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Competition for land resources: driving forces and consequences in crop-livestock production systems of the Ethiopian highlands

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Abstract

Introduction: Ethiopia has made efforts to tackle the challenges of low crop and livestock productivity and degradation of land resources through various rural development strategies. However, increasing demands for food, animal feed, fuel, and income-generating activities are putting pressure on the land. In this paper, we describe the production pressure and competition between crop and livestock production, quantify rates of land-use/cover (LULC) changes, and examine driving forces and consequences of land conversion.

Methods: The study was conducted in Gudo Beret watershed, North Shewa Zone of Amhara region, Ethiopia. It used a combination of methods including remote sensing, household interviews, field observations, focus group discussions, and key informant interviews. Supervised and unsupervised image classification methods were employed to map LULC classes for 31 years (1984–2016).

Results: The results of satellite remote sensing revealed that 51% of the land in the study area was subject to accelerated land conversions. The household survey results indicated that feed resources and grain production pressures were 1.43 and 1.34 t ha^{-1} respectively. The observed annual changes in plantation and settlement areas were 2.6% and 2.9%. This was mainly at the expense of bushland and grazing land systems. Cropland increased (0.4% $year^{-1}$) while grazing land reduced (3.5% $year^{-1}$) under contrasting dynamics and competitive changes. An increase in human and livestock populations and farm expansion were major drivers of land conversion that adversely affected household livelihoods and the natural ecosystem. The consequences of these pressures resulted in a lack of animal feed, low crop-livestock productivity, and a reduction in natural vegetation coverage.

Conclusions: We suggest that sustainable land resource management, more integrated crop-livestock production, and the use of productivity-enhancing technologies could play a role in managing competition for land resources.

Keywords: Cropland, Land pressure, Livestock, Population growth, Production dynamics

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Introduction

In Ethiopia, rain-fed farming and livestock husbandry form the basis of the economy of the highlands. However, traditional crop and livestock production along with rapid growth in human population have put significant pressure on land resources in these parts of the country. Crop production has expanded due to increases in the amount of land dedicated to this activity, though the adoption of agricultural inputs has also contributed to the rise (Alemayehu et al. 2011). Trends in crop production are more uneven than the growth of the human population due to the erratic nature of rainfall and other shocks. Favorable weather conditions in 1 year result in bumper harvests, but severe drought causes crop failures that adversely affect agricultural production. On top of the impacts of population pressure, a lack of appropriate management practices has led to severe land degradation (Hurni et al. 2016; Nigussie et al. 2015; Kindu et al. 2017).

As the result of complex climatic, biophysical, and socioeconomic challenges, Ethiopia has not been able to produce enough to ensure food security at the household level (Guush et al. 2017). Land-use changes have also had direct implications for the natural environment and society (Yodit and Fekadu 2014). Land-related conflicts and the negative impact of climate change—such as impoverished soil structure, poor surface water quality, increasing temperatures, landslides, soil erosion, soil acidity, water stress, feed shortages, and poor vegetation cover—have exacerbated land degradation (Liniger et al. 2011; Bewket et al. 2015).

Competition between different land-use options is a major issue in the highlands of Ethiopia. While some experts argue that the amount of land dedicated to crop production has increased at the expense of grazing and natural vegetation (Binyam et al. 2015), others suggest that croplands have been converted to woodlots (Eleni et al. 2013). In either case, the competition for land between crop and livestock production will persist as demand for income, food, fuel, and feed continues to rise. One of the underlying causes behind the competition is land conversion that is changing the use of land from one purpose to another (Amanuel 2014). Population growth has also exacerbated the situation (Rota and Sperandini 2010). Although crop and livestock farming has been practiced for centuries in the highlands, the introduction and expansion of eucalyptus plantations (Daniel et al. 2016), land redistribution (Ambaye, 2015), and land certification (Deiniger et al. 2008), combined with high population density, have intensified competition for land. Previous studies (e.g., Eleni et al. 2013; Amanuel 2014; Amare 2015; Nigussie et al. 2015) have failed to provide conclusive evidence about the link between LULC changes and crop-livestock systems. Moreover, household surveys complemented with remote sensing are limited in previous studies (Hall 2010).

To facilitate effective planning and targeting of options, it will be essential to identify the interplay between crop and livestock production and determine the associated tradeoffs. It will also be necessary to assess the key drivers of land conversion so that appropriate responses can be made. This can be achieved through understanding the production dynamics, spatial and temporal LULC changes, and shifts in farming systems. In this study, we hypothesize that several driving forces intensify competition among crop-livestock activities for land resources. Hence, our objectives were to (a) evaluate grain production and feed resources pressure in the mixed crop-livestock systems, (b) examine competition between crop and livestock production and the associated tradeoffs, (c) quantify rates of LULC changes due to land conversion, and (d) provide insights on the drivers and consequences of crop-livestock production dynamics associated with ecological changes.

This study supplements previous research findings regarding methods for complementing household survey and satellite remote sensing, which enables to understand the link between LULC and crop-livestock systems. This study shows shifts in the farming system, magnitude of land pressure in terms of feed resources pressure, rate of LULC changes, and grain production pressure. It comprises trends and patterns of LULC changes, human and livestock population, and feed resources. In addition, it demonstrates the extent of crop-livestock competition in quantitative terms and qualitative explanations.

Methods

Description of the study area

The study area (*Gudo Beret* watershed) is located in *Gudo Beret Kebele*, *Basona Worana Woreda*, North Shewa zone, Amhara region of Ethiopia (Fig. 1). Geographically, it is located between 9° 76′ to 9° 81′ north and 39° 65′ to 39° 73′ east. The area covers about 2425 ha of land. The altitude in the watershed ranges between 2828 and 3700 m above sea level rising in elevation from west to east. The mean daytime temperature ranges between 2.4 °C and 19.2 °C. The climate of the watershed is wet and moist highland with a bimodal rainfall pattern (short and long rainy seasons). The mean annual rainfall in the watershed is 1651 mm. The mean temperature has increased by 0.13 °C between 1995 and 2014, while the mean annual rainfall has declined by 4.9 mm between 1995 and 2014.

