conservation, and land use planning.

References

Assefa, E., and Bork, H. R. (2014). Deforestation and forest management in Southern Ethiopia: Investigations in the Chencha and Arbaminch areas. Environmental Management, 53(2), 284–299. https://doi.org/10.1007/s00267-013-0182-x

Babiso, B., Toma, S., and Bajigo, A. (2016). Land Use/Land Cover Dynamics and its Implication on Sustainable Land Management in Wallecha Watershed, Southern Ethiopia. 16(4).

Belay, T., and Mengistu, D. A. (2021). Impacts of land use/land cover and climate changes on soil erosion in Muga watershed, Upper Blue Nile basin (Abay), Ethiopia. Ecological Processes, 10(1). https://doi.org/10.1186/s13717-021-00339-9

Benti, F., and Balemi, T. (2016). Effect of land use types in Miesa Watershed on soil quality and productivity. Science, Technology and Arts Research Journal, 4(3), 83. https://doi.org/10.4314/star.v4i3.13

Berhanu, K., and Poulton, C. (2014). The Political Economy of Agricultural Extension Policy in Ethiopia: Economic Growth and Political Control. Development Policy Review, 32, s197–s213. https://doi.org/10.1111/dpr.12082

Bhat, I. F. ,. (2022). Impact of Land-Use Land-Cover Changes on Ecosystem Services of Jammu and Kashmir, India. Agro-Economist, 9(1). https://doi.org/10.30954/2394-8159.01.2022.14

Brown, D. G., Walker, R., Manson, S., and Seto, K. (2012). G. Gutman et al. (eds.),. Land Change Science, January, 321–322. https://doi.org/10.1007/978-1-4020-2562-4

Chalchissa, F. B., Diga, G. M., Feyisa, G. L., and Tolossa, A. R. (2022). Impacts of extreme agroclimatic indicators on the performance of coffee (Coffea arabica L.) aboveground biomass in Jimma Zone, Ethiopia. Heliyon, 8(8), e10136. https://doi.org/10.1016/j.heliyon.2022.e10136

Chalchissa, F. B., Diga, G. M., and Tolossa, A. R. (2022). Modeling the responses of Coffee (Coffea arabica L.) distribution to current and future climate change in Jimma Zone, Ethiopia. Sains Tanah, 19(1), 19–32. https://doi.org/10.20961/stjssa.v19i1.54885

Chalchissa, F. B., and Kuris, B. K. (2024). Modelling soil organic carbon dynamics under extreme climate and land use and land cover changes in Western Oromia Regional state, Ethiopia. Journal of Environmental Management, 350(October 2023), 119598. https://doi.org/10.1016/j.jenvman.2023.119598

Chinzila, C. B. (2018). Degradation and climate change. The Political Economy of Energy in Sub-Saharan Africa, 2, 119–136. https://doi.org/10.4324/9781315163758-8

Congalton, R. G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. Remote Sensing of Environment, 37(1), 35–46. https://doi.org/10.1016/0034-4257(91)90048-B

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., and van den Belt, M. (1998). The value of the world's ecosystem services and natural capital. Ecological Economics, 25(1), 3–15. https://doi.org/10.1016/s0921-8009(98)00020-2

Demissie, F., Yeshitila, K., Kindu, M., and Schneider, T. (2017). Land use/Land cover changes and their causes in Libokemkem District of South Gonder, Ethiopia. Remote Sensing Applications: Society and Environment, 8, 224–230. https://doi.org/10.1016/j.rsase.2017.10.001

Deng, Z., Zhu, X., He, Q., and Tang, L. (2019). Land use/land cover classification using time series Landsat 8 images in a heavily urbanized area. Advances in Space Research, 63(7), 2144–2154. https://doi.org/10.1016/j.asr.2018.12.005

Ellis, E. C. (2015). Ecology in an anthropogenic biosphere. Ecological Monographs, 85(3), 287–331. https://doi.org/10.1890/14-2274.1

Fitsum, H., John, P., and Nega, G. (2000). Land degradation in the Highlands of Tigray and Strategies for Sustainable Land Management. Policies for Sustainable Land Management in the Highlands of Ethiopia, 30(July 1999), 2–75.

