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Remote sensing and GIS-based study of land use/cover dynamics, driving factors, and implications in southern Ethiopia, with special reference to the Legabora watershed☆

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A R T I C L E I N F O

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A B S T R A C T

This paper investigates the trends, drivers, and consequences of LULC changes in Legabora watershed, Ethiopia, by utilizing remote sensing and geographic systems. Landsat Maltispectiral scanner (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper (ETM+), and Operational Land Imager (OLI) images of years 1976, 1991, 2001, and 2022, respectively, were used to study the dynamics of LULC. Essential image pre-processing steps were carefully carried out to correct distortions caused by sensor limitations. Eight main LULC categories were identified based on supervised image categorization methods and the maximum likelihood classification algorithm. The findings of change detection and cross-tabulation matrix demonstrate that there has been a significant increase in the area of cropland 345.1 ha/year, settlement 5.9 ha/year, forest 38.2 ha/year, and degraded lands 2.56 ha/year, respectively, over the period between 1976 and 2022. In contrast, considerable decreases were observed in grasslands (−248 ha/year) and shrublands (−144 ha/year), whereas other LULC categories augmented. The results revealed that the overall accuracy rates stood at 88.3 %, 88.4 %, and 85.6 % for 1976, 1991, and 2022, respectively. The overall kappa coefficient demonstrated values of 0.86 %, 0.86 %, and 0.83 % for the same period. Surveyed respondents perceived population growth, settlement, agricultural expansion, and infrastructure development as the most noticeable drivers of these LULC changes. In contrast, deforestation, land degradation, lack of livestock fodder, and biodiversity loss were identified as the main consequences of LULC changes. The factors and implications addressed in this study may be helpful tool for the formulation and implementation of evidence-based land use policies and strategies within in the study area and elsewhere.

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1. Introduction

The current global land use/cover (LULC) change is primarily driven by the swift development and expansion of metropolitan centers, rapid population growth, shortage of land, the demand for increased production, and advancing technologies [1]. A few decades ago, global attention was drawn to issues concerning alterations in LULC [2]. Recently, numerous African countries have initiated scientific studies on LULC change [3]. Since the beginning, humans have drastically altered the environment for food, water, medicinal goods, and other necessities [4]. The rapid alterations of LULC, primarily in emerging nations, have led to the shortage of essential resources such as water, soil, and flora [5]. [6] reported, changes in LULC are universally acknowledged as fundamental drivers affecting global biodiversity and ecosystem service. Investigations from various fields have demonstrated that changes in LULC have a significant effect on a diverse array of uses such as water systems, woodland, and biodiversity [7]. These alterations have the potential to significantly impact the natural resources within the watershed. Hence, unsustainable practices like poor cultivation, excessive grazing, mismanagement of water and land exacerbate the watershed degradation. Consequently, degraded watersheds accelerate ecological decline, reduce economic prospects, and increase social challenges [8]. Over the past centuries, there has been a significant and rapid increase in the degree and pace of human-driven changes to the earth's land surface which are driven by a complex interplay of demographic, social, economic, political, technological, and institutional variables, resulting in changes to LULC [3,9]. The driving forces behind these changes in LULC are subject to differences over time and space [10]. The extensive impact of LULC change, include soil degradation [11], loss of biodiversity and diminished ecosystem services [12]. Many researchers reported the efficiency of space-borne imagery in tracking LULC changes, particularly in emerging countries such as Africa. In 2021, [5]; examined the expansion of cities and identified alterations in LULC employing geographic information system (GIS) and space-borne imagery methods in Egypt. However, different scholars used GIS and RS methods to evaluate LULC changes, including [1]; in Kenya, Minale (2013) in Northwestern Ethiopia, Meshesha et al. (2016), in Northern highlands, Ethiopia, [13]; in western Nile delta of Egypt, Twisa and Buchroithner (2019) in the upstream and downstream Wami River, Tanzania, [14]; in Northwestern Ethiopia, [15]; in upper Awash basin of Ethiopia, [16]; in southern Ethiopia, and [17], in Lake Ziway watershed and Central Rift Valley areas. In recent times, some researchers have proposed combining GIS with machine learning to track changes in LULC. In Bangladesh, for example, [18]; examained combining GIS and machine learning to monitor and predict vegetation vulnerability. Similarly, in China, [19]; in Bangladesh, [20]; and in India [21], have also investigated the potential of this approach. Since the mid-1970s, RS has been considered a quick and valuable tool for accurately documenting changes in land use/cover on regional and worldwide levels. In contrast, GIS technology offers a multipurpose platform for gathering, preserving, displaying, and examining digital data required for identifying changes and constructing a database [22–24]. Moreover, the traditional approaches to identifying changes in LULC are expensive, inaccurate, and only give a view of a limited region. Furthermore, on-site surveys of specific regions used to be a laborious and arduous task, but now it has become simplified with the help of actual satellite and GIS information [22,25,26]. Likewise, the advancement in geospatial techniques has made it easier than ever to collect space-borne images for analyzing changes in LULC [27]. Nonetheless, Space-borne imagery and GIS have demonstrated themselves to be highly beneficial for identifying LULC patterns [28,29]. On top of this, with the advancement of optical satellite sensors through remote sensing imagery and geographic information systems, mapping land use and land cover and management of the natural resources have been chosen for enhancing the selection of areas for different purposes (A [20,27,30,31]. For the last few decades, there has been a noteworthy transformation in the LULC of the south-central Ethiopian >1500 m.a.s.l where the current study was conducted [3]. Most predominant forms of LULC change in the south-central regions of the country include deforestation and the expansion of agricultural land into marginal areas. According to reports that discuss changes in LULC, coupled with evidence gathered from local communities, deforestation, land degradation, population pressure, and soil erosion has become a widespread issue in the current research area which led to natural resource deterioration [3]. However, the expansion ofagricultural sector has not yet reached its full potential in Ethiopia due to the ever increasing population [32]. The ongoing expansion of agricultural land into more steeply sloped terrain under natural environments aimed to feed the population. Generally, LULC change in Ethiopia has entailed the alteration of forest land into agricultural uses. It was suggested that subsistence farming has extended into environmentally marginal regions [33]. During the period 1957–1999, grazing land decreased in south-central regions while the cultivated land increased [34]. [35] reported a significant decline in the natural vegetation cover but an increase in cultivated land in the central highlands of Ethiopia between 1957 and 2000. The afromentioned investigations also highlighted that the increase of crop lands has exacerbated the issue of land degradation. However, in the current study area, apart from research on land degradation and deforestation, there is a lack of historical data to comprehensively figure out LULC change and the related issues. To fully understand the dynamic relationship between people and their environments at different scales over time, numerous studies have to be conducted in various regions across the country [3]. Moreover, there is also little or no research on LULC dynamics and the consequences in the current watershed. Thus, to fill these research gaps, the trends, drivers, and effects of LULC have been investigated in the Legabora watershed of Southern Ethiopia. Therefore, effective land-use planning and policies at the spatio-temporal scale of the study watershed require the analysis of LULC changes and their incorporation into land-use science, RS, and GIS technology [36]. In addition, this research tried to contribute to the existing literature by exploring and highlighting the influence of LULC alteration on the environment and biodiversity. Therefore, this study was aimed to examine the LULC dynamics in the study watershed from 1976 to 2022; identify major driving factors and their possible consequences; produce land cover maps, and compute the alterations that occurred during the investigation period; thereby, it seeks to contribute to promoting sustainable development in the study watershed.

2. Materials and investigation approaches

2.1. An overview of the research areas

This research was conducted in the Legabora watershed (Fig. 1), which is situated in southern Ethiopia. The watershed is geographically located between 71,^{0}03′048″–75^{0}00′946″ latitude and 37°,341′711″–38^{0},078‘ 387″ longitude, with a total land area of about 31,080.2 ha. It lies partly in Kedida Gamella and partly in Damiboya Woreda (district). The land feature of the Legabora watershed exhibits an impressive topographic variation, ranging from 2300 m above sea level (m.a.s.l.) in the rift floor up to 3080 m.a.s.l. near the highlands of the Hambaricho mountain range [37]. The study area's middle and upper portions are located in the south-central highlands, while the lower portion is located in the Rift Valley plain [38]. Dry evergreen Afromontane forest predominates in the higher altitude regions of the watershed, while grassland complex vegetation types were more prevalent in the lower altitude areas. However, considering the influence of livestock and agricultural development in low-altitudinal regions, as well as increase in crop production at mid-to high-altitudinal parts of the watershed, the current situation looks to be quite different [37]. Moreover, several native tree species of the area include, such as *Juniperus procera, Cordia africana, Podocarpus falcatus, Olea europaea* subsp, and *Hagenia abyssinica* [39]. Haplic Luvisols, Eutric Nitisols Leptosols, and chromic vertisols are the most common soil types [37]. The soils are typically shallow and sand-covered with poor organic matter due to soil deterioration caused by erosion and constant farming. According to meteorological information gathered from the nearby Angacha and Durame stations, the minimum and maximum annual temperatures fluctuate between 12.2 and 25.4° Celsius. The majority of the region has bimodal annual rainfall, with low-elevation parts receiving 1200 mm and high-elevation areas obtaining 1800 mm between June and August.

The livelihoods of the local community mainly depend on agriculture, which includes crop farming and animal husbandry [40]. *Enset* (*Ensete ventricosum*), is essential source of food crops for the local people in the south-central region. The study area's general land usage is arranged in circular patterns surrounding homesteads, with *Ensete* occupying the innermost areas that encircle the farmhouse. However, south-central Ethiopia is renowned for its favorable agroecological environments for human habitation, the natural forest cover of this research region has long been degraded [41].