The total population size of the study watershed is estimated to be 2070 inhabitants. Subsistence rain-fed cultivation, livestock husbandry, and woodlots are the dominant livelihood sources. Crops produced include barley, faba bean, field pea, wheat, lentil, linseed, Irish potato, and some vegetables (garlic, cabbage, onion). Cattle, sheep, and donkeys are major livestock species. *Regosols*, *Cambisols*, and *Lithosols* are the dominant soils (Kindu et al. 2017). Vegetation cover has declined due to

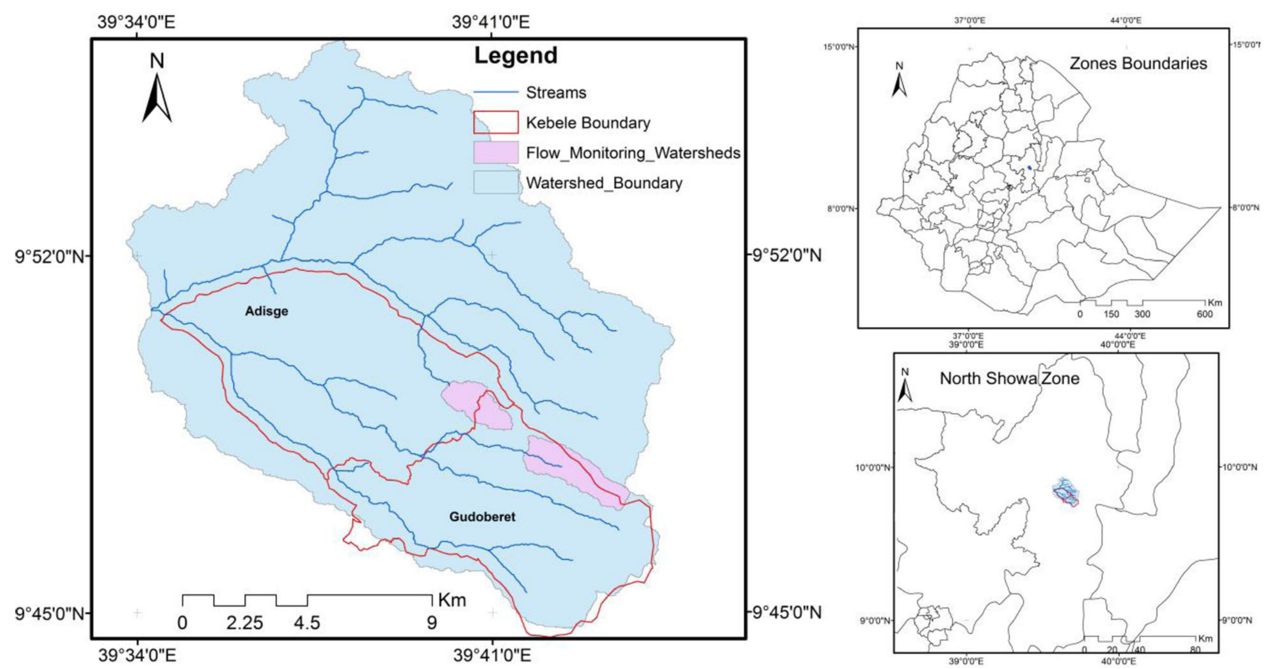

Fig. 1 Location map of the study watershed

anthropogenic factors. The watershed has eucalyptus trees around homesteads, hillsides, and gully buffers. The main infrastructures and institutions found in the study watershed are a small town (Gudo Beret), local market, kebele agriculture office, human and animal health clinics, rural villages, churches, elementary schools, electricity power line, mobile telephone facilities, and asphalt road.

Sampling and data collection procedures

The study watershed was purposively selected for the reason that the study area is part of the USAID, Feed the Future funded Africa RISING project in the highlands of Ethiopia. Moreover, the watershed was selected because of high mixed crop-livestock production potential. The watershed was delineated from a digital elevation model (DEM) following the standard watershed extraction procedure using GIS. The watershed was enclosed starting from the bottom confluence point between two streams, *Feleku* and *Weynabchu*.

There are 447 households in the study area of which 211 (29% female-headed) were selected using systematic random sampling.

The total sample size was determined using the following formula adapted by Yamane (1967):

$$n = \frac{N}{1 + N(e)^2} \quad (1)$$

where n is the total sample size, e is the precision level, and N is the total household in the study watershed. Trained enumerators conducted household interviews from May to June 2016.

In order to gain an overall picture and an adequate description of the study area, preliminary field assessments were carried out in consultation with the agricultural experts. Transect walks and field observations were undertaken to understand the institutions, infrastructure, settlement patterns, and the landscapes in the watershed. Key informant interviews were conducted to identify crop-livestock portfolios, verify LULC changes, and examine crop-livestock-related shifts. The coordinate readings for the outlet point were collected and recorded by a hand-held GPS as part of the field survey from which the watershed is delineated.

Satellite images were acquired and used for LULC analysis (Eleni et al. 2013; Amare 2015). The images include Landsat Thematic Mapper (LTM) of 1984 and a Landsat Enhanced Thematic Mapper Plus (ETM^+) from 2004 and 2016. LTM acquired on December 17, 1984 (path 168, row 053), ETM^+ acquired on January 25, 2004 (path 168, row 053), and on March 28, 2016 (path 168, row 053) were used. More visible and freely available periods (1984, 2004, and 2016) were selected. The 2016 data were used to validate the satellite images with primary data that were collected from respondent households. A spatial resolution of 30 m was applied to all images. Band 7 was used for the first and the second periods, while band 8 was applied for the third period. Seventy-seven ground control points were collected from different LULC types using Google Earth Professional to verify land classification accuracies. A topographic map was used to estimate altitude, interpret images, and visualize landscape features such as cliffs, mountains, forest, and other related information. Arc-GIS 10.1 and Earth Resource Data Analysis System (ERDAS-Imagine10) software were employed to analyze the data.

To collect socioeconomic and satellite data, both remote sensing and household survey were used in a complementing manner. Household interviews were conducted using a semi-structured questionnaire. This questionnaire was designed to capture socioeconomic, institutional, and demographic data including crop varieties, livestock breeds, LULC types, feed resources, feeding systems, household income, and other household attributes. Feed conversion rates and LULC accuracy verification indicators were gathered from both primary and secondary sources. In order to measure the dynamics of crop-livestock production systems, the most important analytical indicators (grain production pressure, feed resources pressure, and LULC changes) were adapted from McIntire et al. (1992) and Liniger et al. (2011). In addition, farmer focus group discussions were conducted to collect ancillary information and perceptions on the availability of feed resources, the major drivers of land conversions, and tenure arrangements. The focus group discussants were household heads residing in the study watershed.

Data analysis

Grain production pressure

Grain production pressure is a measure of grain supply and demand. It considers grain productivity, population size, and grain demand per capita in the study area. The analytical technique was adapted from Huiyi and Shujin (2010).

$$G_p = P * A_d \tag{2}$$

where G_p = the demand side of grain production pressure, p = the population size of the study area and A_d = annual grain demand per capita. Population size was computed in terms of adult equivalents. Conversion factors for children vary from 0.29 to 0.79 adult equivalents depending on their ages, for women ranges from 0.75 to 0.86, and for men ranges from 0.98 to 1.18 (Claro et al. 2010). Grain production pressure might vary in different areas according to population density, agro-climate, soil fertility, dietary preferences, and consumption patterns. The minimum and maximum food consumption demand per capita per adult is between 0.2 and 0.32 t year^{-1} (WHO 2002; Huiyi and Shujin 2010; Guush et al., 2011). Thus, a minimum amount of 357 t year^{-1} and a maximum amount of 536 t year^{-1} was calculated for the 1787 adult equivalents in the watershed. The supply side of crop production was collected from the household survey.

$$C = A * Y \tag{3}$$

where C = the supply side of grain production pressure, A = agricultural area, and Y = crop productivity per unit of land, which was calculated as the total amount of grain produced for the observed year, divided by the total amount of cropland in the study area.

