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# The implications of land use and land cover changes for rural household food insecurity in the Northeastern highlands of Ethiopia: the case of the Teleyayen sub-watershed

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## Abstract

**Background:** Ethiopia has tremendous agricultural potential with vast areas of fertile land. However, agriculture remains underdeveloped and poverty persists, especially in rural areas. Therefore, this study examined the implications of land use and land cover changes on rural household food insecurity in the Teleyayen sub-watershed, which covers an area of 152 km<sup>2</sup>.

**Methods:** Landsat satellite images of 1973, 1986 and 2015 were used to analyze the spatial and temporal changes. LU-LC changes of the study area were detected from a time series of such satellite images using Remote Sensing (ERDAS Imagine 9.2) and GIS (ArcMap 10.3) software. Additional data were collected through Global Positioning System, key informant interviews, focus group discussions and field observations.

**Results and discussion:** The results of the study showed that forest lands declined from 3.8% in 1973 to 0.2% in 2015. The total forest lands cleared between 1973 and 2015 amounts to 552 ha. This is 95% of the forest cover that existed in 1973. Similarly, shrub lands declined from 28.4% in 1973 to 24.9% in 2015. Meanwhile, crop lands and rural settlements increased from 38.6% in 1973 to 44.1% in 1986 and 54.4% in 2015. The greatest expansion of crop lands and rural settlements occurred between 1986 and 2015 (81%). This kind of conversion could be at the expense of grass lands, shrub lands, marginal lands and forest lands. The major driving forces were found to be population growth, shortage of farm lands and shortage of rainfall, which in turn exacerbated the food security problems. Land degradation, rural–urban migration, farm land fragmentation, climate change, crop yield reduction and soil erosion are also identified as major implications of land use and land cover changes.

**Conclusions:** The observed land use and land cover changes are caused by population pressure as well as expansion of agricultural lands through unplanned and inappropriate land management practices in order to meet the food demands of the rapidly growing population. Therefore, it is worthwhile to link food security policies with sustainable land management policies because both are closely interrelated with each other. It is also advisable to decentralize responsibilities and financial resources to local farmers and local administrative bodies so as to improve their food security status. This decentralization could help lead to adequate access to information on agricultural inputs, land management and food security services.

**Keywords:** Land use, Land cover, Land management, Food insecurity, Ethiopia

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## Background

Agriculture is a very prominent economic sector of many developing countries. Agricultural production systems are expected to produce food for a global population that will amount to 9.1 billion people in 2050 and over 10 billion by the end of the century [1]. However, in Ethiopia farm sizes today are <1 hectare per household on average; the livestock population, while considerable and exceeding the capacity of grazing land, is still insufficient to provide enough labor to plow the land. Farm productivity is at a minimal grain output between 0.3 and 1.5 tonnes per hectare, and land degradation due to agricultural practices is widespread, amounting to an average of over 40 tonnes of soil lost per hectare of cropland every year [2]. Hence, to secure and maintain food security, agricultural systems need to be transformed to increase the productive capacity and stability of smallholder agricultural production.

The historical expansion of cultivated land and pastures has largely been at the expense of forests [3]. During the 1990s, there has been an average loss of 16 million hectare of forests per year. Lepers et al. [4] and Haines [5] found that the biggest cause of deforestation—and consequently loss of terrestrial biodiversity—has been agricultural expansion.

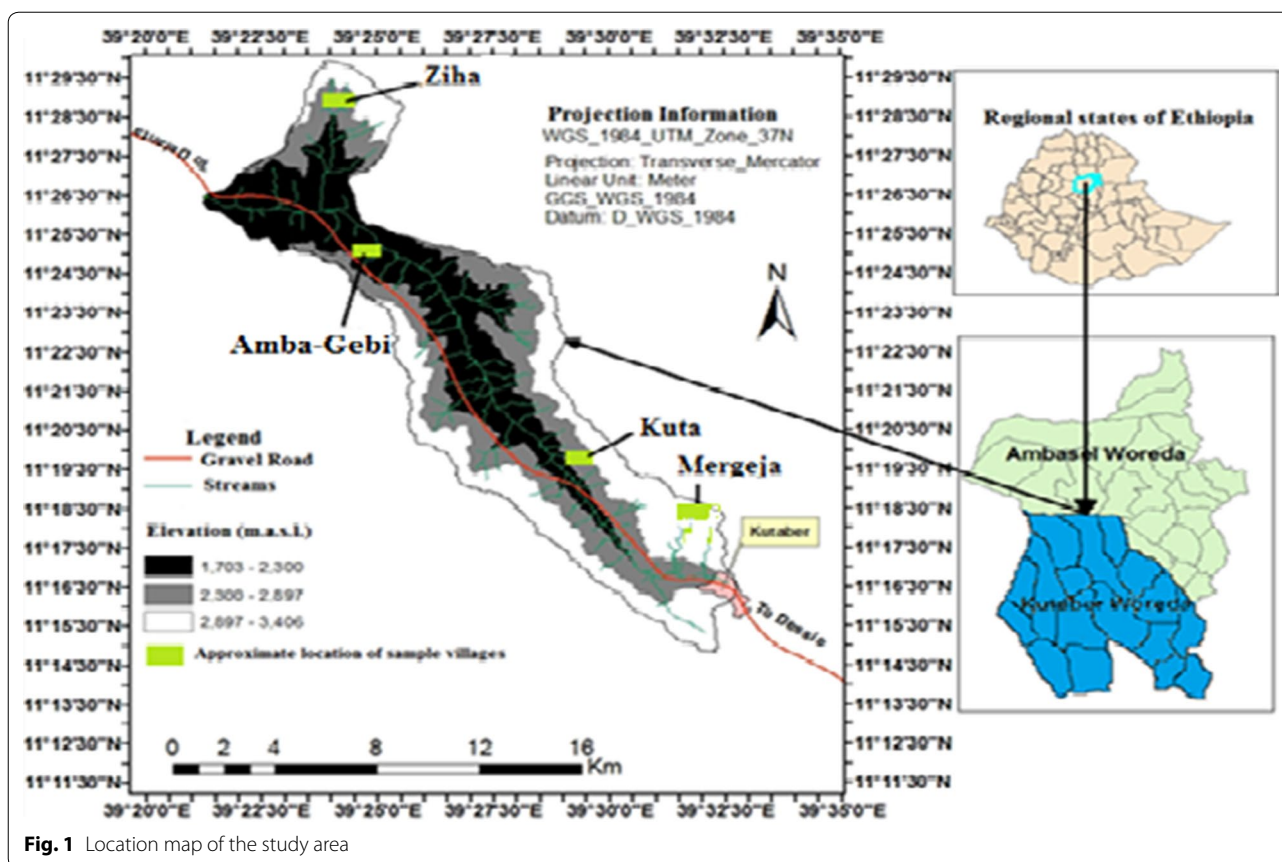
Sustainable land use and protection of soils play a key role in food, climate and human security [6–9]. In spite of this, land degradation has become a global problem occurring in most terrestrial biomes and agroecologies, in both low-income and highly industrialized countries [10]. It affects an estimated 1.5 billion people and a quarter of land area in all agroecological zones around the world [11]. Annually, an area of about 5–8 million hectare of formerly productive land goes out of cultivation due to degradation globally [12, unpublished report]. To rescue the situation, the introduction of appropriate land use policy is mandatory.