3. 2 sources of data and methods of analysis

On a worldwide scale, imagery from satellites is essential for tracking both spatial and temporal changes in the landscape. The

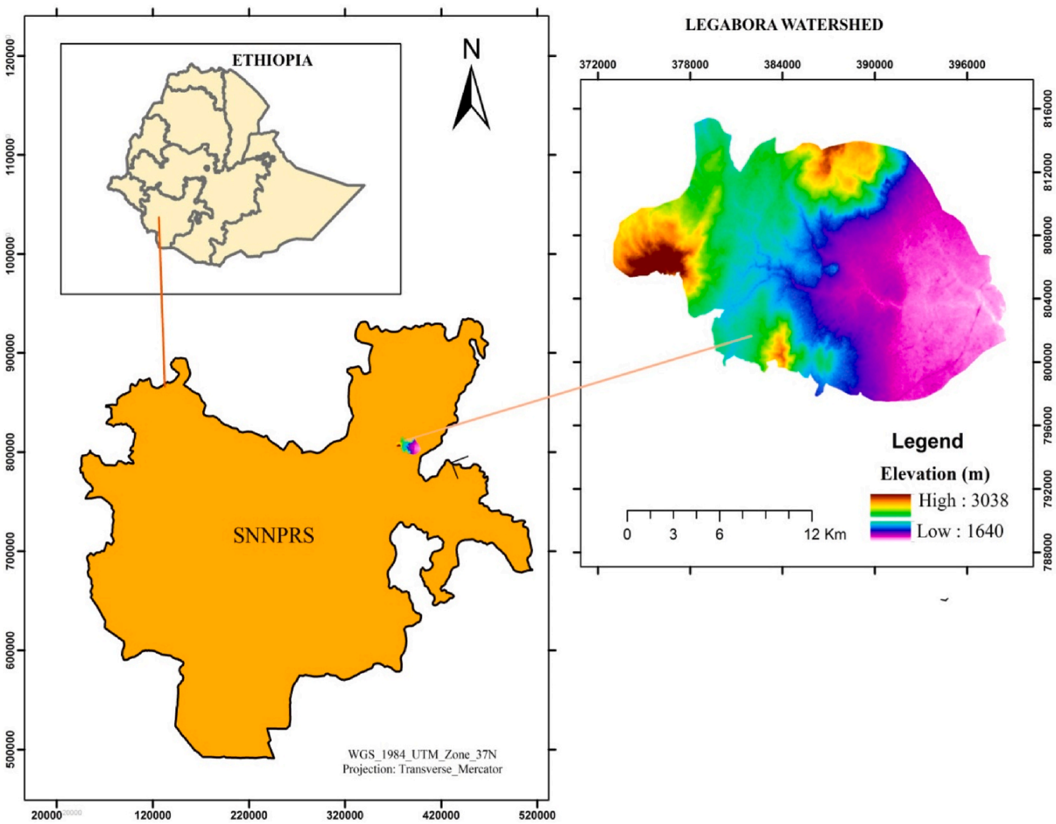

Fig. 1. Location Map of the study area.

subsequent criteria were taken into account when choosing satellite imageries: (i) the major incidents that took place in the region; (ii) the anticipated significant changes; and (iii) consistency from year to year between the study sites [42]. Statistics for the images and data sets were summarized and displayed in Table 1. The study period was further divided into four distinct time intervals, namely 1976–1991, 1991–2001, 2001–2011, and 2011–2022 which were determined based on the accessibility of trustworthy remote sensing data. Orthographic correction techniques were also employed. The analysis of the aerial photographs, which were scanned at 1014 dpi, was conducted utilizing a specific method of Aster DEM data with a resolution of 90 m [3]. Using a preference rating, the severity of significant factors of alterations in the local context was ranked. By following the approach employed by Ref. [8]. The survey respondents of the study area highlighted many changes in LULC drivers. More than Nine substantial drivers were randomly chosen in agreement with the respondents and assigned a numeric value (1, 2, 3, … 9) as a rank. The highest number (9) was assigned to the most significant driving factor, and the lowest value (1) was given for the least significant driver. Furthermore, 14 survey participants who vigorously partaken in consultations were selected to rate the nine acknowledged factors based on the severity level of impact.

The processes involved in image cataloging were outlined as follows. Firstly, the selection of training sites (Danano et al.) was carried out. For this purpose, the polygon sampling method was utilized to allow the drawing of polygons corresponding to specific spectral classes from the processed images. Secondly, to differentiate and categorize these classes effectively varied combinations of bands, image improvement, and color arrangements were employed. The selection of band combinations for this purpose is determined by the relevance of each band as they represent distinct sets of data files. The identification of the study features relied heavily on a particular range of the electromagnetic spectrum. To evaluate the sample's extracted signatures, a histogram method was utilized and multiple trials were conducted. Following this, the signatures belonging to a particular class were combined by selecting all the signatures associated with that class [43]. To categorize LULC classes, a composite image grid using false colors was generated with the support of the ERDAS Imagine and GIS software packages. Then, an unsupervised cataloging technique was employed initially to identify the main land plots, which were subsequently utilized for supervised cataloging.

We calculated the LULC area in ha and percent as well as the LULC percentage change between the specified time frames using the methods suggested by Ref. [44] as it was presented in equations (1)–(3).

$$\text{Area in ha} = \frac{\text{N} \times 900 \text{ or } 3600}{\text{M}} \tag{1}$$

$$\text{Area in } \% = \frac{\text{Q}}{\text{R}} \times 100 \tag{2}$$

$$\text{LULCC IN } \% = \left(\frac{\text{Ar}_2 - \text{Ar}_1}{\text{Ar}_1}\right) * 100 \tag{3}$$

In this example, Ar_1 represents the LULC area at the beginning of the study, and Ar_2 represents the LULC area at the end of the study. When LULCC is positive, it means that the extent has increased, while it is negative, it means that the amount has declined. N stands for the total number of counts, M for 10,000 ha, Q for the value of the identified pixel, and R for the total number of pixels. We developed a confusion matrix to verify the results of our categorization to assess the accuracy [44]. FGD discussants assisted us in gathering ground truthing points during the transect walk. Additionally, GTPs for the LULC maps from 1976 to 1991 were compiled using a false-color composite of those two years' worth of satellite images, along with elders' knowledge and earlier research [45]. Following earlier studies, this study used both supervised and unsupervised cataloging methods [46]. A supervised classification uses training sites to identify land cover, whereas an unsupervised classification uses a request for classes to identify class types [47]. The Landsat images were categorized using supervised signature extraction and the maximum likelihood algorithm. Additionally, editing, overlay analysis, and topological checks have been performed on the vector data that have been digitized. The historical LULC maps from 1976 were eventually produced with finished cartography. On the other hand, only the main LULC types were taken into consideration due to the low resolution of Landsat images (Table 2). After that, using the accuracy assessment tool in ArcGIS 10.6, an accuracy evaluation for each of the classified Landsat images (maps) was done [48].

Table 1
A summary of the data sets and image statistics employed to create the maps of LULC for the Legabora watershed.

Watershed	Satellite sensors	Source	Acquisition date	Resolution scale (m)	Path/Row	Spectral resolution type
Legabora	MSS	USGS	January–1976	57*57[a]	169/55	Multi-spectral
	TM	USGS	February–1991	28.5*28.5	169/55	Multi-spectral
	ETM+	USGS	January–2001	30*30[c]	169/55	Multi-spectral
	OLI-TIRS	USGS	April–2011	30*30[c]	169/55	Multi-spectral
	OLI-TIRS	USGS	March–2022	28.5*28.5	169/55	Multi-spectral

Note: [c] panchromatic enhanced to 15 m to facilitate visual interpretation, but 28.5 resolution images from 1991 to 2022 were used to conduct supervised classification and change analysis.
[a] Mosaic.

Table 2
LULC categorization and their definitions in the study watershed.

Code	LULC class	Their descriptions
ST	Settlement	A land-use type that includes rural settlement area, educational, health, socio-economic facilities, residential houses, administrative buildings, small-scale industrial areas, etc.
WL	Wetland	Land use that is waterlogged and swampy during the wet season, which dries in the sunny season.
CL	Cropland	Smallholder farmers owned land that is used to grow cropland. It is characterized by tilled and planted, bare crop fields, and limited areas temporarily left as fallow.
SL	Shrub land	Areas covered by bushes, and shrubs >20 % cover, and mixed with grasses; less than 20 % tree cover.
FL	Forest land	Land covered with dense trees >80 % canopy cover which includes evergreen forest land, mixed forest, and plantation forests
GL	Grassland	A land-use type where the land is dominated by grasses, forbs, and herbs with nil or little proportion of shrubs.
BL	Bare land	Areas with little or no vegetation cover consist of exposed soil quarries
WB	Water body	The area covered by water (ponds and rivers)

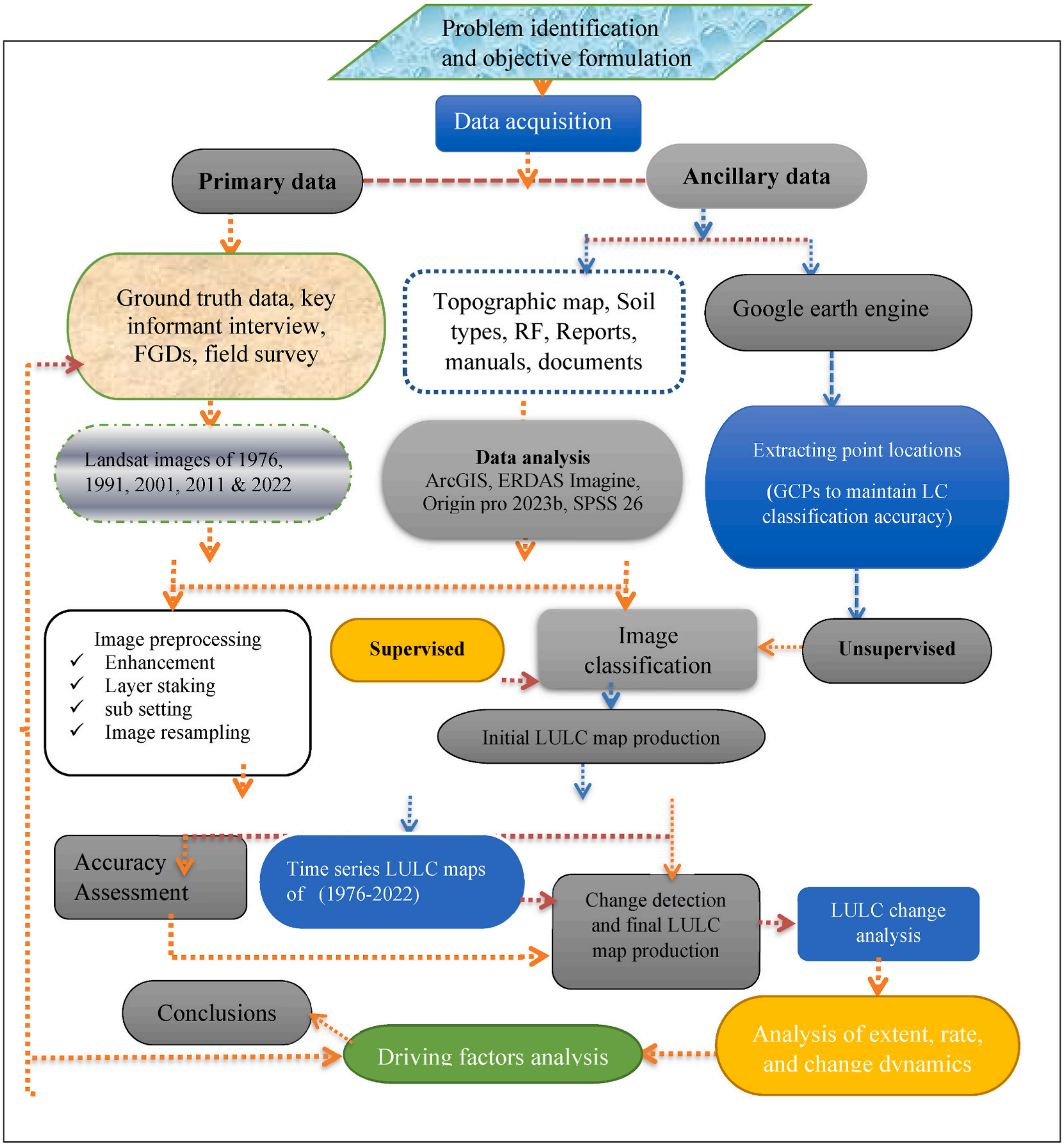

Fig. 2. The flowchart for the entire procedure used for the LULC change assessment Adopted from [41].

