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Land use and land cover changes driven by expansion of eucalypt plantations in the Western Gurage Watersheds, Centeral-south Ethiopia

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ABSTRACT

Land use and land cover (LULC) change is a common trend in all parts of the globe. The possible reasons might be economic, political, social or cultural motives. In Ethiopia, most of the rural and urban people are highly dependent on eucalypts for various purposes, particularly, for fuel wood and construction materials. In the study area, Western Gurage Watersheds of Omo-Gibe Basin, eucalypt plantations have become the emergent and dominant activity next to growing Enset. The specific objectives of this study were to assess the land use and land cover changes driven by eucalypt plantations over time and agro-ecological extent, and to identify socio-economic, demographic, and environmental factors that facilitated expansion of eucalypts plantation.

Landsat images from 1987 (TM), 2001 (ETM) and 2017 (Landsat 8 OLI) were used for detecting LULC changes. Digital image processing operations, i.e. haze removal, geo-referencing, contrast enhancement and classification, were completed using ERDAS Imagine 2011 Software. During the period between 1987 and 2017, the area cover of LULC types, namely plantation forest, Enset-based agroforestry, cereal crop and built-up areas increased in the study watersheds at the expenses of natural forests and grassland. The total forest cover declined in the study period from 1987-2000 and, then, increased from 2001-2017 as a result of expansion of eucalypts in bare land, grazing land and cereal crop land use types. The drivers for the expansion of eucalypts in the watersheds are population growth, 'Meskel' and 'Arafah' celebrations, land degradation and conservation, road development, increased access to markets, and economic factors, such as the growing need for fuel wood, construction materials, and growing need for money. The divergent interest of stakeholders, skepticism and debate around eucalypts are presented; call for further scientific investigations and management options are recommended.

Introduction

The genus *Eucalyptus* (hereafter referred to as eucalypt and eucalypts for singular and plural, respectively) is a genus of over 500 species, mostly in Australia, but extending to the Malaysian region and the Philippines (Friis, 1995). Many species are widely planted in other parts of the tropics and in the warm temperate regions for shelter, timber, fuel wood, production of eucalypt oil, ornamental purposes or as a source of nectar in honey production. Over hundred species of eucalyptus have been recorded from cultivation in East Africa and a little over fifty species from Ethiopia and Eritrea (Friis, 1995). Eucalypts are growing in diverse climates and soil types, ranging in altitude from sea level to above 3000 m (Pohjonen, 1989; Teketay, 2000; Brooker, 2002). Eucalypts are the most planted species in the world with over 100 countries growing eucalypts in plantations. A large number of eucalypt species have been planted throughout the tropical zone, of which the most common species are *E. camaldulensis* Dehnh., *E. globulus* Labill., *E. grandis* Maiden, *E. maculata* Hook., *E. paniculata* Smith, *E. robusta* Smith, *E. saligna* Smith, *E. urophylla* S.T. Blake and *E. viminalis* (Friis, 1995). Eucalypts are among the most planted woody species in the world next to species of *Pinus* and *Cunninghamia* (FAO, 2006; Oballa et al., 2010) and, hence, the most successful trees in adapting a variety of habitats (Davidson, 1989).

In Ethiopia, the genus was introduced during the reign of Emperor Menelik II (1868-1907) in 1895 (von Breitenbach, 1961; Teketay, 2000). The purpose was to supply fuel wood and construction timber to the new and growing capital city, Addis Ababa. In the 1970s, the plantation area around Addis Ababa was about 15,000 ha while in other parts of the country, approximately 76,000 ha of plantations had been established. Between 1975 and 1994, further new plantations were established, mainly, in peri-urban areas with aid from international donors, such as United States Sudano-Sahalian Office, Swedish Inter-

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national Development Agency, World Food Program and World Bank (FAO, 2006). Currently, about 55 species of eucalypts have been grown in Ethiopia, of which between five and ten are widely planted. In Ethiopia, the most widespread species include *E. camaldulensis, E. globulus, E.citriodora* Kook., *E. regnans* F. Muell., *E. saligna* and *E. tereticornis* Smith (Friis, 1995).

The introduction of eucalypts into Ethiopia was a success because of the huge gap between demand and supply as a result of escalating deforestation (Henry, 1973), and the introduction of a fast-growing, browse-resistant plantation species was inevitable (Teketay, 2000; Getahun, 2002; Teshome, 2009) with *E. globulus* known locally as '*Nech-Bahirzaf*' or 'White Eucalypt', and *E. camaldulensis* known as '*Key-Bahirzaf*' or 'Red Eucalypt', being the species most preferred by farmers (Wirtu, 1998; Wolde-Selassie, 1998; Getahun, 2002; Kebebew, 2002; Teshome, 2004).

It is true that exotic tree plantations have played and will continue to play a tremendous role in alleviating the fuel and construction material problems in Ethiopia. The constructions of rural and urban houses in Ethiopia have been dominated by eucalypts. The current construction industry also consumes large quantity of wood, including for scaffolding, of which eucalypts are dominant, with little prospect for a competitive substitute for these trees in the near future. The emerging lucrative export markets in the neighboring countries and the Middle East are encouraging the production of more eucalypt poles and posts since Ethiopia has favorable environmental conditions for planting eucalypts.

Ethiopia has the largest area of eucalypt plantations in East Africa and is one of the ten pioneer countries that introduced the eucalypts (Getahun, 2002). In Ethiopia, eucalypt plantations constitute 58% of the total plantation cover followed by those of *Cupressus* (29%), *Juniperus procera* Hochst. ex Endl. (4%) and pines (2%) (Teketay, 2000; WBISPP, 2004).

Some of the commonly mentioned advantages include quick provision of benefits associated with fast growth, short rotation plantations for production of fuel wood and timber. Under proper management, the species are good sources of forage for bees (honey production), can produce fiber for pulp and paper industries under relatively short rotation, can grow adequately in a wide range of ecological conditions and sites among others (Brooker, 2002; Calder, 2002; Jagger and Pender, 2000; Teketay, 2000).

At present, eucalypts have spread to urban and peri-urban centers, woodlots, homesteads, communal lands, schools, churches and monasteries (Wassie et al., 2005). As a result of their multipurpose use and considerable economic benefit, eucalypts have become important primary species that have improved livelihoods of communities. In some places, they seem to override crop production, and this has made the species among the highly valued tree species in the country. A lot of farmers have also converted their farms to eucalypts and diversified their income (Kidanu et al., 2005). As a consequence, they have become part of the farming systems in certain areas. Where there are few trees to protect the soil, eucalypts have been used as biological conservation measures. As a result of their its fast growth, less soil fertility requirements and high revenue, eucalypts are best fit for countries with high demands for biomass and construction materials, such as Ethiopia (Jagger and Pender, 2000).

The estimated mean annual increment of eucalypt woodlots in Ethiopia is 10-20 m^3 ha^{-1} $year^{-1}$, which is higher than the average yield from plantation forests that is estimated at 10-14 m^3 ha^{-1} $year^{-1}$ (Bekele, 2011). The high yield per year and hectare attracted farmers to plant more every year, which has led to the expansion of eucalypts in the highlands of Ethiopia (Gemechu, 2010; Mekonnen, 2013). Eucalypts can grow in different agro ecological zones, infertile soils and heavy clays, encouraging farmers to continue planting eucalypts (Oballa et al., 2010).