Pressure on feed resources

Feed resources pressure is the ratio of feed/forage demand to feed/forage supply at a given point in time. The carrying capacity of the watershed also was computed as the ratio of animal units to the size of grazing land. Both analytical techniques were adapted from Edward and Scot (2002). According to Gryseels (1988), livestock require a daily dry matter (DM) intake equivalent to between 1.7% and 4.0% (on average 2.5%) of their body live weight, that is, 6.25 kg per tropical livestock unit (TLU) per day. The conversion rate of TLU for ox is 1.1, for a cow/horse/mule 0.8, a bull 0.6, a heifer/donkey 0.5, a calf 0.2, a sheep/goat 0.1, and a chicken 0.01 (Gryseels 1988). Thus, a TLU of 250 kg of live weight animal requires 2.3 to 2.7 t DM year^{-1}. Conversion factors for feed/forage resources were used. The rates to estimate crop residue were 1.5 for barley, 1.2 for wheat/faba bean/field pea/lentil, 4.0 for linseed, and 0.3 for potato. The rates used for aftermath and pastureland were 0.5 and 2.0 (Yihalem 2013; FAO 1987).

Focus group discussions were used to establish local conversion units. "*Chinet*" (a load of pack animals) and "*shekim*" (human carry) are the common local measurements. One animal load (*chinet*) of dry and wet feed/forage is equivalent to between 40 and 60 kg. One human load (*shekim)* of dry and wet feed/forage is equivalent to between 20 and 30 kg. The conversion rate of a given crop multiplied by the total grain yield of the crop gives the total available crop residue of that crop in t year^{-1}. The conversion rate (0.5) multiplied by the total amount of cropped land in the watershed (509 ha) gives the total amount of aftermath. Similarly, grazing land in ha multiplied by its conversion rate (2.0) gives the total amount of feed resources from pasturelands (FAO 1987). The estimated feed/forage supply does not include residues of Irish potato and vegetables due to the insignificant conversion rate for potato and a lack of information on the conversion rate of vegetables (Yihalem 2013). Feed/forage estimations also do not consider losses through wind, fire, rodents, decay, and livestock trampling. Estimations of all feed/forage resources were made regardless of their nutritive contents.

Land-use and land cover change

We employed Arc-GIS 10.1 for analysis and processing of satellite images, and ERDAS imagine 10 was used for supervised and unsupervised image classification (Fig. 2). LULC was categorized into six classes and three periods

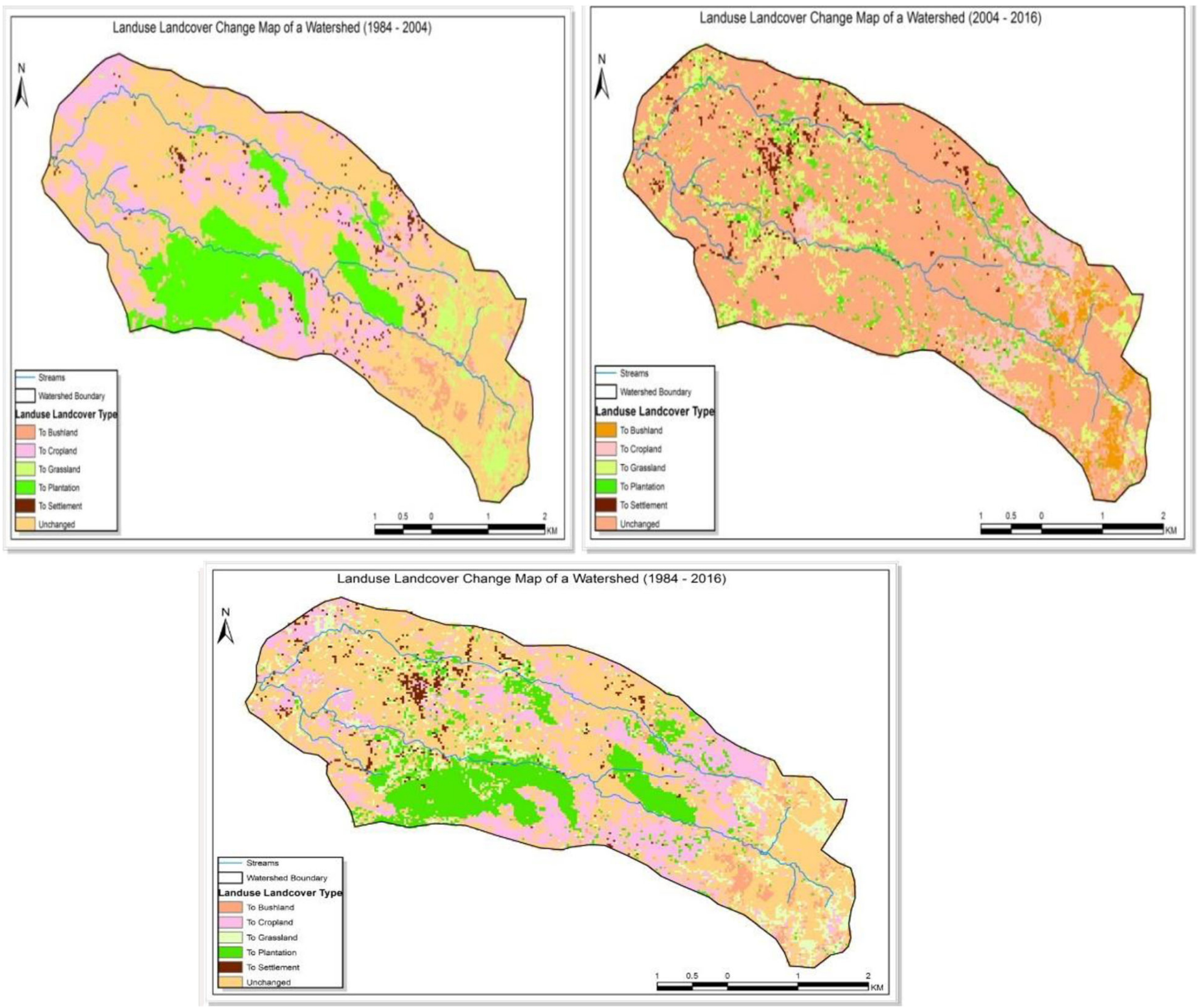

Fig. 2 LULC maps of the watershed in 1984, 2004, and 2016

based on the experience of most studies conducted in Ethiopia (Eleni et al. 2013; Amanuel 2014; Amare 2015; Binyam et al. 2015). Image classification, mapping verification, accuracy calculations, and computation of the transition matrix were the major steps followed in the data analysis for LULC changes.

Accuracy assessment

Classification descriptions for each LULC class were taken from the literature. Bushland refers to areas with sparse tree populations mixed with short bushes, grasses, and open areas, less dense than the forest with few wooded areas, and mixed with some grass areas (Amare 2015). According to Tsegaye et al. (2010), land greater than 20% bush or less than 5 m in height is bushland. If the dominant vegetation cover consists of grass species or grass and herbs with scattered trees and shrubs, such LULC is grazing land (Hurni et al. 2016). Cultivated land refers to all land under cultivation for crop production and scattered rural homesteads. A forest is an ecosystem dominated by woody vegetation (Christy et al. 2007). Ecologists define forests in terms of vegetative structure. A forestland can be also defined as land with more than 0.5 ha covered with trees, trees and shrubs above 5 m height and canopy cover of more than 10% (Ridder 2010). Settlement refers to a small village or town stretched out mainly from the cropland and grazing lands. The land with little or no green vegetation cover is referred to as rock outcrop.

