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Land-use and land-cover dynamics and their drivers in the central highlands of Ethiopia with special reference to the Lake Wanchi watershed

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Abstract Land-use and land-cover (LULC) changes have been recognized universally as fundamental constituents of global biodiversity and ecosystem services change driver. The objectives of this study were analyzing the spatial and temporal LULC dynamics over the past 44 years and identifying the major drivers of these changes. It was conducted in the central highlands of Ethiopia at the social-ecological Lake Wanchi watershed. The study triangulated data from Landsat images of four different time series, ground verifications, focus group discussions, key informants interview, and quantitative analytical approach. The Landsat imageries were processed and analyzed using ArcGIS 10.3 software. Supervised classification was executed using the maximum likelihood technique. The non-quantifiable data were analyzed using qualitative descriptions and the quantitative analytical approach was used to rank the

degree of LULC change drivers. About 62% of the land area in the study watershed experienced LULC conversions. Wetlands, forest-cover, shrub-cover, and water body converted (declined) annually at a rate of 3.3%, 1.4%, 1.3% and 0.6%, respectively. Croplands, bare lands, agroforestry, and settlements, expanded annually at the rate of 10.2%, 5.7%, 2.6% and 2.1%, respectively. Agricultural activities, wood extraction, settlement expansion, and infrastructure constructions were proximate LULC change drivers, while, demographic changes, community conflict, and land tenure policy were the underlying change drivers. To mitigate the rapid LULC changes and safeguard the social-ecological benefits at the local watershed and distant downstream systems of Lake Wanchi, rehabilitation of the watershed specifically, the natural vegetation covers and environmentally sensitive areas, through the application of integrated watershed management strategies is critically important.

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Introduction

The fast growth of the human population and the associated demands for material goods and services is putting increasing pressure on social-ecological systems (Etter et al. 2006). Social-ecological systems are

closely linked systems of people (the social constituent) and environmental processes (the ecological constituent), signifying the existence of complex and interdependent association between human and the natural ecosystems (Berkes and Folke 1998). One approach of measuring human impacts on social-ecological systems is analyzing the land-use and land-cover (LULC) changes and their drivers in a given environmental setting. The critical question raised here is that the likelihood for sustainable linkage between the natural environment and human management practice can be provided by understanding the dynamics of the local resource base and the practices of the local resource users' (Colding and Barthel 2019). Considering the coinciding interests of social and natural scientists in linking social-ecological systems, new approaches for consolidating social and environmental data have emerged that include geographic information systems (GIS) and remotely sensed imagery. Analysis of the LULC changes and the drivers that causes these changes are the focus of the contemporary scientific investigation that attracted increased interests of diverse groups of scientists (Campbell et al. 2005; Etter et al. 2006). This is because of the direct consequences LULC change has on the natural environment and human societies (Yorke and Margai 2012). This, in turn, is of great concern to land-use planners and policymakers, as they look for information on the drivers of LULC changes from scientists in order that planning decisions and policy issues should not focus on indicators only, but upon the ultimate processes that require corrective actions (Campbell et al. 2005).

Currently, LULC changes have been recognized universally as fundamental constituents of global environmental change driver (Butchart et al. 2010). This is particularly detectable in high-mountain watersheds that are very sensitive to LULC dynamics induced by human activities that may alter the resource bases of the watershed (FAO 2019). Watershed degradation, in turn, leads to accelerated ecological deterioration, reduced economic opportunities and increased social crises. Yorke and Margai (2012) stated that LULC change within watersheds and their driving forces are prolonged areas of concern particularly for the Sub-Saharan region of Africa. LULC changes in watersheds have been linked with the impairment of environmentally sensitive areas like wetlands, lakes, riparian areas, hills and steep slopes

leading to the deterioration of the environmental elements of the watershed (Wolter et al. 2008). Assessing LULC change and its drivers in mountain watersheds, where there is severe and widespread watershed degradation resulting from unsustainable management practices including deforestation, improper cultivation, unplanned settlement, overgrazing, road construction, and misuse of water resources is highly relevant (Sheng 1990; FAO 2019). Hence, quantitative knowledge of LULC dynamics and their drivers in highland Lake Watershed is a principal element in providing the information required to reverse the situation and designing future planning and decision making processes.

Several LULC change studies conducted in Ethiopia concluded that LULC change is a common phenomenon and is very intensive in the highland watersheds of the country (Kidane et al. 2012; Minale 2013; Gessesse and Bewket 2014; Hailemariam et al. 2016; Miheretu and Yimer 2017). Moreover, a synthesis of research on LULC dynamics in the Ethiopian highland watersheds over a century (the 1860s to 1980s) revealed a considerable reduction of forests, woodlands, and shrub-cover and radical expansion of cultivated lands (Muluneh 2010). A more recent LULC studies conducted in the watersheds of Ethiopian highlands also exhibited similar trends in the conversion of vegetation cover into sizeable cultivated land and settlements/built-up areas (Gessesse and Bewket 2014; Babiso et al. 2016; Sahle and Yeshitela 2018; Girma et al. 2019; Degife et al. 2019). This change in LULC is initiated by a combination of complex driving forces including proximate (direct), underlying (indirect) and biophysical (soil and physiography) factors (Gessesse and Bewket 2014; Degife et al. 2019). According to these authors, direct drivers include agricultural activities, wood extraction, infrastructural development while indirect drivers include demographic, economic, socio-cultural, political, institutional, and policy factors.

One of the most environmentally affected areas in Ethiopia is the highly populated central highlands of the country, in which the Lake Wanchi watershed (LWW) is located. LWW has experienced rapid and widespread LULC change that could cause deterioration and loss of environmental services on which human livelihood depends. Some studies on LULC dynamics was conducted in the central highlands of

Ethiopia (Berhe 2004; Tefera 2011; Gessesse and Bewket 2014; Tolessa et al. 2017). However, a study on the dynamics of LULC changes and their drivers are not yet conducted at LWW. Basic data on the extent, trends, and drivers of LULC change is lacking; and thus it has been difficult to manage environmental resources, monitor environmental changes and design sustainable environmental management strategies. Hence, understanding the complex interdependence between changing LULC and its major drivers in LWW would help to design suitable land-use planning and appropriate watershed management interventions. Therefore, the objectives of this study were: (1) to analyze the spatial and temporal LULC change patterns using Landsat images of four different time series (1973, 1991, 2003 and 2017), (2) indicate the major LULC change drivers, and (3) suggest possible environmental monitoring and watershed management solutions in LWW.

Study area and methods

Study area

This study was conducted in LWW, Wanchi district, Oromia region, Ethiopia (Fig. 1). It is located in the central highlands of the country at about 155 km to the southwest of Addis Ababa, between Woliso and Ambo towns. Lake Wanchi is a crater lake formed due to

volcanic eruptions. It has maximum and mean depths of 60 and 35 m, respectively and a surface area of about 5.6 km² (Degefu et al. 2014). According to the 1994 and 2007, Population and Housing Census of Ethiopia, the total population of the watershed was 3977 and 5586, respectively (CSA 2012). LWW is a small highland (head) watershed comprising of forestland, agricultural land, shrubland, water bodies, wetlands, rural settlements, agroforestry system, and bare lands. Local livelihoods include mixed subsistence farming and income generating-activities from ecotourism.

