




# Dynamics and drivers of land cover change in the Afroalpine vegetation belt: Abune Yosef mountain range, Northern Ethiopia

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## Abstract

Land use and land cover (LULC) change is a global concern because it could lead to the loss of biodiversity and negatively impact ecosystem services and functions, and has an important contribution to climate change. LULC change dynamics and their driving factors are not uniform globally and locally which makes decision making uncertain. This study seeks to quantify the extent of LULC change in Abune Yosef mountain range. To do this, we conducted a supervised classification using maximum likelihood classifier of 2 Landsat images from 1986 to 2017. Ground reference points and aerial photographs were used for accuracy assessment. Results revealed that the area of Afroalpine grassland has declined by  $-64.76\%$ , from 10,500 ha to 3700 ha. Other declines were seen in grazing land ( $-72.15\%$ , 5900 ha), open woodland ( $-100\%$ , 3900 ha), and shrubland ( $-7.04\%$ , 2500 ha). On the other hand, agricultural land area has increased from 38,300 to 48,700 ha ( $+27.15\%$ ), barren land from 5400 to 8900 ha ( $+64.81\%$ ), rivers, riverbeds, and gullies from 1100 to 3700 ( $+236.56\%$ ), plantation forests from 2500 to 4700 ha ( $+88\%$ ), and urban settlements from 300 to 500 ha ( $+66.66\%$ ). The main drivers of substantial LULC change were identified as increased human population pressure, and temperature and precipitation variability accompanied by the absence of land use policy. Policy developers, decision makers, and local communities may refer this study to develop land use policy, conservation planning, and prioritization to ensure sustainable resource utilization.

**Keywords** Abune Yosef · Agricultural encroachment · Afroalpine grassland · Land use and land cover change · Supervised classification

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## 1 Introduction

Land use and land cover change is a complex process that is influenced by biophysical, social, and economic factors (Arsanjani 2012) including long-term natural changes in climate conditions, inter-annual climate variability, geomorphological and ecological processes, and human-induced alterations of vegetation cover and climate (Lambin and Strahler 1994). Authors often use the term land use and land cover interchangeably. Land cover refers to 'the physical and biological cover over the surface of the land, including water, vegetation, bare soil, and/or artificial structures' (Molders 2012), whereas land use 'involves both the manner in which the biophysical attributes of the land are manipulated and the intent underlying that manipulation the purpose for which the land is used' (Turner II et al. 1995).

Land use and land cover change is a global concern (Lambin et al. 2006) because it can cause a loss of biodiversity, increase pollution, increase climate variability (Arsanjani 2012), and affect air moisture and temperature (Molders 2012). Furthermore, it has potentially a strong influence on ecosystem services and functions (Wang et al. 2015). The multiple impacts of LULC change include loss of provisional services, i.e., lack of food, feed, fiber, and timber; increased disease risks; atmospheric chemistry, climate change, and life support functions; loss of agrobiodiversity and biodiversity; degradation of soil quality; and alteration to freshwater hydrology, agricultural water use, and coastal zones (Chhabra et al. 2006). Bennett et al (2005) also predicted LULC change to be a major driver of changes in the provision of ecosystem services up to 2050.

Land use and land cover change has an important contribution to climate change. Of particular importance, anthropogenic influences such as agricultural expansion, deforestation, and urbanization are the major contributors to CO<sub>2</sub> emissions. According to the Intergovernmental Panel on Climate Change (IPCC 2007), about one-third of the anthropogenic CO<sub>2</sub> emissions since 1750 has come from land use and land cover changes. Moreover, Houghton et al (2012) estimated the net flux of carbon from LULC change from anthropogenic carbon emissions to be 12.5 percent from 1990 to 2010. However, Arneeth et al (2017) claimed that the estimations of CO<sub>2</sub> emissions from LULC change are underestimated and, perhaps, are larger than widely assumed. Its impact varies with countries sensitivity, exposure, and adaptation to the change (Sarkodie and Strezov 2019).

Globally, the pace of agricultural land transformation at the expense of forests and grasslands has been particularly rapid in the last 300 years (Ramankutty et al. 2006). Nevertheless, the dynamics of LULC changes are not uniform both globally and locally. Population pressure accompanied by demand-driven developmental activities is the primary factor for LULC change (Hailu et al. 2015; Menker and Rashid 2014).

Ethiopia is the 12th and 2nd populous country in the world and Africa, respectively, with a population of over 107.5 million people increasing at a rate of 2.46% year<sup>-1</sup> (Worldometers 2018). More than 80% of the population of Ethiopia relies on rain-fed agriculture for subsistence. Hence, LULC change is an important issue in the Country. Reconstruction of pre-agricultural expansion vegetation cover of Ethiopia by Hailu et al (2015) showed that more than one-third of today's farmlands were previously covered mainly by broad-leaved evergreen and deciduous forest. Furthermore, agricultural land expansion in the Ethiopian highlands has been increasing since 1860 at the expense of forests, shrublands, and grasslands (Menker and Rashid 2014).

Research in some parts of Ethiopia has revealed that the major drivers of LULC change are population growth, settlement; agricultural expansion; deforestation and land clearing;

and fire (Kidane et al. 2012; Urgesa et al. 2016). However, the driving factors could not be uniform because of the diversity in vegetation types, environmental history, livelihood, and topography.

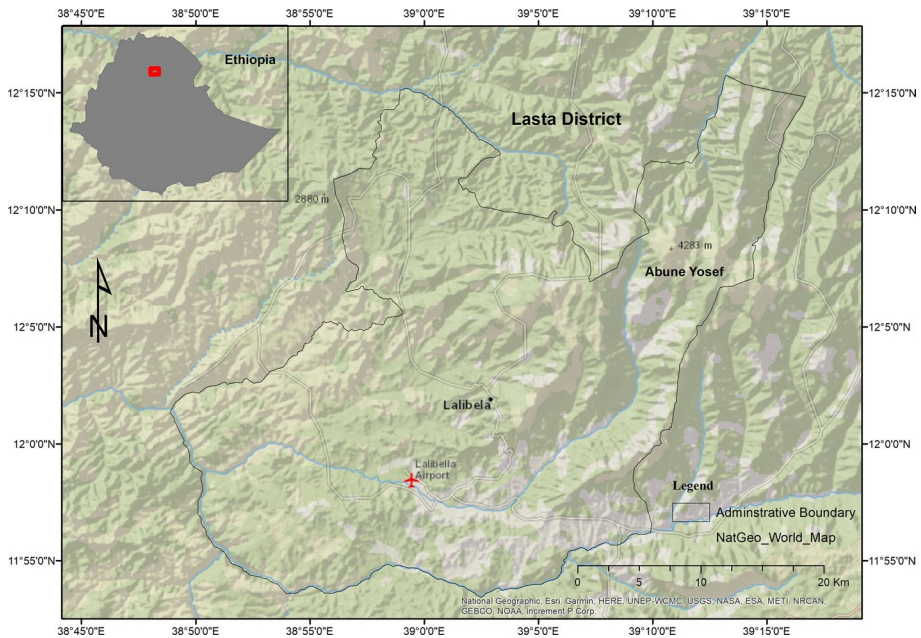
Although National level LULC change products are available for Ethiopia, the overall accuracy is very poor, < 50% for mountainous regions Hailu et al (2018). Moreover, local LULC change researches do not show similar trends in the dynamics and driving factors. Spatiotemporal LULC change dynamics information plays a crucial role to understand the trends in environmental change and develop management interventions. However, there is no empirical information on spatiotemporal LULC change in the Abune Yosef mountain range. Jacob, Romeyns et al. (2015a, b) studied the LULC change dynamics of the Afroalpine vegetation belt in Lib Amba mountain which is partly found in the mountain range and largely in the neighboring administrative boundary. Nevertheless, this makes it difficult to trace back or predict by using known trends in areas that have not been surveyed, although it is broadly possible to summarize most of the LULC change findings as showing competition between vegetation cover and cultivated land (Liyew et al. 2019).