Currently, it is estimated that over 500,000 ha of the land is covered by eucalypt plantations in Ethiopia (Abebe and Tadesse, 2014). The expansion has also contributed to increase the forest plantation cover in the country from an estimated 190,000 ha in 1990 to 972,000 ha in 2010 (Bekele, 2011). As a result, the impact on natural forests has been reduced due to the substitution of natural forest products by those of eucalypts.

Eucalypt growing is expanding very fast in many parts of Ethiopia, particularly by smallholder farmers. Studies of Teklay (1996) from Tigray, Getahun (2002) from Gondar, Mesfin (2002) from Wollo, Negash (2004) from southern Ethiopia and Mekonnen et al. (2007) and Zerga (2016) from central Ethiopia confirm the expansion of eucalypt plantations in their respective study areas. Two species of eucalypts, namely *E. globulus* and *E. camaldulensis* are widely planted, although *E. saligna* and *E. grandis* are also showing increasing importance (Kidanu and Gezahegn 2004). Eucalypt tree farming has become the dominant activity next to growing *Enset* (*Ensete ventricosum* (Welw.) Cheeseman) (hereafter referred to as *Enset*) in the Gurage Zone (Zerga and Woldetsadik, 2016).

During 1930, about 20% of Gurageland was covered with natural forests (Woldetsadik, 1994), which has since been decreasing, and deforestation was, especially, fast during 1991 and 1992, leading to diminishing of their sizes. On the other hand, beginning in the early 1960, the inhabitants started to grow eucalypts at an increasing scale, which has increased the areas of land being covered with trees. This study, therefore, generally tried to show the land use and land cover changes driven by expansion of eucalypt plantations and causes of expansion. Specifically it tried to assess the land use and land cover changes driven by eucalypt plantations over time and agro-ecological extent; and to identify socio-economic, demographic, and environmental factors that facilitated expansion of eucalypts plantations in the Western Gurage Watersheds, namely sub-watersheds of Omo-Gibe Watersheds.

2. Materials and methods

2.1. Study area

The Gurage Zone is located in South Central Ethiopia with the location between $7^0$40' to $8^0$30' North and $37^0$30' to $38^0$40' East and covers an area of 5,932 km^2 (Figure 1). The Zone is bounded with Oromia Region in the west, north and east, Yem Special Wereda (District) in the southwest, and Hadiya Zone in the south. The Gurage Zone consists of thirteen weredas; these include Abeshge, Kebena, Eza, Welene-Gedebano-Kutazer, Sodo, Meskan, Mareko, Gumer, Geta, Cheha, Enemorna Ener, Mihurna Aklil and Endegagn. Topographically, the Zone lies within an elevation, ranging from 1,000 to 3,638 m. The highest point in the Zone is Mt. Zebidar. The climate of Gurage Zone is affected by the altitudinal gradients. The four traditional agro-ecological zones (AEZs), namely Afro-Alpine (Wurch), Temperate (Dega), Sub-tropical (Woina-Dega) and Tropical (Kolla) are found in the Zone. However, Woina Dega is the dominant one. The average temperature ranges from <3 °C in the Gurage mountain chains to 28 °C in the Ghibe Gorge. The annual range of rainfall falls between 600 and 1,900 mm. These ranges of agro-ecology have enabled the Zone to grow different types of crops, such as cereals, pulses, oil seeds, vegetables and fruits as well as support livestock, sheep, goat and pack animals. Different wild animals and birds inhabit the Zone, owing to this climatic diversity.

As noted by Woldetsadik (1994), soil colors in the *Enset* growing areas, like Gurage Zone, range from brown and black to red. Two of the soil groups, Pellic Vertisols and Euric Nitsols, are most common and cover more than 60% of the region. Depending upon the population pressure and local farming systems, Vertisols are intensively cultivated and mostly devoted to grain production in the Dega (high plateaus). However, they are left largely for grazing in the low plateaus, the lower Woina-Dega and the upper Kolla sections of the region. Based on the 2007 census conducted by the Central Statistical Agency (CSA) of Ethiopia, this Zone has a total population of 1,279,646 of whom 622,078 are male and 657,568 are female. The Zone has a population density of greater than 450 person km^{-2}. About 9.36% of them are urban inhabitants and the remaining are rural dwellers. Gurage Zone is one of

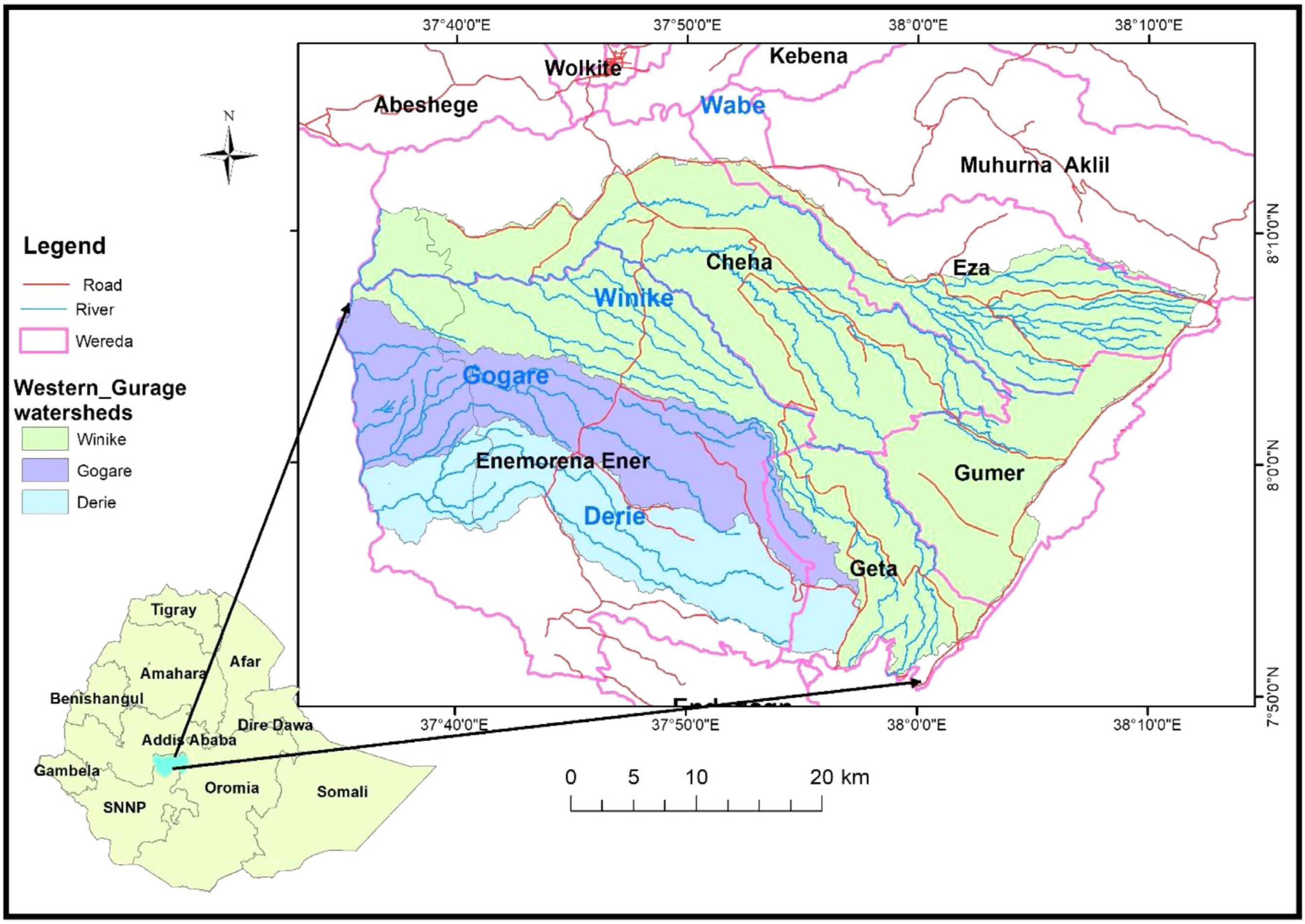

Fig. 1. Location map of the Western Gurage Watersheds.

