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Land Use and Land Cover Change for Resilient Environment and Sustainable Development in the Ethiopian Rift Valley Region

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Abstract

Land use and land cover change (LULCC) are the result of different interacting socio-economic and environmental causes and consequences that have been known since the beginning of agriculture. The study intended to explore the implications and drivers of LULCC in the Ethiopian rift valley region of Gidabo river sub basin from 1986 to 2019. The researchers have triangulated the data from Landsat 5 (TM), and Landsat 8 (OLI) with data obtained from key informants, focus groups and field observation, which is helpful to determine the interaction between the environment and the community. It is also important to mitigate environmental disaster (erosion, landslides, and climate change) and sustainable utilization of natural resources. The LULCC of the past 33 years implied that about 58.4 % of the area was changed to other Land use land cover (LULC) classes. This refers to the fact that about 14% of agroforestry, 2% of the settlement, 1.1% of the forest, and 1% of bare land were expanded at the expense of 10.3% of shrub/woodland, 6.3 % of grassland, and 1% of cropland classes. Therefore, as a result, the highest land cover (46.7%) was observed on the agroforestry system. Participants in group discussion and informant interviews attributed the expansion of agroforestry to the drivers, such as population density, cultural values (Songo, Babbo), traditional beliefs, land policy, and the insecurity resulting from climate change. Whereas, the drivers related to unproductive land, resettlement, urbanisation, and lack of agricultural inputs were considered as threats that will adversely affect the agroforestry system of the area. The study concluded that the high expansion of the agroforestry system has significant contribution to achieve a resilient environment and sustainable development, which integrates the socio-economic and environmental needs of the community. But greater attention should be given to the changes observed in shrub/woodland, grassland, and bare land to enhance environmental protection.

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1. INTRODUCTION

The human impact on land use and land cover change (LULCC) since the Neolithic period has been recognised for thousands of years [Smith and Zeder, 2013; Lambin et al., 2006]. Though LULCC occurs either naturally or due to human factors, human activities are the primary forces of the change [Kabba and Li, 2011]. According to Zahara et al. [2016], the extent, intensity, and rate of LULCC are more significant and complicated than in the past. LULCC has been occurring rapidly, involving the conversion of forestland to agricultural land, rangeland, grassland, and woodland to bare land and vice versa [Lambin et al., 2003]. The change is faster and more noticeable in developing countries [Ellis, 2013; Lambin and Meyfroidt, 2011].

For instance, in Africa, the conversion of forest to agriculture and pasture land accounted for about 75 million hectares between 1990 and 2010 [FAO, 2010]. Ethiopia is one of the African countries that have experienced rapid and progressively noticeable LULCC since the second half of the 20th century [Minta et al., 2018]. LULCC had both positive and negative impacts on socio-economic and environmental conditions [Lambin and Meyfroidt, 2011]. According to Kindu et al. [2018] LULCC is one of the significant factors in natural resource degradation, threatening biodiversity [Yirsaw et al., 2017]; deforestation [Rands et al., 2010]; environmental disaster, such as intensive soil erosion and land slide [Meshesha et al., 2014]; and climate change [Bringezu et al., 2014].

Figure 1. Location map of Gidabo river subbasin

The Ethiopian environmental protection authority (EPA) report [2012] showed that the Ethiopian ecosystem is beyond carrying capacity primarily due to the high population growth, cultivating on steep slopes, LULCC, deforestation, soil degradation, and climate change. Particularly the LULCC are the major factors for socio-economic and environmental problems of the country too [Bekele et al., 2018]. For instance, in Ethiopia, LULCC cause environmental disaster, such as intensive soil loss of cropland that is about 20,000–30,000 tons/ha/yr, and about 2 million hectares of land had been extremely degraded and was unsuitable for crop production [FAO, 1986]. Though various research reports showed LULCC are causes of the land degradation, rarely are LULCC helpful for a resilient environment and sustainable development that have massive environmental, social and economic benefits [Robbins, 2011]. For instance, the report by Degife et al. [2019], Legesse et al. [2018], and Kippie [2002] showed that LULCC caused the expansion of the agroforestry system in south-eastern Ethiopia. According to Abadico [2018], Kiyani et al. [2017], Bishaw et al. [2013], Tesemma [2013], Negash and Achalu [2008], and Bugayong [2003], agroforestry increases productivity, food security, and economic benefits and ensures nutrition security and balanced diet, diversifies ecological goods and services, diversifies crop production, increases income generation, and promotes measures to fight climate change, among other multifunctional actions.

In this regard the LULCC data obtained from remote sensing (RS) and Geographic Information Systems (GIS) offer options for the monitoring and mapping of geohazards [Arnous and Green, 2011], environmental health

evaluation, ecosystem management, conservation, and land use planning of the specific areas [Chamling and Bera, 2020]. It also helps understand soil erosion intensity [Ozsahin et al. 2018] and facilitates a sustainable development process [Tuladhar et al., 2015].

Though LULCC is the result of complex interacting socio-economic and environmental factors, it varies across time and space [Kabba and Li 2011; Wu, 2008 and Lambin et al. 2003]. Knowledge about LULCC always requires locally based studies [Reddy and Gebreselassie, 2011]. Hence, a study on the implications of LULCC and their driving forces of the Gidabo river subbasin of the Ethiopian rift valley region would be helpful to identify the interaction between the environment and the community, allow the mitigation of environmental disasters, and design a plan for natural resources utilization in a way to secure sustainable socio-economic and environmental development of the people.

2. MATERIALS AND METHODS

2.1. Study area description

The Gidabo river subbasin is located in the rift valley region of Ethiopia. The area is specifically located within the limits of 6°11' to 6°34' latitude and 38°12' to 38°32' Longitude. The Gidabo river subbasin is situated in the Southern Nations Nationalities and Peoples and Oromia National Regional State Governments. The highest altitude of the river subbasin is about 3,029 m a.s.l. in the South, and the lowest point is 1,205 m a.s.l. in the western part of the basin (Figure 1).