Hence, in order to manage and conserve the important natural resources, research is needed to understand the spatiotemporal extent and drivers of LULC change in Abune Yosef mountain range. Abune Yosef mountain range is characterized by highly diverse topography and different potential vegetation types; including many endemic species found in the Afroalpine ecosystem. However, it is highly degraded and devoid of vegetation. The only remnant forests are found in the Ethiopian Orthodox Tewahedo Churches and Monasteries. Moreover, settlement and agricultural expansion, unlike other areas of Ethiopia, is common even toward the top of the massif, 3800 m above sea level (m a.s.l.). Agricultural encroachment is threatening the Afroalpine ecosystem, endemic animals, and plants. Therefore, the objective of this study was to quantify the temporal and spatial LULC change in Abune Yosef mountain range. This research will have a great contribution for developing land use policy, planning, and decision making on biodiversity management in the study area with a probable adoption to similar ecosystems.

## 2 Materials and methods

### 2.1 Study area description

Abune Yosef mountain range is located in Amhara Regional State, North Wollo Zone, part of a high basaltic plateau situated west of the main Ethiopian Rift (Coltorti et al. 2007). The area ranges from 11°50'00" to 12°50'00" N and 38°30'00" to 39°25'00" E (Fig. 1). Its altitude ranges from 1581 to 4284 m a.s.l. At least 3 different vegetation types are recognized including dry evergreen Afromontane forest and grassland complex (DAF) with subtypes, dry single-dominant Afromontane forest of the Ethiopian highlands (DAF/SD) and Afromontane woodland, wooded grassland and grassland (DAF/WG), Afroalpine belt (AA) and Ericaceous belt (EB). The soil type in the high mountain areas, Afroalpine belt and ericaceous belt, is dominantly andosols. However, vertisols are also found in some places (Gebrehiwot et al. 2018). The highest rainfall is observed in the summer, 'Kiremt' (June–September) and spring, 'Belg' (March and April) seasons. Abune Yosef mountain range receives a bimodal rainfall, with the highest rainfall received in 'Kiremt' (Gebrehiwot et al. 2018).



**Fig. 1** Map of the study area

## 2.2 Data acquisition and image processing

The overall analysis starting from data acquisition, image processing, image classification, accuracy assessment to change detection was performed based on the designed framework (Fig. 2).

Two Landsat satellite imageries from 1986 (thematic mapper, TM) and 2017 (operational land imager, OLI) were downloaded from the United States Geological Survey (USGS) Earth Explorer (<https://earthexplorer.usgs.gov/>). The satellite images were downloaded from the dry season of the year to minimize misclassification. Furthermore, shuttle radar topography mission (SRTM)—digital elevation model (DEM) with a 30 m resolution was used. Aerial photographs were purchased from Ethiopian mapping agency (EMA) and used for ground referencing of the 1986 satellite image. Detailed information about the satellite images used is shown in Table 1.

The digital numbers of the 1986 satellite image were converted to radiance and then to reflectance and the radiance of the 2017 satellite image was converted to reflectance before proceeding with the supervised classification.

The aerial photographs were scanned with photographic scanner at 300 dots per inch (dpi) and saved in tif format. We used the autosync tool in ERDAS IMAGINE 2015 for georeferencing and orthorectification of the aerial photographs. Aerial photographs were georeferenced based on UTM (Universal Transverse Mercator) projection system. An orthorectified aerial photographs mosaic covering the study area was created. Because the orthorectification was performed in synchrony with the digital elevation model (DEM), it improved the accuracy of the aerial imagery and terrain distortions.