the most densely populated areas in Ethiopia. High population pressure and a long history of settlement have resulted in an increasing quest for agricultural land, wood for farmhouse construction, fuel and other uses. This, in turn, has resulted in the degradation of the natural forests and shrubs along river valleys (Woldetsadik, 2003).

Gurage Zone is divided by four drainage basins, namely Awash, Rift Valley, Blate and Omo-Gibe. With the exception of minor deviations at local level, the streams in the Zone have a dendrite drainage pattern. The direction of flow of the streams may vary depending upon orientation of local relief at micro level. However, all the major streams ultimately drain to west and south-west/east ward following the general inclination of the slope direction of the Zone. The western Gurage watersheds drain to Omo-Gibe Basin and cover large areas. In the western parts of Gurage, several rivers and streams are available, which drains from East to West to Gibe River. The major rivers are Wabe, Winike, Megecha, Rebu, Zizat, Gogare and Dire. These rivers have several numbers of streams, which emerge from the Gurage Mountains and join at different locations. The rivers Winike, Gogare and Derie are the main rivers next to Wabe River, and together cover an area of 173,476 ha (Fig. 1).

From these, the main watershed is Winike, which includes Megecha and Zizat rivers and covers an area of 117,030 ha. The Gogare and Drie watersheds cover an area of 30,739 and 25,707 ha, respectively.

The five districts of Gurage Zone, i.e. Eza, Cheha, Gumer, Geta and Enemorna Ener, are found in these watersheds. These watersheds areas share almost all characteristics of Gurage Zone. These watersheds were selected due to their dense population and high coverage of eucalypts under expansion.

2.2. Methods

2.2.1. State of land use and land cover assessment

Landsat images from 1987 (TM), 2001 (ETM) and 2017 (Landsat 8 OLI) were used for this study. For each of them, digital image processing operations, such as haze removal, geo-referencing the images with known places of the study area topographic map, contrast enhancement (histogram equalization) activities were completed using ERDAS Imagine 2014 software. During classification, the maximum likelihood method was utilized for supervised classification. About 230 representative points believed to represent the various land use land cover classes, and the land uses that are making confusions were marked using GPS with the land use land cover type during the social field survey. These points were used while classifying to verify the classified Land Use/Land Cover (Hereafter referred to as LULC) and an accuracy assessment.

The eight major LULC types considered in this study are listed in Table 1. The classified LULC types were checked by overlaying the collected ground control points with the help of the land use and land cover type information. After supervised classification, some of the land uses, which were classified wrongly, were masked in ArcGIS software by creating polygon features. Then, the raster format of the classified LULC types was converted into a vector format. After renaming the masked shape files to the correct LULC, they were merged with the classified LULC types. The classified images were compared from two periods, 1986–2000 and 2000–2017. Change statistics were computed by comparing image values of one data set to the corresponding value of the second data set for each period (Table 1).

Table 1
Description of the identified land/use/land cover types in the western watersheds of Gurage Zone.

Land Use and Land Cover Type	Description
Bare land	Areas of land that have been without cover naturally or degraded either due to erosion or over-grazing and crop cultivation.
Grazing land	All areas covered with grass and used for livestock grazing.
Cereal crop	Areas of land prepared for growing cereal crop. This category includes areas currently covered with crops and land prepared for cereal cultivation.
Forest	Areas covered by trees, natural or planted, with a minimum size of 0.5 ha.
Woodland	Area with open stands of trees, mainly dominated by *Senegalia/Vachellia* species.
Built up	Urban fabric of residential, commercial, industrial, transportation, and other land
Lake	A small area filled with water surrounded by land, apart from any river.
Enset-based agroforestry	Areas dominated by *Enset* crops mixed with fruit trees, vegetables, chat, coffee, etc. and growing within a home garden.

2.2.2. Accuracy assessment

In this study, accuracy assessments were performed for classified images from 1987, 2001, and 2017. The corresponding reference class for 2017 LULC type was collected from field visits using GPS and visual interpretations of the raw images with the help of personal knowledge of the study area and high resolution images, such as Google Earth, SPOT and Sentinel 2 through random sampling technique. The reference points of 1987 and 2001 were obtained from the topographic map of 1975 from unaltered LULC and the raw images of the study area. In addition, the GCP points were used for those areas, which have unchanged LULC types. In total, for each of the classified LULC, 230 reference points were considered. As a result of the variation in area coverage of LULC types in the study area, the numbers of reference points were diverse. For LULC types, which have large area coverage such as *Enset*-based agroforestry, cereal crop, grazing land and forest (natural and plantation forests, including eucalypts), 50 reference points were considered for each of them. The reference points of bare land were 15. In the woodland, a reference point was not considered because the land cover is found in the Gibe Sheleko National Park, and no major change has occurred. Since the built up area is masked as polygon after classification, a reference point is not considered as well.

The overall accuracy of the classified images from 1987, 2001, and 2017 were 86.9%, 86%, and 86.5%, respectively (Table 2). The kappa coefficients, which show a high level of agreement, were 0.75 in 1987, 0.79 in 2001, and 0.77 in 2017. Producer's accuracy (PA) of the individual classes of the three classified maps ranged from 82% (Forest in 1987 and *Enset*-based agroforestry in 2000) to 100% (Built up and Lake in the three years). The user accuracy (UA) was lowest for the *Enset*-based agroforestry (82.4%) in 2001 and the highest for the Built up and Lake Classification (100%) in the three years (Table 2).

The columns represent actual location of samples on the ground, while rows display classified data showing location of samples in the classified images. Diagonal numbers showed in bold are the correct classifications. The off diagonal numbers in rows and columns are misclassifications or errors.

Built up and Lake LULC classes had a 100% producer accuracy since the areas were masked and replaced by correctly classified shape files before an accuracy assessment was conducted.