Figure 2. Rainfall graphs for different station.
Source: Ethiopian meteorological station [2020]

The Gidabo river subbasin covers an area of approximately 102,738 ha. The river basin has very dynamic and fragile landscapes highly affected by the late tertiary rifting activity and erosion processes [Bekele et al., 2018]. According to Ayenew and Becht [2008], the geological and geomorphologic features of the region are related to Cenozoic volcanic rock (rhyolites, ignimbrites, trachytes, basalt, and pyroclast) and lacustrine sediments.

The economic activities of the people varied along different agroecology or topographic settings. Though the main economic activity of the river basin is forest-based agriculture (agroforestry), mixed farming (livestock production and cultivation of crops) is the principal occupation of the people in the highland and lowland areas of the river basin. Nowadays, agroforestry-based economic activity, caused by population growth and climate variability, greatly dominates the river basin.

The climate of the study area ranges from humid to subhumid in the highlands of the escarpment to semiarid in the rift floor, which is characterised by warm and wet summers and dry, cold, and windy winters [Mechal, 2015]. According to Figure 2, the average rainfall of the study area ranges from 900 to 1,400 mm in the dry and rainy period, respectively. In contrast, the average monthly temperature varies from 21°C to 25°C in the lowlands and from 12°C to 18°C in the highlands. A bimodal pattern characterises the rainy seasons of the study area, the main rainy (*Kiremt*- in the Amharic language) season occurs from June to September, and the minor rainy season (*Belg*- in the Amharic language) occurs between February to May [Bekele et al., 2018]. In Figure 2, rainfall data for the last seventy years were collected from three stations named Bule, Wonago, and Dara.

2.2. Data type and sources

Addressing the complex trends of LULCC dynamics and describing the underlying drivers is compulsory to combine biophysical and socio-economic data with remotely sensed data [Lambin et al., 2003]. For this research work, data were collected from both primary and secondary sources. The primary data sources are field observation, informant interview, and focus group discussions. The secondary data sources are satellite image analysis, published and unpublished literature focused on socio-economic, demographic, climatic, physiographic, soil characteristics and drivers of LULCC.

2.2.1. Land Use Land Cover Change Detection

Different techniques were used to detect change and algorithms on LULC via remotely sensed data [Lu et al., 2004]. The geographic information system and remote sensing produce essential sources to obtain data used to compare the historical and current status of LULCC. Also, it is fairly accurate in representing the trends of land cover dynamics than other indicators [Lambin et al., 2006]. In order to attain the intended research objectives of the study, four time period satellite image data were obtained from Landsat 5 (TM) and Landsat 8 (OLI) from 168/056 path and row (Table 1). The four time periods for the Landsat images are 1986, 2000, 2011, and 2019, downloaded from (<https://glovis.usgs.gov/>).

The criteria to select the year for Landsat images were based on historical events, which significantly influenced the LULC change. For instance, the 1986 image was purposefully selected as a baseline because of the quality of the Landsat

Table 1. Source of Landsat 5 (TM) and Landsat 8 (OLI)

Sensor Type	Path/row	No of Bands	Band combination	Spatial resolution	Acquisition date
Landsat 5 (TM)	168/056	7	RGB 432	30 m	5/Jan/1986
Landsat 5 (TM)	168/056	7	RGB 432	30 m	28/Jan/2000
Landsat 5 (TM)	168/056	7	RGB 432	30 m	10/Jan/2011
Landsat 8 (OLI)	168/056	11	RGB 543	30 m	31/Jan/2019

Source: Downloaded from <http://glovis.usgs.gov> 2019

image and because it represents the effect of formal watershed-based natural resource conservation and the development programme of Ethiopia in the 1970s and 1980s. Though the Federal government came to power in 1991, the new regime has spent time establishing itself in the country after a long period of civil war, formulation, or reconstitution of offices and changing administrative boundaries, which slowed down the work of an environmental conservation project and resulted in delays. Therefore, the year 2000 image was used to reflect the effect of the extensive watershed-based conservation development effort made by the government and non-governmental bodies of the military regime from 1974 to 1991.

The 2011 image was used to represent the effect of the federal environmental policy that was formally approved on 2 April 1997 and the community-based participatory watershed development program of 2005. The fourth image for 2019 was used to assess the effect of the second community-based watershed managed practices of 2010–2011. This period was known for the 30 days of free labour and massive social movements on watershed management. Also, the 2019 image presented a cut point for the overall effect of the federal government conservation movement from 1991 to 2019.

The Landsat 5 Thematic Mapper (TM) sensor was overlaid on Landsat 4 and Landsat 5 to create images consisting of six spectral bands with a spatial resolution of 30 meters for Bands 1–5 and 7 one thermal band (Band 6). While the Landsat 8 satellite image consists of two science instruments, the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS), these two sensors provide seasonal coverage of the global landmass at a spatial resolution of 30 meters (visible, NIR, SWIR); 100 meters (thermal); and 15 meters (panchromatic) (Table 1).

The satellite data selection has been fixed to the dry season, which has a clear sky for the specific years with no cloud cover. Selections of the lowest cloud cover period minimise the cloud effect and associated reflectance [Jensen, 2009]. The downloaded images were stacked with all the band combinations in the dataset. Since the Landsat images were geometrically corrected, their integration with other datasets was checked by overlaying them with the GPS data collected from the field and Google earth imagery. These data are essential in order to identify the different land use and land cover change dynamics.

2.2.2. Radiometric correction and image classification

Using ENVI software, the radiometric correction was carried out using the dark-object subtraction method. This method combines the sun and view angle effects and the sensor calibration with the atmospheric correction. Then image classification was carried out using both supervised and unsupervised classification. The unsupervised classification was done only to get the spectral characteristics of features on the image, while the supervised classification method was widely implemented using the decision rule of maximum likelihood classification algorithm on the ERDAS images 2014 software.

The maximum likelihood algorithm provided a consistent approach to parameter estimation and was developed from many estimations using training samples. Then all satellite data were studied by assigning per-pixel signatures and distinguishing the land area into seven classes based on the specific Digital Number (DN) value of diverse landscape elements [Im and Jensen, 2005]. The major delineating classes of the study were cropland, forest land, settlement, grazing land, agroforestry, bush/shrubland, and bare land (Table 3). For each of the predetermined classes of the study site, we used a minimum of 10 training samples for settlement and 15 training samples for bare land. Then, 30–75 training samples were randomly selected for cropland, forest land, grazing land agroforestry, and bush/shrub land.