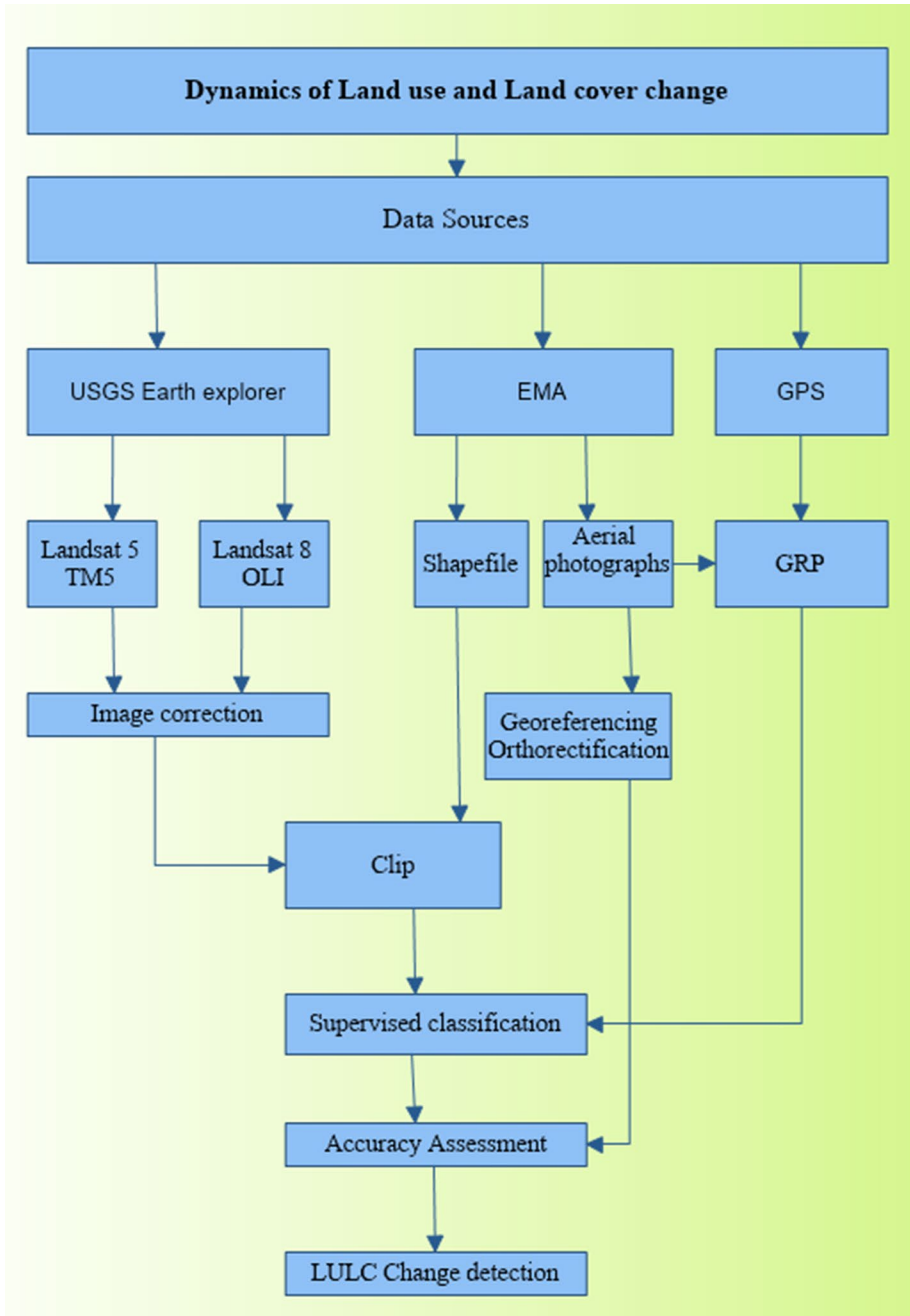


Fig. 2 The conceptual framework of the study

**Table 1** Information about earth observation data used in this study

Path & Row	Date of acquisition	Earth observation data	Image resolution/scale	Data sources
Path 169,	1986/01/28	Thematic mapper, TM	30 m	USGS
Row 052	2017/02/02	Operational land imager, OLI	30 m	USGS
		Aerial photograph	1:50,000	EMA
		DEM	30 m	USGS

### 2.3 Image classification and accuracy assessment

We employed a supervised classification approach using a maximum likelihood algorithm to classify the images based on ground reference points collected. Supervised classification allowed us to categorize the landscape according to ground reference points of land use and land cover classes that are of high interest in the region for the ecosystem services and functions provided (Table 2). Ground reference points were collected from field survey using GPS with  $\pm 5$  m accuracy. We supplemented these with few ground reference points taken from Google Earth because the lowlands were largely inaccessible. After considering the area of each LULC class, stratified random sampling was employed. Even though Congalton (1991) recommended at least 50 ground reference points for each class, the present study used 30–50 ground reference points by considering the cover of each LULC class. Two-third of the ground reference points collected were used for validation.

An accuracy assessment was conducted before analyzing the change (Congalton and Green 2009). We created a confusion matrix for 2017 image using ground reference data. The reference data for the 1986 image was collected from 56 aerial photographs obtained from the Ethiopian Mapping Agency. The photograph scenes were georeferenced and orthorectified using the DEM. Stratified random sampling was applied to generate random points and assess classification accuracy. Stratified random sampling affords the option to increase the sample size in classes that occupy a small proportion of an area to reduce the standard errors of the class-specific accuracy estimates for these rare classes (Olofsson et al. 2014).

The overall accuracy and a Kappa analysis were employed to perform classification accuracy assessment by generating confusion/error matrix. Overall accuracy is computed by dividing the total correct (sum of the major diagonal) by the total number of pixels in the error matrix whereas Kappa analysis is a discrete multivariate technique similar to Chi-square (Tables 3, 4) (Congalton and Green 2009). Kappa analysis yields a Khat statistics which is a measure of agreement between the classified image and ground reference (Congalton 1991). The Kappa coefficient is calculated as in Eq. 1:

$$K = \frac{n \sum_{i=1}^k n_{ii} - \sum_{i=1}^k n_{i+} n_{+i}}{n^2 - \sum_{i=1}^k n_{i+} n_{+i}} \quad (1)$$

where K is the Kappa coefficient, k is the number of rows in the matrix,  $x_{ii}$  is the number of observations in row  $i$  and column  $i$ ,  $x_{i+}$  and  $x_{+i}$  are the marginal totals for row  $i$  and column  $i$ , respectively, and N is the total number of pixels.

**Table 2** Description of land use and land cover classes

No.	Land use and land cover class	Description	Code
1	Afroalpine grassland	<i>Lobelia rynchopetalum</i> , <i>Euryops pinifolius</i> , <i>Alchemilla</i> species, and <i>Festuca</i> species are the dominant species. It is found above 3500 m a.s.l	AAG
2	Ericaceous forest/shrubland	<i>Erica arborea</i> , <i>Hypericum quaritanum</i> , <i>Myrica salcifolia</i> , and <i>Rosa abyssinica</i> are some of the dominant species. It is found between 3000 and 3300 m a.s.l	EFS
3	Church foresta <sup>a</sup>	Some characteristic species of dry evergreen Afromontane forests are found in this area such as <i>Juniperus procera</i> , <i>Allophylus abyssinica</i> , and <i>Olea europaea</i> subsp. <i>cuspidata</i> . It is found surrounding Ethiopian Orthodox churches	CHF
4	Plantation forests	<i>Eucalyptus</i> and <i>Cupressus</i> plantations larger than 0.5 ha	PLN
5	Shrubland	<i>Euclea racemosa</i> , <i>Dodonaea angustifolia</i> , <i>Senna singuana</i> , and <i>Orostegia integrifolia</i> are the dominant species. Plants less than two meters high, with crown cover less than 10%	SBL
6	Agricultural land	Arable or fallow land of annual crops	AGL
7	Grazing land	Grasslands that primarily serve as grazing land for livestock	GRL
8	Urban settlements	Urban areas including towns, industries, and other institutions	URS
9	Barren land	Areas dominated by exposed soils or bedrocks	BRL
10	Rivers, riverbeds & gullies	Rivers are either annual, biannual, or perennial. Riverbeds are bare of water when the river is dry. However, gullies are areas created by erosion which are often bare of water	RBG
11	Open woodland	Land covered by herbaceous vegetation with scattered trees where the canopy cover is less than 3%	WDL

<sup>a</sup>Land spanning at least 0.5 ha covered by trees and bamboo, attaining a height of at least 2 m and a canopy cover of at least 20% or trees with the potential to reach these thresholds in situ in due course (MEFCC 2016)