Topographically, LWW is found in the extreme highland climatic zone of Wanchi district at an elevation ranging between 2810 and 3385 m above sea level. According to WOCAT (2007) slope classification, the slope of the area ranges from flat (0–3%) at the lake water surface to very steeply sloped (> 60%) near the ridges. Based on data obtained from the National Meteorological Agency for the nearest Meteorological station (Darian) the mean annual rainfall from 1989 to 2018 was 1402 mm. The average annual temperature was 17.8 °C, while monthly mean minimum and maximum temperatures were 12.2 °C and 23.4 °C, respectively (Fig. 2). Unimodal type of rainfall with longer rainy periods stretching from May to September is the characteristics of the watershed. Peak rainfall occurs in July and August. The watershed is characterized by chromic luvisols with ashy parental material (FAO 1976). Sub-afroalpine vegetation

Fig. 1 Map of the study area. Upper-left: location of Oromia Region (green color) in Ethiopia, Lower-left: Wanchi Wereda (= district) with Wanchi Watershed inserted and Right: Wanchi Watershed with Lake Wanchi. (Color figure online)

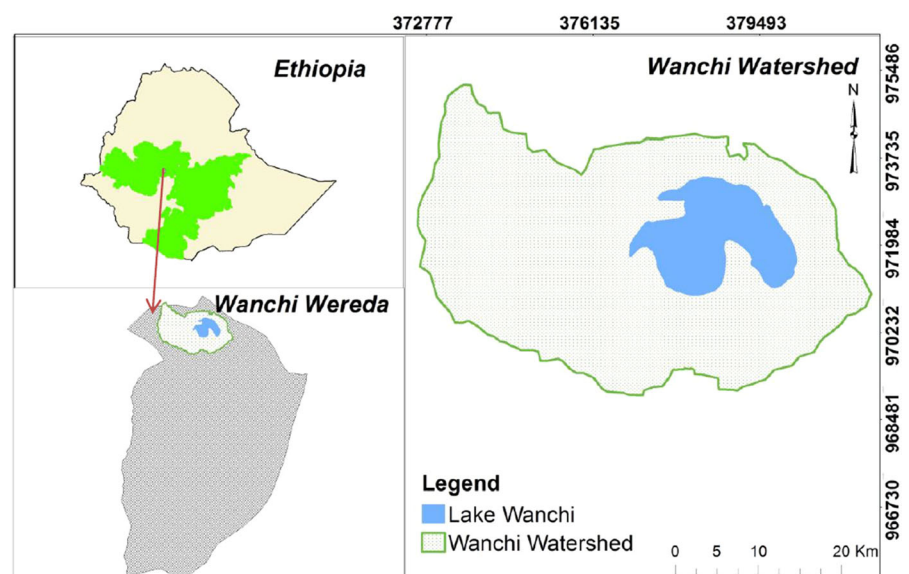
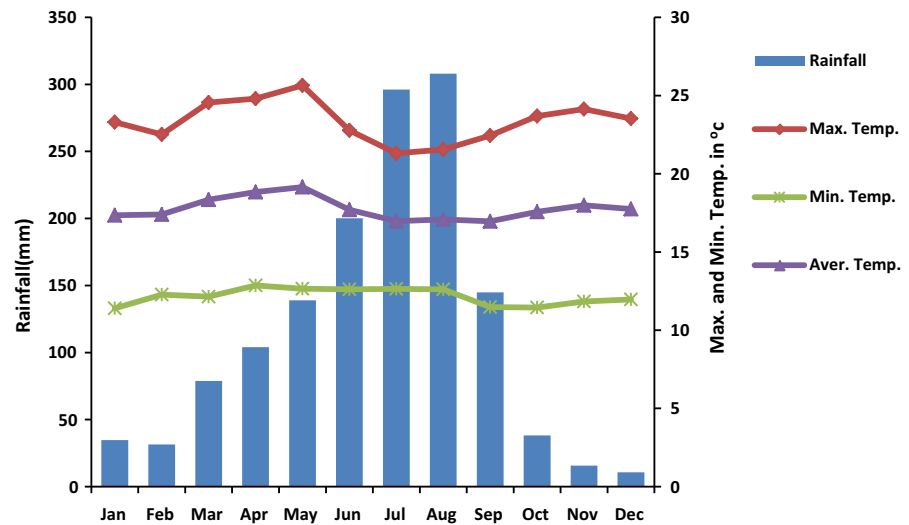


Fig. 2 Mean annual rainfalls, monthly mean maximum and minimum temperature, and average temperature registered at the nearest Meteorological Station (Darian)



dominated by *Erica* species is the characteristic vegetation type of the watershed. However, there are also indigenous tree species such as *Hagenia abyssinica*, *Juniperus procera*, *Olea europaea* subsp., *cus-pdata*, *Ilex mitis* and *Myrsine melanophloeos* (Angessa et al. in press).

Wanchi Mountain is one of the most critical mountains in Ethiopia, dividing two major river basins, namely Gibe and Abay. The western and northwestern parts of the escarpment make the westward flow of streams that join the Rivers Guder, Debis and Huluka, which are tributaries of the Abay (Blue Nile) River. The eastern and southern parts of the escarpment including the outlet of the lake make the southward flow of streams that form Walga River—the main tributary of the Gibe River basin. LWW is the head watershed for the Gibe river basin. Besides, LWW and its surrounding environments are among the most exciting ecotourism destinations in Ethiopia, featuring spectacular natural landscapes, large areas of natural vegetation, mineral waters, and hot springs, and ancient churches and monasteries. As a result, the Wanchi Ecotourism Association (WETA) which is a community-based initiative aimed at fostering the conservation of natural and cultural resources as well as supporting the livelihoods of local communities was established in 2002.

Methods

Land-use and land-cover assessment

Comprehensive reconnaissance survey, visual interpretation of satellite imagery and field verification were used to identify the LULC category of the study area. Accordingly, eight predominant LULC types were identified as agroforestry, bare land, cropland, forest-cover, settlement, shrub-cover, water body and wetland. The detail description of the LULC types is provided in Table 1.

Data acquisition and preparation

The study used four Landsat images of different time series which were downloaded from USGS—<https://earthexplorer.usgs.gov/> as the main input data. The selection of the Landsat images data (years of investigation) was based on the coverage of the study area; remarkable events having significant impacts on the management of land and land resources; enough interval periods for detecting occurrences of change, and availability of high quality (cloud-free) satellite imagery. The Landsat image of 1973 was acquired as a historical image that was used for comparison of change detection against the new time data series. The year 1991 was selected because it was a time of government change in Ethiopia, and the year 2003 signified the establishment of WETA in the study watershed. The year 2017 was selected to show the

Table 1 Major LULC types used for the LULC change detection with their short descriptions

SN	LULC types	LULC description
1	Agroforestry	The agroforestry component is mainly dominated by <i>Enset</i> crop and includes few other perennial fruit trees and vegetables that are growing within the home gardens.
2	Bare land	Bare land is a land devoid of vegetation cover. It includes gravel roads, bare soil, and rocky outcrops as well as degraded abandoned agricultural lands.
3	Cropland	Cropland is a land that encompasses areas allotted mainly for annual/seasonal crop production, but also includes recently fallowed lands and small patches of grazing lands.
4	Forest-cover	Forest-cover is a land-covered with dense stand of trees.
5	Settlement	Settlement includes the dispersed permanent rural settlements, schools, churches and other facilities such as health centers.
6	Shrub-cover	An area of land-covered by a mixture of shrubs (mainly <i>Erica</i> sp.) bushes, herbs and grasses.
7	Wetlands	Includes areas that are waterlogged, marshy and swampy especially during the rainy season.
8	Water body	An area covered by water bodies that include lake, rivers, streams, and springs.

current situation of the study watershed. A detail about the satellite images is given in Table 2.