A satisfactory spectral signature ensures that there is minimal confusion among the land covers to be mapped [Gao and Liu, 2010]. For this research, pixels enclosed by these polygons have been used to record the spectral signatures for the respective land cover types derived from the satellite imagery. As stated by Foody, [2002] there are better results with large samples representing each land cover classes. However, the required number of training samples to train classifiers depends on the classifier going to be used, the number of features considered, and the landscape structure of the classes considered. Since the landscape structure of the present study area consists of little area for settlement and bare land considered in other classes, a few points were randomly selected during an assessment of class labeling, which might be equal to the weighed proportion of the landscape.

Table 2. Accuracy assessments of land use and land cover classes

LULCC	Cropland	Agroforestry	Forest	Grassland	Shrub/WL	Settlement	Bare land	Row total	Users' accuracy
Cropland	44	1	1	3		0	1	50	88
Agroforestry	1	45	2		2	0	0	50	90
Forest	0	3	35		2	0	0	40	88
Grassland	2	0		36	0	0	2	40	90
Shrub / WL	1	2	2	1	33	1	0	40	83
Settlement	2	0	0	1	0	26	1	30	87
Bare land	3	0	0	2	0	0	25	30	83
Column total	53	51	40	43	37	27	29	280	
Producer accuracy (%)	83	88	88	84	89	96	86		

Source: Landsat 8 of 2019 and Google earth imagery (GEI)

Accordingly, through the use of ground-truthing sample polygons and online Google earth imagery data visualization and interpretation, the spectral signatures for the respective land cover types were collected. Then each class was given a unique identity and assigned a particular class testing the spectral distinctness of the training area. Moreover, in order to enhance signature reparability between the Forest and Agroforestry classes and minimise uncertainties of classification, more GPS-based ground-truthing data of natural forest were georeferenced, coupled with analysis of these feature classes using the human brain (texture, tone, size, shadows, and shape) from images.

2.2.3. Accuracy assessment of the images

The accuracy assessment of the images for this research was carried out using ArcGIS 10.4 software, which identifies the truth on the ground and is represented on the corresponding classified image. A simple random sampling method was used to collect a total of 280 reference data points to ensure that all seven LULCC classes were adequately represented depending on the proportional area of each class.

The confusion matrix of LULCC was estimated from Landsat 8 of 2019 and Landsat 5 of 2011, corresponding to the reference data from Google earth imagery (GEI) and GPS collected ground-truthing data. However, the accuracy assessment for the years 1986 and 2000 was not conducted because of the limitation of obtaining ground-truthing data, from aerial photo and historical Google Earth imagery. The accuracy assessment was determined using the Kappa coefficient, overall accuracy, producers' and users' accuracies derived from the confusion (error) matrix adopting the methodology described in Congalton and Green [2009] and Jensen and Cowen [1999].

According to Table 2, the diagonal matrix indicates sample point classes, which are correctly classified, while off-diagonal elements represent commission or omission errors [Foody, 2002]. The error matrix was computed for the overall accuracy of seven (7) land use classes individually and collectively. The overall accuracy was calculated by summing the number of correctly classified values and dividing by the total number of values. The total number of values is the number of values in either the truth or predicted-value arrays. Therefore, the overall accuracy result is 87%, which suggests a strong agreement between classification and truth. The kappa coefficient measures the agreement between classification and truth values. A kappa value of 1 represents perfect agreement, while a value of 0 represents no agreement. The kappa coefficient value of the study is 0.85; this value is closer to 1, which represents perfect agreement between classification and truth.

$$\hat{K} = \frac{N * \sum_{i=1}^k x_{ii} - \sum_{i=1}^k (x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^k (x_{i+} * x_{+i})}$$

i = the class number

N = the total number of classified values compared to truth values = 280

x_{ii} = the number of values belonging to the truth class i that have also

been classified as class i (values found along the diagonal of the confusion matrix) = 244

x_{i+} = the total number of predicted values belonging to class i (row totals)

x_{+i} = the total number of truth values belonging to class i (column totals) correctly classified values 44 + 45 + 35 + 36 + 33 + 26 + 25 = 244

K = number of rows in error matrix

Total number of values 280

Overall accuracy: 244/280*100 = 87%

2.3. Methods of data acquisition

A multistage sampling method was used to collect socio-economic data. Four *woredas* (lower government administrative divisions that form districts) were purposefully selected from highland, midland, and lowland agroecology in the first stage. In the second stage seven *kebeles* (lower administrative divisions) were selected from the *woredas* identified. The criteria for selecting the *woredas* and *kebeles* were agroecological variations, the extent of implementation of the SWC (soil and water conservation) practices, access to transportation, and population density. In the third stage, key informant interviews and focus groups were carried out in the selected *kebeles* found in different agroecology areas.

2.3.1. Focus group discussions (FGD)

Focus group participants in the study area were purposefully selected from the selected sample *kebeles* (the lower administrative divisions) with a maximum of five to six participants. Two *kebeles* were selected from highland and lowland agroecology based on population density while three *kebeles* were selected in the midland area. In the seven *kebeles* sampled, about 14 group discussions were carried out, two group discussions for each *kebele*. The FGD participants included model farmers, experts, administrators, and development agents from the highland, midland, and lowland agroecology. Selection of FGD participants was carried out based on local experience, expertise on agriculture, or natural resource conservation, and acceptance among the community, targeted to understand their perceptions, knowledge, and ideas on the dynamics and drivers of LULCC.

2.3.2. Key informant interview (KII)

Participants for key informant interviews were purposefully selected from seven *kebeles* found at different agroecology/altitudinal belts. For the interview, 9 to 11 key respondents were selected from each *kebele* considering gender, age over 45, local experience of LULCC, resource conservation work, and social recognition. For instance, in the lowlands and highlands, two *kebeles* for each were selected. In contrast, three *kebeles* were selected in the midlands, because the midlands area has a higher population density than the lowlands or the highlands.