Quantitative LULC classification accuracy was computed through an error matrix using producers' accuracy (omission error) and users' accuracy (commission error). The total number of correctly categorized LULC classes divided by the total number of reference data points represents the overall classification accuracy. Kappa statistics (total accuracy) measure the level of spatial agreement or accuracy between the training samples (reference data) and LULC values (remote sensing) of the classified images. The Kappa coefficient is derived from the error matrices to find out the reliability and accuracy of maps produced.

$$K = \frac{P_o - P_e}{1 - P_e} \quad (4)$$

where K is the Kappa coefficient, and P_o and P_e are denoted to observed and expected agreements. Cohen's kappa coefficient is used to assess the level of true agreement beyond chance agreement. A kappa value greater than 81% is considered almost perfect agreement (Tang et al. 2015). The accuracy values of each land class are indicated in Table 1.

Change detection

Once LULC is classified with certain accuracy, the data were used to understand the rate and direction of LULC change and provide information as to where, when, how much, and what type of land cover has changed. The transition matrix was quantified from remote sensing features estimating the losses and gains for each LULC. The matrix showed the spatial and temporal changes taking place over the past 31 years. In the matrix, net change and net persistence ratio explain the persistence and vulnerability of each LULC type. Vulnerable lands, in this context, refer to lands that are exposed to change from a given type of LULC to another LULC in a given period. The annual rate of change (r) for each land class was adapted from Abyot et al. (2014) and computed as follows:

$$r = \left(\frac{a_1 - a_2}{a_1 t}\right) * 100 \quad (5)$$

where a_1 and a_2 = the recent and initial year of each LULC in ha, t = the time taken between a_1 and a_2 in years.

Drivers of LULC changes

First, we employed household survey data through respondent interview using closed and open-ended questions in the interview schedule. Household interviews were employed in order to understand the main drivers of LULC changes in the watershed. Later, we used focus group discussion comprising of five male and one female household heads for triangulation. Group members thoroughly discussed possible drivers of LULC conversions, identified several underlying causes, and made comparisons among drivers. We employed the pair-wise ranking method to identify the top, intermediate, and least important drivers of LULC changes.

Results

Grain production pressure

Households in the watershed cultivated 509 ha of land and produced cereal, legume, and oil crops. Oats, vetches, and vegetables were grown on 47 ha of cultivated land. Thus, according to the household survey, the total cropland size of the study watershed was 556 ha. The average cropland size of households in the study watershed was 1.2 ha, somewhat larger than the 0.9 ha reported by Kuria et al. (2014) in the same kebele. Cereal crops showed better crop productivity compared to legumes and oil crops (Table 2). The total annual grain supply of the watershed was 683 t, of which 28% goes to household annual expenditure such as seed reserve, source of cash income, gift to others, and post-harvest losses. The grain yield was 1.34 t ha^{-1}. The average grain supply per household was 1.52 t (0 to 4 t), indicating that the average household's landholding was a little more than 1 ha. Of the total households, 55% produced less than the average grain yield supply.

The actual total net food supply for the watershed (493 t) exceed the minimum food security level (0.2 t year^{-1}) but was less than the average world consumption level of 0.3 t year^{-1}. The local aggregate food supply was sufficient to meet everyone's minimum

Table 1 Classification of accuracy value for LULC maps for the years 1984, 2004, and 2016

Land classes	Accuracy (%)					
	1984		2004		2016	
	Producers	Users	Producers	Users	Producers	Users
Bushland	86.7	92.9	65.0	76.5	76.5	92.9
Grazing land	88.2	88.2	100.0	73.3	60.0	100.0
Cropland	93.1	90.0	91.5	96.2	100.0	89.7
Plantation	100.0	100.0	93.8	79.0	100.0	83.3
Settlement	–	–	91.0	78.0	100.0	100.0
Overall accuracy	96.0		94.0		95.2	
Kappa coefficient[a]	0.9		0.9		0.9	

[a]Kappa coefficient is dimensionless

Table 2 Crop production, expenditure, and net food supply in 2015/2016 cropping season

Crop types	Cultivated land (ha)	Crop productivity (t ha^{-1})	Total grain yield (t)	Expenditure (t)	Net food supply (t)
Barley	211	1.75	369	104	265
Wheat	64	1.54	98	18	80
Faba bean	115	1.26	144	50	94
Field pea	91	0.72	66	20	46
Lentil	23	0.15	3	1	3
Linseed	6	0.45	3	1	2
Total	509		683	194	490

needs. However, it is doubtful that access to food could be constrained by food inequalities at the individual level. Based on the actual local grain yield per unit of land, households need an extra 46 t of grain or 6.7% additional cropland to raise the grain supply to 0.3 t per capita.

Pressure on feed resources

In the watershed, 509 ha of cropland produced 939 t of crop residues (Table 3). Households used 836 t of crop residues for their livestock and the remaining 103 t of crop residues to generate income, improve soil fertility, and build thatch roofs. The estimated feed/forage resource from aftermath was 254 t. The total supply of feed resources from various grazing lands, such as communal and private lands, and open access areas, was 853 t year^{-1}. Respondent households estimated the amount of harvested feed/forage resources through a cut and carry method. The total amount of available feed/forage resources was 541 t. Feed/forage resources (dry and green) in the watershed include hay, green grass, weed, oats, and vetches. Privately owned lands, cropland, and controlled communal grazing areas were common sources of livestock feeds/forages.

Households purchased 72 t of agro-industrial byproducts such as concentrate feeds, oil cakes, wheat bran, and salt for their livestock. Among sampled respondent households, 38% ($N = 80$) used improved forage for their livestock. The Africa RISING project introduced much of the improved feed/forage resources. The project works on several sustainable intensification interventions. Some of these include livestock feeds/forages and post-harvest feed handling and utilization, improved crop varieties, high-value fruit and fodder trees, mechanization, landscape management innovations, and small-scale irrigation. For instance, 14% of the households in the watershed grow and use tree lucerne (*Chamaecytisus palmensis*). It is used as a supplementary feed source for soil and water conservation measures that harnesses soil fertility (Kindu et al., 2017; Tamene et al. 2017). Households also fed 283 t of local brewery residues, "*Atela*," and leftovers to their livestock.

The total amount of available annual feed/forage resources (2839 t) were sufficient to feed the livestock population for 8.5 months a year. The annual estimated feed/forage demand for 1782 TLU is 4065 t, showing a deficit of 1226 t of DM year^{-1} t, with a feed/forage demand to supply ratio of 1.43 to 1. This feed gap indicates the extent of pressure on feed resources. The average stocking density is computed as the total size of the livestock population (1782 TLU) divided by the total grazing area available (426.5 ha), i.e., 4.18 TLU ha^{-1}. This result is considerably higher than 0.36 TLU ha^{-1} (Aklilu 2006) and lower than that of the 5.60 TLU ha^{-1} reported by Assefa (2005) in the highlands of Ethiopia.

