

# Landscape-based upstream-downstream prevalence of land-use/cover change drivers in southeastern rift escarpment of Ethiopia

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**Abstract** Characterized by high population density on a rugged topography, the Gedeo-Abaya landscape dominantly contains a multi-strata traditional agroforests showing the insight of Gedeo farmers on natural resource management practices. Currently, this area has been losing its resilience and is becoming unable to sustain its inhabitants. Based on both RS-derived and GIS-computed land-use/cover changes (LUCC) as well as socioeconomic validations, this article explored the LUCC and agroecological-based driver patterns in Gedeo-Abaya landscape from 1986 to 2015. A combination of geo-spatial technology and cross-sectional survey design were employed to detect the drivers behind these changes. The article discussed that LUCC and the prevalence of drivers are highly diverse and vary throughout agroecological zones. Except for the population, most downstream top drivers are perceived as insignificant in

the upstream region and vice versa. In the downstream, land-use/cover (LUC) classes are more dynamic, diverse, and challenged by nearly all anticipated drivers than are upstream ones. Agroforestry LUC has been increasing (by 25% of its initial cover) and is becoming the predominant cover type, although socioeconomic analysis and related findings show its rapid LUC modification. A rapid reduction of woodland/shrubland (63%) occurred in the downstream, while wetland/marshy land increased three-fold (158%), from 1986 to 2015 with annual change rates of - 3.7 and + 6%, respectively. Land degradation induced by changes in land use is a serious problem in Africa, especially in the densely populated sub-Saharan regions such as Ethiopia (FAO 2015). Throughout the landscape, LUCC is prominently affecting land-use system of the study landscape due to population pressure in the upstream region and drought/rainfall variability,

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agribusiness investment, and charcoaling in the downstream that necessitate urgent action.

**Keywords** Agroecology · Agroforestry · Drivers · Ethiopia · Gedeo-Abaya landscape · Land-use/cover changes

## Introduction

In the past half millennium, LUCC has been recognized as one of the main factors that lead to “degradation of many terrestrial ecosystems” (Kindu et al. 2015; Wang et al. 2015; MEA 2005). Land degradation induced by changes in land use is a serious problem in Africa, especially in the densely populated sub-Saharan regions such as Ethiopia (FAO 2015). Brink et al. (2014) and Pender et al. (2006) argue that such ecological condition increases the vulnerability of both economic recession and environmental change. The Ethiopian population increases by approximately 2.5 million people per year and is predicted to continue with comparable growth rates (UN Population Division 2015). This population growth causes increased pressure on land resources and is reported to be a principal agent of LUCC drivers in Ethiopia (Brink et al. 2014) and the study region (Mebrate 2007).

LUCC drivers are complex and region-specific, requiring fine local-based studies (Turner et al. 2007). Regional land change patterns are the combined outcomes driven by complex economic, policy, demographic, and market forces at much finer scales (Lambin and Meyfroidt 2010). The summarized main drivers include changes in farming systems (Long et al. 2009), population growth, cultivation, and biofuel (Nyssen et al. 2008), grazing/pasturing (Tsegaye et al. 2010), urbanization (Li et al. 2014; Song et al. 2015), and global market forces (Beilin et al. 2014) as well as institutional or cultural influences (Beilin et al. 2014). For the specific case of Ethiopia, the expansion of settlements (Kindu et al. 2015), fuelwood and charcoaling (Temesgen et al. 2013), population pressure and farmland expansion (Tefera 2011), international horticultural exports and land deals (Brink et al. 2014), drought, and land tenure policy (Tsegaye et al. 2010) are reported to be important causes. These illustrate that the major drivers are inconsistent across time and space throughout the country. Most studies conducted on the *Gedeo-Abaya* landscape (details in [Study area](#)) were focused on the biophysical, ecological, spatiotemporal, and socio-cultural aspects of the Gedeo agroforestry system (e.g.,

Kanshie 2002; Negash 2013; Mebrate 2007; Legesse 2014; Debelo et al. 2017). While, the spatiotemporal distribution of the system was only studied by Mebrate (2007), most of these studies have had a common focusing point towards revealing the immense potential of the system and upcoming sustainability challenges. However, landscape-based LUCC and underlying change determinants were untouched.

Liu et al. (2007) reported that coupling between human and natural systems exhibits nonlinear dynamics across space, time, and organizational units. Thus, given this complexity and the place-based drivers of change, the need for multidisciplinary approaches that integrate socioeconomic and biophysical drivers is now widely recognized (Liu et al. 2001; Mottet et al. 2006). Considering the ever-variable drivers of change that are attributed to location-specific factors, and combining research processes into causes and effects using valid methods is crucial (Lambin et al. 2003; Nunes et al. 1999). This will lead to a deeper understanding of LUCC and their determinants to devise more appropriate policy interventions, especially for areas of critical livelihood and environmental problems such as the Gedeo-Abaya landscape which is a typical area in Ethiopia.

In the upstream part (humid and sub-humid), the majority of agroforestry land-use system on steep terrain is characterized by the highest population density in the country, and (agro) pastoral livelihoods characterize the downstream part (semi-arid) of the study site. With rugged topography and population pressure in the upstream region as well as fragile semi-arid pasture, and land transfer for investors in the downstream, land-use dynamics is deteriorating the agroecological system, with subsequent livelihood crisis (Legesse 2014). There have been some studies of LUCC at the regional or local level focusing on quantifying LUCC using geo-spatial tools. Mapping spatial changes gives quantitative descriptions (e.g., Mebrate 2007) but does not provide an understanding of the relationship between the patterns of change and their driving forces (Liu et al. 2001; Mottet et al. 2006). However, combinations of geo-spatial technology and cross-sectional socioeconomic surveys designed on an agroecological basis have not been employed to investigate the LUCC and drivers behind the agroforestry-dominated southeastern rift escarpment of Ethiopia. Thus, this study aimed to (1) explore the LUCC over the past three decades, (2) investigate agroecological-based upstream-downstream driver patterns throughout the agroforestry-dominated landscape,

and (3) determine the role of population pressure and agricultural investment policy in favor of mechanized farming as major drivers in Gedeo-Abaya landscape.