According to this arrangement, 70 respondents were interviewed in the whole agroecology. The interview was mainly focused on the perception and experience of the community on driving forces and characteristics of LULCC of the study area for 33 years (Table 10). The theoretical framework is given by Turner et al., [1994]; Geist and Lambin [2002] was used to categorise the participants' response about the forces as underlying and proximate drivers of LULCC in the three agro-ecological zones (Table 10).

2.3.3. Field observation

Initially, a reconnaissance survey was conducted across different agroecology. Based on the survey results, the LULC, such as agroforestry, degraded land, shrub/ woodland, forest land, farmland, grassland, and settlement land cover, were identified to be studied.

2.4. Data processing and analysis

Data processing and analysis were carried out using remote sensing, Geographic Information System data processing, and descriptive statistics. The image preprocessing activities of all satellite data were studied by assigning per-pixel signatures and distinguishing the land area into seven classes based on the specific Digital Number (DN) value of diverse landscape elements. The training samples defined for each LULCC class consist of clusters of pixels with similar reflectance values. Based on supervising training data, each cluster would represent the range of spectral characteristics exhibited by its corresponding land cover class.

The maximum likelihood classifier algorithm was used to sort the remaining pixels in the study area into the class with the most similar spectral characteristics. Even if parcel lands less than pixel size are there, each pixel belonging to each class was considered using the majority filter associated with the highest probability. Data collected through qualitative methods (focus group, interviews, and personal observation) were analyzed through descriptive statistics (percentage and mean). Secondary data sources, such as climate, official reports, and published materials were also exploited to support the analysis of key informant interviews and group discussions.

- The magnitude of change for each land use/land cover class was calculated by subtracting the area coverage of the second year from that of the initial year.
- The percentage share of gain or loss for each land-use class in the periods studied was then calculated with the formula shown in equation [1] [Shiferaw, 2011 and Puyravaud, 2003].
 - $$\Delta C (\%) = \frac{At2 - At1}{At1} \times 100 \quad (1)$$

ΔC = Percent change
 $At2$ = The initial year area
 $At1$ = Final year area
- ✓ The rate of change in hectare/year for each land class in the time periods studied was calculated with the formula given by Shiferaw and Singh, [2011] and Puyravaud, [2003].

$$RA = \Delta A = \frac{\text{Recent land cover} - \text{Previous land cover}}{\text{Time interval between the two} - \text{period land covers}} \quad (2)$$

The comprehensive sources, approach to data collection, and analysis methods for this research are depicted in Figure 3.

Table 3. **Classification scheme for the classification and change detection of LULCC**

RN	LULCC Classes	General Description
1	Forests	Land with tree cover (or equivalent stocking level) of more than 10 % and area of more than 0.5 hectares (ha). The trees should reach a minimum height of 5 meters (m) at maturity <i>in situ</i> (FAO, 2010). According to the UNFCCC for REDD+ purposes forest cover in Ethiopia referred to as 0.5 ha of size, 20% canopy cover and 2m height.
2	Grazing Lands	Grass and herb cover with permanent grass cover and some scattered trees or shrubs for livestock grazing including communal, private (protected), and free area. Relatively flat and open areas with good visibility and hill slopes are homogeneous (Eggleston et al., 2006).
3	Cropland	This unit includes perennial and annual crops land area and fallow lands (Hillbrand, et al., 2017).
4	Agroforestry land	Agroforestry is the collective term for land-use systems and technologies in which woody perennials (trees, shrubs, and fruits) are used deliberately on the same land-management units as crops and animals in some form of spatial arrangement or temporal sequence ((Hillbrand, et al., 2017).
5	Shrubs/ woodlands	Shrubs/woods refer to bushes and young tree species co-dominant with herbaceous plants in terms of coverage (Jensen, 2005).
6	Bare land	Land which is unproductive or not used for cultivation or grazing (Ludi and Hurni, 2000).
7	Settlement	It is simply a community where people build houses and live together (Ludi and Hurni, 2000)

Sources: Authors Generated from a different source

Figure 3. Flow chart showing the data sources and methods of analysis of the research

Source: Authors' formulation

Table 4. Land use and land cover change of 33 years (1986 to 2019)

R.N.	LULC Class	1986		2000		2011		2019	
		(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
1	Agroforestry	40,964	39.9	45,715	44.5	49,658	48.3	55,606	54.1
2	Cropland	32,143	31.3	3,5923	35	34,024	33.1	31,100	30.3
3	Shrub and Woodland	13,359	13.0	4,713	4.6	4,806	4.7	2,760	2.7
4	Grassland	11,281	11	9,790	9.5	7,794	5.2	4,876	4.7
5	Forest land	4,729	4.6	5,985	5.8	5,378	5.2	5,837	5.7
6	Settlement	257	0.25	401	0.4	980	0.9	2,406	2.3
7	Bare land	5	0.01	211	0.2	97	0.1	152	0.15
	Total area	102,738	100.00	102,738	100.00	102,738	100.00	102,738	100.00

Table 5. Magnitude, percentage share, and rate of LULCC of 33 years

Land use/cover type	Magnitude of LULC change in %	Percentage share of gain or loss from 1986 to 2019	Rate of change ha/year
Agro forestry	14.2	+35.7	+443.7
Cropland	1.02	-3.2	-31.6
Shrub / Wood land	10.3	-79.3	-321.2
Grassland	6.2	-56.8	-194.1
Forest	1.1	+23.4	+33.6
Settlement	2.1	+836.2	+65
Bare land	0.14	+2,940	+4.5

Source: Classified data from Landsat 5 (TM) and Landsat 8 (OLI)

3. RESULTS AND DISCUSSION

The LULC change of the study area from 1986 to 2019 was illustrated in the form of magnitude (percentage share) of the change, rate of change, LULCC trajectories, and drivers of LULCC. The report by Lambine et al. [2003] showed that LULCC might show periods of rapid and abrupt change followed by a quick recovery of ecosystems that could have various implications. Therefore, the overall research result on the implications of LULCC and its drivers in the Gidabo river subbasin is described in section 3.1 and 3.2.