Households accessed sufficient feed from September to December. Pressure on feed resources tended to peak from January to August when there is inadequate access to alternative feed resources. Feed shortages occur from April to July (Fig. 3). In the study watershed, 92% of households owned livestock, of which most households

Table 3 Major cereal, legume and oil crops, and yield of crop residues in 2015/2016 cropping season

Crop types	Cultivated land (ha)	Crop productivity (t ha^{-1})	Grain yield (t year^{-1})	Conversion rates	Residue yield (DM t year^{-1})
Barley	211	1.75	369	1.5	553
Wheat	64	1.54	98	1.2	118
Faba bean	115	1.26	144	1.2	173
Field pea	91	0.72	66	1.2	79
Lentil	23	0.15	3	1.2	4
Linseed	6	0.45	3	4	12
Total	509		683		939

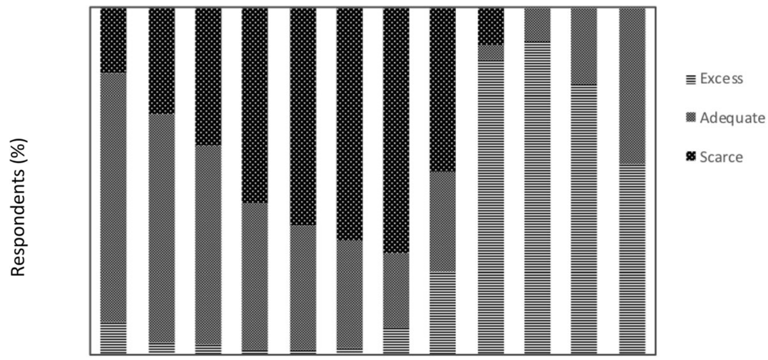

Fig. 3 Feed availability in 2016

(71%) faced critical feed shortages in July. Kuria et al. (2014) also found that the fodder scarcity occurs between July and August. High grazing pressure results in reduced livestock productivity. According to respondent households' evaluations, the performance of cattle, sheep, and goat was low.

The available amount of grazing land and livestock feed has been declining due to increasing demand for cropland to feed the growing population (Amanuel 2014; Duncan et al. 2016). Livestock numbers have increased along with the human population. Livestock holdings per household revealed an upward trend. This result contradicts the findings from other studies conducted in different areas of the country (Amanuel 2014; Yodit and Fekadu 2014). Our findings in the watershed indicate that 18 and 15% of livestock were small ruminants (sheep) and equines (donkeys) respectively. Cattle constituted the highest proportion of the livestock species (oxen—38% and cows—14%). Bulls, heifers, calves, horses, goats, and chickens accounted for only 15%. Within the 5-year period (2012–2016), the number of chickens has increased by 52%. Crop residues are the fundamental resource for crop-livestock integration and a major source of livestock feed (McIntire et al. 1992). Households in the watershed used 89% of crop residue for livestock feed. Endale et al. (2016) and Duncan et al. (2016) reported similar results in the west *Shewa* zone of Ethiopia and Eastern Africa including Ethiopia.

Land-use and land cover changes

Cropland, grazing land, plantation, bushland, settlement, and rock outcrop were the major LULC types identified in the watershed (Table 4). Grain production pressure, pressure on feed resources, and population growth influenced LULC scenarios and resulted in spatial and temporal shifts in the landscape of the watershed. From 1984 to 2004, there was a reduction of 64% in the land allocated to grazing which coincided with afforestation and villagization programs and land distribution. The satellite image for settlement of the small town was not available for 1984. In the second period (2004), land use for settlement had increased to 32 ha. Likewise, the size of plantation had increased from 79.7 ha in 1984 to 289.5 ha in 2004. Policy interventions such as land redistribution and villagization resulted in a rapid loss of grazing and bushland at the rate of 3.4% and 0.8% year^{-1}.

Due to population growth, demand for food and fuel has increased. Increasing population also tends to lead to the conversion of natural landscapes including grass and bushlands to farmlands through encroaching shrubs and grazing fields. Plantation and croplands increased in the watershed by 4.1 and 1.1% year^{-1} during the first period (1984–2004). Continuous farming and massive plantation expansions have adversely affected grazing lands. In addition to low crop productivity and high population growth, the major cause of feed shortages has been the intensive conversion of grazing land mainly to cropland and plantations. Overall, 44% of the LULC changed during the first period (1984 to 2004) with a persistence ratio of 56% (Table 5).

According to the results of LULC transition matrix (Table 6), grazing land showed an increasing rate of 2.1% year^{-1} between 2004 and 2016. This change is associated with the expansion of plantations (0.2% year^{-1}) and settlements (3% year^{-1}) at the expense of a reduction in bushlands (0.7% year^{-1}) and croplands (0.7% year^{-1}). Plantations showed the highest rate of increase between 1984 and 2004 as compared to 2004 and 2016. The rate of reduction in bushland was almost the same both from 1984 to 2004 and 2004 to 2016. Grazing land and cropland showed contrasting trends in both periods. Cropland showed an increasing trend between 1984 and 2004, whereas grazing land showed an increasing trend from 2004 to 2016. Amanuel (2014) reported similar findings for a watershed in Gilgel Gibe, Ethiopia. In the second period, about 71% of the land was persistent in that it had not changed in terms of LULC (Table 6).

Settlement areas, plantations, and cropland showed increases in the conversion rate of 3.2, 2.6, and 0.4%

Table 4 LULC changes between 1984 and 2016 in Gudo Beret watershed

LULC	Area cover (ha)						Change between periods		
	1984		2004		2016		1984–2004	2004–2016	1984–2016
	ha	%	ha	%	ha	%			
Plantation	79.7	3.3	369.3	15.0	379.4	16.0	289.5	10.2	299.7
Bushland	323.9	13.3	280.9	12.0	259.2	11.0	– 43.0	– 21.7	– 64.7
Cropland	1129.0	46.6	1424.0	59.0	1310.1	54.0	295.0	– 113.9	181.2
Grazing land	892.6	36.8	318.7	13.0	426.5	18.0	– 573.9	107.8	– 466.1
Rock	–	–	0.3	0.0	0.9	0.0	0.3	0.6	0.9
Settlement	–	–	32.1	1.3	49.1	2.0	32.1	17.0	49.1
Total	2425.2	–	2425.3		2425.2				

Source: ERDAS imagine 10 classifications

year^{-1} from 1984 to 2016. Grazing land and bushland conversion declined at the rate of 3.5% and 0.8% year^{-1}. In all periods, land dedicated to settlement increased in the watershed. The area allocated to plantation included *Eucalyptus globules*, *Eucalyptus camaldulensis*, and *Cupressus lusitanica*. There are no natural forests in the watershed. This increase in plantation areas is in line with the findings of Eleni et al. (2013) and Amare (2015) but contrary to the findings of Amanuel (2014) and Nigussie et al. (2015). From this finding, it is presumed that manmade woodland cover increases even as natural vegetation declines in Ethiopia, particularly in the study area. Eucalyptus plantation has manifold benefits for 99%, 80%, and 20% of the households as a source of fuel, charcoal, and household income respectively. It is also the main source of raw material for house construction, equipment, and timber. Although eucalyptus plantations were established during the rule of Emperor Menelik II in *Gudo Beret* (Kuria et al. 2014), the existing plantation has been afforested since the 1980s.