Ground-truthing data were gathered on the field to be used for image classification and verification of the satellite imagery. Focus group discussions (FGDs); key informants interview (KII), field observation, and quantitative analytical approach (preference ranking) were used to supplement the data obtained from satellite imagery. Purposive sampling technique was employed for the selection of FGDs to involve individuals having detailed knowledge about the study area and LULC change patterns during the respective study periods. Two FGDs consisting of eight individuals each were conducted. Key informants were selected purposively from different social groups including elders, community leaders, local natural resource experts, and WETA members. The main focuses of the interviews included major driving forces for LULC changes, probable reasons for the specific changes, major impacts concerning the

watershed resources, strategies to reverse the ongoing situation and future management strategies of the study watershed.

Preference ranking was used to prioritize the major drivers of LULC changes according to their degree of severity to the local context. Several LULC change drivers in the study area perceived by the participants were listed. Seven major drivers were selected by consensus of the participants and randomized for ranking. The numerical value (1, 2, 3... 7) was given to the rank, where the maximum value (7) was assigned for the highest LULC change driving force and 1 for the lowest. Then, ten participants (five from each of the two FGD groups), who were well involved in the discussions and contribute more information on the issue under considerations, were selected to rank the seven drivers according to the degree of impacts they impose upon LULC. Individual scores were added up for the ten participants, giving an overall ranking for the specific driver of LULC change.

Table 2 Summary of satellite images used in LULC change detection

S/N	Satellite	Path/row	Dates acquired	Spacecraft	Resolution (m)
1	Landsat Multi-Spectral Scanner (MSS)	181/54	31-01-1973	"Landsat_1"	60 × 60
2	Landsat Thematic Mapper (TM)	169/54	12-12-1991	"Landsat_5"	30 × 30
3	Landsat Enhanced Thematic Mapper Plus (ETM+)	169/54	05-05-2003	"Landsat_7"	30 × 30
4	Landsat Operational Land Imager (OLI)	169/54	01-01-2017	"Landsat_8"	30 × 30

All data were projected to the Universal Transverse Mercator (UTM) projection system with zone 37P and datum of World Geodetic System 84 (WGS84) so as to maintain consistency between datasets during analysis

Finally, to gain insight into participant’s reasoning, the participants were asked to describe why one option is better or worse than another is. Furthermore, this result was cross-checked with the results obtained from the KIIs, the classified LULC images for the respective study years and other secondary sources to apprehend the consistency in the responses.

Data analysis

Image analysis and accuracy assessment The Landsat imagery was manipulated using ArcGIS 10.3 software by applying the basic image processing techniques and quantification works. Some pre-process were undertaken, including geo-referencing and image enhancement to manipulate the selected scenes. Supervised classification was executed using the maximum likelihood classification technique. Post classification processing was performed using a set of generalization tools, namely, majority filter, boundary clean, region group, set null and nibble tools. Accuracy assessment for all the study years of classified images was performed based on the recommendation of a minimum of 50 samples for each mapping class with less than 4000 km² area and fewer than 12 classes (Lillesand et al. 2008). Hence, 50–58 random points were created using stratified random sampling by taking the LULC categories as strata (Obodai et al. 2019). The full report of an error matrix, i.e., users and producer’s accuracy, overall accuracy, and kappa coefficient were generated from the error matrix. Kappa statistics were computed using Eq. (1) below (Jenness and Wynne 2005). According to Viera and Garrett (2005) values of 0.01–0.20 demonstrates slight agreement, 0.21–0.40 fair agreement, 0.41–0.60 moderate agreement, 0.61–0.80 substantial agreement and 0.81–0.99 almost perfect agreement.

$$\hat{K} = \frac{M \sum_{i=j=1}^r n_{ij} - \sum_{i=j=1}^r n_i n_j}{M^2 - \sum_{i=j=1}^r n_i n_j} \tag{1}$$

where \hat{K} = kappa statistics, r = number of rows in error matrix, n_{ij} = number of observations in row i , column j , n_i = total number of observations in row i ,

n_j = total number of observations in column j , and M = total number of observations in matrix.

Land-use and land-cover change detection analysis The LULC dynamics in each study period were assessed using the numerical values extracted from the classified images. To obtain the pattern of change, the classified images from successive periods were cross-tabulated and compared in three periods, that is, 1973–1991, 1991–2003, and 2003–2017. The overall change statistics between the initial (1973) and final (2017) study period was calculated by comparing image values of the first study year with the corresponding values of the final study year. The annual rate of change for each LULC class was calculated using Eq. (2) (Obodai et al. 2019), to determine the annual transformation of the different LULC categories.

Annual rate of LULC change (r)

$$= \left(\frac{1}{t_2 - t_1} \ln \frac{A_2}{A_1} \right) * 100 \tag{2}$$

where A_1 and A_2 are the areas of LULC at the time t_1 and t_2 , respectively.

The change detection matrix was used to describe the conversion transitions of LULC classes that have occurred between 1973 and 2017. To determine the nature of the land conversions “from-to” cross-tabulation was performed by identifying the changes that took place from one type of LULC to another. The method involves the overlaying of two different time classified images, i.e., the 1973 and 2017 generated during the classification process. This procedure was performed in ArcGIS 10.3 software using the function “Zonal” and “Tabulate Area” from spatial analyst tools.

Analysis of the drivers of land-use and land-cover change The data collected through FGDs, KIIs and field observation (non-quantifiable information) was analyzed and interpreted using narrations, context analysis, and qualitative descriptions. The quantitative analytical approach, Preference raking, was used to analyze the degree of LULC change drivers.

Result and discussion

Results

Accuracy assessment

Post classification accuracy assessment for the classified images has resulted in the overall accuracy of 89.6%, 92.0%, 91.8%, and 90.3%, for the study years of 1973, 1991, 2003, and 2017, respectively. The producer's accuracy of the individual classes was lowest (66.1%) for settlement in 2003 and the highest (100%) for shrub-cover in 1973, in 1991 and 2017. The user accuracy for the classified maps ranged from 71.6 to 100% (Table 3). Kappa statistic that measures the difference between actually observed agreement and expected agreement revealed strong agreement for all the study years, that is, 0.85 for 1973, 0.91 for 1991 and 2003, and 0.92 for 2017. Table 3 shows details of the confusion matrixes for the classified images.

Land-use and land-cover status and changes detection

The analysis of LULC change status revealed that shrubland, dominated by the small evergreen *Erica* species was the predominant LULC type during the 1973, 1991 and 2003 study periods, covering 45%, 42%, and 37% of the study watershed, respectively. Whereas, during the 2017 shrubland was the second dominant LULC type next to cropland, covering 26% of the land area in the study watershed. Conversely, the bare land-cover was the least dominant LULC type throughout the study periods. The LULC status for the four study years is presented in Table 4 and their spatial distribution in Fig. 3.