3.1. Result of LULCC

3.1.1. Magnitude and rate of LULCC

Even though all LULC classes have undergone changes in the study area, the magnitude and rate of changes were inherently different. According to Tables 4 and 5 in the initial year (1986), agroforestry and cropland alone accounted for about 71.2%. After 33 years, the size of agroforestry and cropland is about 84.4% of the total LULC of the study area. The dynamics of LULC indicate that for the last 33 years, the study area lost annually about 321.2 ha, 197.1 ha and 31.6 ha of shrub/woodland, grassland, and cropland, respectively.

On the contrary, the land with agroforestry, settlement, forest and bare land showed an annual increment of about 443.7 ha, 65 ha, 33.6 ha, and 4.5 ha, respectively. For instance, in the past 33 years, the highest rate of land cover increment (14%) was recorded on agroforestry and the highest rate of loss (10.3%) occurred on shrub/woodland (Tables 4 and 5 and Figure 4). The image analysis also showed that consistent increment was observed on agroforestry and settlement land classes, whereas grassland covers were consistently reduced in the study period. In the other land use class inconsistent change was recorded, for instance, crop land cover increased from 1986 to 2000, but it continuously decreased from 2011 to 2019 (Table 4).

3.1.2. LULCC trajectory from 1986 to 2019

LULCC trajectory refers to the possibility of land use and land cover change from one land use class to another taking place in a specific period. The LULCC trajectory of the study area was classified in four categories that showed the net loss or gain. The first category of the LULCC classes is the period from 1986 to 2000. In those 14 years, the net loss occurring in the classes was the following: on shrub/woodland, about 8.6%; grassland, about 1.3%; and forest land, about 1.3%. The net gain of LULCC observed

Figure 4. Classified Land Map of the Gidabo river subbasins from 1986 to 2019

Source: Landsat 5 (TM) and Landsat 8 (OLI).

was the following: agroforestry, about 4.73%; cropland, about 3.8%; and on bare land, about 0.19%. According to the LULCC trajectories, about 6.2% of the shrub/woodland was converted to agroforestry, about 6.3% of the grassland was converted to cropland, and about 1.2% of the forest land was converted to cropland cover. In this period, the highest loss (8.6%) and gain (4.73%) were observed on shrub/wood and agroforestry land, respectively (Table 6). The second category of LULC trajectory refers to the period from 2000 to 2011. In this period, about 1.8% of cropland, 2% grassland, and 0.5% of shrub/woodland cover showed a reduction. One of the critical changes observed in this period is cropland. Though cropland has increased in the years from 1986 to 2000, it shows a reduction in the years from 2000 to 2019. The change in the cropland implies that the high population growth causes the farmer to shift from extensive monocropping to a multiple cropping or agroforestry system. For instance, about 2.9% of cropland, 2% of grassland, and 1.7% of forest land were converted to agroforestry. The highest gain of about 3.8% was detected in agroforestry, and the highest loss, about 2%, was recorded on grassland land cover (Table 7).

The third category of the LULCC trajectory refers to the period from 2011 to 2019. In this period, about 5% of agroforestry, 2.2% of forest land, and 1.4% of settlement land have shown expansion. On the other hand, about 4.3% of grassland, 3% of cropland, and 2.1% of shrub/woodland showed a reduction. This category's land use and land cover change trajectory showed that about 4.9% of cropland and 1.37% of shrub/woodland converted to agroforestry. About 1.4 % of grassland was converted to forest and agroforestry land (Table 8). The fourth category of LULCC trajectory refers to the period from 1986 to 2019. In those 33 years, about 10.3% of shrub/woodland, about 6.3% of grassland, and about 1% of cropland showed a remarkable reduction. Conversely, about 14.27% of agroforestry, about 2% of settlement land, about 1.2% of forest land, and about 0.15% of bare land showed expansion. The LULC transition of the fourth category showed that about 8.8% of shrub/woodland and about 6.35% of cropland were added to agroforestry; also, about 1.4% of shrub/woodland and 1.3% of cropland were converted to settlement and forest land, respectively (Table 9).

Table 6. LULC (%) between 1986 and 2000

LULC from 1986 to 2000	Agroforestry land	Bare land	Cropland	Forest land	Grassland	Settlement land	Shrub/ woodland	Total
Agroforestry	35	0.0032	2.6	1.49	0.12	0.02	0.15	39.88
Bare land	0.00	0.0013	0.001	0.00	0.0021	0.00	0.00034	0.0045
Cropland	3.09	0.06	24.22	0.54	2.6	0.012	0.43	31.3
Forest	0.3	0.5014	1.165	2.21	0.053	0.50	0.535	5.76
Grassland	0.024	0.086	6.3	0.11	4.08	0.00156	0.5	11.1
Settlement	0.0036	0.009	0.0094	0.00012	0.013	0.205	0.011	0.25
Shrub/Wood land	6.2	0.04	0.98	0.1134	2.68	0.118	2.98	13
Total	44.6176	0.2009	35.0904	4.46	9.5481	0.36456	4.42134	100

Note: The bolded numbers indicate the persistent LULCC

Table 7. LULC (%) between 2000 and 2011

LULC from 2000 to 2011	Agroforestry land	Bare land	Cropland	Forest land	Grassland	Settlement land	Shrub/ woodland	Total
Agroforestry	41.4	0	2.3	0.36	0.11	0.10	0.23	44.5
Bare land	0.003	0.035	0.027	0	0.12	0.005	0.015	0.205
Cropland	2.9	0.015	27.06	1.5	2.080	0.33	1.10	34.9
Forest	1.7	-	0.77	2.9	0.012	0.013	0.35	5.7
Grassland	1.6	0.014	2.7	0.16	3.86	0.11	1.01	9.5
Settlement	0.02	0	0.012	0.001	0.005	0.35	0.006	0.39
Shrub/Wood land	0.64	0.035	0.20	0.81	1.44	0.17	1.9	5.09
Grand Total	48.263	0.099	33.069	5.7	7.6	1.078	4.611	-

3.2. Discussion

3.2.1. Land use and land cover change implications and driving forces

LULCC have several implications at the local, regional and global scales of socio-economic and environmental conditions. The result on LULCC of the Ethiopian rift valley region of the Gidabo subbasin showed that about 58% of the river basin has been exposed to different LULCC in the past 33 years. About 46.7% of the land was covered by the agroforestry system, which is the largest land size among different land classes from the total land use and land cover size. The result is in agreement with the reports by Degife et al. [2019] and Kippie [2002] on the expansion of agroforestry and settlement land in south-eastern Ethiopia and by Meshesha et al. [2014] on forest land expansion in the Northern Central Highlands of Ethiopia.