### Food security situations in Ethiopia

Ethiopia has tremendous agricultural potential with vast areas of fertile land, diverse climate, abundant rainfall and a large labor force. Yet agriculture remains underdeveloped and poverty persists, especially in rural areas. Drought continues to affect the country, causing considerable damage to rain-fed agriculture. Severe famines have greatly affected the lives of the people and have also hampered socioeconomic development. Consequently, the country has been structurally food deficit since at least 1980. The food gap rose from 0.75 million tonnes in 1979/80 to 5 million tonnes in 1993/94, falling to 2.6 million tonnes in 1995/96 despite a record harvest [13]. Even in that year, 240,000 tonnes of food aid were delivered, suggesting that chronic food insecurity afflicts millions of Ethiopians in the absence of transitory production shocks.

While the vast majority of the populations are engaged in agriculture as the major livelihood, food insecurity remains a serious problem. Put differently, the rural people who have substantial experience practicing agriculture as their major livelihood for generations are among the most vulnerable to food insecurity and unable to produce sufficient food to feed throughout the year. Rural food insecurity is one of the defining features of rural poverty, particularly in the moisture deficit northeast highland plateaus and some pastoral areas [14]. The Teleyayen sub-watershed is among those areas mostly affected by severe food insecurity, drought and natural resource degradation. The ever-increasing human population threatens the future food production in the watershed. Lack of appropriate land use and land cover change, drought and shortage of farm lands are the major reasons for the occurrence of such problems. For example, the output of Palmer drought severity index (PDSI) in the Teleyayen sub-watershed during the periods of 1981 to 2015 indicates the severity of the problem. Accordingly, drought in the study area was severe during the 1985 and 2010. This indicates that the food security problem of the watershed is exacerbated by the occurrence of recurrent drought and inappropriate land management practices among others. Moreover, Kutaber is the most densely populated district in South Wollo Zone. High numbers of ex-servicemen and persons displaced from the resettlement regions add to the already existing problems. The district agricultural workers think that even in a good year the existing arable land capacity will not be able to provide sufficient food for the entire district population. According to the UNDP [15], the average landholding size in the study area is 0.5 hectare per family, on which mixed crop and livestock farming is practiced. This means very intensive agriculture is needed to make a living out of this small piece of land, which becomes a very difficult situation. These land use and land cover change challenges include a growing population and increased demand for land, unsustainable land use, land fragmentation and small land holdings, natural resource pressures, weak land governance institutions and policies that aim to attract land-based investments including Foreign Direct Investment. As landlessness in rural areas is widespread, especially among the young, rental markets have become an important means to access land. Ethiopia has made significant progress over the past few years with the registration of user rights over farmland. Moreover, women's rights over land are formally recognized during registration; however, this is not guaranteed in practice [16].

As underlined by Hurni [17], 'sustainable land management must become the basis of agricultural activity on all land. Policies addressing land use and land cover change, rural–urban linkages, land tenure issues, and questions of



**Fig. 1** Location map of the study area

demographic transition, as well as issues of education and health, can be particularly supportive in accelerating this change. Most of the studies that have been done so far on the issues of land use and land cover (LU-LC) changes in Ethiopia are very general and consider the problems from national, regional and district points of view. While collective data are generally available at the national level, little work has been done to understand the implications of LU-LC changes on rural household food insecurity at the household level in specific sub-watershed. To the best of my knowledge, there are no studies done on assessing such implications for rural household food insecurity in the Teleyayen sub-watershed. The purpose of this study was, therefore, to examine such implications during the period of 1973–2015 in Ethiopia using Teleyayen sub-watershed as a case study. Based on that fact, this study was conducted in order to fill this gap by sharing robust empirical evidence on the implications of LU-LC changes on rural household food insecurity in the study area.

**Methods**

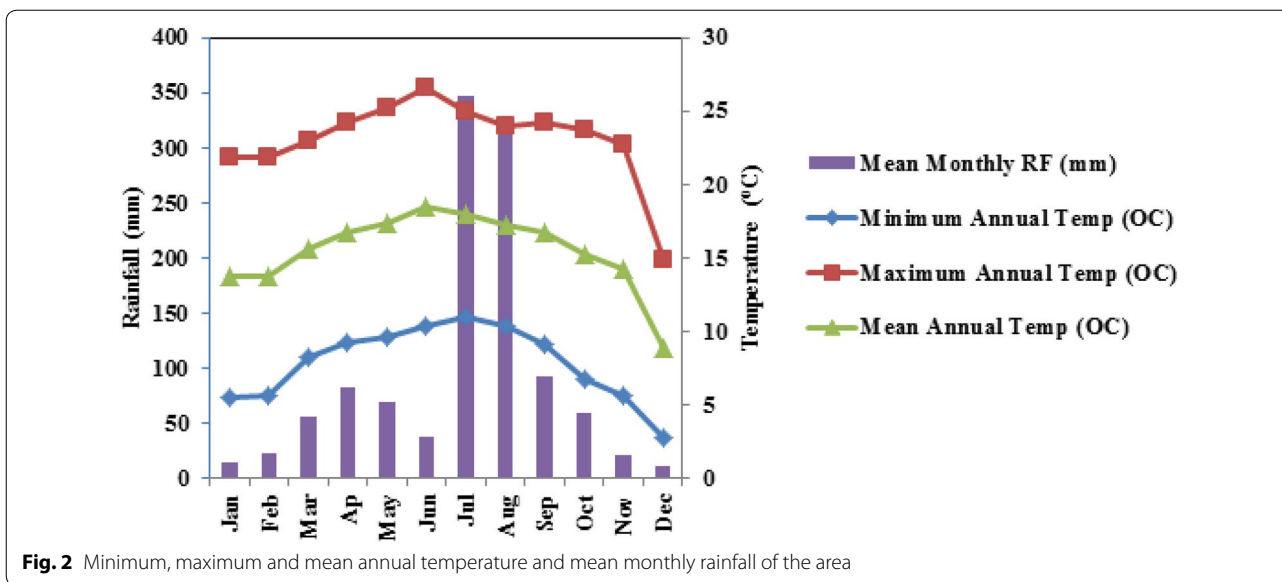
**Description of the study area**

The Teleyayen sub-watershed is located in Kutaber and Ambassel *weredas* (districts) of South Wollo Zone, Amhara

Region of Ethiopia. It covers a total area of 152 km<sup>2</sup>. Of this Kutaber shares 125 km<sup>2</sup> (82%) and Ambassel shares 27 km<sup>2</sup> (18%). Geographically, the sub-watershed is located between 11°14'30"N and 11°29'30"N latitude and 39°21'0"E and 39°33'0"E longitude (Fig. 1), and it is about 441 km North of Addis Ababa (the capital city). It is characterized by diverse topographic conditions that form part of the headstream of the Abay (Blue Nile) basin. Its elevation ranges from 1703 to 3406 m above mean sea level, and it is inhabited by about 20,296 people distributed within eight *kebeles*<sup>1</sup> [18]. A mountainous and highly dissected terrain with steep slopes characterizes most parts of the sub-watershed. Land is a scarce resource in the sub-watershed due to high population pressure and degradation.