Comparison of the land-use and land-cover changes between study periods

The analysis of LULC change during the first comparison period (1973–1991) indicated an increase in area coverage for agroforestry, bare land, cropland, and settlement, while it showed a decrease for forest-cover, shrub-cover, water body and wetlands (Table 5 and Fig. 3). The annual rate of increase during the same period for settlement, agroforestry, bare land, and cropland was 2.3%, 4.4%, 11.9%, and 16.4%, respectively. Whereas, the annual rate of decrease for forest-cover, shrub-cover, water body, and wetlands

was 0.2%, 0.4%, 1.3%, and 3.1%, respectively. During the second comparison period (1991–2003) agroforestry was the only LULC type showed trend deviation (i.e., agroforestry decreased in area coverage), while the other LULC types kept similar trend as of the first comparison period. Whereas, in the same period, the annual rate of change (increment) for bare lands, and croplands reduced nearly by half as compared to the first comparison period (Table 5). At the third period of comparison (2003–2017), only agroforestry and bare land showed a trend deviance as opposed to the second comparison period (i.e., agroforestry showed an increase and bare land a decrease in area coverage), while the other remaining LULC types displayed the same trend as the previous two comparison periods. In general, only agroforestry and bare lands showed instability in LULC change during the three separate comparison periods (Table 5).

The overall LULC change detection (1973–2017), showed there was an increase in area coverage for cropland, bare land, agroforestry, and settlement, while there was a decrease for the rest of the LULC types (Fig. 4). Of the LULC classes showed an increasing tendency, the highest increase in area coverage was observed for cropland, followed by agroforestry, settlement and bare land, respectively. Correspondingly, the highest annual rates of increase (10.2%) was observed for cropland, while it was intermediate for bare land (5.7%) and relatively lower for settlement (2.1%) and agroforestry (2.6%). Of the LULC classes showed a decreasing tendency, the highest reduction in area coverage was observed for shrub-cover, followed by wetland, forest-cover and water body, respectively. However, the annual rate of changes for these LULC classes were slight compared to the annual rate of changes for those LULC classes showed an increasing tendency (Fig. 4).

Land-use and land-cover change matrix

The change matrix results, conforms to the results of the overall LULC change detection, in that, it showed a loss of land size in four of the LULC classes and gain in four of them (Table 6). Of the total land area in the study watershed, only 38% remained unchanged between 1973 and 2017. Even though, the level of changes varied among the LULC types, most of the land area underwent major conversions (loss or gain). For example, out of the total area of wetlands

Table 3 Confusion matrixes for the classified images of 1973 (3a), 1991 (3b), 2003 (3c) and 2017 (3d)

	Reference data								Row total	User's accuracy (%)
	Agroforestry	Bare land	Crop land	Forest-cover	Settlement	Shrub-cover	Water body	Wetland		
(3a) LULC 1973										
Classified image										
Agroforestry	40	0	0	0	3	0	0	3	46	87.0
Bare land	0	48	1	0	1	0	0	0	50	96.0
Cropland	0	0	50	0	0	0	0	0	50	100.0
Forest-cover	2	0	0	52	0	0	0	0	54	96.3
Settlement	0	1	2	0	40	0	0	0	43	93.0
Shrub-cover	5	1	0	4	10	58	1	2	81	71.6
Water body	0	0	0	0	0	0	53	0	53	100
Wetland	3	1	1	0	2	0	2	47	56	83.9
Column total	50	51	54	56	56	58	56	52	434	
Producer's accuracy	80%	91.4%	92.6%	92.9%	71.4%	100%	94.6%	90.4%		
Overall accuracy	89.6%									
Kappa statistic	0.85									
(3b) LULC 1991										
Classified image										
Agroforestry	47	2	0	0	3	0	0	0	52	90.4
Bare land	1	43	1	0	2	0	0	0	47	91.5
Cropland	1	5	53	0	0	0	0	0	59	89.8
Forest-cover	1	0	0	56	0	0	0	0	57	98.2
Settlement	0	0	0	0	44	0	0	0	44	100.0
Shrub-cover	5	0	1	1	1	58	0	1	67	86.6
Water body	0	0	0	0	0	0	51	0	51	100.0
Wetland	0	0	2	0	6	0	2	53	63	84.1
Column total	55	50	57	57	56	58	53	54	440	
Producer's accuracy	85.5%	86.0%	93.0%	98.2%	78.6%	100%	96.2%	98.1%		
Overall accuracy	92.0%									
Kappa statistic	0.91									
(3c) LULC 2003										
Classified image										
Agroforestry	51	0	0	0	3	0	0	1	55	92.7
Bare land	1	50	1	0	0	0	1	0	53	94.3
Cropland	1	2	53	1	7	1	0	0	65	81.5
Forest-cover	0	0	0	55	0	1	0	1	57	96.5
Settlement	0	0	0	0	37	0	0	0	37	100.0
Shrub-cover	1	0	1	1	6	55	2	0	66	83.3
Water body	0	0	0	0	0	0	52	0	52	100.0
Wetland	0	0	0	0	3	0	1	50	53	94.3

Table 3 continued

	Reference data									User's accuracy (%)
	Agroforestry	Bare land	Crop land	Forest-cover	Settlement	Shrub-cover	Water body	Wetland	Row total	
Column total	54	52	55	57	56	57	56	52	439	
Producer's accuracy	94.4%	96.2%	96.4%	96.5%	66.1%	96.5%	92.9%	96.2%		
Overall accuracy	91.8%									
Kappa statistic	0.91									
(3d) LULC 2017										
Classified image										
Agroforestry	45	0	0	0	0	0	0	0	45	100
Bare land	0	56	0	0	0	0	0	0	56	100
Cropland	3	2	51	1	10	0	0	1	68	75.0
Forest-cover	1	0	0	48	0	0	3	4	56	85.7
Settlement	0	0	0	0	37	0	0	0	37	100
Shrub-cover	3	0	3	1	4	54	2	1	68	79.4
Water body	0	0	0	0	0	0	47	1	48	97.8
Wetland	0	0	0	0	1	0	0	44	45	97.8
Column total	52	58	54	50	52	54	52	51		
Producer's accuracy	71.2%	96.6%	94.4%	96.0%	71.2%	100%	90.4%	86.3%		
Overall accuracy	90.3%									
Kappa statistic	0.92									

The columns represent the reference data whereas the rows represent the classification generated from the remotely sensed data. Bolded diagonal numbers represent correctly classified sites according to reference data, whereas off-diagonals represent misclassified with respect to reference data

(584.8 ha) in 1973, 563.4 ha (96.3%) was converted to other LULC types during the study periods. Of the 96.3% changed wetlands, the greater proportion (57.5%) were converted to croplands, followed by agroforestry (16.3%) and settlement (13.7%). Out of the existing forest-cover (602.35 ha) in 1973, 357.8 ha (59.4%) was converted to other LULC types, where the conversion to shrub-cover was the highest (Table 6). Similarly, shrub-cover, which had 1659.4 ha in 1973, was declined by 1020.2 ha (61.5%) in 2017 due to conversions to other LULC types; of which the conversion to cropland took the largest share (53.2%), followed by agroforestry (26.6%). Compared to the other LULC type's water body preserved the largest proportion of the unchanged surface, which was about 396 ha (72.5%). Of the changed area of water body, the one

to croplands was the highest (30.3%). On the other hand, the change matrix analysis showed contrasting trends (i.e., there was land size gaining in some of the LULC types). Cropland expanded by the land area of 1045 ha between 1973 and 2017. The major conversions to croplands were from shrub-cover (about 543 ha) and wetlands (about 323.8 ha). Bare land and agroforestry increased by 45.7 ha and 374.5 ha, respectively. There were also considerable conversions to settlements (118 ha-gains) from other LULC classes, but the one from shrub-cover (78.4 ha) and wetlands (77.2 ha) were the highest. Table 6 describes the overall gain or losses in LULC types in between the initial and final study periods.