4. 3 focus group discussion and a household survey

The information used for both stakeholder and community investigation was obtained from a combination of secondary and primary sources, such as focus groups and household surveys. In order to gain a deeper knowledge of the studied areas, a reconnaissance survey was carried out. Discussions were held during this exploratory survey with an array of participants, including farmers and extension personnel who work closely with the farmers [49]. The study objectives, sampling strategies, and survey instruments were improved using the information from this phase. Following the methods proposed by Ref. [50]; the Kebeles, district, and household respondents were selected utilizing a three-stage sample approach that includes random and purposeful selection, and systematic random sampling to select the household respondents. A socioeconomic analysis of 132 randomly picked households was conducted to verify the data from aerial photographs and images from satellites. In addition to the household survey, 22 FGDs with farmers and development experts were undertaken. The discussions included elderly participants, most of whom were over 55 years old, both sexes who could recall and communicate past agricultural land use events. The discussion topics were how they perceived the causes of deforestation, policy impact, and potential solutions. Each group had between 8 and 10 members. Assistants were used to conduct the interviews. The assistants were educated professionals who spoke the regional languages. A variety of training activities were carried out for the assistants, covering topics like how to make contact, how to conduct interviews properly, and cultural considerations. The early morning and late afternoon, which are normally ideal periods for farmers, were used to conduct interviews with individual households. These were the best times of the day for farmers because neither agricultural work nor any other household-related activities took place then. If the informant refused to provide information, they were asked to recommend a person who would be open to acting as an informant. One household head's interview should take between two and a half hours [38]. The illustration in the figure depicts the overall methodology of LULC change (Fig. 2)

Additionally, the discussion also addressed the matter of land degradation and the pressing issues that demand intervention. Throughout the discussion and the interviews conducted, the primary focus remained on finding solutions to these problems (Danano et al.). In order to gain a deeper comprehension of the significant issues present within the watershed, a combination of transect walks, field walks, and casual conversations with farmers on their land was employed. The farmers were requested to elaborate on the alterations made to specific parts of the landscape. Moreover, the reason for the change was elucidated and expounded upon. Furthermore, the farmers were prompted to articulate the effects of these alterations on their way of life, immediate vicinity, and ecosystem. Additionally, the farmers were requested to provide descriptions of the outcomes stemming from these changes. To gather data, field observations were conducted using checklists that were previously designed to assess the watershed conditions. Pictures of significant sites were also taken to supplement the investigation. By combining the results of field observation, expert insights, and a thorough evaluation of paperwork from federal and local agencies, the study identified eight distinct categories of LULC classes (Danano et al.). In accordance with the proposed research methodology by Ref. [51]; we computed the sample size for the study. Hence, to calculate the 95 % confidence interval, denoted by Y^2, and the sample size, denoted by m, the following formula is used. For n, which denotes the proportion of the total population to be sampled, a value of 0.1 is assumed. For s, which denotes the absence of an event, a value of 0.9 is used. M signifies the total number of households as represented in Eq. (4), which is 3100, and e denotes margin of error, which is 0.05

$$m\frac{Y^2.\ n.\ s.\ M}{e^2(M-1)+Y^2.\ n.\ s} \tag{4}$$

Table 3
Accuracy evaluation for LULC in the Legabora watershed between 1976 and 2022.

Year	LULC	WSD	ST	WB	BL	SL	WL	CL	GL	FL	UA%	K
1976	ST	**Legabora watershed**	**0**	0	0	0	0	0	0	0	0	**0.86**
	WB		0	**56**	3	3	0	0	3	0	81.1	
	BL		0	2	**66**	0	0	3	2	0	90.4	
	SL		0	0	0	**62**	0	6	3	3	83.8	
	WL		0	0	0	0	**0**	0	0	0	0	
	CL		0	0	0	4	0	**68**	0	0	94.4	
	GL		0	1	0	3	0	1	**79**	4	89.8	
	FL		0	0	0	3	0	0	4	**63**	90	
	PA%		0	94. 9	95.7	82.7	0	87.2	86.8	90.		
	OAA	**88.3**										
2022	ST	**Legabora watershed**	**45**	3	5	1	0	5	1	0	75.3	**0.83**
	WB		0	**51**	1	7	0	3	0	1	78.5	
	BL		0	4	**60**	3	1	1	4	0	82.2	
	SL		4	0	1	**65**	0	0	4	0	87.8	
	WL		0	0	0	0	**6**	0	0	0	100	
	CL		0	0	0	0	1	**114**	0	1	98.3	
	GL		0	3	3	0	0	4	**60**	2	83.3	
	FL		0	0	0	6	0	0	5	**49**	81.7	
	PA%		91.8	83.6	85.7	79.3	75	89.8	81.1	92.5		
	OAA		**89.8**									

Note: SL; shrub land, WL; wetland, ST; settlement, BL; bare land, FL; forest land, GL; grass land, CL; crop land, WSD; Watershed.

To pinpoint the principal drivers of land use and land cover (LULC) changes in the Legabora landscape at the household level, logistic regression analysis was conducted as depicted in (Equation (5). The dependent variable was based on the perception of residents regarding the drivers of LULC changes and/or the identified perceived drivers. Independent variables were determined to include socioeconomic characteristics such as age, gender, marital status, and education level. By conducting logistic analysis at the household level, the likelihood of the effects of independent variables on the dependent variables was estimated following the methodology proposed by Ref. [52] as depicted in Eq. 5

$$Logit\ (\mathrm{N}) = \alpha + \mathrm{P}_1\mathrm{Y}_1 + \mathrm{P}_2 Y_2 + \mathrm{P}_3\mathrm{Y}_3 + \ldots \mathrm{P}_n\mathrm{Y}_n \tag{5}$$

Where N = dependent variable indicating the likelihood that N = 1, α = the intercept , $P_1Y_1 \ldots P_nY_n$ = constants of associated independent variables, and $Y_1 \ldots Y_n$ = independent variables

5. Result

5.1. 1 accuracy evaluation for image cataloging

To effectively detect the change, the classification data must undergo individual classification accuracy evaluation. The stratified random approach was used to represent distinct land cover classes in the area for the accuracy evaluation of land cover maps generated from satellite images. Based on ground truth data and visual interpretation, the accuracy was scored out of 100 points. Error matrices were used to perform a statistical comparison of the classification results and the reference data [53].

According to the satellite image analysis, in 2022, wetlands in the Legabora watershed received a 100 % overall user accuracy

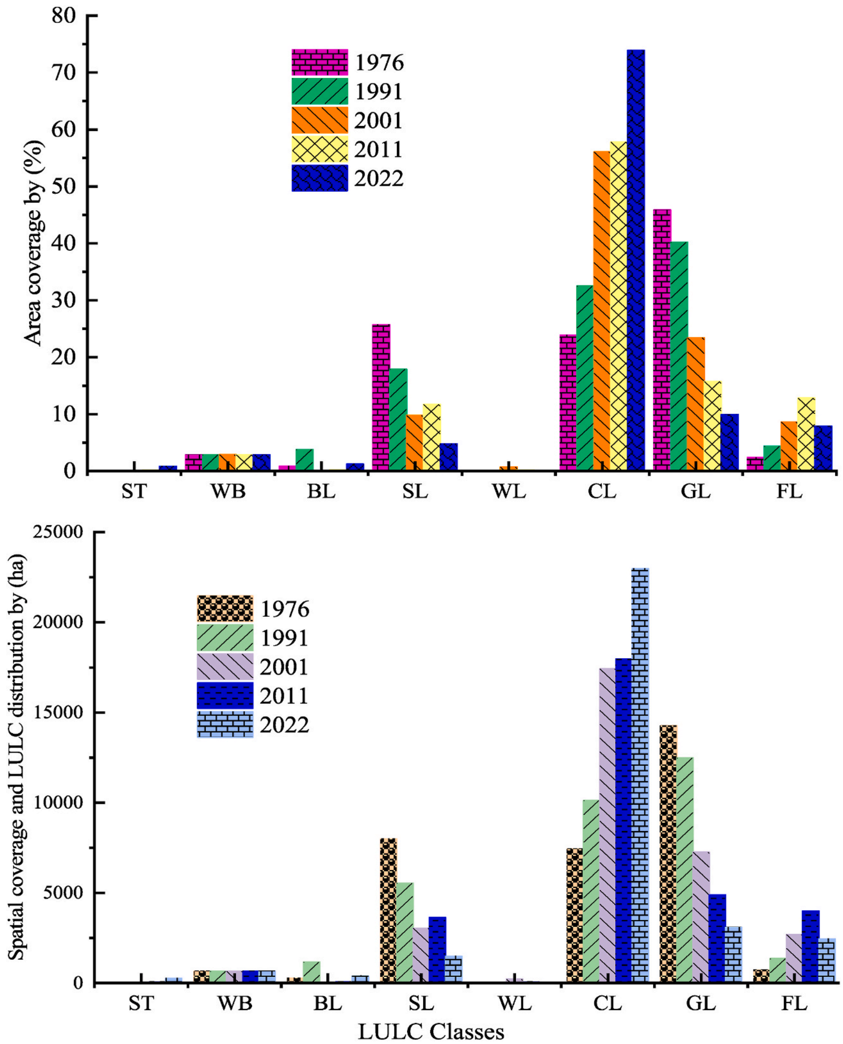

Fig. 3. Percentage and area coverage of eight LULC classes for five investigation periods.

score, while settlements received a 75.3 % evaluation. In contrast, cropland got 94.4 % in 1976, while wetland and settlement had the lowest (both at 0 %). According to (Table 3), the producer accuracy for each type of land in the final study period was (83.6 %) for water bodies, (89.8 %) for cropland, and (92.5 %) for forest. In the initial study span (1976), the settlement had the lowest producer accuracy (0 %), while bare land had the highest (95 %). During our field observation and transaction walk, a total of 750 Ground Control Points (GCPs) were gathered from a GPS. 350 GCPs were used to assess the accuracy of the satellite images, and 400 of these points were used for supervised classification. Every LULC type with an area size of less than 4000 km^2 and less than 12 classes is allocated a minimum of 50 points as suggested by Ref. [54]. [44]; revealed that poor accuracy recordings from producers and users were brought on by the homogeneity of LULC at the spectral scale. For the classification periods of the 1976 and 2022 images, respectively, kappa statistics of 0.86 and 83 were obtained, showing that there is 86 % and 83 % better covenant as depicted in (Table 3). Moreover, the formula for kappa statistics was illustrated in Eq. (6).The rows offer classifications created using data from remote sensing, while the columns provide reference data. Off-diagonal numbers represent incorrectly classified sites, while bolded diagonals display properly categorized sites.