## Materials and methods

### Study area

The study site is predominantly located in the southeastern rift valley escarpment and partly covers the rift valley floor adjacent to lake Abaya (6° 09' 02"–6° 35' 56" N, 38° 00' 01"–38° 31' 18" E) in an area of 1850 km<sup>2</sup>, approximately 375 km south of Addis Ababa. It is in the Gidabo River sub-basin of the eastern Abaya-Chamo in the rift valley lakes basin at altitudinal range of 1100 to 3005 m a.s.l. Its climate consists of bimodal rainfall with a total of 800–1800 mm, and the mean annual temperature is 12.5 to 28 °C. The dominant soil types of the escarpment slopes are well-drained fertile Nitisols, characterized by their deep, reddish-brown, clay and relatively high organic matter content (FAO 1988; Negasa et al. 2017). The upstream region of the study area is in the Gedeo administrative zone of the Southern Nations, Nationalities, and Peoples' Regional State (SNNPRS), and the downstream region is in the Abaya "woreda" (an Ethiopian local administrative group that forms a district/zone) of the West Guji zone, Oromiya Regional State (Fig. 1).

The upstream region is found in the humid and sub-humid highlands (above 1500 m a.s.l.), distinguished by two essential features: (1) the highest population density in Ethiopia, which reaches 1000 persons/km<sup>2</sup> (CSA 2013) and (2) indigenous knowledge-based traditional agroforestry system practiced by local farmers for the purpose of livelihood (Kanshie 2002; Negash 2013). Gedeo historically was relatively self-sufficient, despite its high population pressure and rugged topography (Bishaw et al. 2013; Legesse 2014). However, according to zonal report, except for the two woredas (Bule and Gedeb) whose livelihood depends on cereal cropping, the feed self-sufficiency of the remaining four (Wenago, Dila-zuria, Yirgachefe, and Kochore) have been challenged due to reduced productivity of the agroforestry system in recent decades (Debelo et al. 2017). For instance, population pressure, climate change, and poor management of agroforests have been repeatedly prolonged coffee seeding time, implying productivity reduction of the system (Legesse 2014).

The downstream, Abaya woreda, mostly consists of agropastoral plains (lower than 1500 m a.s.l.) and is characterized by semi-arid agroecology. Abaya is the most populated woreda (110 persons/km<sup>2</sup>) in the zone, although it is sparsely populated when compared to the upstream region. Abaya exists in the northern zonal periphery with similar socioeconomic status and cultural landscape as the Gedeo (Debelo 2007). The transitional type of land use between the up- and downstream parts is a sedentary agropastoral farming system. Maize, wheat, barley, and haricot beans are the major crops. In some parts, *Enset*<sup>1</sup> is also grown and offers a degree of food security during the drought season, and coffee is an important cash crop. Pasture land, woodlands, and wetlands are apparently the dominant land uses, with expanding agricultural investment. The wetlands at the lower foot plain have had a vital importance not only as a biodiversity pool but also as a bridge for cattle and the society during the drought months. During these periods, the upstream farmers also move down their cattle in search of food and water, which shows socioeconomic interdependence of the people from the two locations.

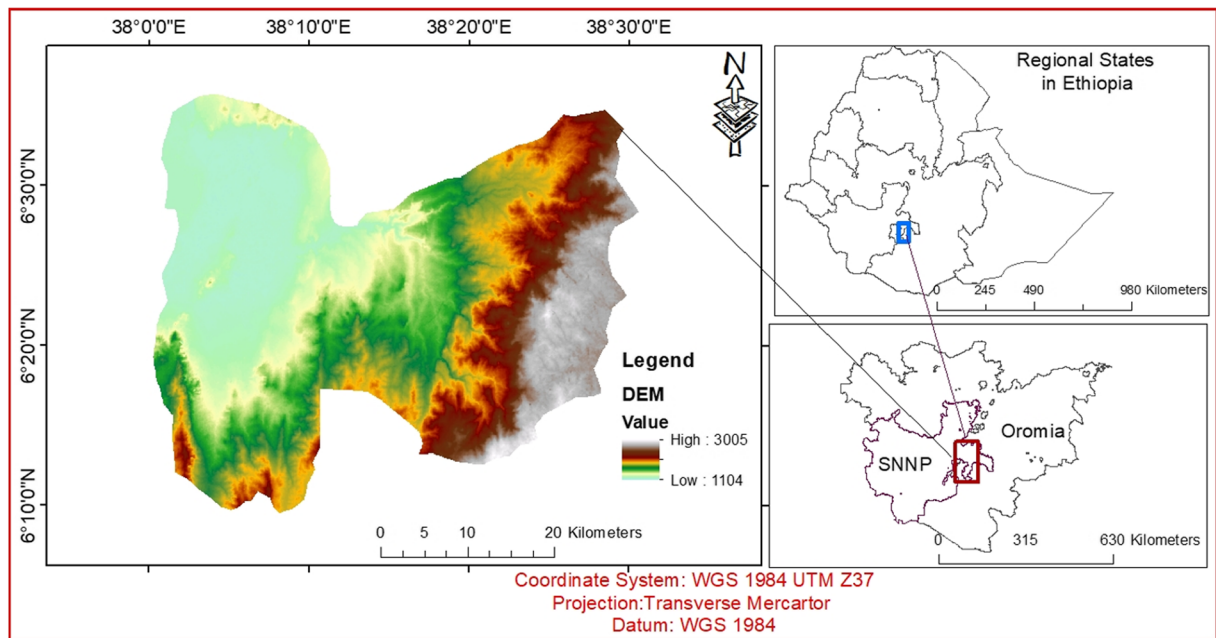
### Data sources and processing

#### Land-use/cover data

Three LUC maps at a 1:100,000 scale in the years 1986 (January 21), 2000 (February 05), and 2015 (January 05) were derived from Landsat images with 30-m resolution. Dataset selections were fixed to clear sky periods, during which the lowest possible seasonal moisture content and lowest percent monthly cloud cover occurred, to minimize the highland cloud effect and related reflectance discrepancies caused by seasonal vegetation fluxes and sun angle differences (Jensen 2009). Other topographic maps, aerial photographs, DEM data, regional land use, and regional administration maps as well as online Google Earth services were used (Fig. 2).

Topographic map sheets at scales of 1:50,000 and 1:250,000 were used for delineation and navigation purposes along with ground truthing and endmember establishment. The topographic maps were first

<sup>1</sup> *Ensete ventricosum* (Welw.) Cheesman, also called "false Bannana," is a perennial herbaceous root crop with long broad leaves and bulky pseudostem. This multi-purpose root crop is widely grown and is a major food security crop in Southern Ethiopia (Kanshie 2002).



