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RESEARCH ARTICLE

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An insight into land use and land cover changes and their impacts in Rib watershed, north-western highland Ethiopia

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Abstract

Land use and land cover (LULC) changes have severely threatened ecological and economic sustainability in highland Ethiopia. A clear insight into its extent and rate is, therefore, a crucial step for effective land use planning and decision making. The main objective of this study was to analyse the nature of LULC change and its impacts in north-western highland Ethiopia over the last four decades, using the integrated approach of remote sensing and geographic information system in combination with field data. Multidate Landsat images were used for spatio-temporal change detection through the help of ArcGIS 10.3 and ERDAS IMAGINE 2014 software. A pixel-based statistical analysis was used to measure class-to-class changes and total losses and gains of each LULC class during the study period. The results show that a significant and widespread change of LULC has occurred in the study area during the period 1973–2016. The cropland, grassland, and shrubland were the dominant LULC types taking more than 95% in total over the entire study period. The cropland and built-up land showed a significant increase from 1973 to 2016, whereas grassland and shrubland decreased gradually over the same time period. The LULC change in the study area has caused severe environmental degradation, which in turn has affected ecological sustainability, agricultural productivity, food security, and rural livelihoods. The results of this study are expected to provide local-level current information on the extent, rate, and impacts of LULC change for decision makers seeking to ensure ecological, social, and economic sustainability.

KEYWORDS

GIS, highland Ethiopia, land use and land cover change, LULC change impacts, remote sensing

1 | INTRODUCTION

In recent years, the increase in human population and associated demands has exerted a high pressure on global ecological systems (Nigatu, Dick, & Tveite, 2014). The land use and land cover (LULC) change is considered to be one of the major driving forces of transformation in ecosystem function (Alphan, Hakan, & Yüksel, 2009; Meshesha, Tsunekawa, Tsubo, Ali, & Haregeweyn, 2014; Molders, 2012; Wubie, Assen, & Nicolau, 2016). Even though LULC change is global in both extent and impacts (Aspinall & Hill, 2008), its severity is more pronounced in developing countries where a large proportion of the human population depends almost entirely on land and its resources for their daily activities (Mwavu & Witkowski, 2008; Miheretu & Assefa, 2017). The rapid dynamics and severe impacts of LULC change in developing countries are highly attributed to low rate of economic growth and increasing demand for agricultural and residential areas at the expense of vegetation cover. The low rate of economic growth indicates low adaptive capacity and, therefore, high vulnerability to the impacts of LULC changes (Vadrevu, Chris, Thenkabail, Narasimha, & Garik, 2015).

Although humankind has changed the global landscape since time immemorial, its acceleration was more witnessed during the last

30 years (Lambin & Geist, 2006). The change in global landscape is always caused by complex and interacting factors resulting from social, economic, and biophysical corners (Brouwer & McCarl, 2006; Kamusoko & Aniya, 2007; Lambin, Geist, & Lepers, 2003). Several studies indicated that both natural and anthropogenic forces have highly changed the dynamics of LULC types throughout the world. However, in recent decades, anthropogenic LULC change has been proceeding much faster than natural (Giri, 2012). Furthermore, a study by Lambin et al. (2003) outlined that institutional, technological, and cultural factors combined with globalization accelerated the impacts of LULC change over the last few decades. The LULC change caused by these and other related drivers has important local, regional, and global impacts on the functioning of socio-economic and environmental systems (Li, Ma, Xu, Wang, & Zhang, 2009).

The timely and accurate detection of change in landscape is essential to better understanding of human–environment interaction (Lu, Mausel, Brondizio, & Moran, 2004; Lambin & Geist, 2006; Dewan, Yamaguchi, & Ziaur, 2012; Butt, Shabbir, Ahmad, & Aziz, 2015) and improve resource management and decision making (Liu, Hu, Chang, He, & Zhang, 2009; Garedew, Sandewall, Söderberg, & Campbell, 2009; Brouwer & McCarl, 2006). The adequate and reliable LULC change information from the past to the present combined with the future plausible changes enables a better understanding of the change impacts on social, economic, and ecological sustainability. Although many ecosystem processes are difficult to observe directly, remote sensing enables prediction and modelling of the extent and rate of LULC change with high certainty by using multitemporal remotely sensed data (Lu et al., 2004). The integration of remote sensing and geographic information system has been frequently used by many types of research and ascertained as indispensable tools and approaches in the assessment of LULC change (Al-Bakri, Duqqah, & Brewer, 2013; Appiah, Schröder, Forkuo, & Bugri, 2015; Dewan et al., 2012). Remote sensing serves as the source of quick, repetitive, and useful data of the earth surface, whereas geographic information system enables integration, storage, analysis, display, and management of multithematic data necessary for change detection (Reis, 2008).

As in the other parts of the world, Ethiopia also faces serious problems of LULC change for long centuries (Getachew & Melesse, 2012; Meshesha et al., 2014; Wubie et al., 2016), usually accompanied by rapid population, urban growth, and poor land use planning. Many recent studies conducted in various parts of Ethiopia (Getachew & Melesse, 2012; Kidane, Stahlmann, & Beierkuhnlein, 2012; Kindu, Schneider, Teketay, & Knoke, 2015; Meire et al., 2013; Meshesha et al., 2014; Shete, Rutten, Schoneveld, & Zewude, 2016; Wubie et al., 2016; Yeshaneh, Wagner, Exner-Kittridge, Legesse, & Blöschl, 2013) have indicated worrying trend of LULC change and its socio-economic and environmental implication. The LULC change is particularly severe in the highlands of Ethiopia where rain-fed subsistence agriculture is the source of livelihood and the base of economic development (Garedew, Sandewall, & Soderberg, 2012). The most proximate implication and negative consequence of this rapid LULC change in the highland areas is severe environmental degradation in the form of soil erosion, soil quality deterioration, loss of biodiversity, habitat distraction and species transfer, and decreasing availability of water (Wubie et al., 2016, Miheretu & Assefa, 2017, Hassen & Assen, 2017; Hassen, Mohammed, Assefa, & Tena, 2015; Tsehaye & Mohammed, 2013). Moreover, a study by Minale and Rao (2012) indicated that LULC change has significantly caused local and regional climate change in the north-western highland of Ethiopia.

The Rib watershed of north-western highland Ethiopia forms one of the seriously degraded areas of the country, mainly caused by dynamic LULC change. Despite the occurrence of severe LULC change and its manifold impacts, there have been limited studies in the area. Therefore, a clear insight into the LULC change scenarios and the resulting impacts is very crucial, which could help in the formulation of better land management strategies and decision-making processes. In this paper, an attempt has been made to analyse and monitor the LULC change in Rib watershed using multitemporal Landsat data for the years 1973, 1986, 2001, and 2016. The study also assessed the impacts of LULC change on ecological and socio-economic conditions of the study area.