According to (Table 3), kappa statistics demonstrated that the cataloging map and ground reference data had a high degree of agreement for all LULC. The final calculation was carried out as follows:

$$K = \frac{N\sum_{i=1}^{n} m_{ii} - \sum_{i=1}^{n} (G_i C_i)}{N^2 - \sum_{i=1}^{n} (G_i C_i)} \quad (6)$$

Where: class numbers are represented by i, classification numbers are designated by (N), classification values are signified by (m_{ii}) where m_{ii} is the number of values which drop into truth classes i categorized as values found on the slanting of the error matrix. A class i prediction is represented by all predicted values of the sum, and a class truth value is denoted by (G_i).

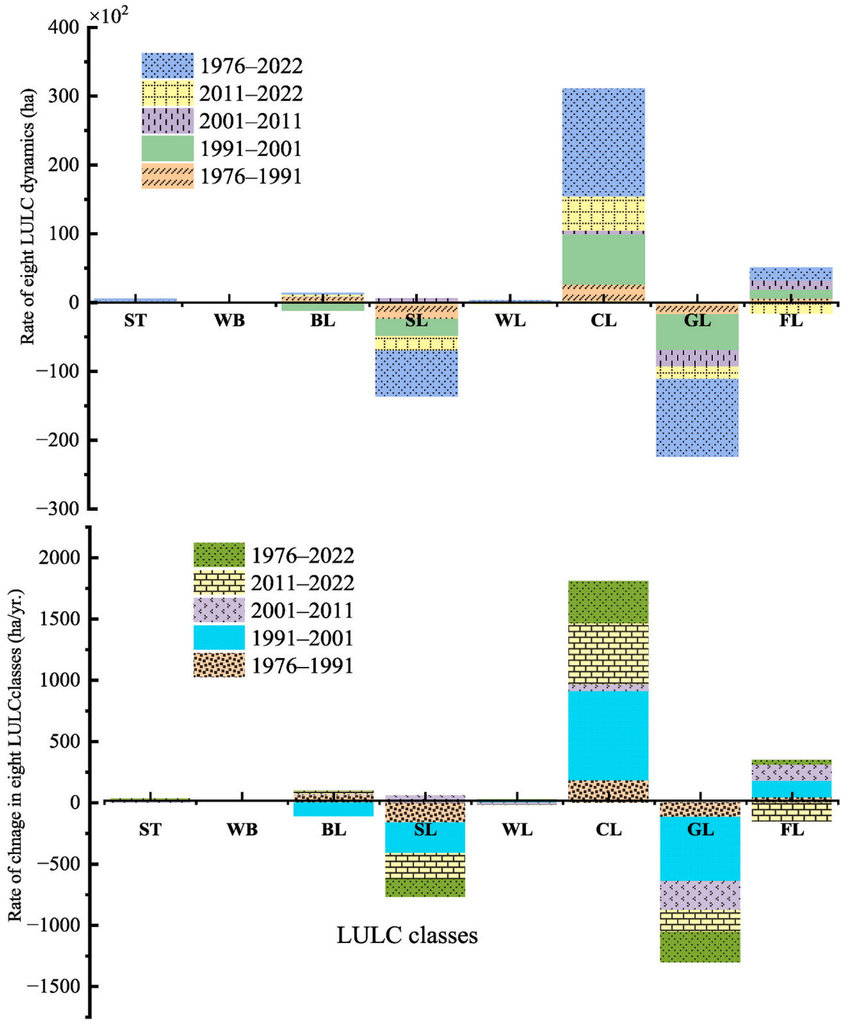

Fig. 4. Annual rate of change (ha/year), and area changed by (ha) between 1976 and 2022.

5.2. Distributions of LULC change over time and space within the Legabora watershed

Croplands covered 23.9 %, followed by water bodies with 2.9 %, and bare lands with the lowest percentage. According to the data shown in (Fig. 3), it is noteworthy that wetlands and settlements were completely lost during this time. During the second study period, which was conducted in 1991, there was a change in the coverage of the land; grassland accounted for 40 % of all land use, followed by cropland (35 %), shrublands (17 %), forest (4), and bare land (38 %). Similar to the first evaluation period, wetlands and settlements were completely lost during this span. Grasslands made up about 23.4 % in 2011, followed by shrublands (9.8 %), which accounted for about 56.1 % of the total land area. The smallest amount of land is occupied by settlements and wetlands in 2022, while croplands accounted for roughly 73.9 % of the study area, followed by grasslands at 9.9 % and forests at 7.9 %. During the most recent study

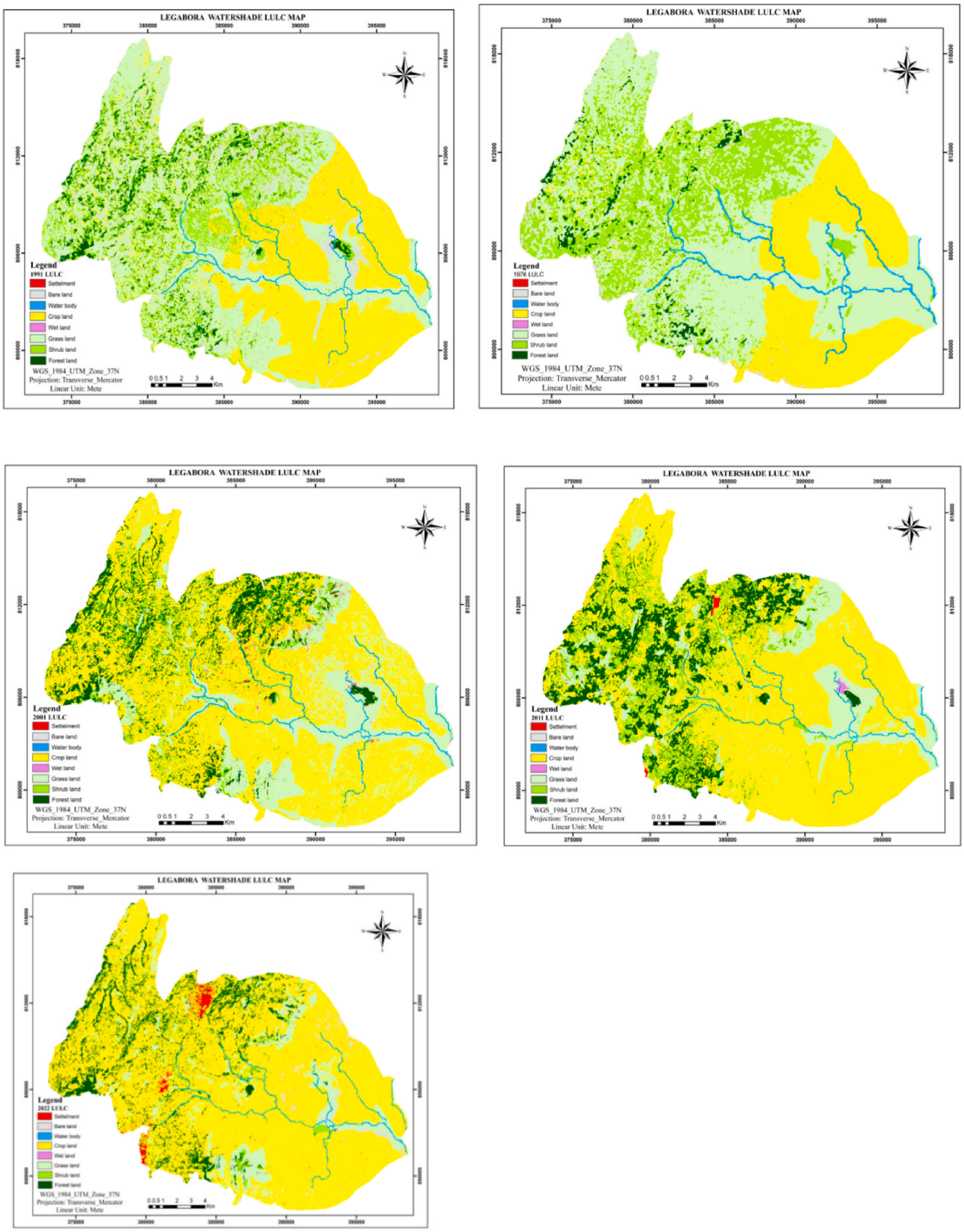

Fig. 5. Classified LULC map of Legabora watershed from 1976 to 2022.

Table 4
Eight LULC classes changed in (ha) and percent (%) between 1976 and 2022.

WSD	LULC	1976–1991		1991–2001		2001–2011		2011–2022		1976–2022	
		(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Legabora watershed	ST	+0	+0	+0.99	+0	+61.85	+6247.5	+200.95	+319.8	+263.8	+100
	WB	+0	0	+0	+0	+0	+0	+0	+0	+0	+0
	BL	+902.62	+328.51	−1143.45	−97.1	+44.8	+132.2	+311.2	+395.1	+115.2	+29.54
	SL	−2441.88	−30.56	−2496.51	−44.9	+585.8	+19.2	−2148.6	−59.1	−6501.2	−436.37
	WL	+0	+0	+230.8	+0	−168.8	−73.1	−18.5	−29.9	+43.5	+100
	CL	+2684.4	+30.02	+7298.8	+72.1	+546.3	+3.14	+4998.9	+27.8	+15528.3	+67.6
	GL	−1775.6	−12.45	−5229.3	−41.8	−2364.7	−32.6	−1799.9	−36.8	−11169.5	−360.63
	FL	+630.5	+86.3	+1338.8	+98.3	+1338.8	+49.6	−1544	−38.7	+1719.8	+70.18

period (2022), about 73.9 % of the study area was covered by cropland, with the remaining percentage being shared by other LULC classes (Fig. 3). depicts the spatial extent and distribution of LULC for each time period.