The meteorological data used for this study were obtained from Kombolcha Meteorological Station, recorded for Dessie site. Hence, the mean annual temperature of the sub-watershed is about 16 °C, and the average annual total rainfall is 1133 mm (Fig. 2). More than 58% of the total rain falls in the 2 months of July and August (summer season); 18% falls in the spring season (March,

<sup>1</sup> *kebele* is the smallest administrative unit of Ethiopia.



April and May); and <5% of the total occurs during the dry months of December, January and February (winter season). The uneven distribution of the rainfall gives rise to a serious shortage of water during the dry season particularly in the lower parts of the sub-watershed.

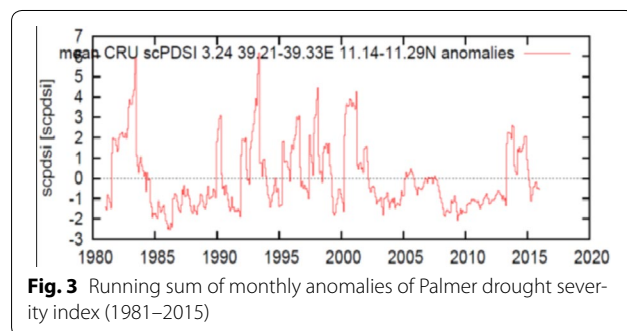
There are several reasons for the selection of the Teleyayen sub-watershed as the site for this study. Firstly, it is a typical representative of the Northeastern highlands of Ethiopia in terms of the various environmental attributes such as topography, soils, climate and the socio-economic conditions. Secondly, the watershed is part of the Northeastern highlands of Ethiopia, which is historically known to be food insecure and highly threatened by severe resource degradation and drought (Fig. 3). Thirdly, the site is accessible for transportation and data-gathering purposes. Fourthly, as far as our reading can discern, no study has been carried out on the issues of land use and land cover changes in this particular sub-watershed. This may be because of the ruggedness of the topography of the study area. Thus, it needs intervention as soon as possible.

**Methods and data sources**

This study was conducted on data that were obtained through a farm household survey administered to a sample of 215 farm household heads drawn through multistage sampling technique. The data used for this study were collected from two sources. First, satellite data provided three years multi-temporal Landsat imageries, Global Positioning System (GPS) and top-sheets (Table 1). The ground truth data were presented in the form of reference points and collected using GPS for the 2015 image analysis and used for image classification and overall accuracy assessment. Second,

to supplement the survey with qualitative information, key informant interviews, focus group discussion (FGD) and field observations were conducted on drivers of LU-LC changes observed in the Teleyayen sub-watershed. Key informant interviews are semi-structured interviews with selected people that have knowledge on LU-LC changes and important aspects of sustainable land management (SLM) practices and its linkage with food security issues in the study area. The key informants were chosen based on their position, experience or responsibilities and can provide information about local facts, attitudes and beliefs. They include farmers, natural resource experts, food security coordinators, productive safety net coordinators and development agents.

The aim of this study was to examine the implications of LU-LC changes for rural household food security in the Teleyayen sub-watershed during the periods of 1973, 1986 and 2015. 1973 was selected as the initial year of study because it was the time in which drought reappeared in Ethiopia in general and in the Northern part



**Table 1 Descriptions of Landsat images and topo-sheets used for the study**

Image	Path	Row	Sensor	Resolution	Bands	Date of acquisition	Source
Landsat 5	181	052	MSS	60 × 60	4	25 October 1973	USGS
Landsat 7	168	052	TM	30 × 30	7	5 November 1986	USGS
Landsat 8	168	052	OLI	30 × 30	9	15 November 2015	USGS
Topo-sheets	–	–	–	1:50,000	–	–	EMA

EMA Ethiopian Mapping Authority, USGS The United States Geological Survey

of Ethiopia in particular, resulting in chronic food shortage and resource degradation. Similarly, we also selected 1986 as a second reference year because it denotes the period in which the country was severely hit by drought; therefore, substantial land use and land cover changes are expected. Finally, in order to know the current LU-LC changes, we preferred to use the 2015 as a third reference year.

Therefore, satellite images of Landsat 5 MSS (Landsat Multispectral Scanner) with a resolution of 60 meters in 1973, Landsat 7 TM (Landsat Thematic Mapper) with a resolution of 30 meters in 1986 and Landsat 8 Operational Land Imager (OLI) with a resolution of 30 meters in 2015 were used in order to produce LU-LC change maps showing the temporal changes throughout 43 years. Accordingly, LU-LC changes of the study area were detected from a time series of such satellite images using Remote Sensing (ERDAS Imagine 9.2) and Geographic Information System (GIS) ArcMap 10.3 software. The images were downloaded from the United States Geological Survey (USGS) Earth Resources Observation Systems (EROS) data centers under the Landsat Archive (URL: <https://eros.usgs.gov/find-data>). Landsat TM is preferred over other satellite imagery such as SPOT because Landsat is a readily and freely available multi-spectral dataset in the medium spatial resolution ranges that are widely used for land use and land cover mapping. Hence, to derive the land use and land cover information, Landsat satellite images of 1973, 1986 and 2015 (Path 168 and Row 052) were used to analyze temporal and spatial changes in the study area. The time series images were classified and visually interpreted.