**Table 3** Confusion matrix 1986

Class	AAG	AGL	BRL	EFS	GRL	PLN	RBG	SBL	CHF	URS	WDL	Total	User's accuracy (%)	Kappa coefficient (%)
AAG	<b>45</b>	2	0	1	0	0	0	0	0	0	0	48	94	
AGL	4	<b>165</b>	0	0	2	0	2	4	0	0	0	177	93	
BRL	1	2	<b>19</b>	0	2	0	0	0	0	0	0	24	79	
EFS	0	1	0	<b>12</b>	2	0	0	0	0	0	0	15	80	
GRL	1	0	0	0	<b>33</b>	0	0	2	0	0	0	36	92	
PLN	2	3	1	0	0	<b>5</b>	0	0	0	0	0	11	45	
RBG	0	2	1	0	0	0	<b>6</b>	1	0	0	0	10	60	
SBL	3	20	2	0	1	1	0	<b>136</b>	0	0	1	164	83	
CHF	0	0	0	0	0	0	0	0	<b>10</b>	0	0	10	00	
URS	0	3	0	0	0	0	0	1	0	<b>6</b>	0	10	60	
WDL	0	0	1	0	1	0	0	1	0	0	<b>15</b>	18	83	
Total	56	198	24	13	41	6	8	145	10	6	16	<b>523</b>	0.00	
Producer's accuracy (%)	80	83	79	92	80	83	75	94	100	100	94		<b>86</b>	<b>82</b>



**Table 4** Confusion matrix 2017

Class	AAG	AGL	BRL	EFS	GRL	PLN	RBG	SBL	CHF	URS	Total	User's accuracy (%)	Kappa coefficient (%)
AAG	<b>15</b>	0	0	2	0	0	0	0	0	0	17	88	
AGL	0	<b>205</b>	2	0	2	1	3	2	0	0	215	95	
BRL	0	0	<b>45</b>	1	0	0	0	1	0	0	47	96	
EFS	1	0	0	<b>12</b>	0	1	0	1	0	0	15	80	
GRL	0	0	0	0	<b>11</b>	0	0	0	0	0	11	100	
PLN	0	5	2	0	0	<b>17</b>	0	1	0	0	25	68	
RBG	0	1	4	0	0	0	<b>16</b>	0	0	0	21	76	
SBL	0	19	5	0	2	0	3	<b>115</b>	1	0	145	79	
CHF	0	0	0	0	0	1	0	0	<b>9</b>	0	10	90	
URS	0	0	1	0	0	0	0	0	0	<b>9</b>	10	90	
Total	16	230	59	15	15	20	22	120	10	9	<b>516</b>	0.00	
Producer's accuracy (%)	94	89	76	80	73	85	73	96	90	100		<b>88</b>	<b>84</b>

## 2.4 LULC change detection analysis

The common post-classification comparison change detection approach was used to compare maps of different sources and provides detailed ‘from-to’ change class (Teferi et al. 2013). It is explained in extent of change on hectare (ha) basis and percent and rate of change. The percent and rate of LULC change was computed for each LULC class based on Eqs. 2 and 3.

$$\text{PoC} = \frac{A2 - A1}{A1} \times 100 \quad (2)$$

$$\text{RoC} = \frac{A2 - A1}{A1} \times \frac{1}{(T2 - T1)} \times 100, \quad (3)$$

where RoC=rate of change, PoC=percentage of change of a particular LULC class, A1=area of the previous land use class, A2=area of the recent land use class and T2=current year, and T1=previous year.

## 2.5 Driving forces, pressures, state, impact, and response (DPSIR) framework

A semiquantitative DPSIR framework (Smeets and Weterings 1999) was used to address the causes of LULCC as demonstrated in the scheme. This framework was designed to assess the relationship between driving forces such as population and climate change and pressures such as agricultural expansion and unsustainable resource utilization. These interrelationships cause transformations in land use and land cover, which affects ecosystem goods and services, and human well-being. A robust application of this framework connects the driving forces and pressures with policy measures to address them. Population data were obtained from central statistical agency (CSA) of Ethiopia. Ethiopia has conducted a population census in 1984, 1994, and 2007. The census is conducted at different administration levels viz. national, regional, zonal, district, and kebeles (lowest governmental administrative structure). It is not possible to get the census data of the study area for 1984 because the census was done at zonal level. Even though the census of 1994 was done at the district level, the study area was merged with other district, Bugina district. A monthly precipitation and temperature spanning 23 years (1993–2015) were obtained from the Ethiopian National Metrological Agency. Rainfall and temperature variability trends were analyzed using linear regression and nonparametric Mann–Kendall’s test. Annual and seasonal (spring and summer) rainfall variability was calculated using the coefficient of variation (CV).

## 3 Results

### 3.1 Accuracy assessment of supervised classification

The confusion/error matrix computation (Tables 3, 4) revealed an overall accuracy of 86% for 1986 and 88% for 2017. The Kappa coefficient was 82% and 84% for the year

1986 and 2017, respectively. Lower user's and producer's accuracy was recorded for barren land, grazing land, plantation and rivers, riverbeds, and gullies LULC classes.

### 3.2 LULC change dynamics

The study revealed a vivid LULC change (Table 5). Only the church forest class experienced no change over the study time period. Agricultural land, barren land, urban settlements, plantation forests, and rivers, riverbeds, and gullies showed an increasing trend. On the contrary, shrubland, open woodland, grazing land, and Afroalpine grassland showed a decreasing trend. Ericaceous forest/shrubland showed only modest change (Fig. 3a, b). LULC change trajectories are depicted in Table 6.

Afroalpine Grassland cover decreased from 10,500 ha (9.61% of the land cover in the study area) in 1986 to 3700 ha (3.43% of the whole land cover in the study area) in 2017 (Table 5). It was converted into agricultural land and grazing land. Shrubland cover in 1986 was 35,500 ha (32.63% of the land area) but it decreased to 33,000 ha (30.36%) in 2017 (Table 5). The open woodland which covered 3900 ha in 1986 was completely converted into shrubland and agricultural land.

The agricultural land and urban settlements, unlike the Afroalpine grassland and shrubland, showed increased cover. The result showed that the cover of agricultural land and urban settlements increased from 38,300 and 200 ha to 48,700 and 500 ha, respectively. In the 1986 map, the only well-established urban settlement recognized was Lalibela. However, in the 2017 map, there were 4 additional small urban settlements. The urban settlements expanded at the expense of agricultural land and shrubland. The agricultural land, however, expanded mostly at the expense of Afroalpine grassland, shrubland, and grazing land (Table 6).