2 | MATERIALS AND METHODS

2.1 | Study area

The Rib watershed, which forms part of north-western highlands of the Blue Nile Basin of Ethiopia, lies between 11°40′–12°20′N latitude and 37°30′–38°20′E longitude (Figure 1). It has the total area of 1,975 km^2 stretched from Mount Guna to Lake Tana. The watershed is the main source of water for Lake Tana, which together with Gumara, Megech, and Gilgel Abay contribute more than 90% of inflow water (Dile, Berndtsson, & Setegn, 2013). The elevation ranges from 1,758 to 4,104 masl. In administrative terms, it is located in Amhara Regional State and comprises four districts of South Gondar Zone: Farta, Fogera, Libo Kemkem, and Ebenat. The topography of the study area is generally increasing in elevation from the downstream to the upstream. A mountainous and hilly dissected terrain with steep slopes characterizes most parts of the watershed.

The study area is characterized by the humid climatic condition. The annual rainfall is highly erratic in distribution where more than 70% of the total rainfall falls in the months of June to September. The weather data of the last ~44 years (1973–2016) collected from the Ethiopian National Meteorological Agency showed high spatial and temporal variation in both rainfall and temperature in the study area. An annual rainfall ranged from 1,040 to 2,151 mm, with mean annual rainfall of 1,502 mm, whereas the mean annual temperature over the same period ranged from 14.95 to 16.4°C. The climatic pattern of the study area can be categorized into three major seasons: main rainy season locally known as *Kiremt* (June to September), a dry season or *Bega* (October to February), and small rainy season or *Belg* (March to May). During *Kiremt* season, the maximum amount of rainfall (more than 85% of total rainfall amount) occurs in the months of July and August.

On the basis of the census result conducted by the Central Statistical Agency of Ethiopia (Central Statistical Authority, 1994, 2007), the total population of the watershed was 352,216 in 1994 with the corresponding population density of 178 persons per km^2 and 376,256 in 2007 with the corresponding population density of 190 persons per km^2. Rainfed agriculture is the main source of

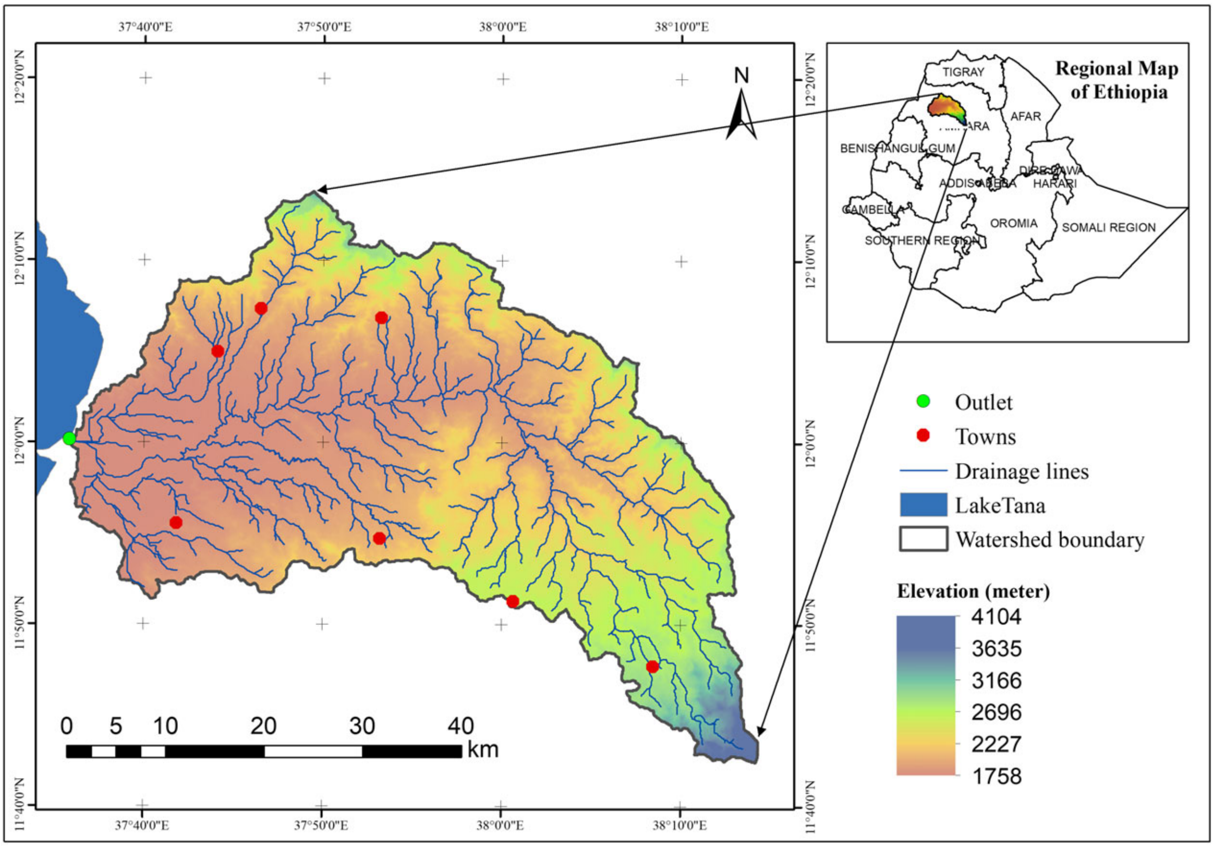

FIGURE 1 Geographical location map of the study area [Colour figure can be viewed at wileyonlinelibrary.com]

livelihood for more than 95% of the watershed communities. Agriculture in the study area is characterized by mixed crop–livestock production and subsistence farming. The major rainfed cereal crops grown in the area include barley (*Hordeum vulgare*), wheat (*Triticum vulgare*), tef (*Eragrostis tef*), maize (*Zea mays*), and oats (*Avena sativa*) and legumes like beans (*Vicia faba*) and pea (*Pisum sativum*). The common types of domestic animals raised in traditional farming include cattle, goats, sheep, donkeys, horses, mules, and chickens. The main sources of food for livestock production are communal and private grazing lands. However, in recent years, zero-grazing practices where the grass is mechanically mown and brought to cattle have become a much more appreciable practice in order to reduce the impacts of free grazing on land degradation.

2.2 | Satellite image data

The time-series remotely sensed images were the main sources of input data for LULC analysis in this study. The multitemporal Landsat images of the years 1973, 1986, 2001, and 2016 with a path/row of 182,169/052 (Table 1) were downloaded from the United States Geological Survey webpage. The images were downloaded at about approximately 15 years' interval to easily visualize the spatio-temporal changes in LULC pattern. However, some ±2-year divergence was considered due to the availability and quality of Landsat images for the area of interest. All satellite images used in this study were geometrically corrected and projected on to a common coordinate system (WGS 84 datum, UTM Zone 37N). To reduce the spectral confusion and error during change detection, the images acquired in ideal condition with minimal cloud cover were utilized. The characteristics of satellite images used in this study are indicated in Table 1.