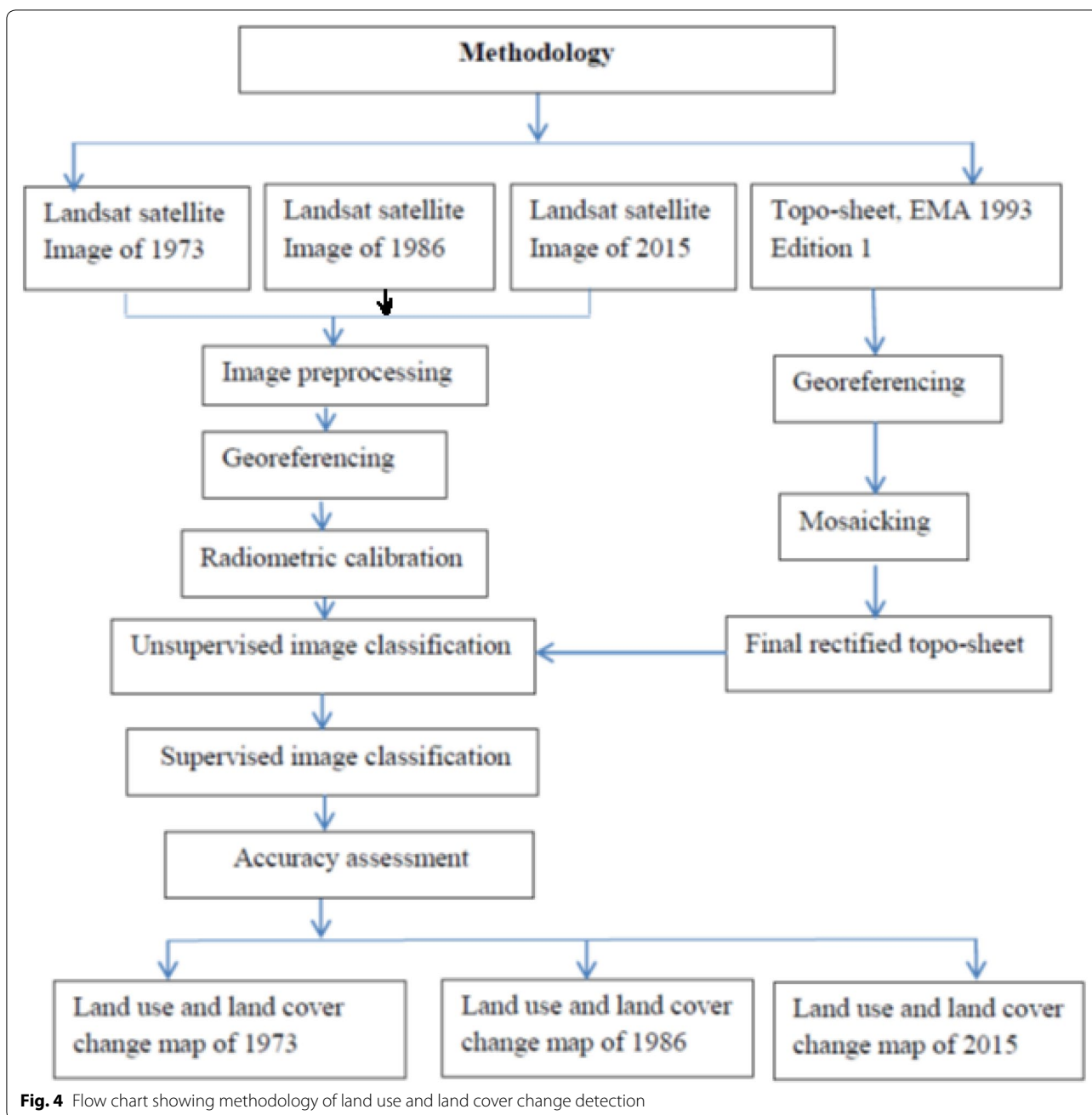
The images were classified using both supervised and unsupervised classifications. Unsupervised classification was used in the image classification before field work to understand the general land cover classes of the study area. This is because unsupervised classification is automated and requires little knowledge of the study area. Moreover, it helps to have an idea of representing the overall land use and land cover clusters of pixels. Consequently, classifications of the Landsat images were carried out within ERDAS Imagine software. Then classified images were assigned a class in the output raster based on their spectral signature using different

band combinations. Finally, supervised classification was performed, based on the result of the unsupervised classification. Areas which had a good spectral clustering in unsupervised classification and represented the recognized classes in the field were taken into account when creating the signatures for the classes. The signature evaluation was performed using the transformed divergence statistical method. The class assignment was performed using the maximum likelihood methods. In order to reduce isolated pixels and improve map representation, a post-classification processing was accomplished using the fuzzy convolution techniques and the distance error image file generated by the maximum likelihood classification (Fig. 4). The accuracy of the classification was evaluated with an error (confusion) matrix and the kappa coefficient, using GPS field collected points and a high-resolution image from Google Earth.

#### Accuracy assessment

In a statistical context, accuracy comprises bias and precision and the distinction between the two is sometimes important as one may be traded for the other [19, 20]. In thematic mapping from remotely sensed data, the term accuracy is used typically to express the degree of 'correctness' of a map or classification. A thematic map derived with a classification may be considered accurate if it provides an unbiased representation of the land cover of the region it portrays. In essence, therefore, classification accuracy is typically taken to mean the degree to which the derived image classification agrees with reality or conforms to the 'truth' [19–22]. A classification error is, thus, some discrepancy between the situation depicted on the thematic map and reality.

Therefore, an accuracy assessment was performed using the standard method of Congalton [23]. Firstly, in the processes of assessment, references were identified from the ground using GPS 60, and references were independent of the ground truths that are used in the classification scheme. Thus, total accuracy and kappa statistics were computed. In principle, all the output maps have to meet the minimum 85% accuracy [24]. For such a purpose, ground control point data collection was conducted by GPS in 2017 at various LU-LC change categories. As a result, 367 ground control points were used



**Fig. 4** Flow chart showing methodology of land use and land cover change detection

for the accuracy assessment of this study. Consequently, the overall accuracy classification was found to be 85.8% and kappa coefficient of 83.4% (Table 2). This indicates a strong agreement between the classified LU-LC changes and ground control point data. Three hundred sixty-seven ground control points were used for the accuracy assessment of this study.

In this study, accuracy assessment was done for the Landsat 8 Operational Land Imager (OLI) of the 2015 satellite image, for which the ground truth data likely

equate. An overall accuracy was calculated by dividing the sum of the correctly classified sample units by the total number of sample units. Therefore, the kappa coefficient was applied to image classification evaluation. It estimates accuracy considering agreement that may be expected to occur by chance [25]. The formula for computing K coefficient is given as follows:

$$K = \frac{\text{Overall classification accuracy} - \text{Expected classification accuracy}}{1 - \text{Expected classification accuracy}}$$

**Table 2 Error matrix (confusion matrix) for 2015 LU-LC change classification map**

Classified data	Reference point data							Row total	User's accuracy (%)
	Water body	Built-up area	Crop land and settlement	Forest land	Bare land	Shrub land	Grass land		
Water body	33	3	1	2	0	2	1	42	78.5
Built-up area	0	30	2	1	1	3	0	37	81
Crop land and settlement	2	0	53	3	4	3	2	67	79.1
Forest land	0	1	1	45	0	2	3	52	86.5
Bare land	2	0	2	0	55	0	0	59	93.2
Shrub land	0	0	2	0	2	55	1	60	91.6
Grass land	2	1	0	0	1	2	44	50	88
Column total	39	35	61	51	63	67	51	367	–
Producer's accuracy (%)	84.6	85.7	86.8	88.2	87.3	82	86.2	–	–

Over all accuracy = 85.8%; kappa coefficient = 83.4%

The kappa coefficient expresses the proportionate reduction in error generated by a classification process compared with the error of a completely random classification. Overall accuracy uses only the main diagonal elements of the error matrix, and as such it is a relatively simple and intuitive measure of agreement [25]. However, because it does not take into account the proportion of agreement between data sets that is due to chance alone, it tends to overestimate classification accuracy [26, 27].