According to the participants in group discussions and interviews, agroforestry has multiple advantages; for

instance, it is used to increase vegetable yields, extend the harvesting season, improve the quality of product, increase the income of rural communities, improve food self-sufficiency, improve quality of life, improve the utilisation of forest products, regulate local climate, reduce soil erosion, and increase biodiversity in a densely populated area. The local community perception indicated that the agroforestry system is helpful to the resilience of the environment and sustainable agricultural production. The report by Brown [2018] suggests that LULCC that encourages agroforestry can improve the agricultural systems and mitigate the impact of climate change.

Though the theory of a resilient environment and sustainable development are independent, several links between the two concepts can be found in the literature [Lew et al., 2016; Derissen et al., 2011]. According to Redman [2014], a resilient environment and sustainable development can be considered complementary approaches because a resilient environment is important to long-term sustainability of livelihood outcomes

Table 8. LULCC (%) between 2011 and 2019

LULCC from 2011 to 2019	Agroforestry	Bare land	Cropland	Forest land	Grassland	Settlement	Shrub/ woodland	Grand total
Agroforestry	45.6		0.4	1.01	0.14	0.88	0.31	48
Bare land	0.002	0.035	0.03	0.04	0.02	0.006	0.002	0.1
Cropland	4.9	0.0079	24.6	1.37	1.4	0.54	0.24	33
Forest	0.9		1.22	2.8	0.10	0.039	0.13	5
Grassland	1.2	0.10	3.09	1.6	2.58	0.16	0.4	9
Settlement	0.016		0.30	0.01	0.049	0.56	0.01	0.94
Shrub and Woodland	1.37	0.009	0.65	0.45	0.45	0.15	1.58	4.7
Total	53	0.15	30	7.2	4.7	2.3	2.6	

Table 9. LULC (%) between 1986 and 2019

LULCC 1986–2019	Agroforestry	Bare land	Crop land	Forest land	Grassland	Settlement	Shrub/ wood land	Grand total	Loss
Agroforestry	37.64		0.48	1.21	0.06	0.42	0.06	39.87	2.23
Bare land	0.0010	0.001	0.002	-	0.0010	-	-	0.005	0.004
Cropland	6.35	0.005	21.06	1.75	1.3	0.53	0.29	31.3	10.24
Forest land	1.05	0.002	0.63	2.5	0.121	0.051	0.3	4.6	2.1
Grassland	0.26	0.081	7.7	0.28	2.44	0.1	0.14	11	8.56
Settlement	0.04	0.067	0.045	-	0.042	0.11	0.011	0.25	0.14
Shrub/ woodland	8.8	0.052	0.355	0.15	0.65	1.14	1.9	13	11.14
Grand total	54.14	0.15	30.3	5.82	4.6	2.34	2.7	100	
Gain	16.5	0.15	9.24	3.3	2.2	2.23	0.8		
Net change	14.27	0.146	-1	1.2	-6.36	2.09	-10.34		

Source: Satellite image analysis

[Harris et al., 2020; Espiner, et al., 2017]. In this regard, the agroforestry system of the study area is the best practice for a resilient environment, which has to be taken into account when one is designing policies for the sustainable development of ecological-economic systems and vice versa.

Nevertheless, the LULCC such as reducing shrubland and grassland and the expansion of bare land, have threatened to adversely affect the efforts on a resilient environment and sustainable development effort of the community. Therefore, the driving factors that contribute to the changes in shrubland, grassland, and bare land should be considered in future studies of LULCC. From this point of view, all the dynamic changes observed in the land cover of the study area were mainly related to such factors as demographic, economic, cultural, natural, institutional (policy), and agricultural intensification technology (Table 10).

The highlands are from 2,300 to 3,200 m a.s.l, the midlands are from 1,500 to 2,300, and the lowlands are from 500-1,500.

3.2.1.1. Demographic factors as drivers of LULCC

Among the identified drivers of LULCC, a demographic factor took the top rank in all agroecology (the altitudinal belt). About 90% of participants in the interview and the group discussion participants perceived that population growth had increased the demand for more land for cultivation, livestock production, tree plantation, and settlement. The high population growth of the study area also increased land fragmentation in holding size. Thus, the farmers started to shift the monocropping system to a mixed cropping or agroforestry system. As confirmed by satellite image analysis, informant interviews, and group discussions, land scarcity increased the conversion of grassland and cropland to the agroforestry system (Figure 5).

According to the report by Temesgen et al. [2018], zonal agricultural office [2020] and the central statistical report of Ethiopia [2013], the population density of the highland and lowland area ranges from 300 to 450 persons per sq.km, while in the midland it ranges

Table 10. Drivers of land use and land cover change in the study area

R.N.	Drivers of LULCC	Current drivers of LULCC (Proximate and underlying drivers)	Respondents in group discussions who perceived drivers of LULCC at different agroecology.			Respondents on interviews participants who perceived drivers of LULCC at different agroecology.		
			Highlands 4 Groups	Midlands 6 Groups	Lowlands 4 Groups	Highlands 21 persons	Midlands 28 persons	Lowlands 21 persons
1	Indirect driver	Demographic factors (population density, settlement)	89%	95%	91%	84%	96%	85%
2	Direct driver	Economic factors (agriculture, charcoaling, fuelwood, daily labouring)	65%	92.1%	87.4%	67.6%	95%	82%
3	Indirect driver	Cultural factors (Songo, and Baabbo)	70%	92.8%	68%	71%	92%	78.9%
4	Direct driver	Natural factors (recurrent high- intensity rainfall and drought)	81%	73.6%	86.2%	80%	91%	83%
5	Indirect driver	Policy or institutional factors (soil and water conservation)	58%	79%	57%	58%	77%	64 %
6	Indirect drivers	Agricultural intensification technology (high yield crops, pesticide and fertiliser)	84%	70.3%	85%	83%	71%	84%

between 774 to 900 persons per sq.k.m. This record is the highest population density in the country. According to Bilsborrow and Ogendo [1992], land scarcity exacerbates the conversion of wildlands to agriculture and other land uses.