**Fig. 1** Study area map, also showing the agroclimatic region of the studied landscape

georeferenced to Adindan/UTM Zone 37 and then transformed to UTM Zone 37 WGS84 to match the satellite image data. Landsat false color composites, field ground truthing with the confirmation of elders, available aerial photographs from closer acquisition periods to the older images, and online Google Earth services were utilized for endmember establishment, classification and validation. A pixel-based supervised image classification with maximum likelihood classification algorithms was performed to map the LUC classes (Lillesand et al. 2000; Jensen 2009) (Table 1). All the data were obtained from the Ethiopian Mapping Authority, United States Geological Survey, and Regional Administration.

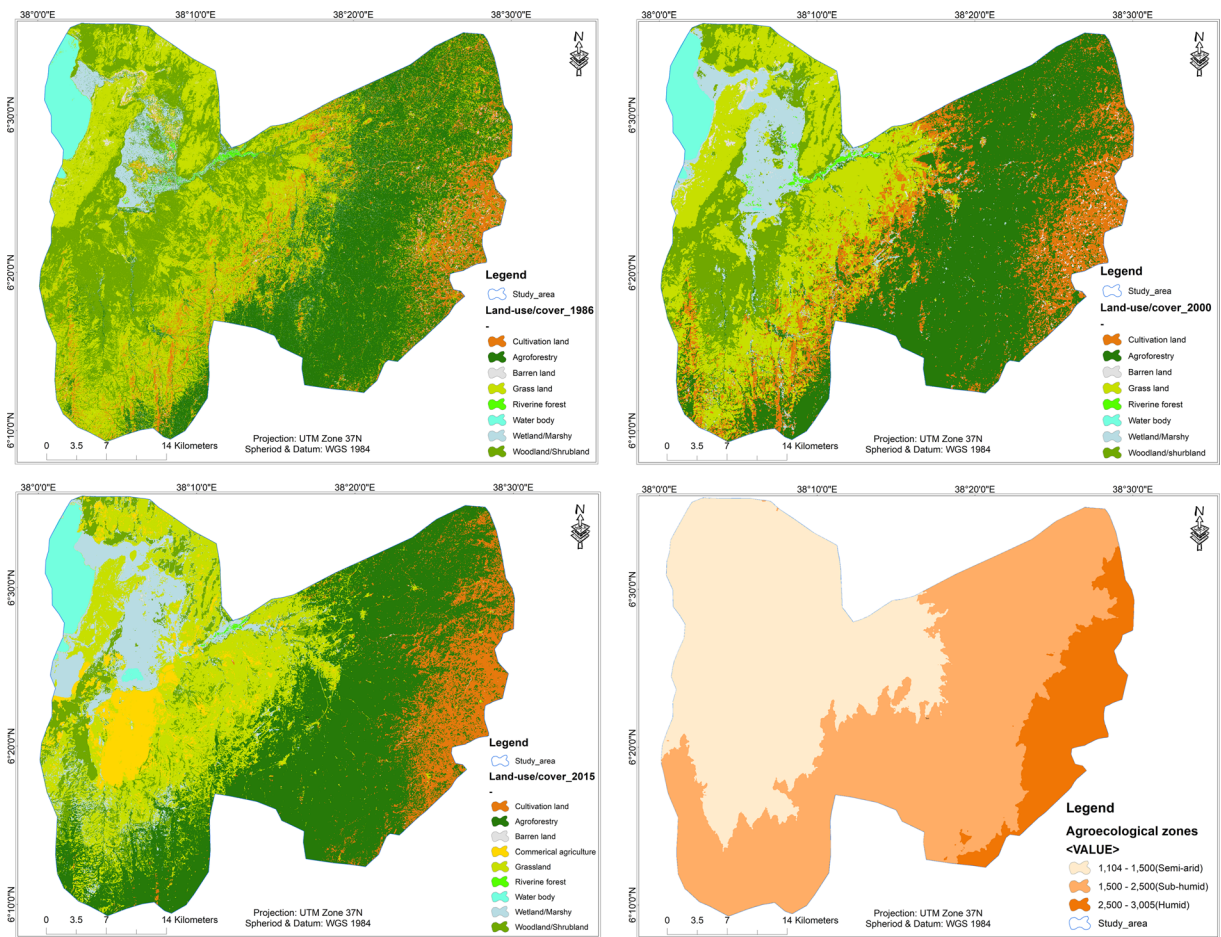
Based on computation results, change patterns were thoroughly investigated and compared between the study periods. The LUCC between the three periods were quantified, and a change detection matrix was derived to show LUC class conversions and transitions during the 30-year period. In relation to the transition matrix, net change and the net change-to-persistence ratio (Braumoh 2006; Pontius et al. 2004) were computed to show resistance and vulnerability levels of a given LUC type. Key informants and focus group discussions (FGDs) were also used to bridge the information gaps between image reference years and to further understand the dynamics of LUCC, possible major drivers and consequences. Finally, overall accuracy, producer and

user accuracies, and kappa statistics were calculated from the error matrix to confirm the viability of the classification process.

#### *Socioeconomic data collection and analyses*

Because of the unavailability of published annual time series data in the country, socioeconomic data were collected mainly through field survey and also from the local government and national statistics agency. For example, local population growth rate was generated based on available data from the Central Statistical Agency (CSA) of Ethiopia. We purposely selected kebele<sup>2</sup> samples as hotspot sites based on their representative distribution along the study landscape, accessibility and farmers' awareness, and population and farming system dynamics that they exhibit. As such, three kebeles were selected from the upstream region ("Sika" from the Bule woreda, "Bula" from the Dilla-Zuriya woreda, and "Mokonisa" from the Wenago woreda) and two from the downstream region (Semero-Gambella kebele and Dibicha kebele). A total of 90 households, approximately 18 from each kebele, were randomly chosen. The number of sample

<sup>2</sup> "Kebele" is a group of villages forming the smallest administrative unit in Ethiopia that forms a "woreda."



**Fig. 2** LUC maps of 1986, 2000, and 2015 and agroecological map of Gedeo-Abaya, southern Ethiopia

households was fixed to the minimum as the study landscape is rugged and hardly accessible to travel to each household house. FGDs with selected stakeholders (mainly elder farmers, development agents, and large-scale farmers) and semi-structured interviews with key informants preceded the formal questionnaire to formulate thorough and well-thought-out survey questionnaires. The discussion was mainly focused on qualifying, justifying, and ranking the major LUCC drivers identified during individual interview. In addition, holding size, land-use policies, and national and local government-supported mechanized agricultural investment policy trends and decision impacts on LUCC were also deliberated (Fig. 3).