TABLE 1 Characteristics of Landsat images used in this study

Path/row	Acquisition date	Data type	Band	Pixel size (m)
182/052	February 1, 1973	Landsat 1 MSS	3, 2, 1	60 × 60
169/052	January 28, 1986	Landsat 5 TM	4, 3, 2	30 × 30
169/052	January 13, 2001	Landsat 7 ETM+	4, 3, 2	30 × 30
169/052	January 17, 2017	Landsat 8 OLI	5, 4, 3	30 × 30

Note. MSS: Multispectral Scanner; TM: Thematic Mapper; ETM+: Enhanced Thematic Mapper Plus; OLI: Operational Land Imager. *Source*. U.S. Geological Survey (https://earthexplorer.usgs.gov/).

2.3 | Field survey data

The socio-economic, biophysical, and institutional data were collected through questionnaire, focus group discussions (FGDs), field observations, and key informant interviews carried out between November 2016 and May 2017. These data were used for the analysis of the drivers and impacts of LULC change and to substantiate the information obtained from satellite imagery. A systematic random sampling technique was used to obtain 210 respondents from randomly selected four villages of the watershed. Although the size of sample households included in the field survey was relatively small (due to various reasons such as financial constraints), intensive group discussions, key informant interviews, and field observations were conducted to gather additional data and validate the results from geospatial analysis and the household survey data.

The household survey was conducted using semistructured questionnaire and covered detailed information about socio-economic, biophysical, and institutional aspects of the watershed. A presurvey test was also conducted in each village to customize the questions to local conditions. The list of households was obtained from local and zonal agricultural offices. Intensive field observations were conducted to gather deep information on the major LULC classes, settlement pattern, farming system, landforms of the watershed, and so forth. The well-experienced and knowledgeable local people including the watershed committee, village administrators, elderly farmers, and extension workers were purposely selected and included in FGDs and key informant interviews.

2.4 | Image preprocessing

The main objective of image preprocessing is to improve the image data that suppress unwilling distortion or enhance some image features important for further processing. In this study, several image preprocessing activities like layer stacking, subsetting, resampling, and image correction were carried out using ERDAS IMAGINE 2014 software prior to image classification and change detection. The Landsat Multispectral Scanner image of 1973 with a pixel size of 60 × 60 m was resampled (downsampled) into a pixel size of 30 × 30 m using the nearest neighbour method to make its pixel size identical with the latest image pixels. A radiometric correction was undertaken to minimize the effect of atmospheric factors.

2.5 | Classification scheme

The LULC classification system of Anderson, Hardy, Roach, and Witmer (1976) was adopted in this study to identify the LULC classes. The basic concepts and structures of this system are still valid today (Biro, Pradhan, Buchroithner, & Makeschin, 2013) and used by many researchers worldwide. This system is normally hierarchically structured with several levels with various degree of detail and contains criteria to distinguish LULC classifications from one another. However, due to the low resolution of satellite images available, only six dominant first-level (Level I) LULC classes including cropland, grassland, shrubland, forestland, built-up land, and waterbody were considered in this study as defined in Table 2.

TABLE 2 The land use and land cover indicators, categories, and description

Indicator	Class name	Description
Vegetation features	Cropland	Areas used for crop production, both annual and perennials. These areas can be planted or bare lands (before the crop cover)
	Grassland	Areas covered with herbaceous species and permanent grass with a low occurrence of shrubs. The bare lands, which are highly degraded, were also grouped under this class due to the difficulty to distinguish
	Shrubland	Areas covered by scattered small trees, shrubs, and bushes and mixed with grass vegetation
	Forestland	Areas covered with dense growth of trees, both natural and man-made, which formed nearly closed canopies (70–100%)
Built-up features	Built-up land	Areas with all types of artificial surfaces including residential areas and urban land. This class also comprises open areas for residential development, roads, paved-over areas, and any infrastructures
Hydrology	Waterbody	The area covered by water (ponds, lakes, rivers, and marshlands)

Similar to the procedure used by Alphan et al. (2009), the areas covered with forest, grass, crop, and shrublands of the watershed were described on the basis of vegetation indicator, and the urban/construction areas and waterbody were described on the basis of built-up and hydrology indicators, respectively (Table 2). The settlement and urban areas were included in the same LULC class, that is, built-up land, due to the difficulty to separate them. The authors' knowledge of the study area and the information gathered from key informants (agricultural experts and elder farmers) were also taken into consideration while grouping LULC classes.

After identifying and defining the LULC classes, image classification was done through both unsupervised and supervised classification techniques. Unsupervised (ISODATA clustering algorithm) classification was used in the first step of the analysis in order to reduce spectral variation in the scenes arising from the complex pattern of land cover (Alphan et al., 2009). In the second step, supervised image classifications were applied using maximum likelihood decision rules (Lillesand & Kiefer, 2000). About 473 reference points collected during the field survey period were used as training sites, and numerical description of the spectral attributes has been developed for each LULC type of interest in the scene.

2.6 | Classification accuracy assessment

One of the first steps in making LULC products useful is to evaluate its quality (Giri, 2012). The LULC maps generated from satellite images always contain some sort of errors originated from several sources, such as classification techniques and methods of image acquisition. As a result, postclassification refinement is needed to improve classification accuracy and reduce errors (Butt et al., 2015) and increase the quality of the information (Biro et al., 2013). In this study, different image accuracy assessment techniques were used to check the precision of the classified images. For the years 1973, 1986, and 2001, the accuracy was assessed through visual interpretation of unclassified satellite images (Biro et al., 2013) and using the farmers' memory of land use history. For the year 2016, several ground control points consisting of different LULC features and their location points were collected using a hand-held Global Positioning System, and the ground control points were used as reference data.

The stratified random sampling method was used to represent different LULC classes and reduce the bias effects. Reference pixels of 241, 282, 215, and 225 representing a geographic location on the classified images were randomly collected for the years 1973, 1986, 2001, and 2016, respectively, and used for accuracy assessment. The comparison of ground truth data and classification results was carried out statistically using error matrices plotted as cross-tabulations. Then, producer accuracy or error of exclusion (i.e., pixels that belong to the truth class but fail to be classified into the proper class), user accuracy or errors of inclusion (i.e., pixels that belong to another class but are labelled as belonging to the class), and overall accuracy (i.e., the total classification accuracy) were computed statistically.

The overall accuracies of 84%, 84%, 85%, and 86% were obtained for images of 1973, 1986, 2001, and 2016, respectively. The producer and user accuracies in all thematic maps ranged from 80% to 92% and 80% to 100%, respectively. In addition to error matrix, a nonparametric kappa test was used to measure the extent of classification accuracy. The kappa statistic measures the degree of agreement between predefined producer ratings and user-assigned ratings (Altaye, Donner, & Eliasziw, 2001; Butt et al., 2015). An important component of kappa statistics is its ability to take into account the amount of agreement expected between raters purely by chance (Nichols, Wisner, Cripe, & Gulabchand, 2010). The kappa test is computed by using Equation (1) (Anthony & Joanne, 2005; Nichols et al., 2010):

$$\kappa = \frac{N * \sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+} * x_{+i})}, \quad (1)$$

where κ is the kappa coefficient, r is the number of rows in the matrix, x_{ii} is the number of observations in row i and column i, x_{i+} are the marginal totals of row i, x_{+i} are the marginal totals of column i, and N is the total number of observations.