2.2.3. Causes of expansion of eucalypts plantations

Group interviews were held with the selected experts of the Gurage Zone and its Wereda Departments of Natural Resources, who have adequate knowledge about the conditions of LULC in the study area. To get detail information from perception of the households and experts, in-depth discussions with focus groups, and key informant interviews were employed. Heads of individual farm households whose ages were more than 70 years old and other knowledgeable persons were pooled to discuss about the eucalypt plantations, reasons for its expansion and conversion of crop land to eucalypt woodlots. They were selected purposefully with the guidance of *Kebele* chairpersons and district experts. Thereafter, three focus group discussions with heads of farm households were conducted in the three districts. Each group included six to eight members. The discussions were guided by facilitators, and group members were encouraged to talk freely on raised topics. Key informant interviews were conducted with purposefully selected and well experienced heads of individual farm households and agricultural experts in each district. Hence, a total of nine key informants were selected from nine sample *Kebeles* of the three districts. Important professional key informant interviews were employed with six agricultural and natural resources experts from the three districts (two experts from each). Moreover, interviews with Agricultural Development Agents (DAs) and *kebele* chairpersons were administered. In each district, individual interviews and informal communications with eucalypt pole traders and brokers (middlemen) were also conducted. From all the focus group discussions and interviews, valuable information was gathered by the principal researcher and assistants with the help of voice recording devise and smart phone camera. After transcribing the audio documents into written words, translation from the local language to English was made.

3. Results and discussion

3.1. Land use and land cover changes, and expansion of eicalypts

3.1.1. ***State of land use land cover***

The LULC of 1987 showed that forest covered 14.8% of the total study are (Table 1; Fig. 2). The grassland and cereal crop occupied about 20.3% and 17.8%, respectively. Only 44 ha (0.03%) of the catchment area was urbanized. Only 0.1% of the catchment was urbanized in 2001. In this year, forests, cereal crop, wood land, and bare land covered 12%, 28.1%, 13.4% and 5%, respectively. Between 1986 and 2000, the areas covered by grassland and forest were reduced in the catchment, whereas the area coverage of the other land uses, such as cereal crops, increased within the watersheds (Table 3).

In 2017, the area covered by cereal crop accounted for 48,906 ha (28.3%). Forest and grassland covered 27,797 ha (16.1%) and 24,364 ha (14.1%), respectively. The built up area covered 567 ha (0.3%), lake 148 ha (0.1%) and *Enset*-based agroforestry 43,144 ha (25%) (Table 1; Fig. 2).

3.1.2. LULC change for the period 1987-2017

The forest cover, which includes both natural and the common plantation trees of eucalypts in the study area, had shown a gradual decline during the study periods (1987-2000). In 1987, forest cover (natural and plantation forests, including eucalypts) was 27,314 ha (14.8%) of the watersheds and decreased to 20,810 ha (12%) in 2001 (Fig. 3). Large percent of forest coverage decreased between 1987 and 2000 as a result of the expansion for agroforestry and cereal crop production. However, the increment of forest cover from 2001 to 2017 was only 4.1% (6,987 ha). This forest cover increment resulted due to the expansion of eucalypts in bare land, grazing land and cereal crop production land uses. The major losses were due to the conversion of forest cover to shrub land (17%) and grazing land (6.6%).

Grazing land decreased from 35,016 ha (20.3%) in 1987 to 30,725 ha (17.8%) in 2000 and, then, to 24,364 ha (14.1%) in 2017. The ob-

Table 2
Accuracy assessment matrix for the classified images of 1987 (a), 2001 (b) and 2017 (c).

Land Use and Land Cover	Bare land	Built up	*Enset*-based agroforestry	Cereal crop	Forest	Grazing land	Lake	Woodland	UA
a)									
Bare land	14	0	0	1	0	1	0	0	87.5%
Built up	0	10	0	0	0	0	0	0	100%
Enset-based agroforestry	0	0	45	2	4	3	0	0	83.3%
Cereal crop	1	0	0	43	2	3	0	0	87.8%
Forest	0	0	3	1	41	1	0	0	89.1%
Grazing land	0	0	2	3	3	42	0	0	84%
Lake	0	0	0	0	0	0	5	0	100%
Woodland	0	0	0	0	0	0	0	0	100%
PA	93.3%	100%	90%	86%	82%	84%	100%	100%	
Over all accuracy = 85%; Kappa Coefficient= 0.83; UA = user's accuracy and PA = producer's accuracy.									
b)									
Bare land	12	0	1	0	0	0	0	0	92.3%
Built up	0	10	0	0	0	0	0	0	100%
Cereal crop	2	0	44	2	0	4	0	0	84.6%
Enset-based agroforestry	0	0	2	42	5	2	0	0	82.4%
Forest	0	0	0	4	44	1	0	0	89.8%
Grazing land	0	0	3	2	1	43	0	0	86%
Lake	0	0	0	0	0	0	5	0	100%
Wood land	0	0	0	0	0	0	0	0	0
PA	83%	100%	88%	84%	88%	86%	100%	100%	
Over all accuracy = 86% Kappa coefficient = 0.84; UA = user's accuracy and PA = producer's accuracy.									
c)									
Bare land	13	0	2	0	0	0	0	0	86.7%
Built up	0	10	0	0	0	0	0	0	100%
Cereal crop	1	0	43	2	1	3	0	0	86%
Enset-based agroforestry	0	0	2	41	4	2	0	0	83.7%
Forest	0	0	0	4	43	1	0	0	89.6%
Grazing land	1	0	3	3	2	44	0	0	83%
Lake	0	0	0	0	0	0	5	0	100%
Wood land	0	0	0	0	0	0	0	0	0
PA	86.7%	100%	86%	82%	86%	88%	100%	0	
Over all accuracy = 86.5% Kappa coefficient = 0.82; UA = user's accuracy and PA = producer's accuracy.									

Table 3
Land Use and Land Cover areas at different period of time in the western watersheds of Gurage Zone.

Land Use and Land Cover Type	1987 (ha)	Proportion (%)	2001 (ha)	Proportion (%)	2017 (ha)	Proportion (%)
Enset-based agroforestry	35,539	20.6	40,400	23.4	43,144	25
Bare land	9612	5.6	8604	5	4603	2.7
Built up	44	0.03	247	0.1	567	0.3
Cereal crop	43,533	25.2	48,589	28.1	48,906	28.3
Forest	25,585	14.8	20,810	12	27,797	16.1
Grassland	35,016	20.3	30,725	17.8	24,364	14.1
Lake	149	0.1	149	0.1	148	0.1
Woodland	23,211	13.4	23,209	13.4	23,208	13.4

served decline during the first period (1986-2017) was due to the conversion of grazing land to cereal cropland and forest, mainly, eucalypt tree plantations. Cereal crop production is the dominant LULC type in the catchment and occupied about 43,533 ha (25.2%) in 1987, 48,589 ha (28.1%) in 2001, and 48,906 ha (28.3%) in 2017, suggesting a consistent increase at the expense of other land use types. Its expansion was at the expense of, mainly, grazing land, *Enset*-based agroforestry and forest areas (Fig. 3).

The area coverage of *Enset*-based agroforestry increased from 35,539 ha (20.6%) in 1987 to 43,144 ha (25%) in the year 2017. This land use gained additional areas, mainly, from cereal crop production and grazing lands. This can particularly be observed in the upper and lower watersheds due to the recent familiarization with the *Enset* crop and expansion of *Catha edulis* (Vahl) Forssk. ex Endl (hereafter *Chat*) crop, a popular stimulant plant cultivated in the study areas (Fig. 2).