The obtained data were statistically analyzed using the SPSS and GraphPad Prism statistical packages. Frequency analysis, descriptive statistics, bivariate correlational analysis, and cross-tabulation techniques were employed. In addition, the rate of population growth for the study

area was generated for the study decades based on the available data from the CSA (Fig. 4). These data were used to analyze potential driving forces resulting in the LUCC.

## Methods

### Post classification

After selectively combining classes, classified images were sieved, clumped, and filtered before producing a final output. Sieving removes isolated classified pixels using blob grouping, while clumping helps maintain spatial coherency by removing unclassified black pixels (speckles or holes) in the classified images (Richards 1999). Finally, a  $3 \times 3$  median filter was applied to smoothen the classified images. All activities related to image processing were performed in ERDAS Imagine 2014. Classified images

**Table 1** Observation and literature-based description of the LUC classes

LUC class	Description
Cultivation land	Cropping fields owned by small holder farmers
Agroforestry	Indigenously managed traditional multi-strata agroforest area in which annual/perennial crops and/or animals deliberately used on the same land-management units
Barren land	Bad areas and rock outcrops
Commercial agriculture	Mechanized agricultural investment area owned by medium- to large-scale investors
Grass land	Grass and herb cover with scattered trees and shrubs
Riverine forest	A broad-leaved tree with closed canopy along river course
Woodland/shrubland	Areas dominated with woody Acacia plants which cover > 20% (height ranges 5–20 m); also includes shrubland covered with small trees and bushes
Wetland/marshy	Includes river beds, intermittent ponds, and marshy areas with shallow water and permanent reed vegetation
Water body	Mainly refers to part of Abaya Lake

were then exported to ArcMap for the remaining GIS analyses and computations.

### Change detection

The LUC maps for 1986, 2000, and 2015 obtained from the digital classification and subsequent GIS analyses were overlaid in ArcMap, and the area conversions between and within classes were computed. These were mainly used to detect the internal variations of LUC in the study landscape between periods of 1986 to 2000, 2000 to 2015, and 1986 to 2015. For each pair of gridded datasets, percent cover change between periods respective to the initial year (Eq. 1) and annual change rates (Eq. 2) were computed, and a change matrix was constructed. Then, for each LUC category, the change between the two periods was calculated according to the following equations:<sup>3</sup>

$$\Delta C = \frac{(A_f - A_i)}{A_i} \times 100 \quad (1)$$

$$r = \left( \frac{1}{(t_2 - t_1)} \right) \ln \left( \frac{A_f}{A_i} \right) \quad (2)$$

where  $\Delta C$  is the percent change of LUC in relation to the initial year coverage;  $t_1$  and  $t_2$  are initial final years, respectively;  $A_i$  is the initial year;  $A_f$  is the final year area

<sup>3</sup> The mean annual rate of change dependence of the “ $r$ ” equation derivation is supposed to improve its reliability over the “ $q$ ” equation used by FAO (1995).

of a given LUC type; and  $r$  represents the annual rate of cover change (Puyravaud 2003; FAO 1995).

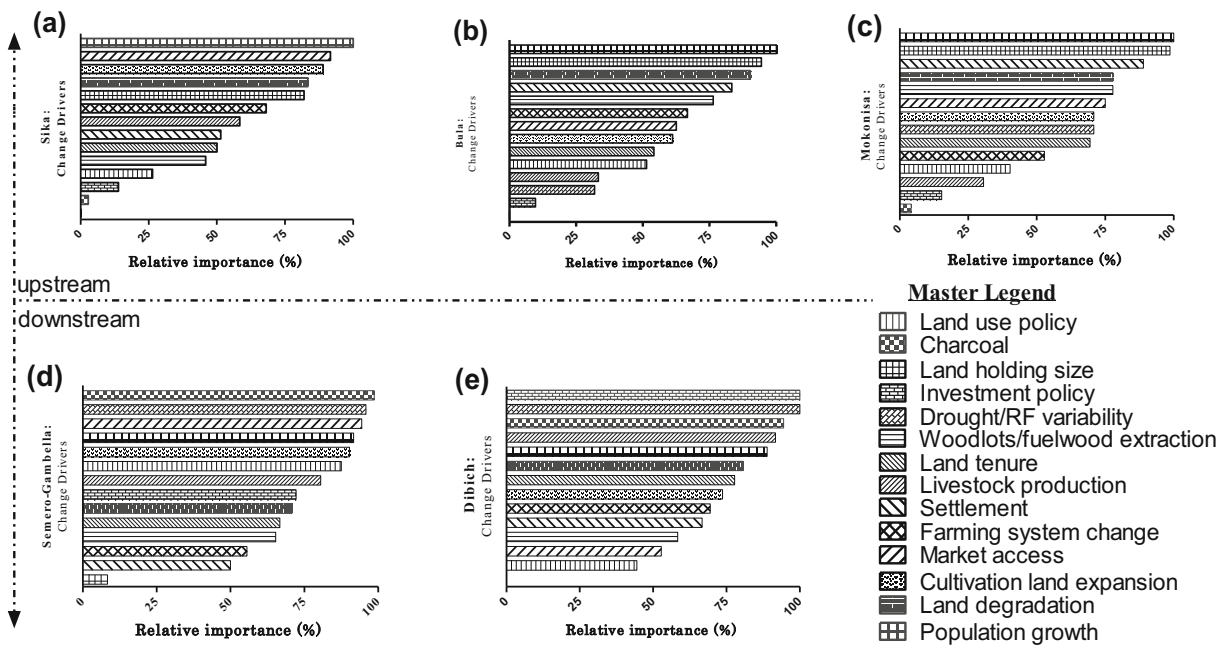
### Socioeconomic data integration

Due to the importance of better understanding of existing biophysical factors (Lambin et al. 2003), socioeconomic survey data were used to explore the possible driving forces contributing to LUCC in the study landscape. Several bivariate statistical analyses were performed to explore the correlations between different socioeconomic variables. The hypothesized role of population increments in triggering the farming system change and eventually LUCC was explained using the combined results of LUC annual change rates, change matrix analyses, and the socioeconomic survey outputs (Table 2).