5.3. 3 trends and LULC dynamics of eight LULC classes from 1976 to 2022

5.3.1. Cropland state of Legabora watershed

A large percentage of rural inhabitants in the Legabora watershed depend heavily on farming, mainly crop production. Cropland expanded at a yearly pace of 729.9 ha/year from 1991 to 2001, resulting in a net loss of grass and shrublands (Fig. 4). From 2001 to 2011, the Legabora watershed had an annual loss of 54.6 ha/year compared to the first and second study periods, but it gradually increased between 2011 and 2022. The decline in cropland may be attributed to rising demand for additional land for eucalyptus plantations and settlement expansion. In the Legabora watershed, crops have been the dominant type of LULC throughout the analysis period, making up 23.9 % in 1976 and 57.8 % in 2011. The situation had changed by the end of the period (2022), it accounted for 73.9 % of the study watershed and other LULC categories for the remaining shares (Fig. 5). LULC classification analysis indicated that cropland was the most dominant type of land use in the Legabora watershed throughout the overall evaluation periods. This demonstrated how croplands were expanded at the expense of shrubs and grassland to increase crop production. The demand for agricultural goods and more readily available land for habitation might play a role in this expansion. Participants in KIIs and FGDs believed that population growth was to blame for both the expansion of farmland and the loss of grasslands and forest cover. These findings are consistent with earlier research by Refs. [39,55]; all of which found a 65 % increase in farmland.

5.3.2. Wetland state

It was shown in Fig. 3 that specific LULC classes in Legabora watersheds underwent spatiotemporal changes. Wetland areas made up 0.8 %, 0.1 %, and 0.3 % of the total land areas in the study watershed in 1976, 2001, and 2011, respectively. But in 2022, this coverage rose to 389.8 ha (1.25 %) Fig. 3. This showed that the wetland area had both escalating and diminishing tendencies during the spatiotemporal study spans. The assessment of LULC trends concluded that wetlands showed growing tendencies by (43.5 ha) between 1976 and 2022, with a percentage shift of (100 %) in the study area (Fig. 4). The results of [36]; reported that wetlands in Ethiopia had significantly decreased by 1.6 %, which is completely contrary to the Legabora watershed research findings. The same results were determined by Ref. [39]; who found that the wetland's area shrunk on average by 172.6 ha/year between 1973 and 2019. Similarly, [56]; found wetland cover decreased by 1.85 % between 1995 and 2010 in North Western Lowlands of Ethiopia.

5.3.3. Bare land state

We produced categorized LULC maps for the Legabora study watershed, as presented in (Fig. 5). It was found that the area of bare land in the research region under consideration had slightly increased over time. However, the LULC analysis revealed that over the past 45 years, the area of bare land steadily increased from 1976 (274.76 ha) to 2022 (389.97 ha). Nevertheless, the LULC studies found that barren land rose by 115.2 ha between 1976 and 2022, increasing annually by 2.56 ha/year and changing by a percentage of 395.1 for the whole study span (Table 4). This might be attributed to inadequate land management practices and poor application of soil and water conservation operations throughout sloppy regions, which aggravated land degradation and eventually left the land completely bare. The spatiotemporal analysis of this research is in contrast with that study by Ref. [53]; who noted that the amount of bare land decreased. In this respect, it is also important to note that the findings of the present research are consistent with an array of other earlier investigations conducted in various regions of the country, for instance Refs. [57,58], both in Ethiopia's central uplands reported identical findings [59]. in the Keleta watershed and [60] in the Shenkolla watershed arrived at quite identical outcomes.

5.3.4. Forestland state

In 1976, 2001, and 2011, the area covered by forest land was 2.4 %, 8.7 %, and 12.9 %, respectively. Nonetheless, the forest cover of the watershed disclosed a tendency towards both an increase and a decline during the fourth and fifth study periods. This increment could be attributable to initiatives like tree plantations that were put in place as a component of the sustainable utilization of resources program. Nevertheless, the LULC data demonstrated that forest area declined by (−1544.1 ha) between 2011 and 2022, with a change by a percentage of −38.7 % (Table 4), and a yearly declining average of −154.4 ha/year. Furthermore, survey respondents described that in 1991/92, the military government was changed in Ethiopia, which has weakened effective law enforcemen that resulted change in the forest lands into changed to new LULC types. The depletion of trees for fuel and charcoal production by young individuals who lack farmland and by farmers who possess small plots of land damage the forested areas. The research results showed that the forest land expanded by (1719.8 ha) between 1976 and 2022, with change by a percentage of 70.2 % and an annual increase of 38.2 ha/year, respectively. Both FGD discussants and KIIs agreed that eucalyptus tree plantations were crucial for producing materials for construction and firewood as well as generating revenue for the local community, which in turn contributed to increasing the amount of forestland cover. [47]; also observed a rise in forest LULC by 1.46 % from 2007 to 2018, which is in line with the present research. Additionally, the rise in the amount of forest between 1964 and 2006 was confirmed by Ref. [61]. In contrast to the results of the current study, [48]; reported a 23.1 % decline in forest-covered areas from 2004 to 2014. The decrease in the amount of forest land was confirmed by Ref. [62]; in northeastern Ethiopia.

5.3.5. Grassland state

Fig. 3, depicted that the grassland areacover in Legabora was 14266.7 (45.9 %) in 1976, 12491.1 (40.2 %) in 1991, 7261.8 (23.4 %) in 2001, and 4897.2 ha (15.8 %) in 2011. These data unmistakably show that the grass cover of the study area gradually decreased from 1991 to 200 and 2001 to 2011 at a rate of −552.9 and −236.5 ha/year, respectively (Fig. 4). The surveyed households, confirmed that private grazing land in particular had been completely abandoned. The communal grassland was largely transformed into farmland. A significant portion of the grasslands were converted to cultivated land between 1976 and 2022, which was confirmed by satellite image interpretation. The loss of grassland was found to be linked to the need for crop cultivation on previously occupied land and the building of new residences in the research site, as revealed by focus groups and in-depth interviews with locals. Similar studies conducted in some other regions of the country have reported findings that are consistent with the current research, for instance, Ref. [63]; described a yearly decline of grassland by 1023 ha between 2005 and 2015. [48]; stated that the extent of grassland coverage declined in the Lake Tana watershed. Similarly, [38]; the conversion of 37 % of highland grasslands into cultivated land from 1973 to 2006. Similar outcomes were published by Ref. [47]; who reported between 2007 and 2018, the grassland in the upper Rib watershed decreased by roughly 15.97 %.

5.3.6. Shrubland state of the Legabora watershed

During the first and second assessment spans, shrub land constituted about 7990.9 (25.7 %) and 5549 ha (17.9 %) respectively, as shown in (Fig. 3). Between 2001 and 2011, shrublands increased by 585.8 ha, or 19.2 % (as depicted in Table 4), with a yearly expansion of 58.6 ha/year. The outcome of research finding indicates that the shrublands dwindled at a rate of −144.5 ha/year over the whole study period. The local people's dependence on them as their primary supplier of wood and other construction materials, as well as the cropland and settlement expansion could cause such losses. This outcome is similar to several earlier studies carried out across the country in various geographical regions, including, [64]; who have reported steady decline in shrubland area cover from 20.8 % in 1958 to 15.6 % in 1980, in the northeastern Ethiopia. [65]; stated that, the size of the shrublands shrunk by 975 ha between 1985 and 2022. Similarly, [8]; declared a yealy decline of by 1.3 % of the shrublands in the central uplands of the country. [66]; found that the extent of the shrublands declined by 16 ha between 1973 and 2013 in the upper blue Nile of Ethiopia. In contrast, [67]; stated that shrublands expanded at a rate of 22.8 ha yearly from 1973 to 2010.

5.3.7. Settlement state of the Legabora watershed

During the first and second comparison periods, which took place in 1976 and 1991, there was hardly any settlement coverage. However, in the Legabora watershed, the size of settlements rose drastically from 0 % in both 1976 and 1991 to 0.2 % in 2011 and 0.9 % in 2022, as illustrated in Fig. 3. This trend persisted and grew even more rapidly in the fourth and fifth comparison periods, with expansion rates of 200.9 and 263.8 ha, respectively. Our analysis shows an average yearly expansion rate of 5.9 ha/year between 1976 and 2022. This could be due to settlers occupation of the public lands and construction new infrastructure for residential and other purposes, as well as population growth. Our findings is consistent with other previous research carried out across the country, for instance, Ref. [68]; reported an increment of settlement by 2.22 % between 1986 and 2006 [56]; identified that the extent of 1.26 % increase between 1995 and 2010, and [69]; also reported an increase in settlement cover between 1964 and 2014 in the northern

Table 5
An error assessment table of the Legabora watershed from 1976 to 2022.

	LULC	WSD	LULC change from the initial year 1976 (ha)									
			ST	BL	WB	CL	WL	GL	SL	FL	Row	Loss
LULC to yr. 2011 (ha) LULC to final yr. 2022 (ha)	ST	**Legabora Watershed**	**0**	4	0	4	0	103	137	8	256	256
	BL		0	**1**	9	238	0	131	6	0	385	384
	WB		0	0	**300**	0	0	0	0	0	300	0
	CL		0	195	216	**6555**	0	10,436	5296	327	23,025	16,470
	WL		0	0	2	12	**0**	23	10	0	47	47
	GL		0	42	69	379	0	**1993**	628	9	3119	1126
	SL		0	6	17	67	0	652	**683**	37	1463	780
	FL		0	14	17	49	0	882	1186	**311**	2460	2149
	Column T		0	262	630	7304	0	14,220	7946	692	0	
	Gain		0	261	330	749	0	12,227	7263	381	–	–
	NC		−256	−123	330	−15721	−47	11,101	6483	−1768	–	–
	NP		−256	−124	1.1	−2.39	0	5.57	5800	−5.68	–	–
	LULC Change from the year 2001 (ha)											
	ST	**Legabora watershed**	**376**	0	0	0	0	0	0	0	376	0
	BL		0	**2689**	125	72	1498	293	15	0	4692	2003
	WB		0	83	**1596**	9	1219	887	0	0	3795	2199
	CL		0	18	19	**9**	11	5	0	0	62	56
	WL		0	3988	474	103	**12,455**	673	17	0	17,710	5255
	GL		0	459	486	37	2160	**1190**	0	0	4333	3143
	SL		0	21	0	0	37	0	**1**	0	59	58
	FL		0	2	1	0	35	4	0	**1**	43	42
	Column T		376	7262	2701	231	17,421	3053	34	1	0	
	Gain		0	4573	1105	222	4966	1863	33	0	–	–
	NC		0	2570	−1094	166	−289	−1280	−25	−42	–	–
	NP		0	0.96	−0.69	18.44	−0.02	−1.08	−25	−42	–	–

highlands of Ethiopia.