The 1987 LULC analysis shows that only 44 ha (0.03%) of the watersheds was used by built up areas within the districts' small towns. The area increased to 247 ha (0.1%) in 2001 and 567 ha (0.3%) in 2017. This indicated that built up areas expanded by 250% over the last 30 years, even though the area coverage was very small. The built up land use expanded, mainly, through the conversion of the grazing and cereal croplands.

The area coverage of the bare land was 9,612 ha in 1987 and 8,604 ha in 2000, showing a decline of 0.6%. In 2017, the area coverage of bare land decreased to 4,603 ha (2.7%). This could be due to the watershed management program implemented in the Gurage Zone and the waste lands used for eucalypt plantations. However, large areas still exist in the watersheds, particularly, in the Woina-Dega AEZs in the Eza, Cheha, and Enemorna Ener Districts.

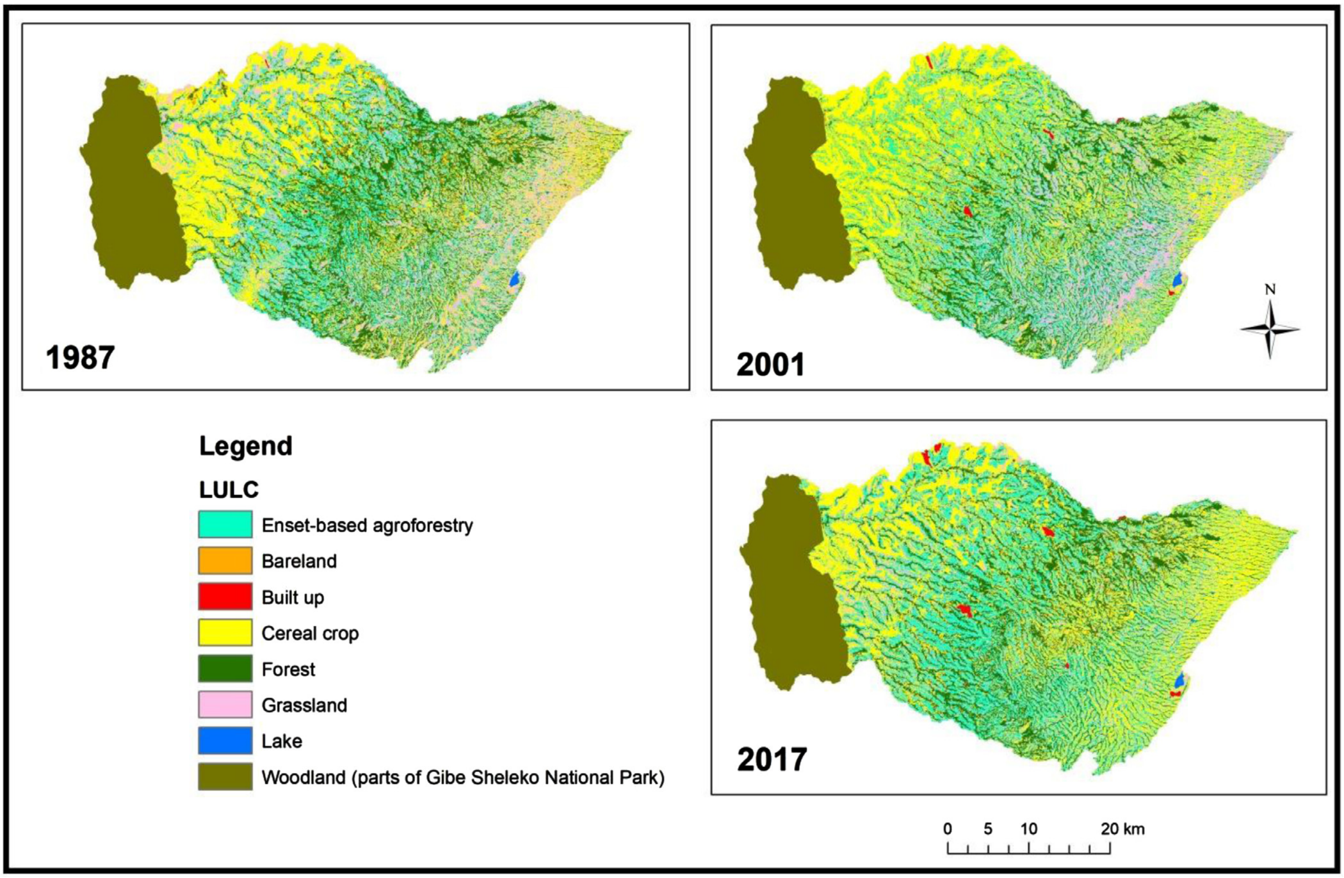

Fig. 2. Land use and land cover in the western Gurage watersheds during the study periods (See the method section for further clarification).

Table 4
Land Use and Land Cover percentage at different watersheds in the Gurage Zone.

Land Use and Land Cover Type	Winike			Gogare			Drie		
Year	1987	2001	2017	1987	2001	2017	1987	2001	2017
Enset-based Agroforestry	20.1	24.4	25.1	18.3	20.4	23.5	19.0	22.5	26.1
Bare land	6.5	5.2	2.9	3.1	4.2	2.0	4.1	5.0	2.6
Built up	0.0	0.1	0.3	0.0	0.3	0.5	0.0	0.0	0.1
Cereal crop	27.8	32.8	34.7	20.3	20.5	15.6	18.9	15.9	14.3
Forest	16.6	11.6	16.2	12.2	9.8	13.3	16.6	16.6	18.9
Grassland	23.6	20.5	15.4	11.9	10.8	11.1	15.0	13.6	11.6
Lake	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Woodland	5.2	5.2	5.2	34.1	34.1	34.1	26.4	26.4	26.4

3.1.3. LULC changes at different watersheds

Compared with the other LULC types in the considered period, large areas of the three watersheds were used by cereal crop, grassland and *Enset*-based agroforestry (Table 3). Relatively, large areas of forest are found in the Winike and Drie watersheds. The declining situation in the forest coverage during 1987 and 2001 and, then, the increase in the period of 2001-2017 can be observed in Winike and Gogare watersheds. This shows that deforestation was high in these watersheds and, then, it regained its size in 2017. This could be due to the expansion of eucalypts since the satellite image observation in the natural forest areas of the watersheds, such as Yotyet/Yewezera, Koter Gedra, Genemar, Genet Mariam, Geme, Yame, Abagiya-Megecha, Geche, Wabe and Shashat-Yeganetiye in Eza Districts and Aftir, Wegepecha, Ye'awre Diber, Zheram, Ager and Yeforehena in Cheha District increased. However, additional forest areas with a regular shape can be observed at different homesteads, roadsides, farmland gully sides, bare lands and river and side parts of the watersheds. These were identified as eucalypt trees through field observation and by overlying the reference points on the classified maps (Table 4).

The tabulated data shows that large parts of the woodland exist in Gogare and Drie watersheds. However, bare land decreased during the study period in Winike watershed, while it increased in some extent in Gogare and Drie watersheds. This is attributable to higher expansion of eucalypt towards this land use in the former than the later ones.