The kappa value lies between −1 and 1, where 1 is perfect agreement, 0 is exactly what would be expected by chance, and negative values indicate agreement less than chance (potential systematic disagreement between the observers; Anthony & Joanne, 2005). The detailed breakdown of kappa values and their interpretation is indicated in the research report by Landis and Koch (1977), that is, the kappa value of <0 denotes “less than chance agreement,” kappa of 0 is “poor agreement,” kappa of 0.01–0.20 is “slight agreement,” kappa of 0.21–0.40 is “fair agreement,” kappa of 0.41–0.60 is “moderate agreement,” kappa of 0.61–0.80 is “substantial agreement,” and kappa of 0.81–0.99 is “almost perfect agreement.” In this study, the kappa values of 80% and above were computed for the years under study (1973, 1986, 2001, and 2016) and used for further image analysis. Table 3 summarizes the statistical results of image classification accuracy of each LULC class during the entire study period.

2.7 | Change detection

The main objective of change detection is to compare the spatial representation of two points in the time by controlling all other variances caused by differences in variables that are not of interest (Lu, Moran, Hetrick, & Li, 2011). Change detection involves the application of multitemporal datasets to quantitatively analyse the temporal effects of the phenomenon (Biro et al., 2013; Lu et al., 2004). Different change detection algorithms have been developed recently. The two most commonly used detection algorithms are principal component analysis and postclassification comparison (El-Hattab, 2016; Lu et al., 2004). Postclassification change detection technique does not only give the size and distribution of changed areas but also gives the percentage of other LULC classes, which are included in change detection process (El-Hattab, 2016; Mwavu & Witkowski, 2008). As a result, a multidate postclassification change detection technique was adopted in this study to compare the changes in different LULC classes.

The “from–to” change information and the area of transformation were determined for LULC classes in four study periods: 1973–1986, 1986–2001, 2001–2016, and 1973–2016. The classified image pairs of consecutive years were compared using cross-tabulation in order to determine quantitative and qualitative aspects of the change (Alphan et al., 2009). The percentages of change for each LULC class were calculated by using Equation (2) (Hassen & Assen, 2017; Meshesha et al., 2014):

$$C = \frac{A_{t_2} - A_{t_1}}{A_{t_1}} * 100, \quad (2)$$

where C is change in per cent, A_{t_1} is the area of one type of land use in t_1 time, and A_{t_2} is the area of the same type of land use in t_2 time. The negative and positive values indicate a decrease and increase in the size of LULC classes, respectively. The overall procedures employed for classification and change detection are illustrated in Figure 2.

TABLE 3 Accuracy assessment (in %) of LULC maps (1973–2016)

LULC class	1973		1986		2001		2016	
	Producer	User	Producer	User	Producer	User	Producer	User
Cropland	85	84	83	86	87	89	91	88
Grassland	80	83	83	80	82	82	82	86
Shrubland	84	86	84	81	82	82	83	83
Forestland	88	82	88	90	87	84	83	81
Built-up land	92	85	83	80	83	83	80	80
Waterbody	86	92	88	100	92	85	87	100
Overall accuracy	84		84		85		86	
Kappa statistic	80		80		81		82	

Note. LULC: land use and land cover.

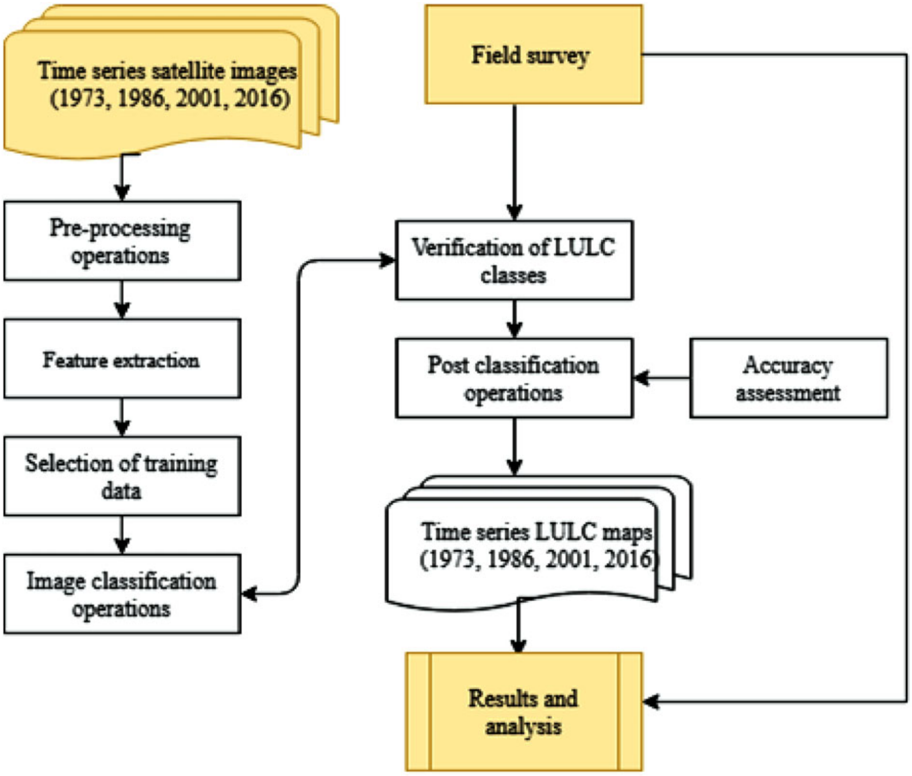

FIGURE 2 Workflow chart. LULC: land use and land cover [Colour figure can be viewed at wileyonlinelibrary.com]

3 | RESULTS AND DISCUSSION

3.1 | Patterns of land use and land cover change

The LULC maps of the study area for the four reference years are given in Figure 3. The trend analysis made for three consecutive periods 1973–1986, 1986–2001, and 2001–2016 has indicated the existence of several spatio-temporal changes in LULC classes. As indicated in Figure 3a, there was no more human influence on the study watershed during the 1970s. The upstream and downstream parts of the watershed were significantly covered with dense grasses and shrubs. However, the cropland and built-up areas stretched to a higher altitude and caused the drop-down of areas in shrubland and grassland in 1986, 2001, and 2016 (Figure 3b–d).

The areal extent of different LULC classes and their rate of change during the study period are summarized in Tables 4 and 5. In all study points in time, the cropland, built-up land, forestland, and waterbody showed a progressive increase. However, grassland and shrubland showed a continuous decline. The overall change detection matrix for the initial year (1973) and the final year (2016) was computed to measure class-to-class changes and total losses and gains of each LULC type (Table 6). The change detection matrix results indicate that most of the LULC classes have lost some of their previous areas and, in turn, gained some area from other classes. As depicted in Table 6, the net change (gain minus loss) was positive for cropland, forestland, built-up land, and waterbody and negative for grassland and shrubland. About 1,445 km^2 (i.e., the sum of main diagonal) of the total landscape was remained unchanged between 1973 and 2016.