5.4. LULC transformation matrix for five study phases in the Legabora watershed

To determine the decline and an increase of the area of all land use categories shown in Table 5, the LULC conversion matrices underwent an evaluation. All study watershed areas experienced significant changes, both gains and losses. LULC dynamics showed significant changes between 1976 and 2022 in Legabora, where (262 ha) of bare cover, 692ha of forest cover 7304ha, cultivated land, 7946 ha of shrub lands, 14,220 ha of grazing/grasslands, and 630 ha water bodies were transformed one to another, respectively, whereas between 2001 and 2011 (7262) of bare cover, 270 ha water body, 3053ha grassland, 34 ha of shrublands, 17421ha of wetlands, 231ha of croplands, and 376 ha of settlement lands were transformed one to another, respectively. In 1976, the grasslands spanned over 12,227 ha, but by 2022, they had decreased to 3119 ha. However, Lagabora's coverage of shrublands and grasslands remained the same, at 683 ha and 1993 ha, respectively, as depicted in (Table 5). This shift in coverage was due to a transfer from one land use category to another, followed by a loss to a different land use type. Among the various land use types, shrublands gained 17, 37, 652, and 67 ha from water bodies, forestlands, grasslands, and croplands, respectively. Likewise, its initial coverage was altered to settlement, forestland, agriculture, and grassland, with an extent of 137, 1186, 5296, and 628 ha, respectively. About 89.3 % of the modified shrubland cover (71.8 %) was converted into farmland, with 12 % and 2.3 % transformed into forestland and grassland, respectively. Over the last 45 years, croplands (327 ha), shrublands (37 ha), and grasslands (9 ha) had replaced forest areas in the watershed. In Legabora watersheds, 379, 238, 67, and 49 ha, respectively, of grassland, bare land, shrublands, and forestland were converted to croplands. The assessment of LULC alterations indicated that bare lands declined from 7262 ha in 2001–4692 ha in 2011, while croplands diminished from 231 ha in 2001 to 62 ha in 2022. The transformation matrix indicated that different LULC classes provided substantial gains to the forest (382 ha), while cropland cover (327 ha) and shrublands (37 ha) provided the greatest coverage in the watershed. Between the years 1976 and 2022, cropland experienced a net gain of 195, 216, 327, 5296, and 10,436 ha from other classes, like, bare land, wetland, forestland, shrublands, and grassland.

Note: The total persistence of the landscape, which refers to areas that remained unchanged, is represented by the figures in bold. The net change to persistence ratio for each class is indicated by the symbol NP, which compares the net change to the diagonals. M; denotes net change, N; represents the diagonals of each class, and NC indicates net change. equations (7)–(10) provided below were used to calculate net change, loss, gain, and net persistence.

$$NP=\frac{M}{N} \tag{7}$$

$$NC = Gain - Loss \tag{8}$$

$$Loss = Row\ total - Diagonals\ of\ each\ class\ (unchanged) \tag{9}$$

$$Gain = Column\ total - Diagonals\ of\ each\ class(unchanged) \tag{10}$$

During the period spanning from 1976 to 2022, the ratio of net change to persistence for settlement exhibited a significant negative trend. Conversely, shrublands, grasslands, and wetlands showed a positive trend. Forested areas, bare lands, and croplands also displayed negative trends, representing the most dominant patterns throughout the study area. The NC-to-NP for other types of LULC was nearby to zero, indicating a higher likelihood of persistence rather than change. A total of 9843 ha remained unchanged across the landscape. The biggest net gain was in grassland, which was mostly obtained from forestland and agricultural land. The study found that from 1976 to 2022, the NC-to-NP ratio was greater for residential areas, shrublands, savannahs, and croplands (negative for settlement/residential and cropland, positive for shrublands and grasslands). The NC-to-NP ratio for other LULC types was closer to zero between 2001 and 2011, while it was higher for forests (negative), croplands (positive), and shrublands (Table 5).

Table 6
Socioeconomic and demographic features of surveyed households.

Household characteristics		Value by percent
Gender	Female	54.5
	Male	45.5
Mean household age (years)		40.8
Marital status	Married	67
	Never married	21
	Divorced	8.1
Education	Primary (1–8)	16.6
	Secondary (9–12)	15.7
	Tertiary (12+)	22.8
	BSc and above	16.3
	Illiterate	9.7
	Read and write only	14.3

5.5. Socioeconomic features of respondents in the study site

The analysis in Table 6 focuses on the households that were surveyed, presenting their socio-economic and demographic attributes. According to the findings from the socio-economic investigation, the participants' ages spanned from 20 to 65 years, with an average age of 41 years. The majority of survey participants (67 %) were married, while 20 % had never been married and 8.1 % were divorced. Female-led households accounted for 45.5 % of the sample, while male-led households accounted for 54.5 %. Educational attainment data showed that 14.3 % of the participants could read and write, 16.6 % completed primary school, and 15.7 % completed secondary school. Additionally, 22.8 % completed tertiary school 16.3 % completed a Bachelor of Science or higher, while 9.7 % had not received any formal education. Based on the findings from the on-site survey, focus group discussions, and interviews with key informants, it has been established that the main sources of income of the study area consists of self-employment including, handicrafts, and small-scale trade activities, along with intermittent employment, full-time private sector employment, crop farming and animal husbandry.

6. Discussion

6.1. LULC change and their drivers perceived by the local community in the Legabora watershed

Several contributing factors led to the perceived alterations in LULC from 1976 to 2022. Respondents listed more than eight distinct drivers that were perceived as crucial to LULC alterations in the study area (Fig. 6). The Legabora watershed's LULC changes were primarily induced by direct and indirect causes, as noticed by KIIs, preference ratings, and FGDs. Accordingly, population expansion, infrastructure development, the extraction of wood, and agricultural expansions were recognized as direct drivers of LULC alterations. The majority of FGD participants confirmed that population increase, expansion of agriculture, settlement, the extraction of wood for charcoal manufacturing, and wildfires were recognized as the primary direct research-based reasons for clearing forests in the watershed as reported before [8]. In addition, human-caused fire was identified as a critical primary method of forest clearing to expand croplands, as mentioned by both discussants and KIIs. Fig. 6 shows the primary driving forces of observed LULC alterations. Surveyed participants, ranked growth in population and expansion of agriculture in the first and second, respectively. Poverty, infrastructure development, agricultural expansion, and settlement came in the third and fourth ranks, respectively. Similarly, KIIs and FGDs arrived at the same conclusion that the growth of population, settlement, and expansions of agricultural are driving forces. The swift increase in the population of the investigation area was attributed to early marriage, and internal migration, as reported before [8]. The majority of local communities were overwhelmingly of the opinion that the population expansion rate accelerated during the investigation period. The trend in population number was estimated from 1976 to 2022 to support local community in understanding impacts of population growth. The population of the study area expanded from 82,143 in 1976 to 295,643 in 2022. The findings depicted that between 1976 and 2022, the increase in inhabitants in the studied region by 359.9 %. Survey respondents proved that the population expansion in the study region has affected local LULC that is linked with the demaned for food, housing, fuel, and building supplies. It was understood from the survey that the population growth has exacerbated the scarcity of farmland. It is more likely that

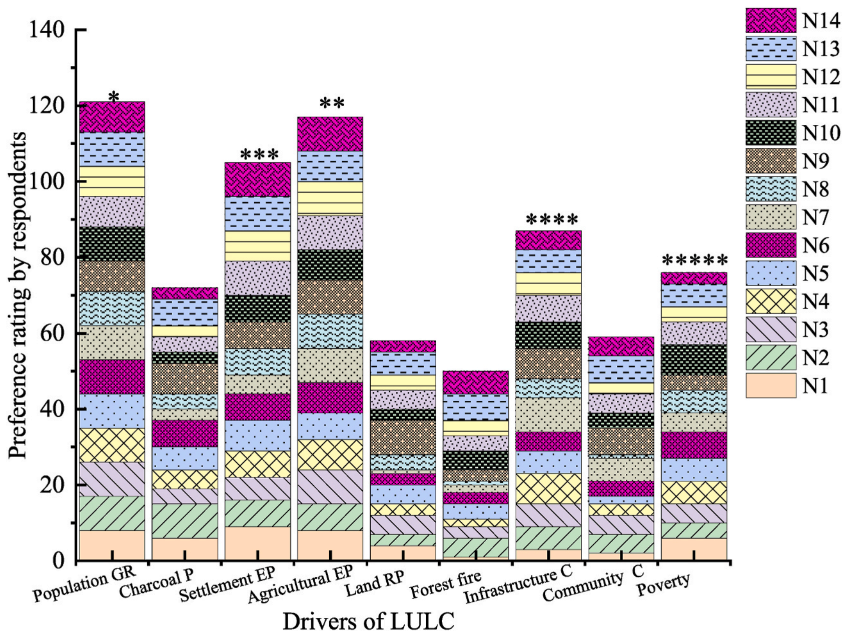

Fig. 6. LULC change drivers identified and ranked by survey respondents adopted from Ref. [8]. Note: * = indicate; ranked 1st; ** = 2nd; *** = 3rd; **** = 4th; and ***** = 5th.

this will result in the transformation of woodland and grazing land into farmland. Earlier LULC change studies reported similar finding by Ref. [70]. In 1976 and 2001, crop and forest cover increases were positively correlated with population growth, but in the second and fourth research periods (1991 and 2011), the relationship shifted, and farmland exhibited dropping trends while forestland cover displayed marginally increasing trend.

$N_1, N_2 \ldots N_{14}$ is to designate 14 FGDs respondents of study area.

Note: GR: growth; P: production; EP: expansion; RP: related policy; C: construction; C: conflict.

During the first and second study periods, when population growth was slightly slower, grassland exhibited a rising tendency. However, when population growth showed an increasing tendency in 2001, 2011, and 2022, grassland exhibited a diminishing trend (Fig. 7). The statement that "more people, more trees" suggested by Ref. [71] was supported by these findings. Therefore, the increase in population was positively connected with the growth of croplands and the decrease in the amount of shrublands; these changes could exacerbate soil erosion in the study area. Similarly, previous research highlighted that the primary cause influencing LULC alterations is an increase in population [72]. Other works also showed that growing populations increase the need for more settlement and farming, which eventually results in land degradation and soil erosion [72–74]. Participants in KIIs and FGDs agreed that land degradation and soil erosion were the most prominent consequences of LULC change on the watershed. They also revealed that one of the significant factors driving LULC changes at the research site was poverty. Prior investigations in the central Malawi region also showed comparable findings [52].