Therefore, the reductions of grassland and shrubland from 1986 to 2019, forest land from 1986 to 2011, and cropland from 2000 to 2019 were mainly related to the expansion of the agroforestry system, which supported the rising demand of large human populations (Figure 5). This result agrees with the report by Ketema et al. [2020] and Temesgen et al. [2018]. Population growth was positively correlated with the expansion of agroforestry land that provides year-round income to support large family sizes (Figure 5).

3.2.1.2. Natural factors as drivers of LULCC

Natural factors such as frequent drought, high-intensity rainfall, steep slope, and soil erosion highly determine the LULCC [Zondag and Borsboom, 2009]. According to Table 10, for about 80% of focus group participants and 85% of interview participants, natural factors such as climate variability, steep slope, and topographic variations ranked second in determining the LULCC of the study area. The

land users said that the climate is not as regular as it used to be: it has frequently been erratic and variable.

The climate variability increases the farmers' insecurity about cultivating a similar type of crop (monocropping), fruits, or vegetables. As a result, they favoured applying multiple types of cultivation, that is, an agroforestry system. The farmers' insecurity feeling for climate change forced them to consider agroforestry as the best option to adapt climate change. This perception was confirmed by the satellite image analysis that showed the expansion of agroforestry land cover from 1986 to 2019. The result agrees with the findings of Temesgen et al. [2018], in which drought/RF variability was perceived as a driver of LULCC in the study area.

The other implication of natural factors on land cover change was observed in the highland agroecology of the study area. Though the land cover in the highland area is gradually converting to an agroforestry system, the satellite image analysis and key informant interview confirmed that comparatively extensive land in the highland area was left for grazing land due to the acidic the soil that is not suitable for crop cultivation (Figures 4 and 6). According to Zhang [2013], high rainfall causes essential soluble salts such as Ca, Mg, K, and Na to be leached away and the insoluble acidic residues (composed of oxides and silicates of iron,

Figure 5. Population growth increased agroforestry system
Source: Field observations in the midlands agroecology

Figure 6. Sample grazing land in the highland agroecology
Source: Field observation

silicon, aluminum to be left with a high amount that not suitable for agriculture.

3.2.1.3. Economy as drivers of LULCC

The Ethiopian economy is highly dependent on agriculture; due to its reliance on rain, it has faced less productivity and fewer unsustainable products. In the study area, economic drivers are the third-highest factors that determine the LULCC. According to Table 10, about 90% of the participants in the midlands, 84.5% in the lowlands, and 66.5% in the highland areas have reported that small farm size caused frequent cultivation in the crop land and reduced productivity due to soil loss. According to the report by MOFED [2012] the study area absolute poverty lines is higher compared to the national level of poverty lines in 2011, because the high population growth, diminishing land-holdings, landlessness and a lack of on-farm technological

Figure 7. Charcoal marketing in the town of Dilla

innovation significantly contributed to the decline in productivity per household [Dorosh and Rashid, 2013]. In the study area many youth farmers who had formal education favored engaging in different off-farm activities, such as daily labouring, riding a motorbike, shoeshine, charcoaling, and commercial farming (Figure 7). According to the DA the off-farm works adversely affected the farmers land management activity, which adversely affected the LULCC of the area. Consequently, farmers are unable to feed their families. In this regard, many farmers are trying to get fertile soil from grassland, shrub/woodland, and other marginal lands, which, in return, contributed to land degradation /soil erosion (See Figure 8). This finding agrees with the report by Ketema et al. [2020], which reported that the economy dependent on agricultural land expansions was the proximate driver of rapid LULC dynamics in Ethiopia.

3.2.1.4. Agricultural intensification technology as a driver of LULCC

Technology can determine the LULCC of the specific area through labour, market, accessibility, and application processes on the land. More than 79% of focus group and interview participants perceived that technology-related issues took the fourth stage to determine the LULCC of the study. According to Table 10, agricultural intensification technology, such as access to chemical fertilisers, seeds, and pesticides, contributed to the LULCC of the area. For example, agricultural inputs (fertiliser, pesticide, and seeds) are necessary to increase productivity and ensure food security. However, the farmers said that the price of agricultural inputs had risen greatly in the last decade. Many farmers cannot afford to cover the high price of chemical fertiliser.

This challenge has forced many farmers to search for fertile soil by encroaching on grassland, forest land, and shrub/ woodland, which has contributed to reducing grassland, wood/shrubland, and the natural forest land of the area (Table 9, Figure 8). The community perception in this study agrees with the reports by Zondag and Borsboom

[2009] and Lambin [2006]. They have reported that the widespread application of biocide (pesticide, fungicide, and insecticide) triggers LULCC intensification.

3.2.1.5. Cultural factors as drivers of LULCC

According to Shiferaw and Singh [2011], culture is a determinant factor in the issue of LULCC. Table 10 shows that about 77% of focus group participants and 81% of the interview key informants agreed that the culture of tree planting, inside the Enset and Coffee plantations and rotating one's own house in the Gedeo and Sidama communities has an important impact on LULCC of the area. Indigenous knowledge of the tree conservation (Songo and Baabbo) and soil treatment (Mona) system were highly accountable for expanding the agroforestry system and forest land. There are cultural institutions named 'Songo', 'Baabbo', and 'Mona' in the Gedeo zone. Songo is a sacred place where trees are reserved for ritual and cultural purposes, and Baabbo is a traditional way of tree conservation for various socio-economic purposes [Alambo et al., 2019; Maru et al., 2019].