Church forests experienced no change at all. However, the Ericaceous forest/shrubland is the least affected LULC class. Only 100 ha was converted to other LULC classes, particularly, agricultural land and barren land. On the other hand, the plantation forest dramatically increased from 2500 ha to 4700 ha from 1986 to 2017, respectively.

**Table 5** LULC area extent for 1986 and 2017

LULC Class	1986		2017		Change (ha)	Percent of change	Rate of change
	Proportion (%)	Area (ha)	Proportion (%)	Area (ha)			
AAG	9.61	10,500	3.43	3700	-6800	-64.76	-2.09
AGL	35.19	38,300	44.71	48,700	10,400	+27.15	0.88
BRL	4.94	5400	8.22	8900	3500	+64.81	2.09
EFS	2.99	3300	2.96	3200	-100	-3.03	-0.10
GRL	7.30	7900	2.02	2200	-5700	-72.15	-2.33
PLN	2.26	2500	4.30	4700	2200	+88.00	2.84
RBG	1.03	1100	3.42	3700	2600	+236.36	7.62
SBL	32.63	35,500	30.36	33,000	-2500	-7.04	-0.23
CHF	0.15	200	0.15	200	0	0.00	0.00
URS	0.27	300	0.44	500	200	+66.67	2.15
WDL	3.61	3900	0.00	0.00	-3900	-100.00	-3.23

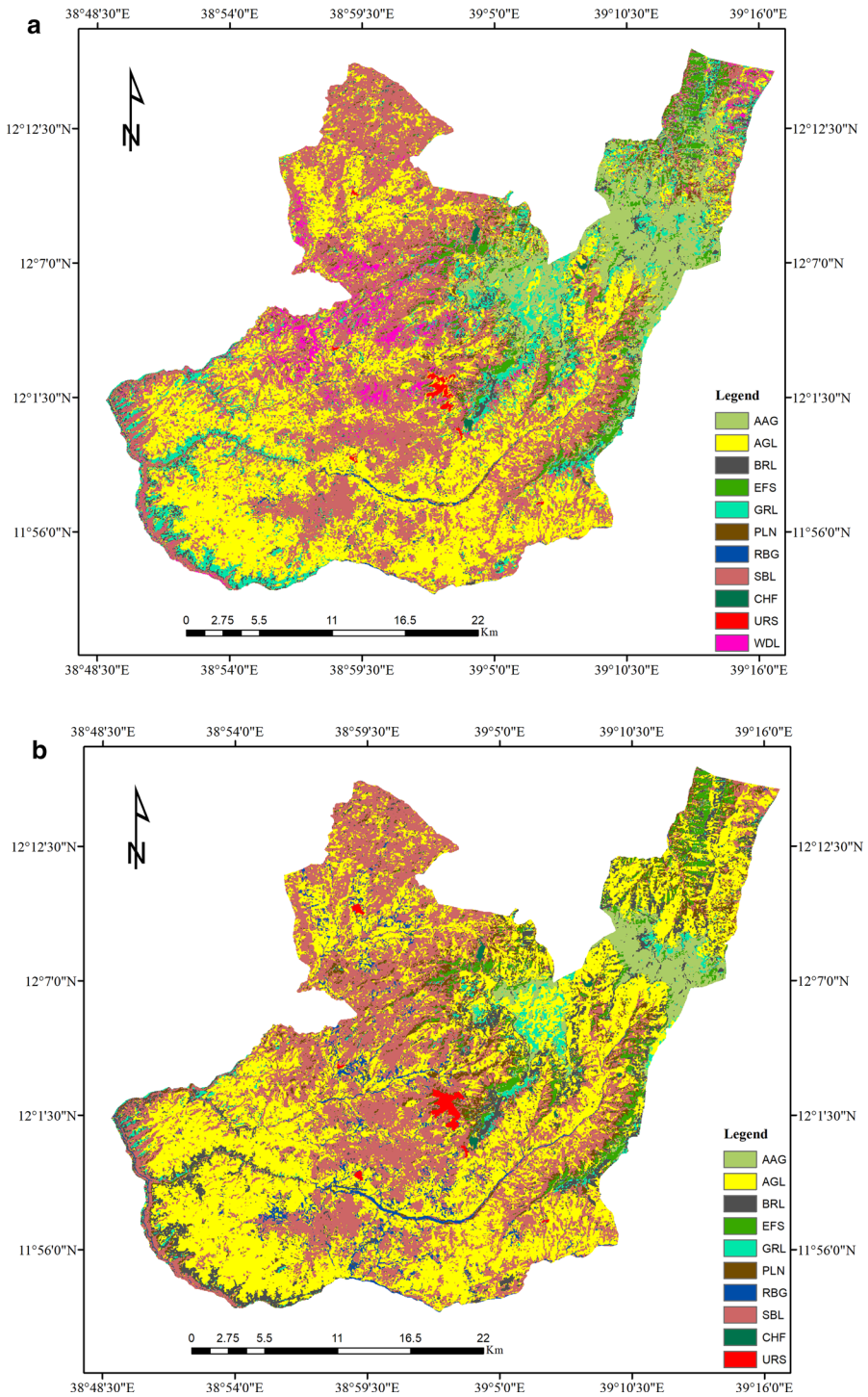
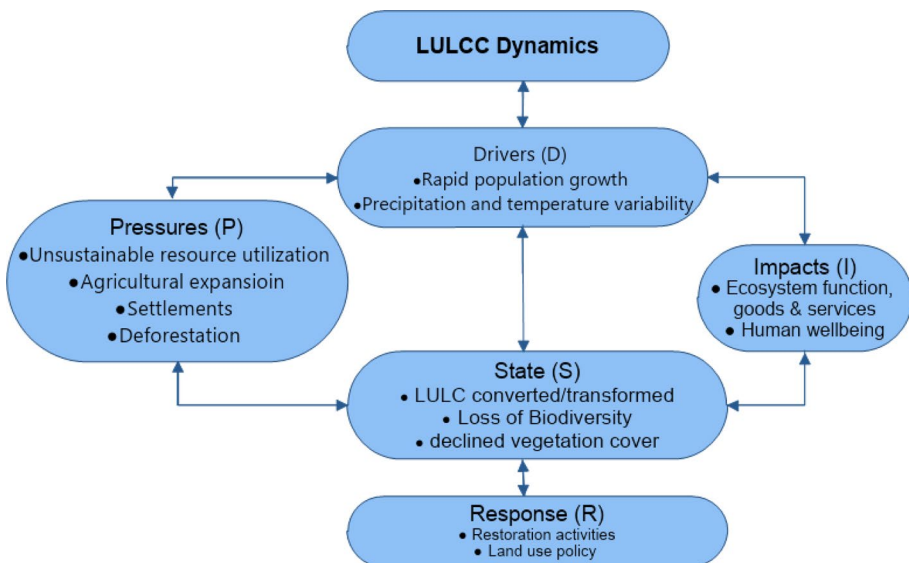