Table 4 Area of classified LULC classes in LWW for the four study periods

LULC classes	1973		1991		2003		2017	
	Area (ha)	% Area	Area (ha)	% Area	Area (ha)	% Area	Area (ha)	% Area
Agroforestry	175.82	4.8	387.18	10.57	308.02	8.41	549.06	14.99
Bare land	4.36	0.12	36.98	1.01	66.45	1.81	52.85	1.44
Cropland	11.97	0.33	231.34	6.32	606.23	16.55	1057.1	28.86
Forest-cover	602.86	16.5	576.74	15.75	491.58	13.42	324.65	8.87
Settlement	76.78	2.1	116.35	3.18	178.02	4.86	196.21	5.36
Shrub-cover	1658.65	45.3	1541.16	42.08	1369.52	37.39	931.94	25.45
Water body	546.88	14.9	430.85	11.76	426.82	11.65	418.75	11.43
Wetlands	585	16	341.72	9.33	215.68	5.89	131.76	3.60
Total	3662.32	100	3662.32	100	3662.32	100	3662.32	100

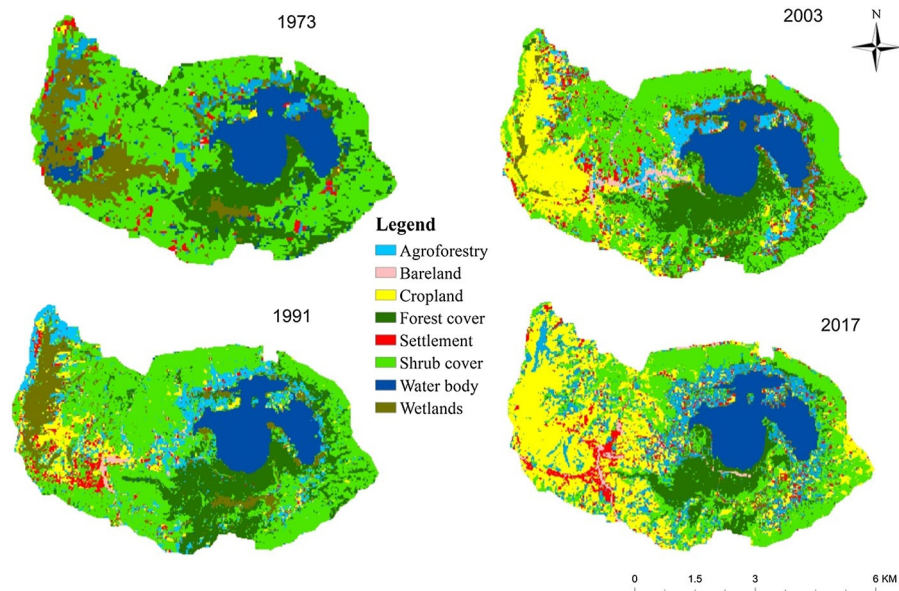


Fig. 3 LULC map showing the spatial distribution of the 1973, 1991, 2003 and 2017 classified images

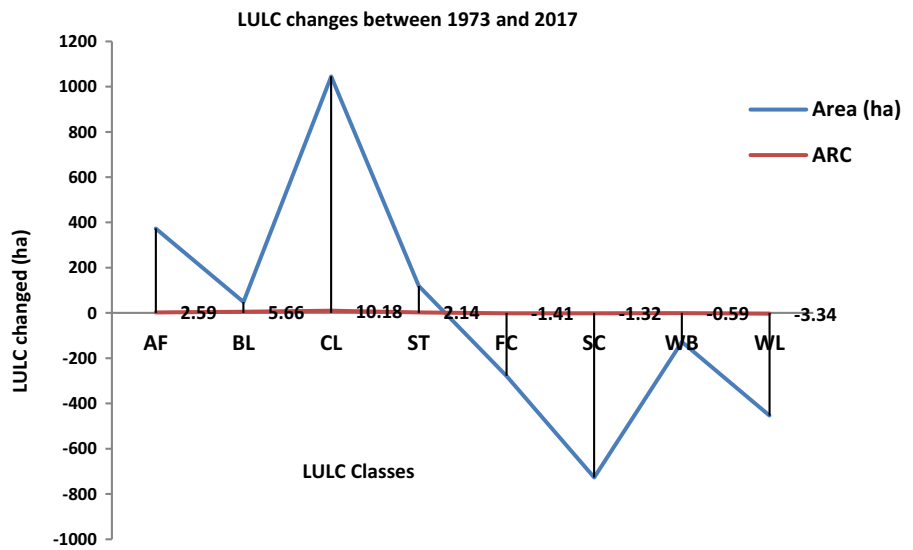
Table 5 Summary of LULC changes showing area changed (ha), percentage change, and annual rate of change for the three study periods

LULC classes	1973–1991		1991–2003		2003–2017	
	Area (ha)	ARC (%)	Area (ha)	ARC (%)	Area (ha)	ARC (%)
Agroforestry	211.36	4.39	– 79.16	– 1.92	241.04	4.14
Bare land	32.62	11.89	29.47	4.92	– 13.6	– 1.57
Cropland	219.37	16.44	374.89	8.0	450.87	3.93
Forest-cover	– 26.12	– 0.22	– 85.16	– 1.33	– 166.93	– 3.0
Settlement	39.57	2.33	61.67	3.58	18.19	0.71
Shrub-cover	– 117.49	– 0.39	– 171.64	– 1.0	– 437.58	– 2.79
Water body	– 116.03	– 1.33	– 4.03	– 0.08	– 8.07	– 0.14
Wetlands	– 243.28	– 3.06	– 126.04	– 3.83	– 83.92	– 3.5

Positive values suggest an increase and negative values a decrease in the extent of LULC type

ARC annual rate of change

Fig. 4 Total land area changed and the annual rate of changes for the eight LULC types between 1973 and 2017



ARC=Annual rate of change, AF=agroforestry, BL=bare land, CL=cropland, ST=settlement, SC=shrub-FC=forest-cover, cover, WB=water body, WL=wetlands

Table 6 Summary of LULC change matrix in hectare from 1973 to 2017

To	From								
	Agroforestry	Bare land	Crop land	Forest-cover	Settlement	Shrub-cover	Water body	Wetland	Total (2017)
Agroforestry	69.38	1.60	2.95	71.85	20.6	271.54	19.71	92.01	549.64
Bare land	1.66	1.02	1.10	3.48	1.48	14.70	10.49	17.16	50.54
Cropland	67.65	0.62	5.68	39.86	33.04	543.02	45.64	323.78	1058.8
Forest-cover	0.62	0.00	0.00	244.54	0.25	47.17	16.11	15.88	324.57
Settlement	8.55	0.86	0.98	11.13	10.80	78.42	6.77	77.24	194.75
Shrub-cover	17.84	0.43	0.86	198.4	5.97	639.2	34.81	34.54	932.05
Water body	2.05	0.00	0.00	7.87	0.25	7.81	396.21	2.83	418.02
Wetland	7.26	0.31	0.25	25.22	3.81	57.51	16.91	21.33	132.60
Total (1973)	175.01	4.84	11.82	602.35	76.20	1659.37	546.65	584.77	3661.0