Gashaw, T., Tulu, T., Argaw, M., Worqlul, A. W., Tolessa, T., and 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. https://doi.org/10.1016/j.ecoser.2018.05.001

Ghosh, D. K., and Bhunia, G. S. (2021). Ecosystem Service Valuation on the Basis of Land Use and Land Cover Data in the Barasat Sadar Subdivision (West Bengal, India). Geography and Natural Resources, 42(1), 88–97. https://doi.org/10.1134/S1875372821010078

Groth, H., and May, J. F. (2017). Africa's population: In search of a demographic dividend. In Africa's Population: In Search of a Demographic Dividend. https://doi.org/10.1007/978-3-319-46889-1

Halefom, A., Teshome, A., Sisay, E., and Ahmad, I. (2018). Dynamics of Land Use and Land Cover Change Using Remote Sensing and GIS: A Case Study of Debre Tabor Town, South Gondar, Ethiopia. Journal of Geographic Information System, 10(02), 165–174. https://doi.org/10.4236/jgis.2018.102008

Hassan, Z., Shabbir, R., Ahmad, S. S., Malik, A. H., Aziz, N., Butt, A., and Erum, S. (2016). Dynamics of land use and land cover change (LULCC) using geospatial techniques: a case study of Islamabad Pakistan. SpringerPlus, 5(1). https://doi.org/10.1186/s40064-016-2414-z

Hoque, M. Z., Cui, S., Islam, I., Xu, L., and Tang, J. (2020). Future impact of land use/land cover changes on ecosystem services in the lower meghna river estuary, Bangladesh. Sustainability (Switzerland), 12(5), 1–18. https://doi.org/10.3390/su12052112

Hu, H., Liu, W., and Cao, M. (2008). Impact of land use and land cover changes on ecosystem services in Menglun, Xishuangbanna, Southwest China. Environmental Monitoring and Assessment, 146(1–3), 147–156. https://doi.org/10.1007/s10661-007-0067-7

Hu, Y., Gao, M., and Batunacun. (2020). Evaluations of water yield and soil erosion in the Shaanxi-Gansu Loess Plateau under different land use and climate change scenarios. Environmental Development, 34(March 2019), 100488. https://doi.org/10.1016/j.envdev.2019.100488

Huq, N., Bruns, A., and Ribbe, L. (2019). Interactions between freshwater ecosystem services and land cover changes in southern Bangladesh: A perspective from short-term (seasonal) and long-term (1973–2014) scale. Science of the Total Environment, 650, 132–143. https://doi.org/10.1016/j.scitotenv.2018.08.430

Hurni, H., Tato, K., and Zeleke, G. (2005). The implications of changes in population, land use, and land management for surface runoff in the Upper Nile Basin Area of Ethiopia. Mountain Research and Development, 25(2), 147–154. https://doi.org/10.1659/0276-4741(2005)025[0147:TIOCIP]2.0.CO;2

Jensen, J. R., and Lulla, K. (1987). Introductory digital image processing: A remote sensing perspective. Geocarto International, 2(1), 65. https://doi.org/10.1080/10106048709354084

Kamble, S., Rashinkar, G., Kumbhar, A., and Salunkhe, R. (2012). Hydrotrope induced synthesis of 1,8-dioxo-octahydroxanthenes in aqueous medium. In Green Chemistry Letters and Reviews (Vol. 5, Issue 1). https://doi.org/10.1080/17518253.2011.584217

Kindu, M., Schneider, T., Teketay, D., and 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. https://doi.org/10.1016/j.scitotenv.2015.12.127

Lambin, E. F., Coomes, O. T., Turner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Folke, C., Bruce, J. W., Coomes, O. T., Dirzo, R., George, P. S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E. F., Mortimore, M., Ramakrishnan, P. S., Richards, J. F., … Xu, J. (2001). The causes of land-use and land-cover change : Moving beyond the myths. Global Environmental Change, 11(December), 261–269.

Lambin, E. F., and Meyfroidt, P. (2010). Land use transitions: Socio-ecological feedback versus socio-economic change. Land Use Policy, 27(2), 108–118. https://doi.org/10.1016/j.landusepol.2009.09.003

Landis, R. ., and Koch, G. (1977). An Application of Hierarchical Kappa-type Statistics in the Assessment of Majority Agreement among Multiple Observers Author (s): J . Richard Landis and Gary G . Koch Published by : International Biometric Society Stable URL : https://www.jstor.org/stab. Biometrics, 33(2), 363–374.