3.1.4. LULC changes along agro-ecological zones

In total, the Kola traditional agro-ecological zone (AEZ) of the watersheds is covered by woodlands and the remaining woodlands existed in Woina-Dega AEZs (Table 4). One of the dominant land uses in the Woina-Dega AEZ is *Enset*-based agroforestry, and the area coverage of this land use increased throughout the study period. This resulted due to the *Chat* crop expansion in the AEZ. Cereal cropland increased between 1987 and 2017 in the Dega AEZ than the others. The forest cover, which was found in Woina-Dega and Dega AGZs of the watersheds decreased in the study period between 1987 and 2001, and, then, increased between 2001 and 2017 (Fig. 4). The extent of grassland was large in the Dega than Woina-Dega AEZs, and there is was a sharp decline between the study period of 2001 and 2017 (Table 5).

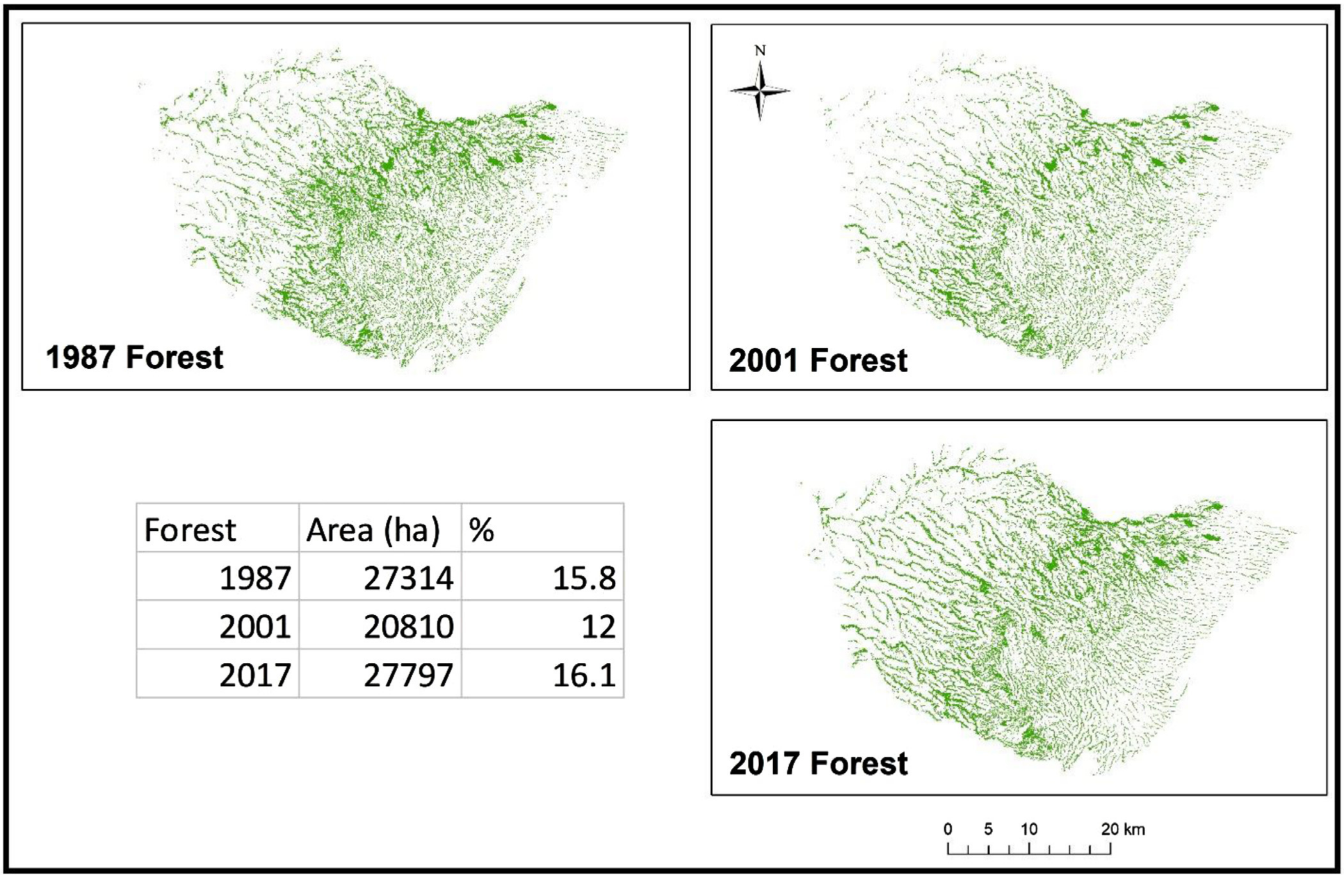

Fig. 3. Forest cover (natural and plantation forests including eucalypts) at different period of western Gurage watersheds during the study periods.

Table 5
LULC of the watersheds along traditional AEZs of Gurage Zone.

Land Use and Land Cover Type	Kola (ha)			Woina-Dega (ha)			Dega (ha)		
Year	1987	2001	2017	1987	2001	2017	1987	2001	2017
Agroforestry	0	0	0	18,596	21,591	24,812	15,223	18,792	18,312
Bare land	0	0	0	3574	5111	2085	6033	3490	2515
Built up	0	0	0	37	210	459	8	36	101
Crop	0	0	0	28,825	33,492	24,769	14,689	15,071	24,108
Forest	0	0	0	13,179	9348	14,234	14,131	11,459	13,560
Grassland	0	0	0	14,573	9040	12,430	20,423	21,664	11,918
Lake	0	0	0	0	0	0	149	149	148
Woodland	13,844	13,844	13,844	9362	9360	9359	0	0	0

In his study of West Gurageland on land use and land cover changes, by using aerial photographs for two periods (1957/71 and 1998), Woldetsadik (2003) observed considerable dynamics in the land use systems of the study area. Accordingly, eucalypt plantation expansion showed an increment of 169% for West Gurageland (including the study area). Woodlands, mainly, eucalypts showed the most extensive expansion. Eucalypt woodlots increased from 4.2% (1957/67/71) to 11.2% (1998). Hence, the expansion was more important in the Dega areas and accounted for about 42% in the aggregate expansion while the Woina Dega and Kolla Kebele[1] Peasant Associations (KPAs) contributed about 34% and 26%, respectively. The expansion of eucalypt plantations has been most important and competitive. Their expansion was largely at the expense of grazing areas and, to some extent, bush lands and croplands (Woldetsadik, 2003).

According to the LULC analysis result, the forest areas showed considerable incremental changes, probably, due to the presence of watershed management and summer planting programs. In another scenario, the role of eucalypts in substituting natural forests in terms of firewood and construction reduced deforestation and, hence, promoted regeneration of the forests. Accordingly, considerable parts of Geche (Shebraden Kebele Peasant Administration's (KPA's) possession), Koter Gedra (Koter Gedra KPA's possession) and Yotyet/Yewzera (Gedeb KPA's possession) forests in Eza District have regenerated and became luxuriant through community governance and protection. Hence, these and other forests in the study area are owned and protected by the adjacent communities. Thus, eucalypts expanded at the expense of others land use and land cover types by way of transformation or through modification without competing with forests.