Producer's accuracy (measure of omission error) was computed by dividing the total number of correct pixels in a category by the total number of pixels of that category as derived from the reference data (the column total). This procedure indicates the probability of a reference pixel being correctly classified. The user's accuracy, that is, a measure of commission error, is computed by dividing the total number of correct pixels in a category by the total number of pixels that were classified in that category (the row total). This procedure is a measure of reliability, which indicates the probability that a pixel classified on the map/image actually represents that category on the ground (Table 2).

A major limitation to this study was that due to lack of transportation facilities, field data collection for error matrix (confusion matrix) at various land use and land cover (LU-LC) change categories using GPS was conducted largely on selected sites that are accessible to the main road.

## Results and discussion

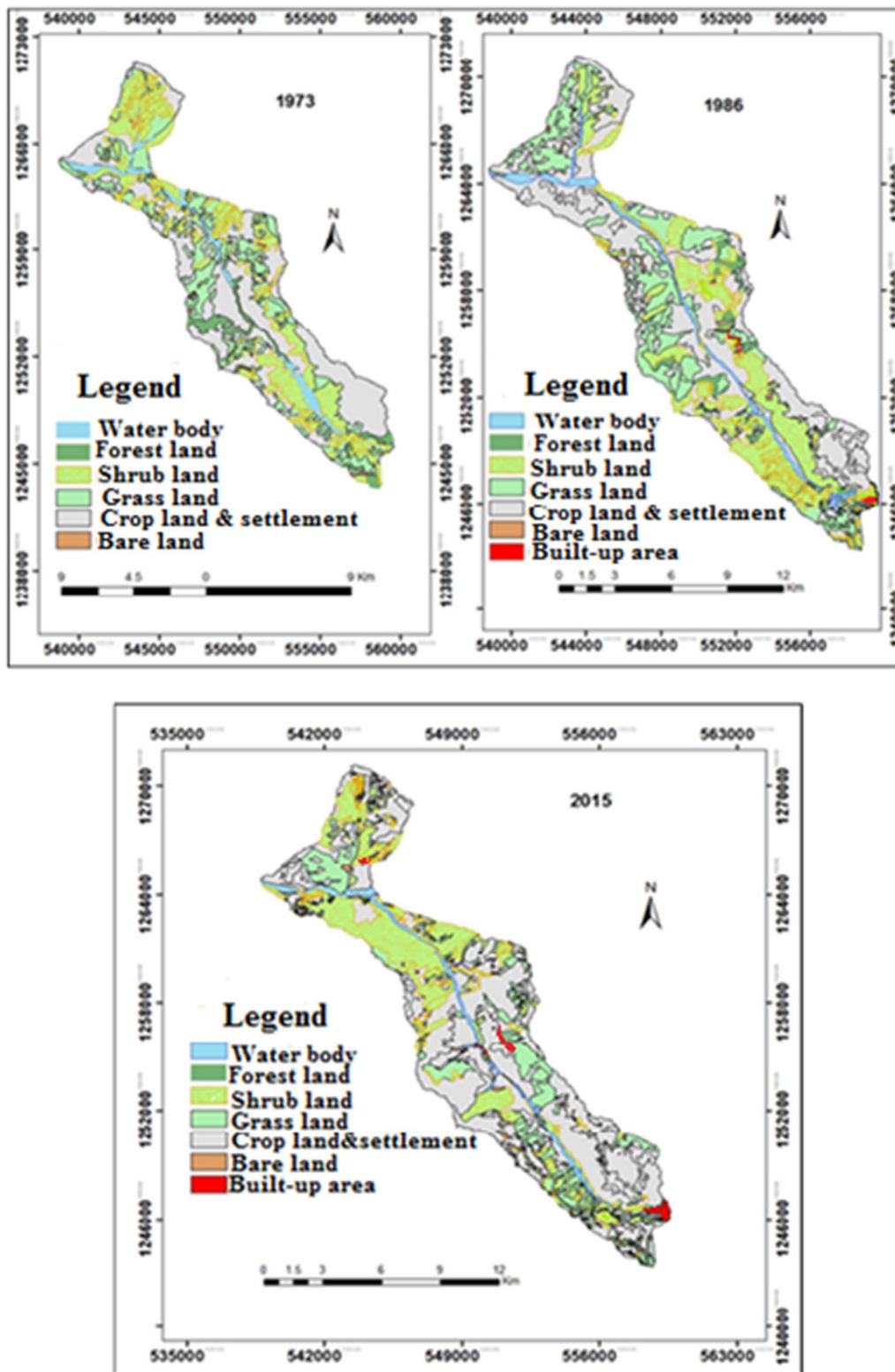
### Land use and land cover change analysis

Land use and land cover changes that occurred from 1973 to 2015 in the Teleyayen sub-watershed were

monitored using GIS and remote sensing approaches (Fig. 5). Because of the age-old tradition of clearing increasingly steeper land for cultivation and the lack of appropriate land use policies, productivity is currently heavily threatened by soil degradation. From the analysis of Landsat images, seven land use and land cover classes, such as water body, forest lands, shrub lands, grass lands, crop lands and rural settlement, bare lands and built-up areas, were identified (Table 3). The analysis of each LU-LC category is presented below.

### Water body

The result of this study showed that water bodies declined from 5% in 1973 to 3.3% in 1986 and to 3.2% in 2015. This could be attributed by the hydro-climatic variables. These variables include stream flow and rainfall. Conway and Hulme [28] reported declining annual rainfall over the Blue Nile and Atbara basins, resulting in a reduction of river flows between 1945 and 1984. In contrast, studies conducted by Du et al. [29] reported that water bodies increased from 125,369 to 1,315,574 ha, at an annual growth rate of 12,389 hectare per year in Jiangsu Province of China during 2000–2005. Recent study done by Tesemma et al. [30] indicated that rainfall over the Upper Blue Nile Basin did not show a statistically significant trend for the last 40 years (1964–2005). Despite the fact that the pattern of rainfall remained constant, hydrological flows in the basin showed a heterogeneous trend. The other reason for such water body decrement could be siltation. For example, a study conducted by Haregeweyn et al. [31] in northern Ethiopia on reservoir sediment surveys showed that the severity of the sedimentation problem is high: Six of the eleven studied reservoirs were



**Fig. 5** LU-LC change maps of the study area for the year 1973, 1986 and 2015



**Table 3 Description of LU-LC classes used for the study**

LU-LC classes	Description
Water body	The part of the earth's surface covered with water such as a river or a stream
Forest land	Land containing or covered by trees forming closed or nearly closed canopies
Shrub land	Land covered by small trees and bushes in which shrubs are the dominant vegetation
Grass land	Land covered with grasses and other soft plants but not with bushes and trees
Crop land and rural settlement	Land on which mainly food crops are grown on areas allotted to rain-fed and/or irrigated cultivation and rural settlements
Bare land	Areas that have little or no vegetation cover, mainly with classic gullies and exposed rocks
Built-up area	Any land on which buildings are present, normally as part of a larger developed environment such as developed land lot and urban area

experiencing extreme sedimentation so that their economic life will be reduced to half of the design life.