## Result

### Classification accuracy and state of land use/cover

The overall accuracies of the classification for the three reference years 1986, 2000, and 2015 were 91.71, 89.06, and 89.74% respectively, with kappa values ranging from 0.87 to 0.90 (Table 3). These results show that the maps are sufficiently accurate for use in further analysis. High levels of agreement could be seen from the kappa results for each classified image. Reasonably lower user and producer accuracy values were obtained for wetland/marshy and barren lands in the recent images, which might be



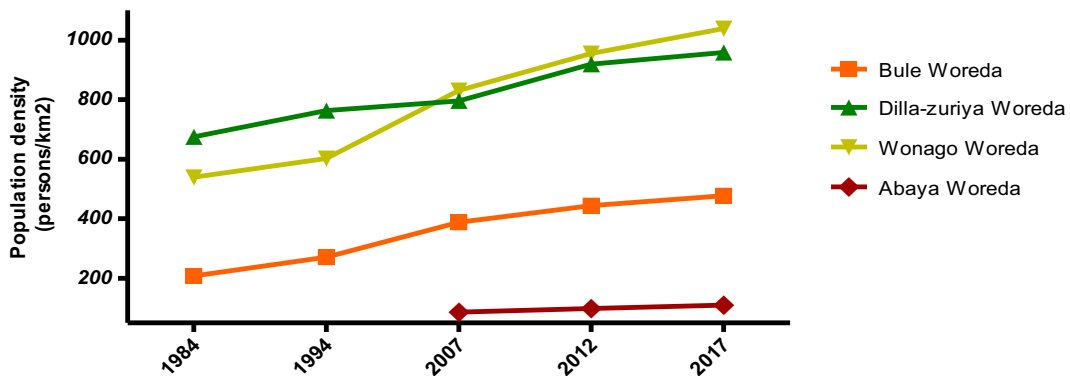
**Fig. 3** The weighted relative importance of drivers in the selected five studied kebeles. **a** Sika kebele, the most humid region; **b** Bula kebele, the upstream sub-humid region, at the middle; **c** Mokonisa kebele, the upstream sub-humid region, in low place; **d** Semero-

Gambella kebele, the downstream semi-arid agropastoral region; and **e** Dibicha kebele, the semi-arid pastoral region, in the foot plain

attributed to the land-use dynamics in the past 2 decades. However, among these driving factors, population is regarded as the most important driver elsewhere in developing nations (e.g., Kindu et al. 2015; FAO 201)

Figure 2 presents the LUC maps for 1986, 2000, and 2015 in Gedeo-Abaya, southern Ethiopia, and Table 4 depicts the corresponding data. In 1986, agroforestry (32.4%), grassland (30.5%), and woodland/shrubland (20.9%) were the dominant classes. In 2000, agroforestry still accounted for the largest part (36.4%), followed by grassland (22.9%) and cultivated land (15.2%). In

2015, agroforestry dominated (40.5%), followed by grassland (23.6%) and wetlands (9.6%). Agroforestry is the dominant class with more than 95% of the total area coverage in the upstream region. In the downstream region, grazing land and woodland/shrubland were the dominant classes in 1986, while grassland and wetlands were in 2015. Unlike woodland and grassland, riverine forest increased in 2000 mainly due to its inaccessible location, and it declined in 2015. As per our field observation and focus group (FG) discussants, this reduction attributed to Gidabo irrigation dam which has been



**Fig. 4** Population density trends (source: CSA 2013; Legesse 2014)

**Table 2** Sample household characteristics in the study landscape ( $N=90$ )

Household attributes	Value		
	Upstream	Downstream	Landscape
Sex (female, %)	13	25	24.4
Average age (years)	51.22	50.58	50.97
Marital type (polygamy, %)	18.5	25	21.1
Educational status (illiterate, %)	88.9	77.8	60
Mean family size (Nr)	10.61	9.69	10.24
Mean land holding size (ha)	0.8	3.22 <sup>a</sup>	1.12
Mean number of land holding plots (Nr)	4.37	3 <sup>a</sup>	4.01
Mean income (USD/annum)	594.25	780.66	668.82
Average income diversity (Nr)	3.3	3.44	3.34

<sup>a</sup> Land holding issue seems not applicable at communal pasture area; thus, the figure was calculated only for Semero-Gambella kebele where agropastoral farmers inhabited

under construction since 2008/9 devastating part of the forest and also made accessible to be commercialized. Commercial agricultural land was depicted only in the recent decade with 5.9% coverage following extensive investment in the downstream. In an FGD, elders in downstream pointed out that before a decade, agribusiness covered small areas by a few small-scale investors. Since then, it increased in the downstream region due to gentle slopes and a sparse population compared with the

rugged, steep slopes and dense population in the upstream region.

#### Land-use/cover change

Based on the analysis, agroforestry land-use type has exhibited an increasing trend and has remained dominant throughout the study period (Table 4; Fig. 2). However, as confirmed by about 86% of interviewee

**Table 3** Classification accuracy and area coverage summaries of LUC in 1986, 2000, and 2015

LUC classes/types	Area, km <sup>2</sup>						Classification accuracy (%)					
	1986		2000		2015		1986		2000		2015	
	UA <sup>a</sup>	PA <sup>b</sup>	UA	PA	UA	PA	UA	PA	UA	PA	UA	PA
Riverine forest	5.4	0.29	8.6	0.46	1.5	0.08	84.21	84.12	88.89	88.89	100.0	80.0
Grass land	562.9	30.46	422.5	22.87	435.8	23.58	93.62	93.62	93.88	88.46	94.64	98.15
Agroforestry	598.3	32.38	672.9	36.41	748.6	40.51	90	81.25	66.67	54.55	70.0	70.0
Cultivation land	156.3	8.46	280.0	15.15	169.2	9.15	–	–	–	–	100.0	81.25
Woodland/shrubland	386.9	20.94	223.8	12.11	143.8	7.78	91.49	95.56	97.06	91.67	81.40	100.0
Wetland/marshy	68.4	3.70	165.1	8.93	176.4	9.55	100.0	90.0	80.0	80.0	81.82	100.0
Water body	47.7	2.58	50.8	2.75	57.1	3.09	91.43	94.12	84.62	95.65	100.0	72.22
Commercial agriculture	–	–	–	–	108.8	5.89	84.62	78.57	79.17	95.0	80.0	80.0
Barren land	22.1	1.20	24.4	1.32	6.9	0.37	100	100	100	100	100.0	100.0
Total	1847.9		1847.9		1847.9							
Overall classification accuracy							91.71		89.06		89.74	
Overall kappa statistics (dimensionless)							0.90		0.87		0.88	