The detection matrices show the dynamics of land conversions for the past 31 years. The matrices include the patterns and trends of LULC changes. Gains, losses, net changes, and net persistence show the resistance and vulnerability to change of land classes in each period. Rock outcrop appears in the middle-upper catchment of the watershed between bush and cropland that has increased from 0.3 ha in 2004 to 0.9 ha in 2016. However, the matrix results do not include rock outcrop due to insignificant values. The LULC persistence ratio from 1984 to 2016 is 49%. That means 51% of the LULC went through land conversions (Table 7).

Households implemented various indigenous and improved soil and water conservation structures on their farmlands such as soil bunds, soil faced stone bunds, trenches, and other physical and biological conservation

Table 5 LULC transition matrix of major changes in the landscape from 1984 to 2004 (%)

	To final state (2004)						
	Bushland	Grazing	Cropland	Plantation	Settlement	Total 1984	Loss
From the initial state (1984)							
Bushland	220.4	95.7	7.1	0.6	0.1	323.9	103.5
Grazing land	56.9	221.3	440.2	156.7	17.6	892.6	671.3
Cropland	3.0	1.2	907.1	203.5	14.2	1129.0	221.9
Plantation	0.6	0.5	69.6	8.5	0.5	79.7	71.3
Settlement	0.0	0.0	0.0	0.0	0.0	0.0	0.0
						1357.3[a]	
Total (2004)	280.9	318.7	1424.0	369.3	32.1		
Gain	60.5	97.4	516.9	360.8	32.1		
Net change [b]	– 43.0	– 573.9	295.0	289.5	32.1		
Net persistence[c]	– 0.2	– 2.6	0.3	34.2	–		

Bolded diagonal elements represent each land-use/cover class that was static (persistent) between 1984 and 2004. The loss column and gain row indicate the size of the landscape that experienced gross loss and gain in each class

[a]The sum of diagonals represents the overall persistence (i.e., the landscape that did not change)

[b]Net change = gain – loss

[c]Net persistence refers to the net change to persistent land (i.e., net change/diagonals of each class)

Table 6 LULC transition matrix showing major changes in the landscape 2004–2016 (%)

	To final state (2016)							
	Bushland	Grazing land	Crop land	Plantation	Settlement	Rock	Total 2004	Loss
From the initial state (2004)								
Bushland	185.0	64.2	20.4	10.1	0.8	0.0	280.9	95.5
Grazing land	55.9	134.6	113.2	14.7	0.4	0.0	318.7	184.1
Cropland	13.9	167.8	1125.4	74.2	42.8	0.0	1424.0	298.6
Plantation	3.7	57.7	26.6	278.6	2.7	0.0	369.3	90.6
Settlement	0.4	2.5	24.6	1.9	3.1	0.0	32.4	29.3
Rock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
							1726.1	
Total (2016)	259.2	426.5	1310.1	379.4	49.1	0.0		
Gain	73.8	292.1	184.8	100.8	46.7	0.0		
Net change	– 21.7	108.0	– 113.9	10.2	17.4	0.0		
Net persistence	– 0.1	0.8	– 0.1	0.0	5.7	0.0		

measures. Eucalyptus plantations, resident villages, bush and shrublands, grazing areas, and cultivated lands are the dominant features in the mixed farming systems. The *Amhara* Region Forest Enterprise has managed the state-owned eucalyptus plantation in the southwest part of the watershed. Open-grazed and enclosed communal pasturelands covered the steep slope and hilltops of the watershed, which farmers have used for open grazing and cut-and-carry systems. Households, residing in the upper part of the watershed, are encroaching on bushlands close to the steep slopes and expanding their farmlands. The loss of bushland has usually been attributable to crop production, plantation, and livestock grazing in the three consecutive periods. Communal grazing areas and bushland coverage are found mainly in the upper escarpment of the watershed.

Shrubs and grass species—such as *Erica arborea*, *Dodonaea viscose*, *Helichrysum citrispinum*, *Lobelia rhynchopetalum*, *Festuca spp (Guassa* grass), *Thymus schimperi*, and other afro-alpine species—are available in the top part of the catchment. According to key informants and field observation, the natural vegetation has both product and service functions from which smallholder farmers benefit. Firewood, furniture, construction materials, grazing reserves, medicinal plants, tourism, biodiversity, wildlife opportunities, and many others are the product functions whereas soil and water conservation, environmental restoration, and climate stabilities are service functions. For instance, dense vegetation cover significantly reduces soil loss and is less susceptible to livestock and humans (Tamene et al. 2017). High mountain vegetations such as afro-alpine species are very important for the livelihoods of local communities and improve water balance. From a practical perspective, the upper part of the watershed has economic, ecological, socio-cultural, and biophysical significance.

Table 7 LULC transition matrix showing major changes in the landscape 1984–2016 (%)

	To final state (2016)						
	Bushland	Grazing land	Crop land	Plantation	Settlement	Total 1984	Loss
From the initial state (1984)							
Bushland	199.6	95.0	23.4	5.9	0.0	323.9	124.3
Grazing land	50.2	194.4	460.2	179.8	8.0	892.6	698.2
Cropland	5.8	116.6	782.7	184.1	39.8	1129.0	346.2
Plantation	3.6	20.7	43.8	9.6	2.0	79.9	70.1
Settlement	0.0	0.0	0.0	0.0	0.0	0.0	0.0
						1186.3	
Total (2016)	259.2	426.5	1310.1	379.4	49.1		
Gain	59.6	232.3	527.4	369.8	49.1		
Net change	– 64.7	– 465.9	181.2	299.7	49.1		
Net persistence	– 0.3	– 2.4	0.2	31.1	–		

In many developing countries including Ethiopia, land parcels are small (Todaro and Smith 2012). Among several dynamics and human needs, the demand for cropland and grazing land is increasing due to the increase of both human and livestock population. Consequently, crops and livestock are competing for land resources (crops for nutrient and livestock for grazing). Increasing household demand for cropland and grazing land results in crop-livestock competition for land resources (Fig. 4). As a result, changes in LULC are mainly associated with deforestation of natural vegetation and an expansion in agricultural production for food. Ethiopia has experienced various types of spatial patterns and temporal trends of LULC changes in different parts of the country (Table 8).