**Forest lands**

Forest lands declined from 3.8% in 1973 to 3.4% in 1986 and to 0.2% in 2015 (Table 4). The total forestland cleared between 1973 and 2015 amounts to 552 hectares. This is 95% of the forest cover that existed in 1973. The result of this study is in agreement with the findings of Miheretu and Yimer [32]. They reported that forest lands have declined over 50 years (1964–2014) in the Gelana sub-watershed of Wollo area. A study conducted by Alemayehu [33] also found similar results. In his study in northeastern Wollega, he reported that, forest land has declined by about 36% during the study period of

1972–2015. On the other hand, studies conducted by Amare et al. [34] reported a substantial increase in forests at the expense of cropland and grazing land since the late 1970s in the Eastern Escarpment of Wello. Studies conducted by Asmamaw et al. [35] also found similar results. In their study in the Gerado catchment, North-eastern Ethiopia, they documented an increase in forest land throughout the period of 1958–2006.

**Shrub lands**

Shrub lands declined from 28.4% in 1973 to 26.8% in 1986 and to 24.9% in 2015. This could be attributed to crop land and rural settlement expansions. This result is in line with the findings of Asmamaw et al. [35]. They reported that shrub lands declined from 15.6% in 1980 to 13.2% in 2006, in the Gerado catchment, Northeastern Ethiopia. In contrast, study conducted by Tesemma et al. [30] indicated that shrub lands generally increased by 19% during the study period of 1972–2015. Amare et al. [34] also came with the same result. They reported a substantial increase in shrub lands at the expense of cropland and grazing land since the late 1970s in the Eastern Escarpment of Wello.

**Grass lands**

Based on the LU-LC change analysis, grass lands decreased from 23.6% in 1973 to 21.3% in 1986 and to 15.8% in 2015. This result is in line with the findings of Asmamaw et al. [35]. They indicated that grasslands decreased from 5.8% in 1980 to 4.1% in 2006 at 1.17% annual rate, in the Gerado catchment, Northeastern Ethiopia. The study conducted by Abate [36] in Borena *wereda* of South Wello highlands also showed that grass lands reduced in size between 1972 and 1985 with a rate of 73 ha/year. But, the result of this study is inconsistent to the findings of Belay [37]. They reported that during the three-decade time period (1972–2006), there was an expansion of grasslands in Awash National Park, Ethiopia.

**Table 4 LU-LC changes of the study area for the year 1973, 1986 and 2015**

LU-LC class	1973		1986		2015		Rate of changes in hectare		
	Area in ha	%	Area in ha	%	Area in ha	%	1973–1986	1986–2015	1973–2015
Water body	764.5	5.0	499.2	3.3	488.7	3.2	–265.3	–10.5	–275.8
Forest land	583.5	3.8	520.0	3.4	31.5	0.2	–63.5	–488.5	–552.0
Shrub land	4317	28.4	4083.5	26.8	3789.1	24.9	–233.5	–294.4	–527.9
Grass land	3583.8	23.6	3230.3	21.3	2394.1	15.8	–353.5	–836.2	–1189.7
Crop land	5853.8	38.6	6694.5	44.1	8265.2	54.4	+840.7	+1570.7	+2411.4
Bare land	77.0	0.5	130.4	0.9	148.1	1.0	+53.4	+17.7	+71.1
Built-up area	0	0	36.8	0.2	78.0	0.5	+21.7	+41.2	+62.9
Total	15,194.7	100.0	15,194.7	100.0	15,194.7	100.0	–	–	–

**Crop lands and rural settlements**

Our study revealed that crop lands and rural settlements increased from 38.6% in 1973 to 44.1% in 1986 and 54.4% in 2015. The greatest expansion of crop lands and rural settlements occurred between 1986 and 2015 (81%). This kind of conversion usually occurs because of rapid population growth and at the expense of grass lands, shrub lands, forest lands and marginal lands. Consequently, farmers in the area are encroaching and cultivating sloppy and marginal areas, which exacerbated land degradation and soil erosion, which in turn results food crop reduction. Based on the data obtained from key informant interviews, the expansion of crop lands and rural settlements, and the decrement of forest lands, occurred because of population pressure that is exacerbated by returnees to the study area from resettlement areas to their places of origin. Returnees in this case are among hundreds of thousands of people, mainly ethnic Amharas and Tigrayans from throughout the northern highlands who were resettled to several lowland sites in southwestern Ethiopia during 1977/78 and 1984/85. They returned at different times between 1978 and 2000 depending on the specific circumstances of their resettlement. The majority of returnees, however, returned following the fall of the *Derg* Government in 1991 [38]. Such a dramatic LU-LC change, particularly crop lands and rural settlements expansion within about three decades and the increasing proportion of completely degraded lands, clearly indicates the prevailing danger of land degradation, which aggravates the food security problem of the area. Moreover, it has a negative impact on the environment and socioeconomic settings because it results in soil fertility loss and the degradation of ecosystem components. This finding is in line with the findings of Woldeamlak, Aklillu and Gessesse [39–41], who showed that land use change is brutal and there has been agricultural land size expansion at the expense of natural vegetation cover lands and marginal areas without any appropriate conservation. Similarly, Gete and Hurni [42] have also documented the expansion of cultivated land at the expense of forestlands between 1957 and 1982 in Dembecha area, Northwestern Ethiopia. The study conducted by Gashaw et al. [43] in Dera district of Ethiopia showed that cultivated lands had increased at a rate of 38.29 ha/year in the last 26 years at the expense of forest lands, shrub lands and grass lands. Daniel [44] also found similar results. He indicated that cropland and settlement areas increased by 12.5 hectare per year in the upper Dijo river catchment, Silte Zone, Southern Ethiopia.