Fig. 3 a LULC map of 1986 and b LULC map of 2017

**Table 6** Change matrix of LULC change types (ha) between 1986 and 2017

	LULC class	Area (ha) 1986										
		AAG	AGL	BRL	EFS	GRL	PLN	RBG	SBL	CHF	URS	WDL
Area (ha) 2017	AAG	3700	0	0	0	0	0	0	0	0	0	0
	AGL	5000	35,900	700	100	2600	0	0	4300	0	0	200
	BRL	1800	300	3700	0	3100	0	0	0	0	0	0
	EFS	0	0	0	300	0	0	0	0	0	0	0
	GRL	0	0	0	0	2200	0	0	0	0	0	0
	PLN	0	500	500	0	0	2500	0	1200	0	0	0
	RBG	0	1500	500	0	0	0	1100	600	0	0	0
	SBL	0	0	0	0	0	0	0	29,300	0	0	3700
	CHF	0	0	0	0	0	0	0	0	200	0	0
	URS	0	100	0	0	0	0	0	100	0	300	0
	WDL	0	0	0	0	0	0	0	0	0	0	0

The grazing land which covered 7900 ha in 1986 decreased to 2200 ha in 2017 being converted mainly into agricultural land and barren land. In contrast to grazing land, the cover of barren land increased from 5400 ha in 1986 to 8900 ha in 2017. The area coverage of rivers, riverbeds, and gullies also increased from 1100 ha to 3700 ha in 1986 and 2017, respectively. The cover of rivers, riverbeds, and gullies increased at the expense of mostly agricultural land followed by barren land.



**Fig. 4** DPSIR framework

### 3.3 Major drivers of LULC change dynamics

The semiquantitative DPSIR analysis revealed that population and climatic variability are the main drivers of land use and land cover change (Fig. 4). The rapid population growth, and precipitation and temperature variability posed pressures such as unsustainable resource utilization, agricultural expansion, settlements, and deforestation, which is shown in the LULC change dynamics (Table 5). These have influenced the ecosystem functions causing ecosystem transformation such as decline in vegetation cover. However, the response doesn't recognize these transformations. As a result, a negligible conservation intervention such as land use policy is being observed during the study period.

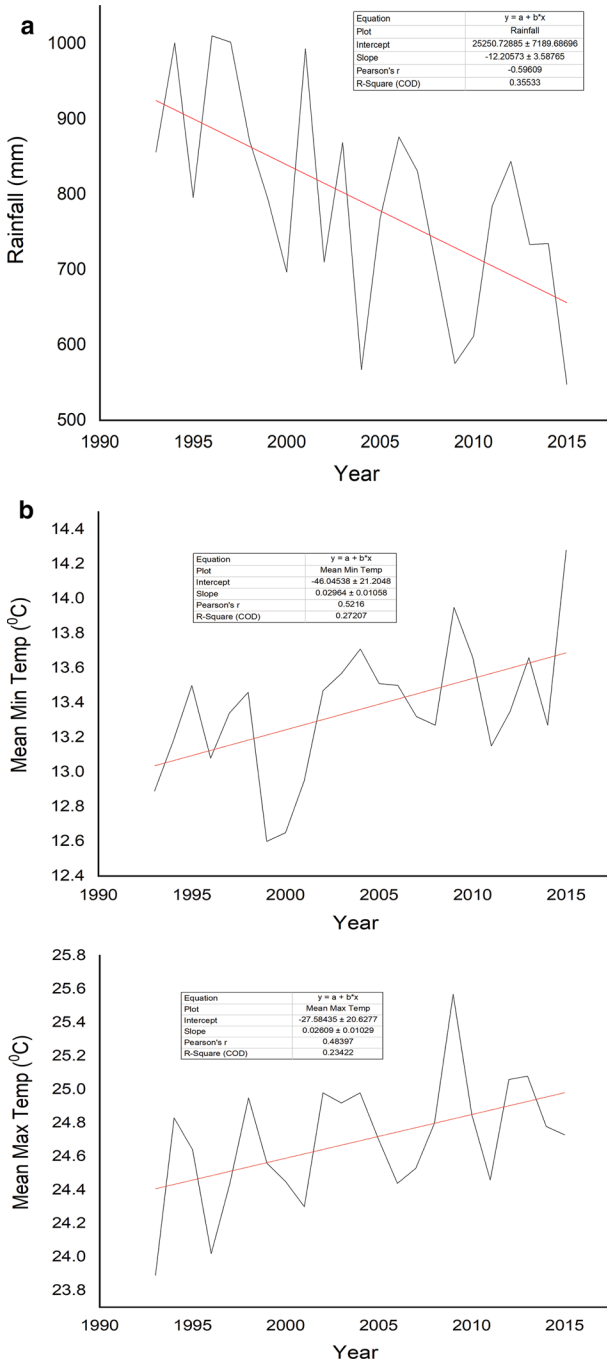
#### 3.3.1 Population

The population census data of 1984 and 1994 obtained from central statistical agency of Ethiopia do not fit the current administrative boundary, except the last census, which was conducted in 2007. Hence, this made calculating the population growth rate extremely challenging. However, agricultural expansion and urban settlements, which are presumably the outcome of population growth, have positively increased at a rate of 0.88 and 2.15 per year (Table 5). The only population data that match the current administrative boundary is Lalibela town with a population of 8484 (CSA 1994) which almost doubled to 17,367 in 2007 (CSA 2007). The latest census revealed that the total population of the study area is about 117,777. This shows that there is a tremendous increase in population of the district in the defined period. Population in turn demands a resource for their existence. Hence, pressures such as land use changes, for example, agricultural expansion, are inevitable to feed the ever-growing population. Consequently, conversion of natural vegetation into other land use types is a common phenomenon.

#### 3.3.2 Climate variability

According to the linear regression model annual, spring (small rain season), and summer (main rain season) rainfall showed a trend (Fig. 5a). However, the coefficient of determination ( $R^2$ ) is lower in the spring rainfall. The  $R^2$  of annual, summer (main rain season), and spring (small rain season) rainfall is 0.36, 0.22, and 0.07, respectively. High variability was received in spring with rainfall ranging from 23 to 306.2 mm ( $CV=57\%$ ) and summer rainfall showed low variability with rainfall ranging from 286.2 to 852 mm ( $CV=22\%$ ) (Table 7). The non-parametric Mann–Kendall's test revealed both the annual and seasonal rainfall had a declining trend (Table 7, Z-test). However, Kendall's tau showed only the annual rainfall showed a strong significant declining ( $P=0.006$ ).