In general, the resulting decline in the size of natural forests and grazing land, and the increase in eucalypt plantations and agricultural land areas of the western watersheds of Gurage was confirmed by the group discussion of experts, and is consistent with the results of other studies conducted in Ethiopia (Tekle and Hedlund, 2000; Zeleke and Hurni, 2001; Tegene, 2002; Dessie and Kleman, 2007; Shiferaw, 2011;

[1] Kebele is the lowest administrative unit in Ethiopia.

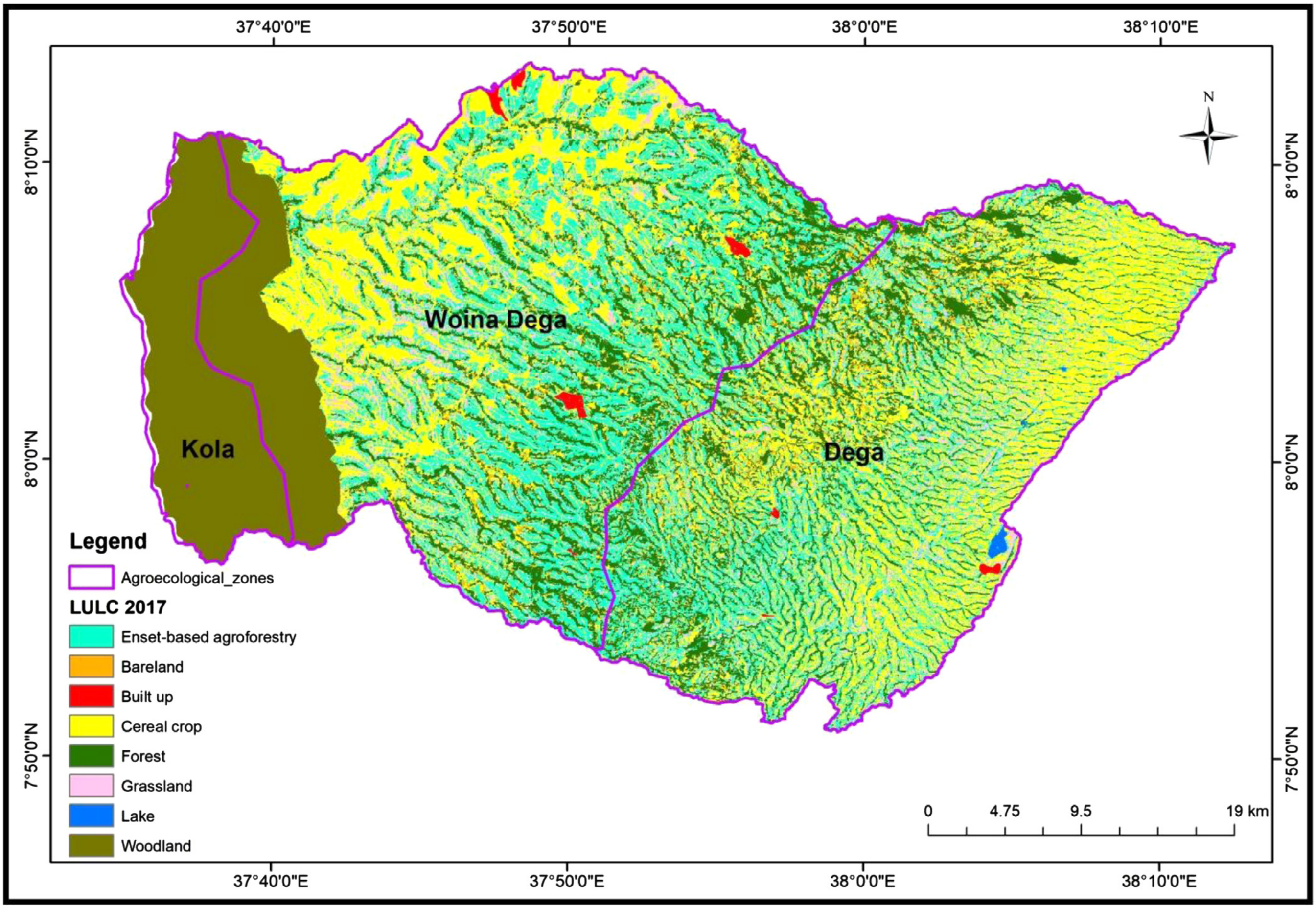

Fig. 4. Land Use and Land Cover of the Western Gurage watersheds along traditional AEZs (periods (See the method section for further clarification)).

Kindu et al., 2013; Wubie et al., 2016; Miheretu and Yimer, 2017; Sahle et al., 2018).

3.2. Causes of expansion of eucalypt plantations

3.2.1. Population pressure and expansion of eucalypts

Through supporting Boserupian Theory, Woldetsadik (2003) noted that an increase in the density of the population, i.e. the number of people who can be served from an individual location (other things being equal), increases, the cost of providing service to a given number of people falls. At the same time, the number of other individuals, with whom one person is likely to interact, will rise, which will tend to increase the exchange of ideas and flow of information and increase the likelihood of new ideas and innovations being generated. This, in turn, will assist in solving the supply problems generated by population growth. Hence, this situation confirms the notion "more people more trees".

Woldetsadik (1994) also revealed that the growing need of wood for construction and firewood, partly due to population growth, has been one of the major drives to plant more eucalypts. Based on the 2007 Census conducted by the Central Statistical Agency (CSA) of Ethiopia, Gurage Zone had a total population of 1,279,646 with an area of 5,893 km^2 and a population density of 217 km^{-2} (Sahle, 2018). From this, only 119,822 (9.4%) were urban inhabitants. The population growth rate of the region is 2.9%. There were 286,328 households in the Gurage Zone in 2007, indicating the presence of an average of 4.47 persons per household (CSA, 2009).

Hence, in order to fulfill socio-economic needs, households preferred to plant more trees in their landholdings without taking some considerations to land diminution, which is the very serious issue in western watersheds of the Gurage Zone. The interview conducted with local experts showed that an increase in the human population in the watersheds was one of the indirect causes that resulted in the changes of expansion of eucalypts.

3.2.2. 'Meskel'[2] and 'Arafah'[3] celebrations and the associated fuel wood consumption

The attachments of Gurage People to *Meskel* and *Arafah* celebrations are quite unique in terms of long duration of the celebration, cost, high number of people reterning for the celebrations many number of returnee people from different parts of Ethiopia. The households start engaging with preparation for *Meskel* celebration before three months. Among other things, fire wood is fetched well in advance before one to two months. Starting from June, i.e. before three months of the celebration week, to the third week of September, every household begins to prepare fuel wood of higher quality. The best and readily available firewood in this regard obtained from is eucalypts, which are often used for this purpose. This has been the experience since the time of the eucalypt introduction. Discusions with elders in the study districts revealed that the people living in the Gurage area particularly in West Gurageland (Sebat Bet Gurageland), including the study area, would not consider celebrations of *Meskel* and *Arafah* as the best without the proper fuelwood preparation, one may not be able to say he had celebrated *Meskel* or *Arafah* in Gurage area in general and West Gurageland (Sebat Bet Gurageland) including the study area in particular. The accumulations of split eucalypt logs are displayed in impressive arrangement in

[2] Celebration of Christians associated with the founding of the "True Cross".