<sup>a</sup> User's accuracy

<sup>b</sup> Producer's accuracy



**Table 4** Land-use/cover changes between 1986, 2000, and 2015 reference years (Gedeo-Abaya landscape)

LUC type	Cover change between times (%) <sup>a</sup>			Annual rate of change <i>r</i> (%/year) <sup>b</sup>		
	1986–2000	2000–2015	1986–2015	1986–2000	2000–2015	1986–2015
Riverine forest	57.33	– 82.73	– 72.83	+ 3.10	– 11.64	– 4.32
Grass land	– 24.93	3.14	– 22.57	– 1.91	+ 0.21	– 0.85
Agroforestry	12.47	11.25	25.12	+ 0.78	+ 0.71	+ 0.75
Agricultural land	79.07	– 39.58	8.20	+ 3.89	– 3.36	+ 0.26
Woodland/shrubland	– 42.15	– 35.74	– 62.82	– 3.65	– 2.95	– 3.30
Wetland/marshy	141.48	6.86	158.05	+ 5.87	+ 0.44	+ 3.16
Water body	6.48	12.41	19.69	+ 0.42	+ 0.78	+ 0.60
Commercial agriculture <sup>c</sup>				–	–	–
Barren land	10.15	– 71.81	– 68.95	+ 0.57	– 8.42	– 3.90
Total						

<sup>a</sup> Calculated as per “Eq. 1”

<sup>b</sup> *r* was calculated as per “Eq. 2”

<sup>c</sup> Commercial agriculture is an emerging new land use since 2007/8

and all the FG participants in the upstream, agroforestry has declined rapidly in terms of modification (see details in Discussion) although this cannot be easily portrayed by image classification (Turner et al. 1995; Lambin et al. 2003). The fact that the LUCC have not occurred at equal rates during all time intervals, a rapid reduction in woodland and grassland was observed between 1986 and 2015 in the downstream region (Table 4). The rates of change (loss) of woodland/shrubland and grassland were - 3.7 and - 1.9% per annum, respectively; whereas, wetland/marshy and cultivated land significantly expanded during 1986 to 2000. Among identified LUC classes, the highest annual change rate of + 5.9% was registered for wetlands. Between 2000 and 2015, wetland expansion steadily continued, while woodland continually declined.

Table 5 shows the transition matrix in the past three decades (1986–2015). A total area of 823.2 km<sup>2</sup> (44.6%) has changed. Woodland, grassland, and riverine forest are among the classes converted to other land uses, accounting for 15.5, 0.3, and 16.3%, respectively. Woodland/shrubland was largely converted to grassland (7.4%) followed by commercial agriculture (3.6%). Most of agricultural and grassland conversions were to agroforestry. Nearly all increases of grassland (7.4% ≈ 136 km<sup>2</sup>) and commercial agriculture (3.6% ≈ 66.5 km<sup>2</sup>) came from woodland conversion (Table 4). Concurrent with studies in the central rift valley of Ethiopia (Biazin and Sterk 2013; Temesgen et al. 2013), charcoaling and investment policy are

among the top change drivers in the downstream (see Drivers of land-use/cover change) to enhance woodland conversion.

Of the natural vegetation cover types in the downstream region, riverine forest and woodland/shrubland experienced the lowest persistence, whereas agroforestry was the most persistent, with net change-to-persistence ratios of - 4.7, - 2.6, and 0.3, respectively (Table 4). A larger net change-to-persistence ratio (whether negative or positive) shown by LUC classes indicates the dominance of the trend in the changing landscape. Conversely, a smaller net change-to-persistence ratio, i.e., one closer to zero, implies a higher tendency to persist, rather than decline or increase in the changing landscape. In general, the sum of diagonal figures (i.e., 55.4%) of the total landscape remains unaffected by the dynamics.

#### Drivers of land-use/cover change

Using researchers’ experience together with the narratives of informants, experts, and local administrators, a range of biophysical and socioeconomic LUCC driving factors were designed. Specifically, “*land use policy*”—existing rules/regulations that can permit or/and restrict land utilization approaches were considered, while in the case of “*investment policy*,” local and national government-supported investment decision impacts of mechanized farming were focused. With regard to “*farming system*,” either through government initiative,

**Table 5** LUC change transition matrices (%) for the initial and final reference years for the Gedeo-Abaya landscape, 1986–2015

LUC classes/types	To final year, 2015										Total 1986	Loss
	RF	GL	AF	CL	W/SL	WL/Mr	WB	CoA	BL			
From initial year 1986												
Riverine forest (RF)	<b>0.05</b>	0.02	0.04	0.00	0.00	0.16	0.00	0.01	0.00	0.29	0.25	
Grassland (GL)	0.00	<b>14.15</b>	8.27	1.30	1.70	3.01	0.16	1.82	0.05	30.46	16.31	
Agroforestry (AF)	0.01	0.66	<b>27.18</b>	3.45	0.31	0.63	0.01	0.09	0.04	32.38	5.20	
Cultivation land (CL)	0.00	1.47	2.91	<b>3.68</b>	0.08	0.25	0.00	0.03	0.03	8.46	4.78	
Woodland/shrubland (W/SL)	0.00	7.36	1.85	0.02	<b>5.42</b>	2.59	0.10	3.57	0.02	20.94	15.52	
Wetland/marshy (WL/Mr)	0.02	0.25	0.66	0.01	0.07	<b>2.32</b>	0.25	0.08	0.04	3.70	1.38	
Water body (WB)	0	0	0	0	0	0.01	<b>2.56</b>	0.00	0.00	2.57	0.01	
Commercial agriculture (CoA)	0	0	0	0	0	0	0	<b>0</b>	0	0	0	
Barren land (BL)	0.00	0.20	0.17	0.46	0.00	0.30	0.02	0.02	<b>0.02</b>	1.20	1.18	
										<b>55.39<sup>a</sup></b>		
Total 2015	0.08	24.11	41.08	8.94	7.59	9.27	3.10	5.63	0.21			
Gain	0.03	9.96	13.90	5.26	2.17	6.95	0.54	5.63	0.19			
Net change <sup>b</sup>	-0.22	-6.35	8.70	0.48	-13.36	5.57	0.53	5.63	-0.99			
Net persistence (NP) <sup>c</sup>	-4.73	-0.45	0.32	0.13	-2.46	2.40	0.21		-49.38			

<sup>a</sup> Is the sum of bolded diagonals showing unchanged total

<sup>b</sup> Net gain = gain – loss

<sup>c</sup> NP refers to net change-to-persistence ratio (i.e., net change/diagonals of each class)

market or/and, climate change-induced land-use change acts of farmers within smallholders realm were seen as LUCC drivers during socioeconomic survey. Figure 3 shows that more than 11 drivers were identified by the respondents as being principal change agents and shows how these drivers vary in space and time as perceived by the respondents. Accordingly, what was being perceived as principal driving factors in the upstream region were found to be having no impacts to the downstream region and vice versa. In fact, there are some driving factors that remain common to both areas.