**Bare lands and built-up area**

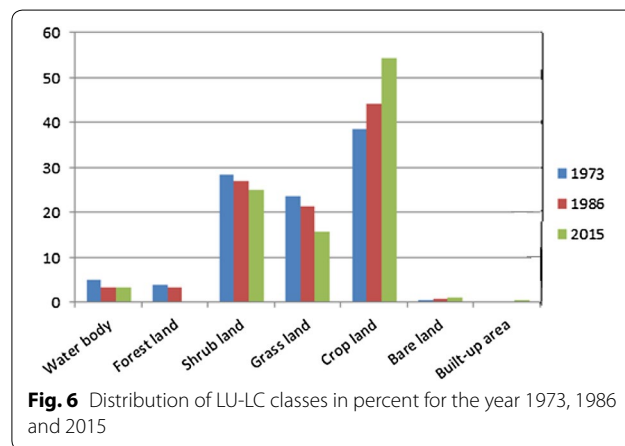
The result of our study showed that bare lands increased from 0.5% in 1973 to 0.9% in 1986 and to 1% in 2015. In

similar way, built-up areas increased from 0.2% in 1986 to 0.5% in 2015. These results are in line with the findings of Miheretu and Yimer [32]. They found that bare lands and urban built-up areas have expanded over a period of 50 years (1964–2014) in the Gelana sub-watershed of Wello area. A study conducted by Daniel [44] also reported similar results. He found that increase in bare land by 24.8 hectare per year in the upper Dijo river catchment, Silte Zone, Southern Ethiopia.

Generally, the LU-LC changes observed in the study area revealed that the conversion of forest lands to crop lands and rural settlement, as well as bare lands and built-up areas, was constantly increased in all the three reference years (1973, 1986 and 2015). In this regard, human activities are taken into consideration for the expansion of agricultural lands through unplanned and inappropriate land management practices (exploitation of forest resources and marginal lands) to meet the food demand of the rapidly growing population (Fig. 6).

**Drivers of LU-LC changes in the Teleyayen sub-watershed**

Land use and land cover change is a complex phenomenon that directly and indirectly is influenced by multiple socioeconomic and biophysical driving forces that operate over different scales. With respect to this topic, data were collected from key informants about drivers of LU-LC changes of the area. A considerable numbers of respondents (80%) expressed population growth, crop land expansion, landlessness, overgrazing, climate change, land degradation, drought and shortage of rainfall as drivers of LU-LC changes. Among these driving factors, population growth and shortage of rainfall were acknowledged as the main land use and land cover change drivers. Because of population growth in the area, farmers are forced to cultivate steeper slope and marginal lands, which are not recommended for agricultural activities. This type of cultivation in turn



exacerbates soil erosion, exerting a profound influence on LU-LC changes and SLM practices, resulting in severe land degradation and crop yield reduction. The response given by respondents about the existence of rapid population growth in the area is supported by the population data obtained from ANRS-BOFED and ANRS-BOFED [45, 46]. According to these reports, the total population of Kutaber district in the year 2015 and 2016 was 102,997 and 104,467, respectively. Similarly, the total population of Ambassel district in the same year was 135,120 and 136,979, respectively. Landless youths and farmers having very small farm land are contributing to LU-LC changes negatively by cutting trees for the sale of firewood and charcoal, therefore putting a burden on the existing forest lands. This is a common practice in the area because it is a means of living for many resource poor individuals, especially jobless and landless youths and women in the area. Hence, it needs urgent response; otherwise, it will result serious socioeconomic and environmental chaos. The solution may include introducing off-farm activities, revising the land use policy, introducing proper family planning programs and think of land redistribution. Furthermore, encourage them to engage in off-farm income-generating activities with help and support in the forms of capacity building (provision of skill and business management trainings), provision of credit and facilitating markets.

The key informants were also asked about their opinions on how to improve the current effort toward sustainable land management practices and food security services. They underlined among other things that the need for incentives in a form of a productive safety net program (PSNP), water harvesting, the construction of water retention ponds to collect and store runoff for irrigation purposes, and awareness raising. Besides, they reported improving farmers' willing participation in natural resource conservation programs, ensuring security of long-term land use rights and reducing population pressure on land. Therefore, particular attention should be given to indigenous knowledge in the formulation and implementation of activities related to farming, SLM and development of appropriate strategies for rural household food security problems.

#### **Implications of land use–land cover changes on food insecurity**

Food security is determined by food availability (the overall production of food by the agricultural system), food access (distributional and entitlement issues), food stability (the risk of losing temporarily or permanently access to food), and food utilization (all food safety and quality aspects) [47, 48]. Land-based production provides the major biophysical basis for food security. Land

system change, that is, the spatial and temporal changes in the interplay of social and ecological systems in shaping land use and land cover, is central to food security assessments.

Several questions arise with regard to the rapid land use and land cover changes and associated impacts in the area. Of these questions, this study addresses: What are the implications of the LU-LC changes for the food security problems that prevailed in the study area? This question is addressed based on spatial and temporal analysis of LU-LC changes from 1973 to 2015 and investigation of possible implications for SLM practices and food security problems. LU-LC changes, trends in expansion of crop lands, livelihood changes occurred in response to the LU-LC changes and associated results are presented.

Accordingly, FGDs were conducted in 2016 in order to get information on the implications of LU-LC changes on rural household food security in the study area, because focus group discussions are an effective ways for understand the local conception of community in the area. Participants were selected based on their specific characteristics like gender, farm experience, age, job and position. Three FGDs were formed: one focus group in each of the upper-highland, highland and mid-land agro-climatic zones. The key informants include *kebele* administrators, elders and PSNP beneficiary farmers; each group of eight persons included both men and women. The results of the discussion showed that land degradation, farm land fragmentation, shortage of farm land, climate change, crop yield reduction and increasing rate of soil erosion are the major implications of LU-LC changes for rural household food insecurity in the study area. In order to obtain historical information on LU-LC changes, socioeconomic issues, policy changes and food security, farmers aged over 50 years were intentionally selected to be participants of the discussion. Therefore, they reported that the year 1973 was recognized as a hard time for all of the communities of the sub-watershed because it was the time in which drought reappeared throughout the Northern part of Ethiopia and resulted chronic food shortage and resource degradation.

Participants in the focus group discussions were also asked about their opinions on how to improve the current food security problem and land management practices. Like key informants, they indicated the need for relief support and continuation of PSNP. They also noted the needs of land redistribution because some of them believed that there are some farmers who owned large farm size since the *Derg* Regime. Furthermore, they indicated as a solution the need of income diversification programs, water harvesting, ground water resources and spring development for irrigation agriculture.

Therefore, it is desirable to raise awareness among relevant stakeholders, such as land use planners, agricultural expertise and decision- or policy-makers, about the speed and degree of land degradation and its long-term consequences, particularly on food security. Moreover, such stakeholders and other developmental organizations should work hard on improving the country's SLM policy, planning and physical implementation, such as integrated natural resource management at watershed level, which are needed to protect potential agricultural lands in this part of the country from further deterioration through loss of soil productivity.