In the table row total sums the amount of land area for each LULC types of the initial study year (1973) and column total sums the amount of land area that was converted to each LULC types of the year 2017. The bold diagonal values represent the area of each LULC class that remained unchanged while the off diagonal values represent the changed area. The values in each of the cells represent the amount of land that was converted from one land-cover type to another

Major land-use and land-cover change drivers

Summary outputs of FGD, KII, field observations, and preference ranking scores at LWW indicated that there are both proximate (direct) and underlying (indirect) LULC change drivers that have resulted in a change of the critical resource bases of the watershed. Here,

agricultural expansion, wood extraction, settlement expansion, and infrastructural development were the top proximate LULC change drivers. Whereas, demographic changes, community conflict, and land tenure policy were the three underlying LULC change drivers. The ranking orders of the major LULC change drivers are presented in Table 7. Even though

understandings on the LULC change drivers differ from individual to individual, participants were more or less consistent in scoring the change drivers. Although not ranked, the FGDs and key informants mentioned other minor LULC change drivers, as livestock grazing, accessibility to road and market availability.

Discussion

The fundamental processes that drive LULC change are multidimensional that involve the integration of multiple methods of analysis with thorough justifications of different kinds of field data and the understanding of social differentiation within the study environment (Jiang 2003; Campbell et al. 2005). This study integrated data from multi-temporal satellite imagery, ground truth points, field observation, FGDs, KII and quantitative analytical tools to provide quantitative and qualitative information on the LULC dynamics and their drivers in the highlands of central Ethiopia, with special reference to the social-ecological LWW. The findings from this study revealed that there was evidence for massive LULC changes as a result of proximate and underlying drivers. Here, these findings were discussed concerning other studies elsewhere.

Land-use and land-cover change detections

Accuracy assessment describes the quality of the map extracted from remotely sensed data and the extent of correspondence between what is on the ground and the classification results (Foody 2002; Congalton and Green 2009). The overall accuracies attained in this study for all the study years were much greater than the minimum threshold level (85%) designated for

effective accuracy assessment (Anderson et al. 1976). This implies that the image classification results for this study were accurate. Similarly, the kappa coefficient analysis from this study revealed strong agreement for all the study years, signifying that the LULC classes observed in the field and those on the classified map demonstrated better congruence than by chance alone. The quantitative results of change analysis of the three comparison periods (Table 5) and the overall changes from the 44 years (Fig. 4) showed the extent of changes that occurred in different LULC classes.

The LULC change detection between 1973 and 1991 revealed a substantial increase for croplands and a decrease in wetlands (Table 5 and Fig. 3). This could be attributed to the 1974/75 government change that nationalized land. As evidenced from FGDs, this land tenure arrangement has resulted in the draining of wetlands for small scale subsistence cereal crop cultivation. A study by Tefera (2011) and Degife et al. (2019) also reported increased crop cultivation following the 1975 land tenure arrangements in Nonno district in central Ethiopia and Lake Hawassa watershed in southern Ethiopia, respectively. Another probable reason stated for the decrease of wetlands was the establishment of Hero Wanchi rural town during this specific study period. Initially, the town was established at the fringe of wetlands following the road networks, but gradually expanding and occupying most of the area of the wetlands. This was witnessed from the image classification results (see Fig. 3). The land-use change in the wetlands, in turn, may have resulted in the highest shrinkage of the water body during the same comparison period. The increase in bare land-cover during the period is mainly attributed to the construction of Ambo-Woliso gravel

Table 7 Preference ranking of the major LULC change drivers as perceived by FGD participants

LULC change drivers	Participants coded (P ₁ –P ₁₀)										Total	Rank
	P ₁	P ₂	P ₃	P ₄	P ₅	P ₆	P ₇	P ₈	P ₉	P ₁₀		
Agriculture expansion	7	6	7	7	7	6	6	7	7	6	66	1st
Settlement expansion	5	4	5	6	5	4	2	6	5	7	49	3rd
Infrastructure const	2	1	2	1	2	3	1	2	3	5	22	7th
Land tenure policy	3	5	3	3	4	1	3	1	1	1	25	6th
Population growth	4	3	4	5	3	2	7	5	4	2	39	4th
Community conflict	1	2	1	2	1	5	4	4	2	4	26	5th
Wood extraction	5	7	6	4	6	7	5	3	6	3	52	2nd

P₁, P₂...P₁₀ is to represent the 10 participants

road that removed the vegetation and resulted in exposed bare soils during the specific period.

The LULC change analysis for the period 1991–2003 also revealed the highest increase for croplands. This could also be attributed to the 1991 government change in the country. The FGDs and KIIs stated that since there was a scarcity of land per household and most young farmers were landless, following the regime change (1991/92) there was high competition among the landless local farmers to occupy communal lands. Tefera (2011) also reported that since the landholding size per household in Nonno district in central Ethiopia was very small, farmers were forced to encroach into the natural vegetation for cropping, grazing and settlements. Duguma et al. (2009) and Degife et al. (2019) reported that state-owned forests experienced enormous damages following the 1991 government change in Ethiopia (see also Mezgebu and Workineh 2017).

Between the 2003 and 2017 comparison period, the highest and yet comparable changes were experienced by cropland expansion and shrubland reduction (see Table 5). The key informants and focus group discussants associated these undertakings mainly with the investment activities and the introduction of improved crop seed varieties. Agricultural investment was introduced into the wetlands of the study watershed within this specific period. Hence, it drained vast areas of wetlands for agricultural practices including cereal crops, vegetables, root and tuber crops, and floriculture production. A study by Mezgebu and Workineh (2017) reported the introduction of agricultural investment in Bale eco-region as LULC change driver that has resulted in a change of afro-alpine ecosystems. The recently introduced improved potato varieties into the study watershed were also one of the reasons for the expansion of agricultural lands during the specified period. During the field visit, it was observed that potato farms, formerly restricted to home gardens, were seen widespread in the study watershed replacing vegetated covers including wetlands and steep slope areas. Similarly, a study by Tefera (2011), reported a very rapid decrease in the vegetated lands and an increase for cultivated lands, between 2002 and 2007 in Nonno district, central Ethiopia.