3.1.1 | Cropland change analysis

Cropland was the most dominant LULC type in the study area during the entire period of study with the share of 75% (1,489 km^2), 77% (1,532 km^2), 85% (1,685 km^2), and 88% (1,737 km^2) of the total area of the watershed in 1973, 1986, 2001, and 2016, respectively (Table 4 and Figure 4a). The change detection analysis results (Table 6) indicate that from the total of 1,489 km^2 that was cropland in 1973, 1,371 km^2 remained as cropland in 2016, and the remaining 118 km^2 was changed into grassland (55 km^2), shrubland (14.5 km^2), forestland (26 km^2), and other LULC types. However, the loss of cropland to these LULC classes was compensated with a gain from grassland (219 km^2), shrubland (122 km^2), and other LULC types (23.67 km^2). During the whole study period, cropland gained 365 km^{2}and lost 118 km^2, which led to the net change of 247 km^2 (Table 6).

As it was outlined by participants in FGDs, the major reason for the expansion of cropland was attributed to population growth and associated demand for agricultural lands at the expense of grass and shrublands. The result of change detection matrix also confirmed that from the total of 365 km^2 land gained by cropland between 1973 and 2016, about 341 km^2 (93.4% of total gain) was from grassland and shrubland. Numerous studies conducted in the north-western highlands of Ethiopia (Hassen & Assen, 2017; Minale & Rao, 2012; Sewnet, 2015) also cited population growth as the basic cause for conversion of vegetated areas into cropland. For example, a study by Sewnet (2015) in Infraz watershed, north-western highlands of Ethiopia, revealed that areas under cropland and settlement increased from 4,492 ha in 1973 to 11,177 ha in 2011.

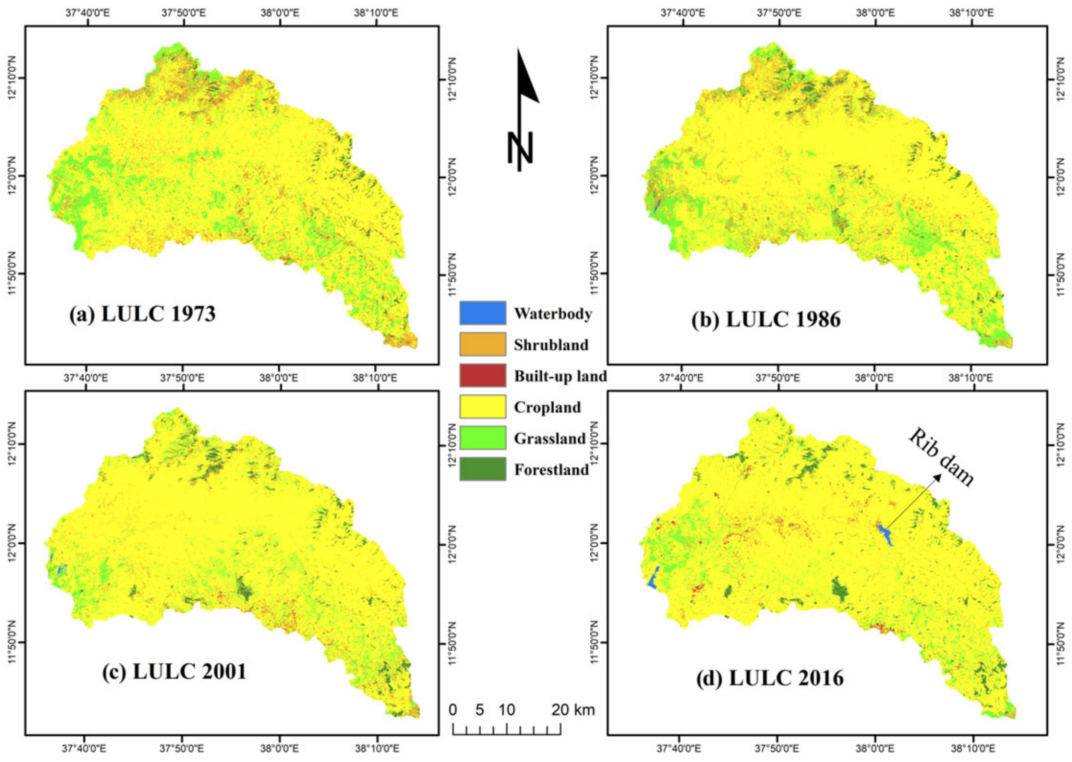

FIGURE 3 Land use and land cover (LULC) maps for the years 1973, 1986, 2001, and 2016 [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 4 Area and percentage of LULC classes between 1973 and 2016

	1973		1986		2001		2016	
LULC class	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Cropland	1,489	75.39	1,531.7	77.55	1,685	85.32	1,736.5	87.92
Grassland	277	14.03	241.6	12.23	145.5	7.37	118	5.97
Shrubland	163.5	8.28	142	7.19	77	3.9	25	1.27
Forestland	40	2.03	51	2.58	55	2.78	68	3.44
Built-up land	5	0.25	8	0.41	11	0.56	21	1.06
Waterbody	0.5	0.03	0.7	0.04	1.5	0.08	6.5	0.33
Total	1,975	100		1,975	100		1,975	100

Note. LULC: land use and land cover.

TABLE 5 Rate of change in LULC classes between 1973 and 2016

	1973–1986		1986–2001		2001–2016		1973–2016	
LULC class	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Cropland	43	2.87	153	10	52	3.06	248	16.62
Grassland	−35	−12.78	−96	−39.77	−28	−18.9	−159	−57.40
Shrubland	−22	−13.15	−65	−45.77	−52	−67.53	−139	−84.70
Forestland	11	27.50	4	7.84	13	23.64	28	70
Built-up land	3	60	3	37.50	10	90.91	16	320
Waterbody	0.2	40	1	114.28	5	333.34	6	1,200

Note. LULC: land use and land cover.

The growth of cropland during the second period of study (1986–2001) was 3%, whereas its growth was 10% during the third period (2001–2016). This implies that there has been reducing tendency of cropland expansion in the watershed over the last few years, which might be most probably due to improved land use and management conditions through participatory watershed management approach. This result agrees with recent findings by Nyssen et al. (2008) and Haregeweyn, Fikadu, Tsunekawa, Tsubo, and Meshesha (2012), which revealed the increasing improvements in surface cover and land management in the northern highlands of Ethiopia as a result

TABLE 6 The LULC transition matrix (km²) for the period 1973–2016

	From initial state (1973)							
	CL	GL	SL	FL	BL	WB	Total	Gain
To final state (2016)								
CL	1,371	219.45	122.32	18.78	4.45	0.44	1,736.5	365.44
GL	55	48.65	14.65	0.2	0.18	0.01	118	70.04
SL	14.55	2.33	6.98	1.1	0.03	0.01	25	18.02
FL	26.65	3.8	17.72	19.7	0.00	0.02	68	48.19
BL	17.28	2.11	1.00	0.29	0.33	0.00	21	20.68
WB	4.64	0.66	1.13	0.00	0.01	0.03	6.5	6.44
Total	1,489	277	163.5	40	5.00	0.51		
Loss	118	228	156.82	20.37	4.67	0.48		
Net change	247	−158	−138.8	27.82	16.01	5.96		

Note. LULC: land use and land cover; CL: cropland; GL: grassland; SL: shrubland; FL: forestland; BL: built-up land; WB: waterbody.