The linear regression model of the mean minimum and maximum annual temperature showed a moderate trend with  $R^2$  of 0.27 and 0.23. Unlike the rainfall trend, both the mean minimum and maximum annual temperature showed an increasing trend (Table 8, Z-test). The Kendall's tau also revealed the trend is statistically significant for both the mean minimum ( $P=0.028$ ) and mean maximum ( $p=0.044$ ) annual temperature (Fig. 5b).



**Fig. 5** **a** Annual rainfall distribution during 1993–2015. Data source: Ethiopian National Meteorological Services Agency. **b** Mean annual minimum (top) and mean annual maximum (bottom) temperature during 1993–2015. Data source: Ethiopian National Meteorological Services Agency

**Table 7** Statistics on rainfall data (1993–2015)

Season	Minimum rainfall (mm)	Maximum rainfall (mm)	SD	Mean	CV (%)	Z-test	Kendall's tau
Annual	547.6	1010.7	138.88	790.44	18	-2.75	-0.42*
Spring	23	306.2	66.97	116.76	57	-0.74	-0.11
Summer	286.2	852	123.41	561.91	22	-1.69	-0.26

CV = coefficient of variation, \*Trend statistically significant at  $p$  value = 0.00602

**Table 8** Statistics on temperature data (1993–2015)

Mean annual	°C	Z-test	Kendall's tau	Coefficient of determination ( $R^2$ )
Minimum temperature	13.36	2.0086	0.31**	0.27
Maximum temperature	24.69	2.1944	0.33*	0.23

\*Trend statistically significant at  $p$  value = 0.028

\*\*Trend statistically significant at  $p$  value = 0.044

## 4 Discussion

### 4.1 LULC change dynamics

An accuracy level of 85% was introduced by (Anderson et al. 1976) and it is now widely accepted and used as a standard in map accuracy assessment. The overall accuracy assessment in our analysis is higher than the accepted standard, and feel comfortable making recommendations based on this analysis. Furthermore, a Kappa coefficient of  $\geq 80\%$  shows strong agreement between classified classes and ground reference data (Taffa et al. 2015).

Throughout Ethiopia, agricultural land is expanding at the expense of other land use types. Hailu et al (2015) showed that 75% of the agricultural land today was covered by vegetation, and indicated that sparse vegetation and grassland were least affected by the agricultural expansion. However, our results revealed that Afroalpine grassland is one of the most rapidly changing land use and land cover classes in Abune Yosef mountain range. This could be due to the grasslands are becoming the target for agricultural expansion. However, research in a similar ecosystem reported agricultural expansion at higher elevation took place at the expense of Afroalpine grassland (Fetene et al. 2014; Jacob, Frankl et al. 2015a, b; Kidane et al. 2012; Nune et al. 2016; Teferi et al. 2013). However, an increase in Afroalpine grassland coverage was reported in some parts of Ethiopia (Tadesse et al. 2017; Urgesa et al. 2016). The deviations could emanate from the management practices applied in the grasslands. An increasing trend of agricultural land and urban settlements cover is observed throughout Ethiopia (Kidane et al. 2012; Nune et al. 2016; Sahle et al. 2016; Teferi et al. 2013; Worku et al. 2016). The Agricultural land expanded mostly at the expense of Afroalpine grassland and shrubland. The urban settlements were expanded at the expense of agricultural land and shrubland. As shown earlier, the population of the study area has increased tremendously which is the cause for the expansion of agricultural land and urban settlements.



Global warming could have also contributed to the expansion of agriculture to higher elevations by making those areas more hospitable to crops. The areas above 3200 m a.s.l. were very cold and didn't support crop growth except for varieties of barley (e.g., *Hordeum vulgare*). However, today even crops such as Beans and Lentils—which are normally cultivated at much lower altitudes—are being grown in higher altitudes, implying that the Afroalpine area is becoming warmer.

The declining trend of shrubland is observed in other parts of the country. Conversion of a large portion of shrubland into agricultural land has been reported throughout Ethiopia (Fetene et al. 2014; Nune et al. 2016; Teferi et al. 2013; Worku et al. 2016) and this trend holds in Abune Yosef mountain range as well. The shrubland was found in low and medium elevations in the study area which is prone to agriculture and settlements. Similar to the present study, Gebrelibanos and Assen (2015) reported declined trend in shrubland cover due to agricultural land and settlement expansion. This could be attributed to the reliance of the people living in this region on woodland and shrubland resources for their construction and firewood needs—there are no other alternatives that provide suitable substitutions. The open woodlands that existed in 1986 were converted almost entirely into shrubland. Data on the important woodland cover dynamics of Ethiopia are very limited. The FAO (2015) estimate of the woodland cover of Ethiopia showed a slight decrease (0.4%) from 1990 to 2015. However, studies at regional, district or watershed level showed contradicting result unlike their counterpart, forests. For example, an increase in woodland cover was reported in some parts of Ethiopia (Tadesse et al. 2017). On the contrary, a decrease in woodland cover was reported in different parts of Ethiopia (Alemu et al. 2015; Nune et al. 2016; Sahle et al. 2016; Taffa et al. 2015). Similar to the present study, a total transformation of woodlands was reported in Gubeta-Arjo, central rift valley of Ethiopia (Garedew et al. 2009). These results are in contrast to a previous study (Nune et al. 2016) which claimed woodland is one of the least affected LULC classes.

The remnant dry evergreen montane forests in the study area are found in the surroundings of the church forests. These forests persist likely because harvesting trees is prohibited in the church forests. Wassie and Teketay (2006) described Ethiopian Orthodox church forests as a safe haven for biodiversity, and indeed, there has been no significant church forest cover change in the present study. However, Ericaceous forest/shrubland showed very slight declines. Ericaceous forest/shrubland is found at high slopes, which may have prevented its conversion to agriculture, as these areas are not conducive to growing crops. The importance of hilly terrain for preserving vegetation was also reported in southcentral Ethiopia (Wassie and Teketay 2006). Forest change detection study based on historical images in Lib Amba mountain showed loss of 63% forest between 1982 and 2010 as a result of increasing population (Jacob Romeyns et al. 2015a, b).

In contrast to the other forest types in the study area, plantation forest showed a dramatic increase in its cover. This is likely due to two reasons. These are the loss of woodlands and shrinkage of shrublands; and the fact that some conservation and restoration practices have prohibited the utilization of woody plants from shrublands. Both of which may have caused local people to plant more plantations forests. The increasing trend of plantations (mainly *Eucalyptus* spp.) has been reported throughout Ethiopia (de Mûelenaere et al. 2014; Jacob, Romeyns et al. 2015a, b).