**Land use and land cover change cross-tabulation matrix**

An important aspect of change detection is to determine what is actually changing to what category of land use and land cover type, i.e., which land use class is changing to the other type of land use class. This process involves a pixel to pixel comparison of the study year images through overlay analysis. The land use and land cover change matrix depicts the direction of change and the land use type that remains as it is (Table 5). Accordingly, from 1973 to 1986, 212.37 ha (36.84%) of forest lands were converted to shrub lands. Similarly, from 1973 to 2015, 200.53 ha (34.78%) of forest lands were converted to grass lands. This indicates the rate at which forest lands are destroyed from year to year. On the other hand, from 1973 to 1986, 233.26 ha (30.43%) of water bodies were converted to crop land and settlement. Likewise, from 1973 to 2015, 199.14 ha (25.98%) of water bodies were converted to crop land and rural settlement land use category. This denotes the rapid expansion of crop land and rural settlement at the expense of water bodies. These conversions may be because of both natural and man-made factors.

**Conclusion**

This research, which is intended to examine the implications of LU-LC changes for rural household food insecurity in the Teleyayen sub-watershed, has revealed that there were substantial land use changes in the area during the 1973, 1986 and 2015 reference years. The most important changes were the conversion of forest lands to crop lands and rural settlements and to bare lands; decline in water body resources, forest lands, shrub lands, grass lands; while crop lands and rural settlements, bare lands and built-up areas showed increment. Moreover, the expansion of crop lands and rural settlements and the decrement of forest lands were occurred because of population pressure, which is exacerbated by returnees to the study area from resettlement areas to their places of origin.

**Table 5 LU-LC change matrix of 1973, 1986 and 2015**

Changed from	Changed to	1973–1986		1973–2015	
		Hectare	Percent	Hectare	Percent
Water body	Water body	340.50	44.41	337.02	43.96
	Forest land	1.40	0.18	0	0.00
	Shrub land	133.69	17.44	159.45	20.80
	Grass land	57.79	7.54	64.75	8.45
	Crop land and settlement	233.26	30.43	199.14	25.98
	Bare land	0	0.00	6.26	0.82
	Built-up area	0	0.00	0	0.00
Forest land	Water body	45.95	7.97	39.68	6.88
	Forest land	106.53	18.48	9.74	1.69
	Shrub land	212.37	36.84	102.35	17.75
	Grass land	119.76	20.77	200.53	34.78
	Crop land and settlement	89.19	15.46	172.68	29.95
	Bare land	1.39	0.24	2.08	0.36
	Built-up area	1.39	0.24	49.43	8.57
Shrub land	Water body	49.43	1.14	34.81	0.01
	Forest land	253.45	5.86	6.26	0.00
	Shrub land	2091.03	48.32	1778.38	0.41
	Grass land	761.76	17.60	785.44	0.18
	Crop land and settlement	1130.11	26.11	1699.70	0.39
	Bare land	35.51	0.82	20.19	0.00
	Built-up area	6.26	0.14	2.78	0.00
Grass land	Water body	41.77	1.16	41.77	1.16
	Forest land	9.74	0.27	9.74	0.27
	Shrub land	1141.95	31.78	1141.95	31.78
	Grass land	671.24	18.68	671.24	18.68
	Crop land and settlement	1690.65	47.05	1690.65	47.05
	Bare land	24.37	0.68	24.37	0.68
	Built-up area	13.92	0.39	13.92	0.39
Crop land	Water body	16.71	0.29	36.20	0.62
	Forest land	36.90	0.63	5.57	0.10
	Shrub land	719.29	12.30	597.43	10.22
	Grass land	1006.17	17.21	654.53	11.19
	Crop land and settlement	4019.82	68.74	4452.93	76.15
	Bare land	43.86	0.75	92.60	1.58
	Built-up area	4.87	0.08	8.35	0.14
Bare land	Water body	2.08	2.61	2.78	3.48
	Forest land	1.39	1.74	0	0.00
	Shrub land	18.10	22.61	7.65	9.57
	Grass land	7.65	9.57	13.92	17.39
	Crop land and settlement	50.83	63.48	55.00	68.70
	Bare land	0	0.00	0.69	0.87
	Built-up area	0	0.00	0	0.00

The implications of LU-LC changes on rural household food insecurity of the study area include land degradation, farm land fragmentation, shortage of farm land, climate change, crop yield reduction and increasing rate of soil erosion. The expansion of farm lands and degraded lands in the sub-watershed was at the expense of grass lands, shrub lands and forest lands. These changes are caused by expansion of agricultural lands through unplanned and inappropriate land management practices to meet the food demand of the growing population. Furthermore, population growth, crop land expansion, landlessness, overgrazing, climate change, land degradation, drought and shortage of rainfall are mentioned as drivers of LU-LC changes. Among these driving factors, population growth and shortage of rainfall were acknowledged as the main land use and land cover change drivers. Landless youths and farmers having very small farm land are also contributing for LU-LC changes negatively by cutting trees for sale of firewood and charcoal selling, therefore creating burden on the existing forest lands. This is a common practice in the area because it is a means of living for many resource poor individuals, especially jobless and landless youths and women in the area. Hence, these changes need urgent response because it has unquestionable consequences in relation to the livelihood of the communities dwelling in the sub-watershed in particular and in the region in general. Therefore, it is clear from the results of this study that the government and other stakeholders should work on redesigning appropriate land management policy and make small-scale farmers adapt farming practices and land tenure systems that will take care for the growing population and natural resource utilization. Such practice would include always checking on how much of the natural resources (especially agricultural land) are available to sustain the population. In this way, measures in alleviating rural household food security problem by combating population growth and resource utilization would be determined. This will reduce the risks to human future life in terms of land and food availability in the study area.

#### Abbreviations

FGD: focus group discussion; GIS: geographic information system; GPS: Global Positioning System; LU-LC: land use and land cover; PSN: productive safety net program; SLM: sustainable land management; ANRS-BOFED: Amhara National and Regional State Bureau of Finance and Economic Development.

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#### Authors' contributions

AAA has contributed in designing of the study, collection of data, analysis and interpretation of data, and he wrote the manuscript. KNS also contributed in reviewing and writing the draft manuscript as well as editing the manuscript. Both authors read and approved the final manuscript.

#### Acknowledgements

The authors would like to thank Addis Ababa University for supporting this study. Our special thanks also go to farmers' and development agent workers who took part in the survey.

#### Competing interests

The authors declare that they have no competing interests.

#### Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

#### Consent for publication

Not applicable.

#### Ethics approval and consent to participate

Not applicable.

#### Funding

This study was financially supported by Addis Ababa University. Hence, it played a great role in the design and collection of data for the study.

#### Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Received: 13 April 2017 Accepted: 21 July 2017

Published online: 01 January 2018

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