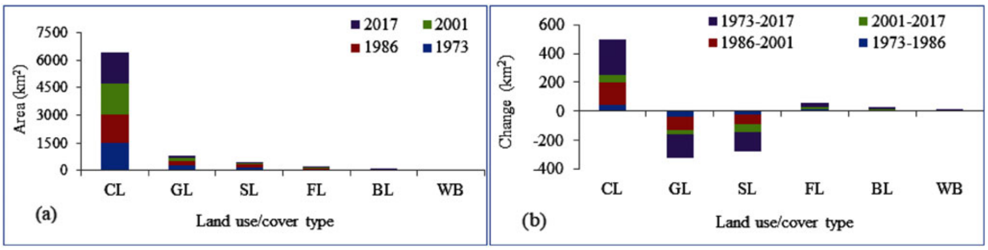

FIGURE 4 (a) Trend of land use and land cover dynamics for the years 1973, 1986, 2001, and 2017; (b) rate of change in LULC during the periods 1973–1986, 1986–2001, 2001–2017, and 1973–2017. CL: cropland; GL: grassland; SL: shrubland; FL: forestland; BL: built-up land; WB: waterbody [Colour figure can be viewed at wileyonlinelibrary.com]

of the improved agricultural system and full participation of local community at all stages of the watershed management system.

3.1.2 | Grassland and shrubland change analysis

Grassland and shrubland were the second and the third largest LULC types in the watershed, respectively, next to cropland (Table 4 and Figure 4a). Unlike other LULC classes, the area under grassland and shrubland showed a persistently declining trend (Figure 4b). The area under grassland reduced from 227 km² (14%) in 1973 to 118 km² (6%) in 2016, and shrubland reduced from 164 km² (8.3%) to 25 km² (1.27%) during the same time period. Grassland and shrubland retained only 48.65 and 7 km² in 2016 from their total area of 227 and 164 km² in 1973, respectively (Table 6). The net change for grassland between 1973 and 2016 was negative (−158 km²), with the total gain of 70 km² and total loss of 228 km². Similarly, shrubland gained 18 km² and lost 156.8 km² (i.e., 138.8 km² net loss) during the same time period.

As explained elsewhere in this paper, the expansion of cultivated land was the main reason for continuous shrinkage of grassland and shrubland. The change detection matrix result indicated that about 219.45 km² of grasslands (79.2% of its total in 1973) and 122.32 km² of shrublands (75% of its total in 1973) were shifted to cropland between 1973 and 2016. The participants in FGDs and key informant interviews outlined that a significant part of grassland and shrubland were reallocated to landless farmers and changed to cropland during the last four decades. The illegal expansion of cropland to the adjoining vegetation area was also outlined as the basic reason of reduction in grassland and shrubland. The trend of decline in shrubland was observed to be close to constant rate during the three stages of the studied period.

Contrary to shrubland, the rate of loss in grassland was relatively slight during the time period 2001–2016 (28 km², 18.9% loss) compared with the period 1986–2001 (96 km², 39.77% loss; Table 5 and Figure 4b). This trend of change in grassland indicates that its shrinkage is slackening off, which might be highly attributed to better management of grasslands by the local community and government bodies. The results of field survey also confirmed that most of the farmers have been practicing cut-and-carry livestock feeding mechanism and area exclosures to restore the disappearing plant species and improve grass cover. The slight transformation of grasslands between downstream and upstream areas was also observed during the periods of analysis. For example, the area of grassland increased upstream and decreased downstream in 1986 compared with the year 1973. On the other hand, the grass cover increased downstream and decreased upstream in 2016 compared with the year 2001. This slight shift could be highly attributed to the seasonal dynamics of vegetation cover in bareland, which was categorized under grassland during image classification as well as the frequent shifting practices of grazing lands in the watershed.

3.1.3 | Built-up land change analysis

The built-up land is the other LULC type that showed significant growth during the study periods. The area under built-up land increased from 5 km² in 1973 to 21 km² in 2016 (320% rise). During the entire study period, the expansion of built-up land was largely contributed by cropland (17 km^2) and grassland (2.11 km^2) notwithstanding the largest part of its initial extent was converted into cropland (4.45 km^2). This high exchange of area between built-up and cropland is attributed to the existence of rural settlements in and around the agricultural lands and continuous switchover from one type to another.

The major reason for the significant growth in the built-up land during the periods of analysis was the expansion of urban areas. There are seven big and small urban areas (towns) in the watershed (see Figure 1). All of these towns indicated substantial expansion at the expense of cropland and grassland. Moreover, the interview and field observation results indicated that the expansion of infrastructures (e.g., roads and institutions) and high demand for residential areas for growing population have also significantly contributed to rapid growth of built-up areas. Similar to our result, the LULC studies made by Alemayehu et al. (2009), Yeshaneh et al. (2013), Garedew et al. (2012), Teka, Van Rompaey, and Poesen (2013), and Wubie et al. (2016) reported continuous and rapid growth of built-up lands in different parts of Ethiopia, which was basically exacerbated by factors such as population growth, expansion of rural towns, and increase in settlement areas.

3.1.4 | Forestland change analysis

The other peculiar phenomenon observed in this study was a slight increase in forest cover. The recent research reports in different parts of Ethiopia have indicated encroachment of people towards forest areas and conversion of vegetation to agriculture and other land use types (Getachew & Melesse, 2012; Haregeweyn et al., 2012; Hassen & Assen, 2017; Tekle & Hedlund, 2000; Wubie et al., 2016). All of these studies revealed a continuous decline in forest cover in Ethiopia. However, our study showed continuous growth of area under forest cover over the study period. The forestland increased from 40 km^2 in 1973 to 51 km^2 in 1986, 55 km^2 in 2001, and 68 km^2 in 2016 (Table 4). The increase in forestland during the 1970s and 1980s can be highly associated with the regeneration of natural forests due to the afforestation programme of the *Derg* regime (a military junta that ruled Ethiopia from 1974 to 1991). The study by Bewket (2002) indicated that there was a strong initiative during the *Derg* period to preserve the remnant indigenous trees and expand forest cover through afforestation in different places of the country.

The other major reason for the expansion of areas under forest cover, particularly in recent times, is attributed to the plantation of eucalyptus (*Eucalyptus globulus*). The area is one of the most known eucalyptus planting areas in Ethiopia. Eucalyptus was included under forestland category during image classification. Because of its better performance in areas with a shortage of water and degraded soil, almost all interviewed farmers showed a clear preference for eucalyptus plantation than other indigenous trees. Eucalyptus in the study area is the main source of income, fuelwood, construction materials, and means of stabilizing gullies and landslides. Therefore, directly or indirectly, eucalyptus formed the basis of the livelihood in the community.