"Mona" is a traditional acid soil treatment approach with animal dung using a circular fence constructed from bamboo plants to herd domestic animals (particularly for cattle and horses). The farmers are applying several agricultural practices in the treated soil such as production of enset, cereal crops and vegetables (potato, ginger, taro, chives) and livestock husbandry (sheep, cattle, and horses), side to side of eucalyptus trees, which is contributing for the expansion of agroforestry system (Figures 9 and 10). The result was compatible with the reports by Kura [2013] and Kippie [2002] about the cultural role for the expansion of the agroforestry system of the study area.

3.2.1.6. Institutional factors as drivers of LULCC

Institutional arrangements influence land-use decision making. The government policies are part of institutions that play an important role in LULCC [Briassoulis, 2009]. In the last 33 years, the government of Ethiopia formulated different policies on natural resource conservation. About 65% of FGD participants and 64% of the interview participants confirmed that the government policies impact LULCC of the study area (Table 10). For instance, the 1980s policy of SWC, agricultural intensification (resettlement, land privatization and access of agricultural inputs), the 2005 community-based SWC program and the 2011 green economy initiatives considerably determined the LULCC of the study area. The government policy that is related with urbanization and infrastructure development causes LULC change through conversion of land use classes, such as farmland and forests to built-up areas and infrastructures [Anteneh, et al., 2018]. The report by Yeshaneh et al. [2013] showed that the 1975 land proclamation of Ethiopia take away all lands from the landlords and distributed to the landless, which in turn caused a large deforestation for the purpose of agricultural expansion. The tenure of all rural

Figure 8. Forest encroachment for the sake of fertile land
Source: Field observations

Figure 9. Indigenous acidic soil treatments (Mona)
Source: Field observations from the highlands agroecology

Figure 10. Traditionally conserved forest (sacred place)
Source: Field observations from the midlands agroecology

Figure 11. Sample plantation forest carried through the SWC programme

and urban lands by the state led to a lack of belongingness to natural resources by the individual farmers, which in turn triggered vast deforestation.

The information obtained from key informant and experts revealed that the 2005 and 2014 community based SWC conservation program contributed to the improvement of shrub/woodland from 2000 to 2011, forest land from 2011 to 2019 and agroforestry from 1986 to 2019 (Table 9, Figure 11). Farmers also indicated that during the 1970s and 1990s law enforcing institutions were weakened following the social unrest and many trees were cut for construction, charcoal production and fuel wood. The interviewees also indicated some factors that were not mentioned by farmers, such as lack of institutional coordination, poor infrastructure, illiteracy and poverty. Similar result report by, Alemayehu, et al. [2019] and Temesgen et al. [2018] showed that cultivated land has expanded from 1986 to 2000 in southwestern and southeastern Ethiopia, respectively, mainly related to different land-use policies of the government.

4. CONCLUSIONS AND RECOMMENDATION

A study on the implication of LULCC and its driving forces is helpful to identify the interaction between environment and the community, gives opportunity to mitigating environmental disasters, predict future change, and plan for sustainable utilization of natural resources. The Gidabo river sub basin of the Ethiopian rift valley region exposed to different land use land cover change (LULCC). In the past 33 years (1986 to 2019), about 58.4% of the river basin showed LULCC. Accordingly, about 14.27% of agroforestry, 2% of settlement land, 1.2% of forest land, and 0.15% of bare land showed expansion. On the other hand about 10.3% of shrub/woodland, 6.3% of grassland, and 1% of cropland showed a remarkable reduction. Though cropland has been declining, the dominant LULCC class was shared by agroforestry (about 46.7%) and cropland (about 32.4 %). These two land classes alone accounted for about 79.1% of the total LULCC of the area. The changes ongoing in this

region are typically exemplary for the positive interaction between the community and the environment that is expanding agroforestry that have multiple feedbacks.

According to the key informant interviews, focus group discussants, and field observations, the driving factors such as high population growth, small land size, insecurity of climate change and the indigenous conservation culture of the community contributed to the expansion of the agroforestry system and plantation forest. Many researchers reported that the expansion of agroforestry system is vital to mitigate environmental disasters, build resilient environmental systems, regulate local climate, stabilize the slope and secure sustainable development.

Conversely, the factors such as rain-fed and less productive agriculture, deforestation (charcoaling) and lack of access to agricultural inputs (fertilizer, pesticide and seed) contributing for the expansion of degraded land. Due to this increasing crop productivity without the use of fertilizer is becoming very difficult. In general unmanaged conversions to cultivated land, built-up, shrub/wood land and bare land had caused various environmental problems. This necessitates urgent action to avert unplanned LULCC as it is threatening the sustainability of natural resources in the watershed. Hence, integrated watershed management that included creating awareness among the farmers, appropriate land use planning, encourages productive agroforestry, sustaining existing vegetation cover, and rehabilitation of degraded land are the important actions that need to be taken.

LIST OF ABBREVIATIONS

AAU	Addis Ababa University
A.S.L.	Above Sea Level
FGD	Focus group discussion
EPA	Environmental Protection Authority
GEI	Google Earth Imagery
GIS	Geographic Information System
GPS	Global Positioning System
KII	Key Informant Interview
LULC	Land Use Land Cover
LULCC	Land Use Land Cover Change
ND	Digital Number
NIR	Near-infrared
RS	Remote Sensing
SWC	Soil and Water Conservation
SWIR	Short Wavelength Infrared
TM	Thematic Mapper

DECLARATION

Not applicable in this section

CONSENT FOR PUBLICATION

Not applicable in this section

AVAILABILITY OF DATA AND MATERIALS

The study's data are available with the corresponding author upon reasonable request.

COMPETING INTERESTS

The authors have no competing interests.

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AUTHORS' CONTRIBUTIONS

GH contributed to the design of the work, data acquisition, analysis, interpretation, and write-up of the manuscript. **AB** designed the work, supervised, and substantively revised the work. **AT** designed the work, supervised, and substantively revised the work. **MM** designed the work, supervised, and substantively revised the work. **DL** contributed to satellite image analysis.

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