Shifts in the farming system

GPS, SRS, and GIS techniques may not capture some endogenous and exogenous shifts in the production process and LULC changes (Liniger et al. 2011). Several predictable shifts are also indicators of the dynamics in the smallholder farming system, which permit exploration of the spatial and temporal features of crop-livestock production. Some crop varieties and livestock breeds have shifted to market-demanded activities within the farming system. The evolved highland fruits such as apple and malt barley seed varieties are among the predominant shifts in cropping systems. Although fallowing and intercropping have declined, the uses of compost and Nitrogen-Phosphorus-Sulfur (NPS) fertilize1rs have increased over time to improve soil fertility and increase crop productivity. In terms of body size, households have replaced their large livestock with small animals (calves, chickens, sheep, and donkeys). The prevalence of animal diseases has dropped somewhat. Changes from open grazing to stall feeding are important shifts in livestock feeding systems. Industrial feed byproducts and improved forage trees have been introduced to farms and other landscapes. The reduction of springs and river flows has also caused considerable shifts in the farming systems. *Erica arborea*, *Hagenia abyssinica*, *Rosa abyssinica*, *and Juniperus procera* are threatened indigenous tree species. Kuria et al. (2014) reported over 20 extinct tree species in the study and neighboring areas.

Although lifestyles—in terms of housing conditions, the use of electric power, and improved access to potable water for domestic purposes—have changed, human and livestock population is increasing and putting pressure on land resources. One third of households have access to mobile phones. The main tarmac road cuts through the center of the watershed and the small town of *Gudo Beret*. These facilities have improved communication networks. The social positions and responsibilities of households and a number of *kebele*-level extension workers have been enhanced. The numbers of governmental and non-governmental organizations operating in the watershed have also increased over time. Increases in the human and livestock populations, land conversion, shortages in animal feed, low crop-livestock productivity, and a reduction of natural vegetation are noticeable shifts in the study area.

Drivers and consequences of LULC change

A number of interacting forces, anthropogenic and natural drivers, are driving losses and gains in LULC. Respondent households identified drivers of LULC conversions. Focus group participants identified the ranks for more than 14 drivers as being important to LULC changes in the study area (Fig. 5). The results of pair-wise ranking demonstrate that human population pressure, farm expansion, and high stocking density are the most important drivers of land conversion followed by soil degradation, dynamic land tenure arrangements, increased demand for fuelwood, and household income. The average population density of the highlands, including in the study area, has increased almost twofold within 25 years, from 44 individuals per km^2 in the 1990s (Gryseels 1988) to 85 km^2 in the 2010s. The extent of carrying capacity has changed from a medium to high level of density within two decades. As the human population increases, demand for food, fuel, income, and other means of livelihood also increase. High stock density, combined with frequent

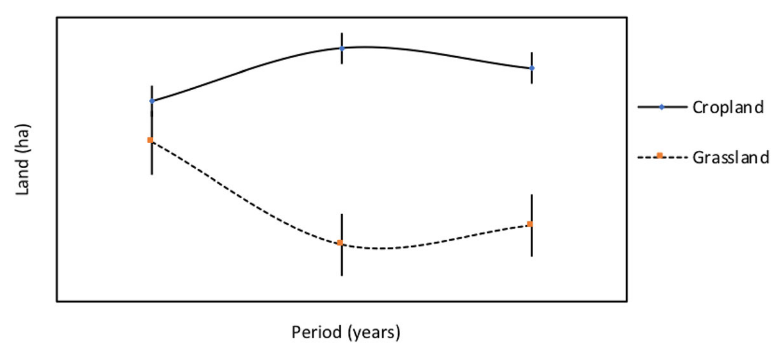

Fig. 4 Land-use/land cover changes in crop and grazing lands from 1984 to 2016. Vertical bars show standard errors of the mean

Table 8 Temporal and spatial land-use dynamics in some catchments of Ethiopia

Study areas	Land-use change		References
	Increase	Decrease	
Beressa watershed (North Shewa)	Crop and grazing land	Natural vegetation	Aklilu 2006
Northern Tigray	Cropland	Grazing land	Hadgu 2008
Fogera Woreda (South Gondar)	Cropland	Grazing land	Hussein 2009
Lenche Dima (North Wollo)	Shrubs	Cropland and grazing land	Hussein 2009
Aba'ala district (Northern Afar)	Cropland	Grassland and woodland	Tsegaye et al. 2010
Nonno district (West Shewa)	Cropland	Wood and grasslands	Messay 2011
Kebribeyah district (Somali region)	Cropland	Grazing land	Yodit and Fekadu 2014
Mecha Woreda (West Gojam)	Woodlots and pasture	Cropland and vegetation	Eleni et al. 2013
Gilgel Gibe watersheds (Rift valley)	Cropland	Grazing and vegetation	Amanuel 2014
Banja district, Awi zone	Cropland and settlement	Grazing and vegetation	Abyot et al.2014
Infraz watershed, West Gojam	Forest and grassland	Bush and wetlands	Amare 2015

Source: Compiled from different empirical studies

cultivation and farm expansion, leads to soil degradation. Eleni et al. (2013) and Yodit and Fekadu (2014) reported the combined effects of some of the main drivers on LULC changes.

The focus group participants revealed the importance of land-use certificates. Certification of land minimizes land-related conflicts and enhances stability. According to household interviews triangulated with focus group discussions, 59% of households experience land security threats. Access to tarmac roads and the expansion of market opportunities has increased demand for market-oriented commodities such as eucalyptus poles, grain, and livestock products. Policy changes, changing of rainfall patterns from bimodal to unimodal, and declining of water availability are possible drivers of LULC changes (Kuria et al. 2014). The most important driving force, however, is population growth, while the lack of animal feed, low crop-livestock productivity, and a reduction of natural vegetation are the principal consequences of crop-livestock competition for land resources.

Discussion

Demands for crop and livestock production are increasing along with household consumption and income generation. Maintaining the momentum of growth in agricultural productivity will remain crucial, as the production of

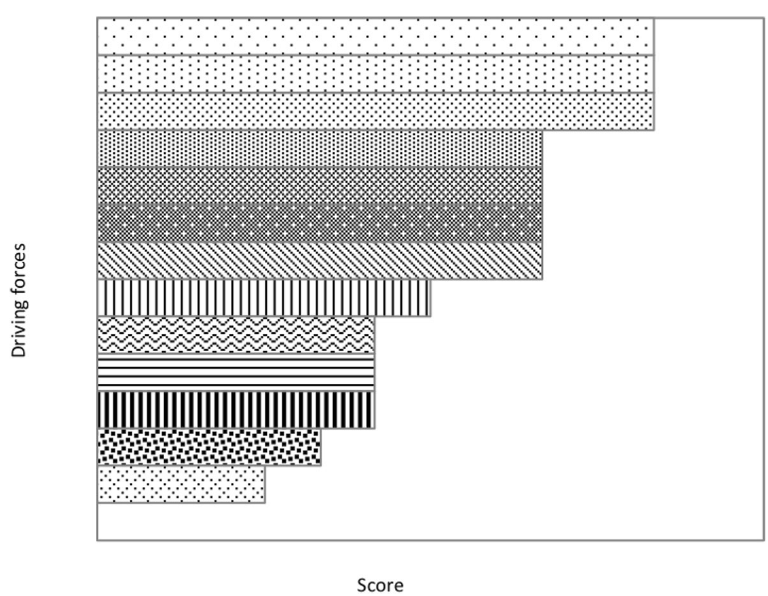

Fig. 5 Major driving forces of LULC changes ranked by focus group discussion

basic staple foods need to increase. Mixed farming is an important livelihood strategy that plays a fundamental role in reducing risks and improving nutritional outcomes. In the watershed, 97% and 93% of households respectively produce crops and rear livestock to fulfill their subsistence needs. More than half of households receive 18% of their annual cash income from crop yields. Households depend largely on crop production for home consumption. The average landholding size of households to produce crops, keep animals, and grow woodlots is 1.3 ha. More than 60% of households own not more than 1 ha of fragmented plots. Even though crops contribute a lot, the types of varieties planted are limited and poor in productivity. The majority of grain yields are lower than the average productivity of crops. High grain production pressure arises when the productive capacity of grain is lower than the actual productivity of crops. If climate conditions are unfavorable, the consequences will affect crop-livestock systems adversely and significantly. This pressure will intensify when food supply is less than food demand for the study population.