In the upstream region, apparently, all the respondents perceived population growth (100%) and land holding size (91.67%) as the major drivers. However, drought/rainfall (RF) variability, investment policy, and charcoaling were not considered major drivers, despite being top drivers in the downstream region. The population doubled within three decades. For instance, the population density of Wonago woreda increased from 539.6 to 1039.2 persons/km<sup>2</sup> from 1984 to 2017 (Fig. 4), in which the figure climbs 1300 persons/km<sup>2</sup> in some kebeles such as Mokonisa. Critical land shortage (Table 2) in upstream region makes mechanized agricultural investment less likely, except for coffee washing

plants along river courses. At the same time, due to lack of any livelihood alternatives, land shortage drives farmers to intensively utilize the land and cut indigenous trees to meet their daily source of income, leading to agroforestry modification. Gedeo elders confirmed that charcoaling is not among the livelihood practice of the Gedeo people; however, commercializing woodlots (66.67%) is currently the most common practice that drives agroforest modification (Bishaw et al. 2013).

In the downstream, drought/RF variability was ranked first, at 97.9% of aggregate relative importance. With the exception of Sika and Bula kebeles', drought/RF variability was perceived to be an important driver with 70.8, 95.8, and 100% mean value in Mokonisa, Semero-Gambella, and Dibicha kebeles, respectively (Fig. 4). As per farmers' accounts in Mokonisa and Semero-Gambella, increased risk with mono-cropping and the extended seed-setting interval of coffee has been prevailing over time. In the Dibicha kebele, drought periods are gradually increasing and challenging cattle rearing. Land holding size was not recognized as a major driver, not because of land abundance but because of uncommon individual holding. During the FGDs, the people of the Dibicha kebele attributed these issues to

land tenure problems (71.5%) in the pastoral land policy environment. Therefore, investment policy was the second major driver. This is the main reason that woodlands and pastures have been transformed to commercial agriculture since 2007/8. Charcoaling, indicated by the dramatic reduction of woodland coverage (62.8% lost from 1986 to 2015), was one of the major top drivers, due to the commercialization of charcoal as a common practice. This is convergent with findings reported by Temesgen et al. (2013) and Tsegaye et al. (2010) from the upper and central rifts of Ethiopian semi-arid region.

Among all drivers, population pressure (93.75%) is important for both up- and downstream regions. Although the downstream region is less populated, there is a clear shortage of land due to human and livestock population growth; for example, the population density of the Abaya woreda increased from 86 to 110 persons/km<sup>2</sup> from 2007 to 2017. Local administrators accredited this increase to community resistance to government family planning efforts and dominant polygamous marital culture (25% of informants were in polygamous families) (Table 2). Unlike in the upstream region, livestock production was perceived to be among the top drivers, with an average of 93.06% of relative importance. Based on the FGD, participants and informants agreed on the fact that cattle population is increasing in the area (but decreasing per household) with decreasing productivity. As a result, the local government has been persistently advising the pastoralists to modify their farming systems with a specific focus on more productive ways of animal husbandry.

## Discussion

### Upstream dilemma behind agroforestry expansion

According to our spatial analysis and field observation, agroforestry has shown “*spatial expansion*”<sup>4</sup> and has also been the predominant LUC type during the past 3 decades. However, the results of socioeconomic field surveys showed deterioration of agroforestry systems although this requires further investigation. According

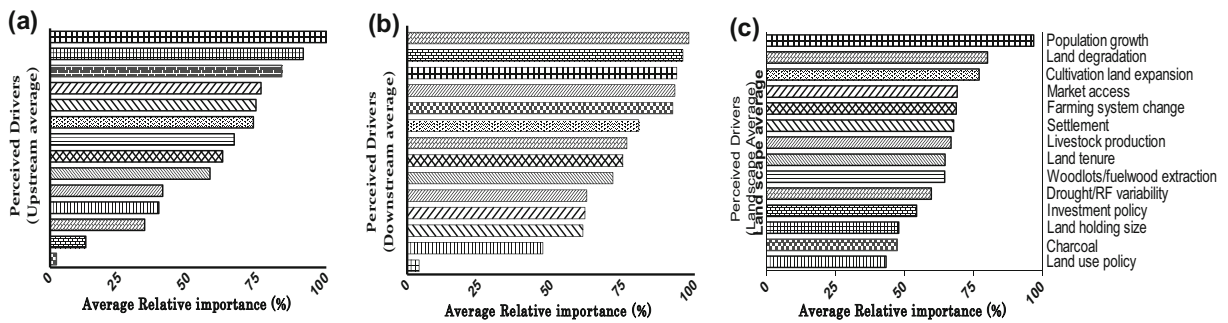
<sup>4</sup> *Land cover conversion* and *land cover modification* are the two types of changes in land cover. The former constitutes the complete replacement of one cover type by another. Land cover modifications, in contrast, are more subtle changes that affect the character of the land cover without changing its overall classification, which may either improve or diminish its ability for ecosystem service (Turner et al. 1995; Lambin et al. 2003; Lambin and Geist 2008).

to local administrator FG discussants, a number of factors are contemplated in contributing to the expansion of agroforestry. These are (1) government-led annual soil and water conservation and enrichment planting campaigns; (2) chemical land degradation problems (soil acidity) in the humid part of the upstream which have been abandoned cultivation lands, and then farmers were forced to put it under perennial cropping which steadily developed to agroforests; and (3) increased risk of crop failure in the transitional belt between up- and downstream due to recurrent drought/RF variability that forced farmers to convert mono-cropping fields to agroforestry system.

Despite the determination of farmers to continue life with agroforestry practices (Tables 3 and 4), the system has been unable to make them feed self-sufficient. According to Gedeo zonal statistics of 2016, among six woredas in the zone, only two woredas (Bule and Gedeb) whose dominant livelihood source depends on crop cultivation are feed self-sufficient. In the FGDs, the elders noted that the gradual decrease in productivity of agroforestry land use has been challenging the existence of many families. Gedeo elders attribute this crisis to rapidly increasing human population, with subsequent reduction and fragmentation in land holding size accompanied by lack of off-farm jobs for young farmers and youths who commercialize the tree component of agroforests and woodlands as well as rainfall variability that prolongs coffee seeding time and reduces its productivity. The elders’ attributions are also confirmed through empirical findings of allied researchers (e.g., Debelo et al. 2017; Legesse 2014). Legesse (2014) reported that the agroforestry system of Gedeo is gradually losing its resilience and is unable to cope with the existing dynamics. Negash (2013) also suggested that the increasing population and the incentive of simplifying the system to favor cash crop result in the deterioration of the system.