After a series of notable alterations to the political and governmental systems in Ethiopia in the years 1974, and 1991, the country has implemented numerous modifications to its institutional and policy approaches to environmental management. These changes in LULC as well as administration frameworks in Ethiopia were largely due to the frequent shifts in political and governmental structures within the region. The end of the imperial regime, which was succeeded by the 1975 land reform that granted farmland to landless tenants while simultaneously removing it from landlords and clearing forested and shrubs, was the main policy-driven catalyst for the LULC changes. In line with this research, it has been argued that the government's land tenure and land resource-related policies significantly impacted changes in LULC [75,76]. Similar results were reported by prior studies in the Lake Tana watershed in Ethiopia [48]. [59]; claimed that the absence of proper land use and forest policies, as well as the associated legislation, contributed greatly to the country's deforestation. According to Ref. [33]; population growth had less of an impact on LUCC changes in southwest Ethiopia than did the instability of land tenure. [70]; acknowledged land-related policy as a LULC driver in Ethiopia. Over the years, Ethiopia has seen major changes in its land resource governance policies and institutions, especially after significant political and governmental changes in 1974 and 1991. These changes have resulted in revisions in both land usage patterns and administrative frameworks, leading to changes in land use and land cover. However, farmers in the Legabora watershed area lack confidence in their land rights, leading to encroachment on vegetated lands for cultivation, grazing, and settlement, which has led to deforestation and land degradation. Focus group participants understood that the "Sefera program" implemented between 1987 and 1990 during the Derge regime played a significant role in the expansion of human settlements and agricultural land [75,76]. Moreover, the absence of comprehensive land use plans has also contributed to the encroachment of vegetated regions, particularly forests, grazing areas, and cultivation on steep slopes, without proper regulatory oversight and planning. Focus group discussions reveal the ineffectiveness of law enforcement in the area, leading to corruption and delays in the judicial decision-making process. Furthermore, participants in these discussions emphasized that changes in land tenure systems have also contributed to shifts in forest and vegetation cover, driven by

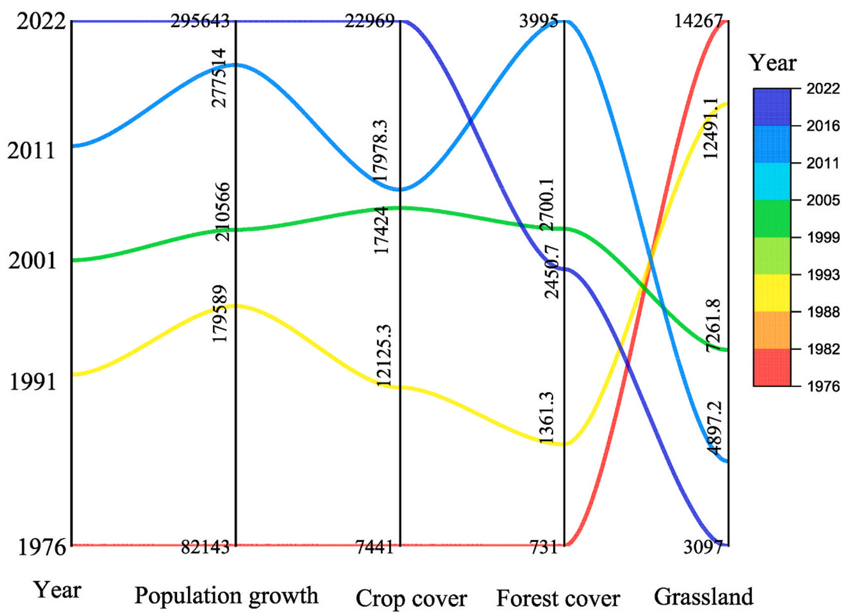

Fig. 7. LULC trend vs. total number of population growth between 1976 and 2022.

policy decisions.

6.2. Land use/cover dynamics in the Legabora watershed

Throughout the analysis period, the Legabora watershed has undergone significant changes in land use and land cover (LULC). One notable trend has been the increasing dominance of crops in the area. In 1976, crops accounted for only 23.9 % of the LULC, but by 2011, they had risen to 57.8 %. The expansion of the area could be a result of the growing need for agricultural products and the increasing demand for land to build homes and settlements. The observed transformation in the landscape primarily attributed to the rapid increase in human population, which has led to significant conversion of grasslands, shrublands, and forestlands into human settlements and agricultural lands. The key informants have confirmed that the increasing human activities, such as urbanization and agriculture, have caused significant changes to the landscape and the ecosystem. As the population expanded, more land was converted for human use, leading to the loss of natural habitats for various plant and animal species. This has resulted in a decline in biodiversity and an increase in vulnerability to natural disasters, such as floods and landslides. The assessment of LULC trends concluded that wetlands showed growing tendencies by (43.5 ha) between 1976 and 2022. This highlights the importance of preserving and protecting these valuable resources for future generations to come. The unlike results were determined by Ref. [39]; who found that the wetland's area shrunk on average by 172.6 ha/year between 1973 and 2019. The area of bare land steadily increased from 1976 (274.76 ha) to 2022 (389.97 ha) [60]. in the Shenkolla watershed arrived at quite identical outcomes. The research results showed that the forest land expanded by (1719.8 ha) between 1976 and 2022, with change by a percentage of 70.2 % and an annual increase of 38.2 ha/year, respectively. It is believed that the decrease in shrub land can be attributed to the expansion of cropland and built-up areas. Both FGD discussants and KIIs agreed that eucalyptus tree plantations played a crucial role in producing construction materials, firewood, and generating revenue for the local community. This, in turn, contributed to an increase in the amount of forestland cover. In contrast to the results of the current study, [48]; reported a 23.1 % decline in forest-covered areas from 2004 to 2014. Satellite imagery interpretation has confirmed that a substantial part of the grasslands has been converted into farmland between 1976 and 2022. [63]; described a yearly decline of grassland by 1023 ha between 2005 and 2015. Between 1976 and 2022, shrublands dwindled at a rate of −144.5 ha/year. The conversion of shrub land to agricultural or urban areas has been identified as a major cause of its decline. In contrast, [67]; stated that shrublands expanded at a rate of 22.8 ha yearly from 1973 to 2010.

Table 7
Socioeconomic variables affecting respondents' perceptions of LULC drivers.

Observed drivers	Independent Variable	Estimate	Std. Error	Wald	*P*-Value	Lower Bound	Upper Bound
Charcoal production	Gender	0.114	0.141	0.647	0.421	−0.163	0.391
	Age	−0.125	0.066	3.562	0.059	−0.255	0.005
	Marital status	0.035	0.080	0.189	0.664	−0.121	0.191
	Education	−0.040	0.035	1.318	0.251	−0.109	0.028
Infrastructure construction	Gender	0.130	0.142	0.834	0.361	−0.149	0.408
	Age	−0.247	0.067	12.042	0.001	−0.379	−0.115
	Marital status	0.110	0.080	1.900	0.168	−0.047	0.267
	Education	−0.091	0.035	6.589	0.005	−0.160	−0.021
Agricultural expansion	Gender	0.164	0.140	1.366	0.242	−0.111	0.439
	Age	0.036	0.066	0.307	0.579	−0.092	0.165
	Marital status	−0.142	0.079	3.219	0.073	−0.297	0.013
	Education	0.012	0.035	0.111	0.739	−0.056	0.080
Wild/Bush fire	Gender	0.230	0.148	2.402	0.121	−0.061	0.520
	Age	0.186	0.070	7.130	0.008	0.049	0.323
	Marital status	−0.230	0.082	7.818	0.005	−0.391	−0.069
	Education	−0.017	0.037	0.211	0.646	−0.089	0.055
Population Growth	Gender	−0.106	0.177	0.360	0.549	−0.453	0.241
	Age	−0.278	0.086	10.513	0.001	−0.446	−0.110
	Marital status	−0.150	0.110	1.870	0.171	−0.366	0.065
	Education	−0.095	0.045	4.527	0.033	−0.182	−0.007
Settlement expansion	Gender	−0.093	0.143	0.424	0.515	−0.372	0.186
	Age	−0.061	0.067	0.827	0.363	−0.192	0.070
	Marital status	−0.242	0.082	8.663	0.003	−0.403	−0.081
	Education	−0.120	0.036	11.378	0.001	−0.190	−0.050
Land related policy & Community conflict	Gender	−0.003	0.145	0.002	0.983	−0.282	0.288
	Age	−0.122	0.068	3.165	0.075	−0.256	0.012
	Marital status	−0.305	0.086	12.648	0.001	−0.474	−0.137
	Education	−0.127	0.036	12.285	0.001	−0.198	−0.056
Poverty	Gender	−0.243	0.145	2.832	0.092	−0.527	0.040
	Age	−0.193	0.068	7.976	0.005	−0.326	−0.059
	Marital status	0.008	0.082	0.011	0.918	−0.152	0.168
	Education	−0.140	0.036	14.950	0.001	−0.210	−0.069

6.3. Perceived drivers of LULCchange at the household level based on logistic regression in Legabora watershed

Results showed that independent variables such as education level and age had a negative and substantial impact on local attitudes towards infrastructure construction and other issues ($p < 0.005$). According to the findings (Table 7), the residents' high opinions of settlement expansion and infrastructure development as LULC drivers in the study area were adversely and substantially ($p < 0.005$) impacted by education level. On top of this, age, gender, educational level, and marital status had no noticeable impact on charcoal production or agricultural expansion in the current study landscape, respectively. The result of logistic regression analysis showed that independent variables such as age and marital status had a negative and substantial impact on local attitudes towards wildfires and other issues ($p < 0.005$). On the other hand, the analysis of logistic regression showed that marital status and education level had negative and substantial impact on local attitudes toward settlement expansion in the current study area.

The result of logistic regression analysis showed that independent variables such as education level had a negative and substantial impact on local attitudes towards population growth, land-related policy, community conflict, and poverty ($p < 0.005$). According to the findings presented in Table 7, the residents' high opinions of population growth and poverty as LULC drivers in the study area were adversely and substantially ($p < 0.005$) impacted by age. On the other hand, the results showed that gender had no negative and substantial impact on local attitudes towards population growth, land-related policy, community conflict, and poverty ($p < 0.005$) in the current investigation landscape.