Conversion of communal grazing lands into agricultural lands was reported in Ethiopia (Gebremedhin et al. 2018; Worku et al. 2016), and this is also occurring in the study area. Most of the grazing land that existed in 1986 was converted into agricultural lands mainly due to the need for securing food for the rapidly growing population. The remnant grazing land is found in very small fragments in higher elevations, and some of it has converted

to barren land. Overgrazing and/or trampling by livestock tends to disturb the herbaceous layer and is likely a driver of barren land conversion.

The large barren land cover in the study area is attributed to the volcanic and rocky nature of the mountains, and these results contradict claims by Worku et al. (2016) of a decreasing trend of barren land in the Beressa watershed northern central highland of Ethiopia. In 1986, gullies were restricted to large rivers and riverbeds. In 2017, however, gullies had expanded everywhere including into agricultural land. The gullies correspond to land use change and deforestation. Apart from changing the landscape mosaics, gullies can cause loss of cropland, accelerate aridification by increasing the drainage (Nyssen et al. 2004; Valentin et al. 2005). The increasing trend of riverbeds was reported by Jacob, Romeyns et al (2015a, b) in Lib Amba mountain northern Ethiopia.

## 4.2 Major drivers of LULC change dynamics

In the era of Anthropocene; rapid population growth and climate change have a strong influence on LULC change dynamics. Nevertheless, failure to use ecosystem services sustainably could have also a crucial role. The causes of LULC change dynamics are examined and explained.

Experts in the field attributed the LULC change dynamics to the rapidly growing population (Meyer and Turner II 1990, 1992; Turner II et al. 1994; Turner II et al. 1995). The population in developing countries such as Ethiopia is almost entirely dependent on natural resources which leads to resource deterioration and deforestation. The population of the study area showed a tremendous increase in 31 years. Although rapid population growth is one of the primary drivers of LULC change, it is not necessarily the root cause of LULC change rather it is the absence of land use policy that engages conservation efforts and practices.

In Africa, deforestation and unsustainable utilization of natural resources are the main causes of LULC change (Waweru et al. 2016). Agricultural expansion and settlements at the expense of other natural land use types and deforestation without restoration are some examples of unsustainable land management. The complete conversion of woodland into shrubland and agricultural land in the present study is a typical example of unsustainable utilization.

Human-induced climate change has also its own share. Recently published article by Guo et al (2018) revealed that land use change interacts with climate. Analysis of temperature trend in Ethiopia for the year 1983–2013 showed that temperature has already increased by 0.0265–0.1112 °C per year in Ethiopian highlands since 1983 (Mekonnen 2017). Precipitation also showed a decreasing trend. The variability was pronounced in mountains with elevation > 2000 m a.s.l. Thus, human-induced climate change is also affecting the LULC, particularly vegetation cover, of the study area due to the temperature and rainfall variability.

Although the Afroalpine vegetation is designated as a community conservation area, the response of the people in the community and the government is very limited. During the course of the study, we noticed that conservation and restoration practices, particularly, in the Afroalpine vegetation are ignored.

Lack of alternatives and absences of land use policy, not lack of awareness is forcing the community to utilize resources in every possible way. Socioeconomic survey research by Eshete et al (2015) showed that people living in the Afroalpine areas perceived the need of protecting the Afroalpine vegetation. However, the trade-off between ecosystem services

and human population is not an easy task. It is the question of feeding the human population or conserving nature (Cazalis et al. 2018).

### 4.3 Implications of the observed land use and land cover changes: biodiversity conservation and soil erosion

Vegetation, especially forests, woodlands, shrublands, and grasslands serves as habitat for several wild animals. It also hosts several endemic plants and animals. The Afroalpine grassland is particularly for the endemic and endangered Ethiopian wolf (*Canis simensis*), several endemic birds, and mammals (Saavedra, Díaz et al. 2009a; Saavedra, Such-Sanz et al. 2009b). Furthermore, several endemic species such as *Lobelia rhynchopetalm*, *Primula verticillata*, *Becium grandiflorum*, *Cineraria sebaldei*, *Euryops pinifolius*, and *Inula confertiflora* are found in the mountain range (Gebrehiwot et al. 2019). An assessment of plant conservation status in the mountain range also showed most of the plants are rare and few species are in the IUCN Red List (Gebrehiwot et al. under review). The apparent cause is the declining of vegetation cover due to the transformation of forests, woodlands, shrublands, and grasslands into other land cover classes. Hence, policy developers and decision makers might consult this study for the effective management of biodiversity in the study area. Furthermore, the local community may refer this research to initiate conservation planning and prioritization.

Scanty vegetation is extremely exposed to soil erosion. Even though the user's and producer's accuracy is low in comparison to the other LULC classes, Barren land and Rivers, Riverbeds and gullies showed an increasing trend in the study time. Moreover, agricultural land expanded at the expense of other LULC classes such as shrubland and the Afroalpine grassland. Hence, the land use and land cover classes that are devoid of vegetation are potentially vulnerable to soil erosion in the future provided that conservation measures are not implemented. River beds and gullies are indicators of severe land degradation (Morgan 1995). Thus, it is possible to envisage the study area is prone to land degradation. This is also a common phenomenon in Ethiopia. As estimated by Gebreselassie et al. (2016), land degradation associated with LULC change is responsible for the annual loss of about \$4.3 billion in Ethiopia.

Considering complementary nature of biodiversity, land degradation, and economy, the implications of the observed land use and land cover changes could help to understand the trade-off of these situations. The implications are significant both nationally and globally.

## 5 Conclusion

The study revealed there is substantial land use and land cover change. All land use and land cover classes except church forest in the study area showed either positive or negative changes. Generally, agricultural land, barren land, urban settlements, plantation forest, and rivers, riverbeds, and gullies showed an increasing trend. On the contrary, shrubland, open woodland, grazing land, and Afroalpine grassland showed a decreasing trend. Ericaceous forest/shrubland, however, showed modest change. Rapid population growth and climate variability are the main drivers of land use and land cover change dynamics. Pressures such as settlements, agricultural expansion, deforestation, and unsustainable utilization of resources impacted the ecosystem goods, functions, and services which leads to loss of vegetation cover, and land use and land cover transformation.

The Afroalpine grassland is critically shrinking in size. This would definitely have a pronounced impact on the ecosystem and livelihood of the people. Thus, cautiously protecting this land use and land cover class by establishing a buffer zone is recommended. Abune Yosef though its nomenclature is a community conservation area; it is managed by the local government. Either the community or the government, like other protected areas in the country, should take a responsibility to safeguard Abune Yosef Afroalpine grassland.

Furthermore, restoring the barren land and reducing soil erosion and gully formation could also have a crucial role in restoring the extremely degraded mountain range. Policy developers, decision makers, and local communities may refer this study to develop conservation planning and prioritization to ensure sustainable resource utilization.

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