Several studies (Bewket, 2002; Gebrehiwot, Woldeamlak, Annemieke, & Kevin, 2014; Nyssen, Simegn, & Taha, 2009; Sewnet, 2015) also reported that there has been a continuous growth of forest cover in highlands of Ethiopia due to eucalyptus plantations and regeneration of some natural forests. The report by Food and Agriculture Organization (2010) indicated 0.8% per year increase in forest coverage (2005–2010) in the whole parts of Ethiopia due to eucalyptus and other plantations. Generally, forest cover change and trend in the study area can be characterized by the continued diminishing of natural (indigenous) forests and expansion of eucalyptus. Further study is needed to examine the ecological impacts of eucalyptus in the watershed.

3.1.5 | Waterbody change analysis

The waterbody in the Rib watershed was found in the western and south-eastern parts of the watershed. Continuous growth was observed in this LULC type over the whole study period. Despite its smallest areal coverage, that is, 0.5 km^2 in 1973 and 6.5 km^2 in 2016, waterbody showed the highest increase (1,200%) during the last four decades (1973–2016). Here, the highest percentage of increase does not mean that a large part of the watershed was cover by waterbody; rather, it refers to the proportion of growth during the specified period. The growth of waterbody was particularly rapid during the period 2001–2016 (5 km^2, 333% rise) compared with the period 1973–2001 (0.2 km^2, 40% rise) and 1986–2001 (1 km^2, 114% rise), which is attributed to the construction of Rib dam (at the north-eastern part of the watershed, Figure 3d). The regeneration of forests in upland areas was also highly anticipated to increase water at downstream part through infiltration and spring development. Similar to our result, Descheemaeker et al. (2006) also investigated the permanent spring development and availability of water in the downstream areas of Tigray (northern highlands of Ethiopia) due to vegetation regrowth in the upstream areas.

3.2 | Major causes of land use and land cover change

The LULC change of an area is always the result of aggregate interaction among demographic, socio-economic, biophysical, and institutional agents (Hassen & Assen, 2017; Lambin et al., 2003). In this study, the respondents participated in the field survey (n = 210) perceived eight factors as the key drivers of LULC change in the watershed (Figure 5). Among identified factors, population growth was perceived by more than 80% of the respondents as the leading cause of LULC change during the three periods being analysed. Rapid population growth in the study indicates that there is pressure on the existing land resources through increasing demand for more agricultural lands, fuel wood, and construction materials. As a result, conversion of shrublands and grasslands into farmlands, deforestation, and land degradation remained the peculiar phenomena in the study area. As indicated in Table 6, about 79% grassland and 75% shrubland were converted to cropland between 1973 and 2016.

In agreement with our finding and explanations, recent studies in north-western highlands of Ethiopia (Gashaw, Taffa, Mekuria, & Abeyou, 2017; Wubie et al., 2016) indicated fast population growth and the consequent impacts on LULC change and associated land resource problems. For example, Wubie et al. (2016) stated that population growth has led to the increased use of crop residues and

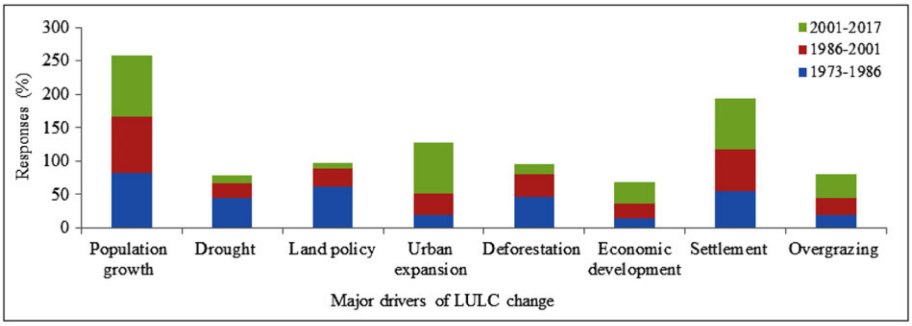

FIGURE 5 Drivers of land use and land cover (LULC) change perceived by farmers in Rib watershed (source: field survey) [Colour figure can be viewed at wileyonlinelibrary.com]

animal dung for fuel instead of using it for soil fertility management. The expansion of settlement and urban areas was the other highly perceived driver of LULC change next to population growth (Figure 5). The changing land policy, deforestation, recurrent drought, overgrazing, and the growing demand for land for investment were also the other factors pointed out by respondents as major factors of LULC change. The detail and further analysis of factors affecting LULC change in the study areas were beyond the scope of this study, which can be addressed by some other studies in the future.

3.3 | Impacts of land use and land cover change

Several previous studies reported that there have been considerable environmental and economic impacts of rapid LULC change in the highlands of Ethiopia (Miheretu & Assefa, 2017; Wubie et al., 2016; Gashaw et al., 2017). The interview and field observation results have indicated multiple effects of LULC change in the study area between 1973 and 2016. Even though there were some positive impacts related to the slight expansion of areas under forestland and waterbodies, LULC change has significantly and negatively affected the ecological and socio-economic condition of the watershed. The major consequences of LULC change in the study area are indicated in Figure 6 and discussed in the following paragraphs.

The LULC change has been acknowledged as one of the most important causes of deterioration in soil quality and its productivity in the watershed. The LULC change, through the removal of soil cover, accelerates the loss of topsoil (Miheretu & Assefa, 2017). As explained elsewhere in this paper, more than 75% of vegetated areas (most importantly, grass and shrublands) were shifted to agricultural lands during the study period. The magnitude and trend of soil erosion in the Rib watershed and its correlation with LULC change can be found in the paper by Moges and Bhat (2017). According to Morgan (2005), the change in land use and land cover from vegetation into agriculture accelerates soil erosion 3,000 times faster than erosion in undisturbed areas. The reason how the vegetation cover affects soil erosion can be explained in various ways. Vegetation cover not only directly protects the surface soil from splash erosion and slows runoff velocities but also influences the properties controlling soil erodibility (Wijitkosum, 2012).

Soil erosion in Rib watershed has frequently affected both upstream areas through reduction of top productive soil/nutrients and the downstream areas through sedimentation. The results from FGDs, key informant interviews, and field observations realized that the large portions of the watershed are intensively cultivated and highly degraded with steep slopes. As a result, significant parts of the watershed are less capable of absorbing and holding the rainfall, which has facilitated the removal of the top fertile soils and recurrent flooding. Combined with inadequate watershed management practices, the exposition of upstream areas to intensive agriculture has resulted in a higher sediment concentration at the downslope areas and river banks. This result is in line with the findings of Teklemariam et al. (2017) and Mekonnen, Keesstra, Stroosnijder, Baartman, and Maroulis (2015), who reported high sedimentation in their study sites due to intensive commercial farming at upstream areas. The interview results and analysis of unpublished data from agricultural offices also indicated that almost all farmers have been forced to use fertilizers (at an unaffordable price) on their farm plots to reverse the nutrient loss and sustain productivity.