Liu, S., Li, X., Chen, D., Duan, Y., Ji, H., Zhang, L., Chai, Q., and Hu, X. (2020). Understanding Land use/Land cover dynamics and impacts of human activities in the Mekong Delta over the last 40 years. Global Ecology and Conservation, 22, e00991. https://doi.org/10.1016/j.gecco.2020.e00991

Marshall, J. D., Dawson, T. E., and Ehleringer, J. R. (1994). Integrated nitrogen, carbon, and water relations of a xylem-tapping mistletoe following nitrogen fertilization of the host. Oecologia, 100(4), 430–438. https://doi.org/10.1007/BF00317865

Megersa, T., Nedaw, D., and Argaw, M. (2019). Combined effect of land use/cover types and slope gradient in sediment and nutrient losses in Chancho and Sorga sub watersheds, East Wollega Zone, Oromia, Ethiopia. Environmental Systems Research, 8(1). https://doi.org/10.1186/s40068-019-0151-3

Megerssa, G. R., and Bekere, Y. B. (2019). Causes, consequences and coping strategies of land degradation: Evidence from Ethiopia. Journal of Degraded and Mining Lands Management, 7(1), 1953–1957. https://doi.org/10.15243/jdmlm.2019.071.1953

Miheretu, B. A., and Yimer, A. A. (2018). Land use/land cover changes and their environmental implications in the Gelana sub-watershed of Northern highlands of Ethiopia. Environmental Systems Research, 6(1). https://doi.org/10.1186/s40068-017-0084-7

Mikias, B. M. (2015). Land Use/Land Cover Dynamics in the Central Rift Valley Region of Ethiopia: Case of Arsi Negele District. African Journal of Agricultural Research, 10(5), 434–449. https://doi.org/10.5897/ajar2014.8728

Nuñez, A. M., and Murakami-Ramalho, E. (2012). The demographic dividend: An opportunity for Ethiopia's transformation. Academe, 98(1), 1–6.

Nzunda, N., Munishi, P., Soka, G., and Monjare, J. (2013). Influence of socio-economic factors on land use and vegetation cover changes in and around Kagoma forest reserve in Tanzania. Ethiopian Journal of Environmental Studies and Management, 6(5), 480–488. https://doi.org/10.4314/ejesm.v6i5.5

Obsa, F., Kefale, B., Kidane, M., and Tolessa, T. (2021). Data on the dynamics of landscape structure and fragmentation in Ambo district, central highlands of Ethiopia. Data in Brief, 35, 106782. https://doi.org/10.1016/j.dib.2021.106782

Sahle, M., Saito, O., Fürst, C., Demissew, S., and Yeshitela, K. (2019). Future land use management effects on ecosystem services under different scenarios in the Wabe River catchment of Gurage Mountain chain landscape, Ethiopia. Sustainability Science, 14(1), 175–190. https://doi.org/10.1007/s11625-018-0585-y

Sewnet, A., and Abebe, G. (2018). Land use and land cover change and implication to watershed degradation by using GIS and remote sensing in the Koga watershed, North Western Ethiopia. Earth Science Informatics, 11(1), 99–108. https://doi.org/10.1007/s12145-017-0323-5

Siswanto, S. Y., and Sule, M. I. S. (2019). The Impact of slope steepness and land use type on soil properties in Cirandu Sub-Sub Catchment, Citarum Watershed. IOP Conference Series: Earth and Environmental Science, 393(1). https://doi.org/10.1088/1755-1315/393/1/012059

Sun, X., Crittenden, J. C., Li, F., Lu, Z., and Dou, X. (2018). Urban expansion simulation and the spatio-temporal changes of ecosystem services, a case study in Atlanta Metropolitan area, USA. Science of the Total Environment, 622–623, 974–987. https://doi.org/10.1016/j.scitotenv.2017.12.062

Talukdar, S., Singha, P., Mahato, S., Shahfahad, Pal, S., Liou, Y. A., & Rahman, A. (2020). Land-use land-cover classification by machine learning classifiers for satellite observations-A review. Remote Sensing, 12(7). https://doi.org/10.3390/rs12071135

Tewabe, D., and Fentahun, T. (2020). Assessing land use and land cover change detection using remote sensing in the Lake Tana Basin, Northwest Ethiopia. Cogent Environmental Science, 6(1). https://doi.org/10.1080/23311843.2020.1778998

Tolessa, T., Senbeta, F., and Kidane, M. (2017). The impact of land use/land cover change on ecosystem services in the central highlands of Ethiopia. Ecosystem Services, 23(June 2016), 47–54. https://doi.org/10.1016/j.ecoser.2016.11.010

Tschakert, P., Sagoe, R., Ofori-Darko, G., and Codjoe, S. N. (2010). Floods in the Sahel: An analysis of anomalies, memory, and anticipatory learning. Climatic Change, 103(3), 471–502. https://doi.org/10.1007/s10584-009-9776-y

West, P. W. (2006). Growing plantation forests. In Growing Plantation Forests. https://doi.org/10.1007/3-540-32479-8

Zhao, M., He, Z., Du, J., Chen, L., Lin, P., and Fang, S. (2019). Assessing the effects of ecological engineering on carbon storage by linking the CA-Markov and InVEST models. Ecological Indicators, 98(October 2018), 29–38. https://doi.org/10.1016/j.ecolind.2018.10.052