The LULC change detection for the 44 years (1973–2017) showed an increasing tendency for croplands, settlements, agroforestry, and bare lands, while it showed a decreasing tendency for forest-

cover, shrub-cover, wetlands, and water body. Studies by Gessesse and Bewket (2014) in Modjo watershed in central Ethiopia for the period 1973–2007 and Degife et al. (2019) in Lake Hawassa watershed in southern Ethiopia for the period 1972–2017 reported similar trends for all the LULC types considered in this study. In particular, croplands showed the highest changes with a 10.2% annual rate of expansion from 1973 to 2017 in the current study watershed. Similarly, several studies elsewhere in Ethiopia also reported the expansion of croplands at the expense of other LULC types (Dwivedi et al. 2005; Babiso et al. 2016; Mezgebu and Workineh 2017). Conversely, wetlands and shrubland showed the greatest reduction in the watershed during the study period (Fig. 4). Likewise, many studies on LULC change in the highland watersheds of Ethiopia reported a decline in shrub-cover and riverine vegetation (Tekle and Hedlund 2000; Tegene 2002; Assen 2011; Degife et al. 2019). The increase in *Enset* dominated agroforestry land-cover type in the LWW during the study period could be associated with the importance of *Enset* crop as subsistence food, feed and cash crop in the central and southern highlands of Ethiopia. Newly established households are generally expected to plant *Enset* crops on new areas mostly at their backyards, which should also be expanded gradually until well-established *Enset* farm will be attained. Those households who attained a well-established *Enset* farming status are usually substituting the chopped *Enset* crops for household consumption and/or selling. This agroforestry system has many ecological, socio-economic and cultural benefits for the local community. For instance, it is extremely important for biodiversity conservation in fragmented landscapes by establishing movement corridors between natural and mosaic habitats (Perfecto and Vandermeer 2008). Similarly, Sahle and Yeshitela (2018) reported an increase in the area of *Enset*-based agroforestry LULC type at the Gurage Mountains of Ethiopia from 1986 to 2017.

Most of the LULC types in LWW (62%) underwent major conversions (loss or gain) with variable magnitudes in the last 44 years (1973–2017). A similar result was obtained by Kindu et al. (2013), in the Munessa-Shashemene landscape of Ethiopia from 1973 to 2012, where they reported 60% of land conversion in their study landscape. A more extreme episode was reported by Degife et al. (2019) in Lake Hawassa watershed, where about 74% of the

watershed experienced land-cover conversions in 45 years (1972–2017). In the LWW, the natural vegetation covers (wetlands and shrublands) experienced dramatic conversions, of which the conversion to cropland was the highest. Various studies on LULC changes in different parts of Ethiopia also indicated the highest conversion of natural vegetation to agricultural lands (Kindu et al. 2015; Mezgebu and Workineh 2017; Sahle and Yeshitela 2018; Degife et al. 2019). Even though, it is the lowest compared to the conversion of other LULC types nearly one-fourth (27.5%) of the water body (mainly Lake Wanchi) was converted to other LULC types. Similarly, Kindu et al. (2013) reported that although consistently declined, the water body showed fewer conversions during their study period (1973–2012). A similar trend was also reported for Lake Hawassa by Degife et al. (2019). Of the converted water body, the conversion to cropland was the highest. This was verified during field observation, where the dried portions of Lake Wanchi margins were covered mostly with potato (*Solanum tuberosum*) farms. Similarly, a study by Assen (2011) in the dried Lake Haramaya in Ethiopia revealed that the dried portion of the lake basin was cropped in short rooted crops including potato.

Land-use and land-cover change drivers

From land-use planning and sustainable watershed management perspective, it is important to have a spatially explicit understanding of LULC changes and the knowledge of their proximate and underlying drivers (Etter et al. 2006). The analysis of the drivers of LULC changes indicated the presence of both the underlying (indirect) and proximate (direct) drivers in the LWW. The findings revealed that population pressure is one of the major indirect drivers of LULC changes in LWW. Study by Shube (2011) specified that population density in Wanchi area is ever-increasing and put pressure on existing natural resources including the lake. Moreover, the 1994 and 2007 population and housing census of Ethiopia (CSA 2012); and data obtained from Hero Wanchi rural Kebele (the lowest administrative level) and Hero Wanchi town administration office (from 2010 to 2017) confirmed that the population of LWW is constantly increasing. The FGDs also remarked that in addition to the natural population growth, owing to the establishment of Hero Wanchi rural town, there were

human influxes from the neighboring districts and Kebeles. Likewise, studies elsewhere in rural Ethiopia reported population growth as the major driver of LULC changes (Gessese 2018; Sahle and Yeshitela 2018; Degife et al. 2019). Therefore, to support the rising population of the watershed there was a need for extra land for agricultural activities with continuous crop cultivation and biomass extraction for fuel-wood and construction materials. These increased demands for additional agricultural land and wood extraction resulting from population growth forced the local farmers to encroach into natural vegetation covers and marginal lands including steep slopes; intensified the pressure to the LULC changes.

The findings also specified land-use policy as the major indirect contributor to the changes in LULC in the study watershed. The FGDs and key informants evidenced that following the overthrow of the imperial rule in 1974, land and land resources were divided into pieces among local landless farmers under the motto of '*land to the tillers*' in 1975 and the ensuing proclamation of the socialist government of the time. During the FGDs, elders stated that the 1975 land reform changed the land tenure system by nationalizing all rural lands, which made '*land tillers landowners*'. This state of affairs provided a fertile ground for agricultural land expansion to other LULC types in the watershed. Besides, the regime organized smallholding farmers under the promotion of Agricultural Producer Cooperatives to increase agricultural production, which also intensified the exploitation of mainly communal lands and vegetation covers for crop cultivation in the watershed. Study by Gessesse and Bewket (2014), Sahle and Yeshitela (2018) and Degife et al. (2019) in different highland watersheds of Ethiopia also reported land tenure as the indirect driver of LULC changes.

After the fall of the socialist regime of Ethiopia in 1991, the government of the Federal Democratic Republic of Ethiopia has made some changes in the land tenure system. The 1995 Ethiopian new constitution and the federal rural land administration proclamation 89/1997 of Ethiopia handed over the authority for land administration to regional governments including the power to distribute land and formulate their land policies (Crewett et al. 2008). The Oromia Regional State's (where the current study watershed is located) rural land-use and administration proclamation 56/2002 granted higher levels of

tenure security than any other regional state land-use policies in the country. The proclamation ruled out the redistribution of land plots and allowed '*lifetime usufruct rights*' over the use of rural land to all male and female citizens whose existence mainly depend on agriculture (Crewett et al. 2008). Furthermore, according to the 'Oromia rural land administration and use regulation No. 39/2003' the land-use rights can be cancelled out in case land-users fail to use their land in each production season (except in the case of fallow); after a period of 3 years without cultivation, the land will be appropriated (Oromia Regional State 2003). The significant improvements in tenure security that encouraged farmers coupled with the regulation of terminating the land-use rights, the agricultural community in the study watershed were forced to drive farmlands at the expense of other LULC types including vegetation covers and environmentally sensitive areas.

Moreover, our findings revealed that community conflict is one of the underlying drivers of LULC changes in the study watershed. The FGDs and key informants stated that the conflict between local communities was another indirect driver of LULC changes. The conflict occurred mainly between WETA members and non-WETA members over the use of land and land resources. The villages surrounding Lake Wanchi to the western side are relatively more accessible to tourists and most residents in these villages are members of WETA, getting some income by sharing the revenues generated from ecotourism. Whereas the villages to the eastern side of the lake are less accessible, most residents are non-WETA members and are not entitled to the benefits from ecotourism income. Indeed, their livelihood activities depend on agricultural activities mainly crop cultivation. Usually, the non-WETA members are expanding their croplands at the expense of vegetation covers (mainly shrub-cover), but, the WETA members need the preservation of natural vegetation to attract visitors. This incompatible interest between the two groups created disagreement and contributed to the further clearance of natural vegetation mainly at the eastern side of the LWW. This observation was supported by the results of the classified map of 2017, where the encroachment into shrubland for crop cultivation was manifested in the eastern sides of Lake Wanchi (see Fig. 2). Previous study by Ogato et al. (2014) and Ketema (2015) in the study watershed also

identified the conflict among the local stakeholders as one of the challenges encountered WETA in establishing sustainable natural resource management in the LWW. Similarly, a study by Kent (2005) indicated that the implementation of preservation strategies in Canoas (Brazil) created a paradox over the use of natural resources between ecotourism supporters and the local community and leads to over-exploitation of the remaining natural resources.