6.4. Implications of LULC alteration noticed by local society

Over the past 45 years, between 1976 and 2022, the LULC modifications and land fragmentation in the Legabora watershed have increased significantly. In the second period between 1991 and 2001, both croplands and shrublands were the main LULC classes that dominated the landscape. Croplands, the main LULC category that dominated study watershed in the fourth period between 2011 and 2022, brought about a change in the situation. Conversely, the farmers were forced to relocate to the lowlands of the watershed where grassland and wetlands predominate the landscape due to the high inhabitant density and land scarcity. The first comparison period (1976–1991) was characterized by an increase in croplands, which was accompanied by a decline in the grassland and shrublands, in the Legabora watershed. During this time, the Ethiopia had experienced severe drought and famine. To combat these effects and boost agricultural productivity, the government implemented nationwide planned resettlement and village development programs. The efforts attempted to relocate peoples from closely inhabited highlands and areas affected by drought to consolidate settlements in less-populated prospective areas, mainly in the lowland regions. According to the reports of participants in focus groups, changes in land

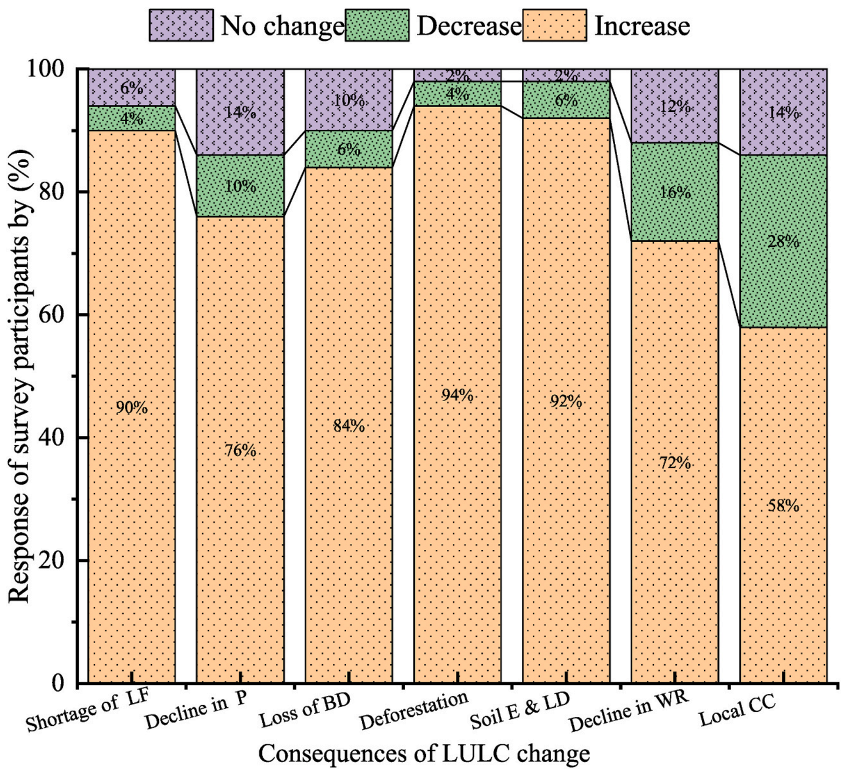

Fig. 8. Consequences of LULC changes perceived by respondents of Legabora watershed. Note: LF; livestock fodder, P: production; BD: biodiversity; E: erosion; LD: land degradation; WR: water resources; CC: climate change.

use and land cover have brought about a variety of consequences. Ninety-four percent of respondents noted that deforestation was a direct outcome of these changes, which resulted in soil wearing away and deterioration of the land (92 %), a scarcity of livestock fodder (90 %), biodiversity loss (84 %), reduction in productivity (76 %), a decrease in availability of water (72 %), and variations in the climate change 58 % (Fig. 8). The ongoing population shifts, the persistence of LULC variation, and the variable climate conditions all exert pressure on a farmer's production system of the current study. Moreover, these elements have a huge influence on the livelihoods of the watershed community. Likewise, 84 % of survey respondents reported a loss in plant biodiversity, including valuable woody species. Other effects of LULC stated by the respondents include the extinction of indigenous multipurpose tree species, and a decrease in the diversity of medicinal plant species. Furthermore, the same percentage of participants (94 %) also stated that household energy sources have changed as a result of deforestation, moving away from wood to cow dung, and agricultural waste. In the past, the majority of people relied on forests and shrublands for energy; however, access to these areas is now limited. Female members of the focus groups also noted that the collection of firewood from natural forests in earlier times provided opportunities for social interaction, informal conversation, and the discussion of societal issues. Fig. 8, depicted that deforestation is considered as disadvantageous by 94 % of those surveyed participants. During interview sessions, it was found that 72 % of the respondents stated that the depletion of small water sources is due to climate change. This drying up of water supplies is a major concern. Women face significant challenges as they have to travel long distances to access fresh water for their daily needs. The discussants in the FGDs also recognized that male farmers have to transport their animals over vast stretches to find drinking water sources.

Information gathered from field studies and KIIs indicates that agricultural expansion in community grazing areas reduced public grassland. [77]; reported similar effects indicating that a scarcity of livestock fodder posed a serious issue for some parties in the country. Similarly, the lessening of grassland was significantly influenced by the redeployment of grazing lands to landless youth, farmers with limited farm size, and military experts. As a result of pasture land conversion to other LULC classes, livestock populations have decreased in the watershed. However, in regions that rely on Enset-based agroforestry, which is common among farmers in this area, the loss of livestock does not pose a significant threat to their ability to maintain food security and withstand risky situations like drought. During the last research span from 1976 to 2022, the watershed experienced a substantial reduction in grassland due to a rapid expansion in population and the associated conversion of grassland to croplands. [78]; noted the significant degradation of rangelands in southwest Ethiopia. Fig. 8 shows that 92 % of the survey respondents who lived in the study area indicated that the region was at high risk of land degradation and soil erosion. Survey respondents viewed soil deterioration and erosion as the primary causes of the decrease in agricultural output, particularly in the south-central regions. In all of the investigation areas of the watershed, severe soil erosion and land degradation issues were confirmed by field observations (Fig. 9). Seventy six percent of the survey participants noted that historically, farmers had produced adequate yields from their plots of land. Nevertheless, as the land becomes less fertile and productive, they are currently turning some of their agricultural lands into eucalyptus plantations. Participants in KIIs and FGDs remarked that the decline in agricultural output has been related to a lack of soil fertility. In addition, survey respondents claimed that high levels of soil wear and land deterioration make the agricultural sector less productive.

According to a 60-year-old man, the watershed's past and present conditions can be described as follows: "*I spent my childhood in Legabora rural community, where I was born and raised. The watershed was once covered by vast stretches of forests, woodlands, and savannahs, and was inhabited by a diverse array of wildlife such as tigers, elephants, warthogs, and buffalo. In my younger days, together with my*

Fig. 9. Soil erosion and land degradation in the Legabora watershed.

friends, I used to gotothe bushbuck and buffalo hunting. Currently, finding animals like buffalo and tigers in the study watershed is no longer possible due to the clearing of the forests, which has resulted in their disappearance from the area.

As per the respondents, a considerable number of migrants from other regions arrived, particularly in the aftermath of the severe drought of 1984–1985. The frequency of this influx increased even more rapidly following the change in government in 1991, which resulted in a swift growth of croplands and settlement areas in the watershed. According to the KIIs, migration also contributed significantly to the decline in shrubland areas surrounding the Legabora watershed. Road development, rural electrification, contemporary irrigation systems, the production of charcoal, and the sale of firewood were also cited as significant change-agents, primarily in the watershed's lowland region. During the interview session, FGD discussants and agricultural experts all brought up the development of small towns and villages alongside the main roads, the redeployment of land (mostly grazing land and shrublands to farmers with small land sizes, youth and military experts, and other factors) as potential consequences of changes in LULC.

7. Conclusions

This study aimed to analyze the trends, driving factors, and consequences within the sub-watersheds of Legabora using a combined approach of remote sensing and socioeconomic survey. The finding of the study demonstrate three significant LULC changes, primarily the increase in croplands, settlement, and a slight gain in forest and degraded lands from 1976 to 2022; grasslands have been significantly decreasing in size, and shurublands have declined continuously. Croplands increased at the expense of grassland and shrublands. There has been a decline in the amount of shrublands and grassland by −144 and −248 ha per year, respectively. The findings indicate that approximately 68.3 %, of the watershed's land area underwent significant changes in LULC between 1976 and 2022. The outcome of the LULC analysis and the cross-tabulation table revealed the conversion of approximately 73.1 % of grasslands and 66.3 % of shrublands into intensive land uses such as croplands between the years 1976 and 2022. The results revealed that the overall accuracy rates stood at 88.3 %, 88.4 %, and 85.6 % for 1976, 1991, and 2022, respectively. The overall kappa coefficient demonstrated values of 0.86 %, 0.86 %, and 0.83 % for the same period. Surveyed respondents perceived population growth, settlement, agricultural expansion, and infrastructure development are the most prominent socioeconomic and environmental issues that placed strain on the environment and natural resources. The local community noticed that deforestation, land degradation, a lack of livestock fodder, and biodiversity loss were the main effects of LULC changes. Moreover, the 1975 land reform of the study area caused the provision of farmlands to landless tenants, which resulted in the clearing of bushes and shrublands to expand farmlands to feed the growing population and also assisted in the LULC changes of the area. The present study is limited by the lack of high-quality spatial resolution data. It would be advantageous to consider the utilization of SPOT, Radarsat, Quick bird and other space-based satellite sensors for LULC categorization in future studies. Furthermore, achieving effective land-use management in the watershed requires the adoption of sustainable development practices and the utilization of advanced technologies like remote sensing and GIS. Moreover, this studies can aid sustainable development by analyzing land transformation's impact on environment, society, and economy. Thus, sustainable land use planning and management, appropriate implementation of forest, and water conservation actions,and providing alternate livelihood strategies should be implemented for local communities to inverse unsought situations associated with LULC changes of the study area. Likewise,to minimize adverse impacts of the LULC changes in the Legabora, this study recommended sustainable management of the watershed, which includes designing a proper land use strategy and execution measures with the active engagement of the local community.The factors and implications addressed in this study may be helpful tool for land use planning in the study area and elsewhere. Moreover, the present research establishes a foundation for comparison with other nationwide watershed investigations.

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I confirm that the data included here is accurate and comprehensive. I hereby certify that this work has not been previously published and has not been submitted for publication to any journal.

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[79,80].

CRediT authorship contribution statement

Mehari Mariye: Writing - review & editing, Writing - original draft, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Li Jianhua:** Writing - review & editing, Validation, Supervision, Investigation. **Melesse Maryo:** Writing - review & editing, Visualization, Supervision, Methodology, Conceptualization. **Gedion Tsegaye:** Writing - review & editing, Visualization, Investigation, Formal analysis. **Eskedar Aletaye:** Writing - review & editing, Methodology, Investigation, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests.

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