### Downstream investment expansion and the fate of (agro) pastoralists

The study identified that most LUC classes exist in the downstream region, where rapid reduction of most vegetation classes was observed. Particularly, woodland and riverine forests were left with only less than one third of their original sizes. In a similar manner, Kindu et al. (2015), Biazin and Sterk (2013), and Temesgen et al. (2013) which are studies conducted elsewhere in tropical



**Fig. 5** Drivers ranked based on the weighted average of relative importance as perceived by respondents. **a** Upstream average (situated in Gedeo zone), weighted from results of three kebeles (Sika, Bula and Mokonisa). **b** Downstream average (situated in

Abaya woreda, Borena zone), weighted from results of two kebeles (Semero-Gambella and Dibicha). **c** Landscape average, weighted from results of five kebeles along the landscape—it also represents legend pattern for all

lowlands reported a decline in woodland/shrubland, which is usually attributed to agricultural expansion. More specifically, Biazin and Sterk (2013) reported a 79% loss of woodlands within 5 decades, and Temesgen et al. (2013) discussed a 45.6% loss within 3 decades in the central Ethiopian rift valley. In our study area, the contribution of smallholder agriculture for the declining trend of woodland is not as significant as the ones in those reports. Increased tree exploitation mainly for charcoaling plays the largest role. Recently emerged commercial agriculture also plays a major role in continued woodland reduction. This could be the manifestation of increasing trends of agricultural production with investors in order to fulfill growing food demand, particularly since 2007/8 (Headey and Jayne 2014).

#### Driver prevalence and dynamics and the deeds of population and investment policy

Unlike the upstream region, where agroforests predominantly cover the landscape and are seemingly persistent, the downstream region exhibits both LUC diversity and dynamics, with nearly all drivers perceived to be important with limited variation (Fig. 5). This finding implies that LUCC and their drivers entail locality-specific mechanisms, as proved by Liu et al. (2007), who reported that scale-dependent drivers exhibit nonlinear dynamics across space and time (Kindu et al. 2015; Lambin et al. 2003; Mottet et al. 2006; Turner et al. 2007). However, among these driving factors, population is regarded as the most important driver elsewhere in developing nations (e.g., Kindu et al. 2015; FAO 2015).

Following Agricultural Development-Led Industrialization policy framework of Ethiopia, efforts were made to promote agricultural investment (MoFED 2006:pp46)

and achieved a total land transfer of 1.2 million hectares to investors in 2004–09 (Deininger and Byerlee 2011). Supporting irrigation facilities and measures to improve land tenure security and increase land availability were among the instruments to achieve the plan. More aggressively, 2010–15 development plan of the country underlined the special focus paid to agricultural investment so as to enhance transition effort to large-scale farmers. In line with this, we tried to link recent evolutions of large-scale mechanized farms to land-use policy changes and hence change drivers. In land tenure and land-use policy contexts, land holding size and fragmentation trends, re-distribution and consolidation attempts, and awareness work on existing or/and new land-use policies were assessed. Accordingly, unlike land-use policy which was poorly understood by respondents, investment policy was well recognized as a potential change driver in the downstream. Nowadays, following national development policy, large-scale agribusinesses have been expanding at the expense of small holder's farmers in the downstream study region. Although the expansion of such a large-scale agribusiness has unpaid contribution to the national economy and societal livelihood, this can only be realized when the local people that are affected by the investment participates in the process. The agribusiness introduced into the area is a top-down, and hence, it was not tuned to the local situation of the area in a way it strengthens the lifestyle of the local people, which was evidenced by the respondents' perception on the recognition and benefits of agribusiness to their livelihood. Since global increase in food price<sup>5</sup>

<sup>5</sup> 2007/8 is the period during which the annual Commodity Food Price index showed peak value causing a rise of global agricultural land demand.

(World Bank 2012), there are similar practices in which formal long-term leases have been mainly used to provide land to international and domestic investors in recent large-scale land acquisitions in Ethiopia and most parts of Sub-Saharan Africa (Cotula et al. 2009; Deininger and Byerlee 2011; Brink et al. 2014). Weinzettel et al. (2013) also highlighted that following an international trade that accounts for about a quarter of the global land tracks, the region has been increasingly concerned by this globalization of land-use process.

In general, the pattern of landscape-level drivers is highly diversified and varied throughout the landscape. Expectations regarding population and investment policies being among the top driving agents of land-use change are virtually observed as they were perceived. However, investment policy was inadequately perceived by the upstream respondents; investment policy was among the poor level of aggregate perception results throughout the landscape.

## Conclusion

Based on remote sensing-derived land-use/cover changes and socioeconomic validations, this article provided spatiotemporal dynamics of LUCC and drivers behind agroecological zones of the Gedeo-Abaya landscape from 1986 to 2015. Compared with those in the upstream region, LUC classes in the downstream landscape are more dynamic and diverse, and these classes are affected by nearly all anticipated driving agents. In the upstream landscape, there is a rapid agroforestry LUC modification due to intensive marketable woodlots extraction. As a result, it appears unable to realize population livelihood, despite farmers' determination to continue cultivating, and even expanding to the downstream being adopted by (agro) pastoral farmers.

The findings also implied a general trend of woodland decline in the downstream area. Human and livestock populations, charcoaling, and agricultural investment are the major drivers of most of the loss of vegetation classes. Unlike other findings, the dependence of most farmers on agroforestry or (agro) pastoral systems makes smallholders' agricultural expansion a less significant driver. Among the identified LUCC drivers, nearly all are perceived as important, with limited amounts of difference in the downstream semi-arid region compared with the upstream humid region. This clarifies that the agroecological setup significantly

determines driver prevalence and calls for locality-specific mechanisms to study LUCC and their drivers.

In general, landscape-level LUCC and their driver patterns were found to be diverse and varied. There is a reverse of top drivers between the lower foot plain (semi-arid region) and the peak part (humid region) along the slope. Agroforestry land use is at a critical rate LUC modification, bearing a large population in the upstream. Woodlands and grasslands are shrinking due to drought/rainfall variability, investment, and charcoaling, which is threatening (agro) pastoral life. Throughout the landscape, LUCC is deteriorating both the landscape and well-being of society, necessitating urgent action. Thus, this article showed qualitative and quantitative changes in the pattern of land use and major driving agents in the landscape, which becomes quite important information to support landscape-level decision-making and sustainable planning in order to avert the ongoing undesirable land-use/cover changes.

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