Regarding the proximate (direct) drivers of LULC change, the findings indicated agricultural activities, wood extraction, settlement expansion, and infrastructural development as the top direct driving factors of LULC changes. The focus group discussants and key informants remarked these factors as the most driving forces determining the LULC changes of the watershed. This was confirmed with the results from the quantitative analytical approach (Table 5) and maps generated for this study (Fig. 3). The numerical values of the classified maps indirectly indicated that these factors are the major LULC change drivers of the study watershed, i.e., croplands, settlements and bare lands were the LULC types showed a general expansion in area coverage, while the LULC types with vegetation covers showed a general reduction in area coverage through the study periods. Several studies on LULC change drivers in Ethiopia reported similar incidences (Gessesse and Bewket 2014; Sahle and Yeshitela 2018; Degife et al. 2019). Agriculture has become the world's single largest driver of environmental degradation, and it is pushing the Earth beyond its natural boundaries (Scott and Udall 2018). As the watershed is characterized by a rain-fed subsistence farming system, it is credible that smallholder agricultural land expansion is the most extensive direct driver of LULC changes in the study watershed. These expansions are at the expense of other land-covers, mainly of natural vegetation. This observation was confirmed by the results from change detection analysis in that about 1045 ha of other LULC types were converted to croplands between 1973 and 2017, of which the greatest conversions came from forests, shrublands, and wetlands, which are the basic ecosystem service providers.

Wood extraction to fulfill the energy needs and construction materials of the society is one of the major drivers for clearing an extensive area of vegetation cover and trees in Ethiopia (Gessesse and Bewket 2014). The findings on the drivers of LULC

change indicated that wood extraction was the second predominant direct driver of LULC change damaging natural vegetation (Table 7). This was confirmed by the fact that the natural vegetation covers such as forests, shrub-covers and wetlands showed declined trend, during all the study periods. The local natural resource conservation experts also noted that firewood collection and charcoal making are tremendously increasing over time in the study watershed. Discussion with elders also specified that some poor resident households in the study watershed are highly dependent on firewood and charcoal sales for their survival. Similarly, studies elsewhere in Ethiopia reported that some rural residents were highly dependent on woody plant exploitation both for income generation and domestic uses (Tefera 2011; Mezgebu and Workineh 2017; Milkias and Toru 2018). The FGDs and key informants stated that firewood and charcoal selling is considerably high, during the period of decline or failure of crop production. Such surviving mechanisms were also observed in other parts of the country (Kindu et al. 2015; Degife et al. 2019).

Settlement expansion and infrastructure extension (mainly road constructions) were identified as other direct drivers of LULC changes in the study watershed. The key informants and focus group discussants related the expansion of settlements in LWW mainly with the recently emerging rural town of Hero Wanchi, which is at the expense of mainly wetlands. They also added that the unplanned rural settlements following the road networks as disturbing the shrublands. These were verified from the classified images, in that, about 77.2 ha and 78.4 ha of the lands used for settlements were wetlands and shrub-cover, respectively. Also, the constructions of tourist lodges at the lakeshore were increasing the area coverage of settlements, while negatively affecting wetland resources. Information derived from change detection analysis using the classified maps confirmed that settlement land-covers increased from 2.1% in 1973 to 5.4% in 2017 in the study watershed. Regarding infrastructure construction as LULC driver, the local natural resource experts specified that the previous gravel road construction and the currently Ambo-Woliso tarmac road under construction affected the natural vegetation cover of the area. It was observed that road construction specifically removed the ecologically and economically important indigenous tree

(Vivero et al. 2005), *Hagenia abyssinica* usually growing at high elevations along the roadsides.

Conclusions and recommendations

This study analyzed LULC dynamics and their driving forces using multi-temporal satellite imagery and information from field studies in the central highlands of Ethiopia. Satellite imagery was used to inspect the spatial extent and patterns of change and the field studies were used to verify the classified images and identify the major drivers of LULC changes. Focusing on the social-ecological LWW, the findings revealed that in the earlier decade's shrubland was the most predominant LULC type, while currently it is preceded by croplands. There was an increasing tendency for croplands, settlements, agroforestry, and bare lands at the expense of natural vegetation covers and environmentally sensitive areas. Particularly, croplands showed the highest expansion, while wetlands and shrublands showed the greatest decline in the study watershed. The water body (mainly Lake Wanchi) also showed a consistent shrinkage during the study period. About 62% of the land area found in the study watershed experienced LULC changes in one way or the other during the study periods. Specifically, the natural vegetation covers (which are the basic ecosystem service providers) experienced dramatic conversions, of which the conversion to croplands was the highest. Agricultural expansion, wood extraction, settlement expansion, and infrastructure development were the top proximate LULC change drivers, while demographic changes, community conflict, and land tenure policy were the major underlying drivers.

Generally, given the current social-ecological dynamics in Ethiopia, particularly in the central highlands where there is high population pressure, it is credible that LULC changes exacerbate wood extraction, agricultural and settlement expansion towards marginal lands and environmentally sensitive areas. To support the growing population of the watershed to lead their livelihoods sustainably, there is a need for conducting efficient agricultural activities and finding alternative clean energy sources to replace wood extraction for fuel-wood. Spaces for settlements (including infrastructures) should also be designed with efficiency addressing conservation principles.

The paradox over the use of land and land resources between ecotourism groups and non-groups should also be resolved to sustainably manage the resources of the watershed. The study findings clearly showed that the rapid deterioration of the potential resource bases of the watershed that raise growing concerns about the existence of the watershed as a social-ecological system that would sustainably support environmental resources in the future. On the other hand, if properly managed the agroforestry system dominated by drought-resilient *Enset* crop and the ecotourism activity may have numerous ecological, socio-economic and cultural benefits for the local community.

To reduce and mitigate the rapid rates of LULC conversions at local, watershed and distant downstream systems of Lake Wanchi and other watersheds elsewhere with similar social-ecological setting, the application of integrated watershed management strategies is critically important. In this regard, it is suggested that: (1) Promote the rehabilitation and conservation of the natural vegetation covers and environmentally sensitive areas, so as to benefit both the upstream and downstream watershed dwellers. (2) Design strategies that manage the rapid population growth (including family planning) in the study watershed. (3) Control the expansion of crop cultivation into marginal lands including steep slopes through the application of smart agricultural practices that increase the efficiency of using limited space with increased crop production. (4) Integrate multipurpose perennial highland fruit trees plantation with the *Enset* dominated agroforestry system. (5) Strength and support the scaling up of the ecotourism association over the rest of the study watershed.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical statement All ethical practices have been followed in relation to the development, writing, and publication of the article.

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