Likewise, livestock provide manure, food, fuel, draft power, transportation, cash income, and reduce risks and vulnerability during critical periods (McIntire et al. 1992). A majority (64%) of households receive 38% of their annual cash income from livestock products. Rising populations, together with increasing livestock density and grain production pressure exerts considerable pressure on land resources. As the livestock population increases, stocking rate and grazing pressure also increases (Duncan et al. 2016). The spatial dimension of LULC for grazing land has declined. This result is consistent with the findings of other studies (Yodit and Fekadu 2014; Amanuel 2014). A common bottleneck for livestock productivity is feed shortages and a reduction and degradation of pasturelands (Endale et al. 2016). The majority of the households (72%) practice open grazing combined with other feeding strategies. One fifth (22%) of households have used zero grazing, while 5% and 1% of households practice strip and rotational grazing strategies.

Crop production, livestock husbandry, and LULC are the key indicators of land pressure in the mixed crop-livestock systems. Traditional production systems have come under increasing pressure due to competition for land resources. For instance, eucalyptus plantations have competed with croplands for soil nutrients and water resources (Kuria et al. 2014). The findings of this research reveal that 180 ha of grazing lands and 184 ha of croplands have been converted to plantation within three decades (1984–2016). On the one hand, households have been involved in extensive agriculture, expanding their farms through cultivation of the natural vegetation in the upper part of the watershed. Alternatively, households have faced animal feed shortages because of high livestock densities along with a decline in grazing lands. On the other hand, intensive agriculture has been practiced in terms of the use of immense external inputs such as pesticides and herbicides that affect the environment adversely (Kuria et al. 2014). These two parallel scenarios have led to crop-livestock competition for land resources as well as potential threats for soil degradation and land-related conflicts.

Cropland is the leading LULC in the study watershed and in most other catchments of Ethiopia. Amanuel (2014), Yodit and Fekadu (2014), Amare (2015), and Binyam et al. (2015) reported similar findings. However, we have observed a wide gap between the satellite imagery and household survey regarding cropland. The remotely sensed images accessed in 2016 showed that 1310 ha of LULC was classified as cropland, but respondent households did not account for 57% of the land detected by satellite imagery. The possible explanations for the discrepancy between remote sensing and household survey relate to accuracy issues. The user accuracy showed an error of commission while pixels committed error classes. The satellite images show 10% of error commission in the transition matrix. In this detection matrix (Table 5), the expansion of 527 ha of cropland is mainly at the expense of 460 ha of grazing land. It means the detection matrix has misclassified more than 123 ha of land gained from grazing land, bushland, and plantation to cropland. The satellite images include not only land covered with annual crops but also areas covered by scattered villages, homesteads, roads, degraded farmlands, gully buffers, waterways, lands transferred to household members through inheritance or gifts to youth groups, and farmlands held by households who settled outside the watershed are classified under croplands. With this in mind, it would appear that satellite remote sensing provides opportunities to measure land cover (Hall 2010), while the household survey describes a land use for cropland more effectively.

Respondent households described cropland as "cultivated areas that produce only annual crops." This finding is in agreement with the proclamation of article 24, sub-article 6 and regulation 5, sub-article 1 of *Amhara* region. The decree states that the land below a minimum holding of 0.25 ha could not register in landholding certificates (BoEPLAU 2010). It implies that households who own unregistered parcel of land in their book of holdings may not report it in household interviews. This is also likely to be a contributing factor in explaining why the quantitative data for remote sensing was higher than the data collected from the household survey. Accordingly, we have used the satellite images to understand the LULC conversions across different periods and the extent of land stability, while the data obtained through the household survey have been used to estimate animal feed, crop productivity, food supply, and grazing pressures. Therefore, one can deduce that the rapidly changing legal framework and different data sources, coupled with technical limitations, create a significant divergence between satellite imagery and household survey with regard to LULC for croplands. Nevertheless, the discrepancy between remote sensing and household survey towards cropland should not lead to a deceptive conclusion. According to previous findings, the size of farmland land per household in the study area is not more than 1.0 ha (Kuria et al. 2014). The remote sensing data were tested using Cohen's kappa coefficient and the result suggests that the classification is highly perfect, corresponding to 89.7% accuracy rate. According to Tang et al. (2015), it is above the required level of agreement (81%).

Conclusions

Remote sensing along with household surveys is an innovative approach to assess farm system dynamics. LULC change, grain production pressure, and pressure on feed resources are the three major indicators that measure land conversion and food and feed balance. Conservation structures, woodlands, water resources, irrigation activities, afro-alpine reserves, access to road and local market, and recently introduced practices—such as highland fruits, malt barley seeds, tree lucerne seedlings, and improved animal breeds—are important interventions to improve land productivity, economic gains, and food security. Increased numbers of endangered tree species, high grazing pressure, and intensive land conversions are, however, potential threats to enhance the management of improved land resources. Settlement and plantation have increased tremendously, in line with the increasing human population. The rising population is also causing a concomitant shrinkage in natural vegetation. If the underlying crop-livestock dynamics affecting the system remain unchanged, competition for land resources and environmental damage is certain to accelerate. This situation warrants further investment in sustainable land resource management and efficient institutional arrangements that can preserve the natural landscape and minimize the extent of crop-livestock competition. Promoting multipurpose forage and crop varieties could provide enough biomass to meet the needs of humans and livestock as well as enhance soil fertility. Increasing crop production alone will not be sufficient to meet the farmers' animal feed. We conclude that the adoption of improved forages and fodder species and better integrating crop-livestock production can sustainably alleviate human food and animal feed demands in the highlands of Ethiopia.

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Availability of data and materials
The authors declare that the data and materials presented in this manuscript can be made publicly available by Springer Open as per the editorial policy.

Authors' contributions
WM has contributed in designing the study, collection, analysis, and interpretation of data. He also participated in writing the manuscript. KM contributed in the designing of the study, writing, and reviewing of the manuscript. PT provided technical support and reviewed the manuscript. MB, LT, and WA reviewed the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate
Not applicable

Competing interests
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