The other major impacts of the LULC change in the study area are related to the expansion of urban areas. The urban sprawl due to the population increase and migration of people to towns has resulted in the acquisition of most suitable agricultural lands for urban development. Farmers also reported that urban expansion has resulted in

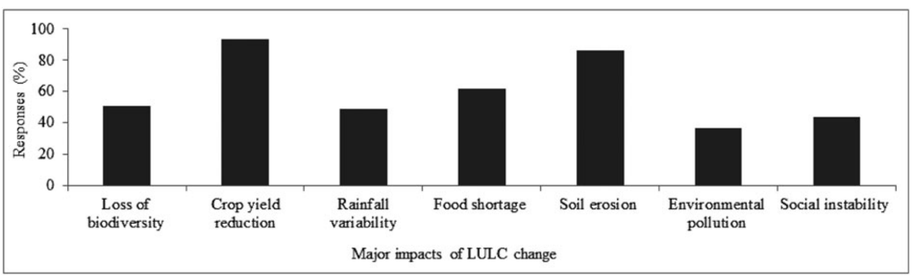

FIGURE 6 Impacts of land use and land cover (LULC) change perceived by local farmers in Rib watershed (source: field survey)

increased price of agricultural lands, overconsumption of irrigable water, and increased price of food and fuel. As indicated in Figure 6, about 36% of the households involved in the survey, particularly those on the urban fringe, outlined that urban sprawl and associated wastes have resulted in manifold effects of environmental pollution (e.g., contamination of soil through chemical and other liquid wastes).

The LULC change in the study area has also adversely affected the food security (perceived by 62% of the respondents, Figure 6) and rural livelihood sustainability issues. The LULC change and food security are interconnected at different scales and domains (McConnell & Viña, 2018). As explained elsewhere in this paper, the livelihood of the almost entire population of the study area depends on agriculture. However, in recent decades, soil erosion caused by LULC change has highly affected this sector, which in turn directly determines productivity, food security, and livelihood sustainability. The participants of key informant interviews explained that expansion of cultivated land at the expense of grassland has resulted in less availability of fodder and decline in the quality and number of livestock production. This has, in turn, led to worsening of food and income from livestock products, as well as limited use of livestock wastes for soil fertility management.

In line with our findings, the study by Meshesha et al. (2014) reported that an increase in agricultural activities and reduction in grassland have caused lack of available suitable grazing lands, which in turn has caused overgrazing and discouraged the households to raise the large size of animals. Almost all of those interviewed clearly indicated that LULC change has posed serious consequence of soil erosion, deterioration in animal forage, and a decline in productivity of crops and livestock. As a result of the limited availability of feed resources, the livestock of the watershed suffers from lack of feed. This decline in agricultural production has seriously affected food security issues of the area. The study by Endale, Mengesha, Atinafu, and Adane (2014) indicated that Farta District (one of the four districts drained by the Rib river) is one of food insecure areas in the region, where more than 70% the households faced food shortage and most of the farmers could not feed their family properly throughout the year.

Rapid population growth coupled with a decline in agricultural production (mostly caused by LULC change induced soil erosion) and unstable economic growth has posed a serious challenge of migration accompanied by social and/or political instability. The situation has, even more, affected the youth and women who have migrated overseas in search of better livelihoods and economic opportunities. About 43.5% of respondents (Figure 6) confirmed that LULC changes, directly or indirectly, have caused social instability in the study area. In line with this result, the findings by Wubie et al. (2016) and Meshesha et al. (2014) indicated multiple socio-economic impacts of LULC change in the highlands of Ethiopia. According to Wu (2008), expansion of the urban areas at the expense of croplands presents many challenges for farmers on the urban fringe, which include the conflict with nonfarm neighbors, destruction of crops, and contamination of farmlands.

The LULC dynamics is one of the major impacts on biodiversity persistence (Mantyka-Pringle et al., 2015). Many recent studies around the world (Mantyka-Pringle et al., 2015; Schulp, Teeffelen, Tucker, & Verburg, 2016; Eitelberg, Jasper, Jonathan, Elke, & Peter, 2016; Masum, Asyraf, Shahrul, & Hwee, 2017; Liu, Lei, Xiaojian, & Peng, 2016; Chaudhary & Thomas, 2016; Cervelli et al., 2017) clearly indicated the negative impacts of LULC change on biodiversity. All of these studies concluded that human-induced LULC change has exacerbated the loss of habitats and fragmentation of biodiversity by increasing the susceptibility of biological populations to stochastic extinction risk. The greatest threat to biodiversity loss through LULC change is the conversion of vegetation, which is the home of animals and microbes, into agricultural and some other land use types. As indicated in Figure 6, more than 50% of the respondents perceived the negative impacts of LULC change on biodiversity losses in the study area.

According to the participants in FGDs and interview, deforestation and replacement of natural forests by exotic plants, such as eucalyptus species, have caused the extinction of natural trees in the study area. For example, indigenous trees like *Cordia africana*, *Hygenia abyssinica*, *Olea* species, *Acacia bussei*, *Podocarpus falcatus*, *Pouteria altissima*, and *Rosa abyssinica*, which were once dominating the area, almost disappeared, and few remnants are confined to churches and inaccessible areas only. A person who participated in FGDs, aged 84 years, has lived in the watershed for long years. He clearly explained that before 30–40 years, the watershed was well known by abundant natural forests and wild animals, which are currently vanished due to the human influence.

The results of this study could provide specific and local-level information for decision makers and natural resource conservationists to reduce erosion and related environmental problems through proper land use planning and conservation activities.

4 | CONCLUSIONS

In order to understand the state of change in land use and land cover in Rib watershed, we used time-series satellite images between the years 1973 and 2016. The results indicate that significant LULC change has occurred in the study area over the last four decades. The major changes observed during the study period were the conversion of grass, shrub, native forest, and woodlands to cropland and built-up areas. The rapid LULC change of the study area has been driven by multiple factors such as population pressure and associated pressure on land, expansion of rural towns, and climate change. The historical LULC change trend of the watershed clearly suggests that the small leftover grasses and shrubs will be converted into agriculture, and built-up land is more likely to share large agricultural land in the future. This study also attempted to investigate the impacts of LULC change in the study area. Among others, LULC change has resulted in severe land degradation in the form of soil erosion, loss of biodiversity, and soil fertility depletion, which in turn impeded agricultural and ecological sustainability. Clear understanding and mapping of LULC change can be used as a stepping stone in the process of correction of the LULC change trends in the study area. On the basis of the findings of this study, we highly recommend further studies to predict the future land use changes in the Rib watershed and design appropriate and comprehensive land use planning. The drivers of LULC change identified in this study can be used as an input for land use change modelling and prediction. It is also important to restore and protect the few remnant forests, shrubs, and grasses through proper land rehabilitation and land use planning packages. It needs strong synergy between farmers, researchers, and government authorities at local, regional, and national levels to control the future threat of LULC changes and natural resource degradation in the watershed.

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