[3] Islamic holiday calendar, the 9th day of Dhul-Hijjah (the Month of Hajj).

all *"Guye Bet"* (big houses) of Gurages. After *Meskel* celebration, the remaining collected firewood is used until the end of October or, in some cases, until November and December.

Thus, for the prime reason of social values, such as *Meskel* and *Arafah*, eucalypt plantations are expanding despite their possible negative ecological effects and land use competition. This is figurative when it is compared to the number of Orthodox Christian, Muslim, Catholic and Protestant followers, which celebrate either *Meskel* or *Arafah.* Most of the people in the Gurage community are followers of one of these religions. Hence, all the Christians collectively use ample amount of eucalypts fuel wood for celebrating *Meskel* for *'Demera'* (large bonfire), cooking food, heating and lighting.

Therefore, eucalypts remained part and parcel of *Meskel* or *Arafah* celebration requirements in the study area similar to other Gurage regions and, hence, their expansion has accelerated in the past and will continue to do so in the future.

3.2.3. Land degradation and conservation

Population growth may not lead to environmental degradation if there is a reasonable amount of natural resource base, significant access to internal and external markets, opportunities for non-farm income sources, active private trading network, fair social and physical infrastructure, reasonable social and political stability, forward looking society and good governance (English, 1993; Woldetsadik, 2003).

Recently, eucalypt plantations have rapidly expanded in the study watersheds. As noted by Woldetsadik (2003), the link between population and environment, on the one hand, and population and the economy, on the other hand, is one of the most critically debated issues. Many people consider that the most unfavorable changes in the environment and the economy of many pre-industrial societies, most particularly degradation and poverty, respectively, are the result of fast population growth. But, there is a new school of thought that views population growth, all other things remaining in a normal course of move, can induce innovation, environmental recovery and, consequently, growth in the economy.

As stated by Woldetsadik (2003), in West Gurageland, including the study area, one farmer has planted, on the average, about 61 trees. This could have partly contributed to the environmental recovery particularly in the degraded areas and justify the "more people more trees' situation, although it may be partly attributable to some other factors. In addition to population growth, other factors, such as improved road access to town, market and information have induced people to plant trees in and outside degraded areas, and serving also for the purpose of environmental conservation and recovery.

This, therefore, encouraged people to start farm forestry practices, such as planting eucalypts in their degraded land holdings. Thus, in the study area, farmers practice conservation of their land to cope with the environment since land diminution is a common problem. Such practice is undertaken not necessarily for the sake of government plans and policies rather for survival in such limited landholding sizes.

As reported by key informant and focus groups, for restoring their degraded and rugged lands, farmers have begun a new practice in environmental conservation by planting eucalypts mixed with native tree species of *Podocarpus, Juniperus* and *Hagenia.* The reason behind this, as they reported, is due to the fear of the adverse ecological effects of eucalypts, such as its high consumption of water as well assoil erosion and nutrient depletion.

3.2.4. Road development

As one of the basic infrastructure, road development has great role in the integration of economic, social, political and cultural conditions of any country of low economic development like Ethiopia. The development of all-weather roads in the Gurageland contributed to the land use and land cover change (Woldetsadik, 1994). As one of the factors of production, roads stimulate farmers to plant cash crops, which have high demand in the market. Due to its nearness to Addis Ababa and other towns, the Gurage areas, including the study areas, have great actual and potential advantages with regard to income diversification. With the efforts of Gurage Road Construction Organization, almost every Wereda has at least one all-weather road, which links to the nearby markets and towns.

Eucalypt poles, therefore, are transported by households using these road facilities. Particularly, farmers that reside in the Kolla and Woinadega AEZs benefit more due to the flat nature of the topography since the purchasers can reach areas with eucalypt woodlots, but without road networks during the dry season since the terrain is not rugged. In Kolla AEZ, higher man power is not needed to transport eucalypt poles than the Dega AEZ with the need to transport from rugged areas to flat surfaces, in most cases. Thus, road development has facilitated expansion of eucalypts in these areas. Hence, the development of all season motorable road networks in the region since about 1960's has been reported as one main factor in the expansion of eucalypt plantations.

3.2.5. Increased access to markets

The sample Kebeles of the study area are accessible to rural market places and towns. Agena, the capital town of Eza District is about 8, 7 and 20 km away from Worit, Shebraden and Zigba Boto Kebeles, respectively. Emdibir, the capital town of Cheha District is about 15, 5 and 8 km away from Azerina Sise, Wodro and Moche Kebeles, respectively. Gunchire, the capital town of Enemorna Ener is about 18, 10 and 7 km away from Gonche Bete, Terede and Agata Kebeles, respectively. Poles can be transported using all weather roads to the towns in reasonably short time. On site sale of poles is also possible. Thus, farmers can sale their tree products either on site or transport to other secondary market places, such as Yefintiye, Gubre, Terede located in Eza, Cheha and Enemorna Ener, respectively. Wolkite, Butajira, Hosaena and Addis Ababa are also other accessible market centers.

Middle men *('Dellalas')* provide assistance in creating links between woodlot sellers (farmers) and merchants. Therefore, improved access to market places considerably facilitated and will facilitate the expansion of eucalypt plantations in the study area.

3.2.6. Economic factors

Economic factors are, by far, the most important catalysts of eucalypt plantation expansion in the study area and other areas of the Gurage Zone. With the growing trend of population pressure and degradation of natural forests, farmers' decision to plant fast growing trees, such as eucalypts is unquestionable in the study area, which is one of the most densely populated areas of the country. The main economic reasons for planting eucalypts in the study area include the growing need for fuelwood, construction and money for different purposes.

3.2.6.1. The growing need for fuel wood. In rural areas, biomass products have been the most important source of household energy. These sources come mainly from firewood, crop residues and animal dung. In the study area, due to the substitution of eucalypt, natural forests are rarely used as source of fire wood, which promoted their natural regeneration. Thus, to cope with energy demands in households, farmers started planting fast growing species, mainly, eucalypts. The survey result showed that in the study area, dependency on natural forest for firewood has been shrinking because of the extensive expansion of eucalypts, particularly, to fulfill domestic energy requirement. Using animal dung and crop residues as source of energy was common before the expansion of eucalypt woodlots. Only some farmers use these products, mainly, in dry seasons in Dega (upland) and Kola (lowland) areas.

3.2.6.2. The need for construction materials. Before 30 years, using eucalypts as source of construction raw materials was less common, particularly, in the Woinadega (midland) and Dega (upland) AEZs. The main sources of house construction materials were obtained from own indigenous woodlots and natural forests. However, these days, because of the

restriction of cutting of the trees from existing natural forests by Government, the communities at large and individual households, in particular, shifted their attention to using fast growing trees, such as eucalypts. Previously, timber from *Juniperus procera* Hochst. ex Endl. was the most preferred and strong for house construction. However, as a result of its slow growth, lack of availability and the high cost, its use for house construction purpose became less important. However, in Woinadega areas, it is still used for house construction proposes to some extent.

Farmers prefer, particularly, using *E. camaldulensis* (Red Eucalypt) than *E. globulus* (White Eucalypt) for construction purposes as a result of its physical attractiveness and resistance to termites in the ground. The straight nature of Red Eucalypt is also more conducive than the White Eucalypt. The need of eucalypts by farmers for construction purpose is increasing. In addition to house construction, eucalypts have great role in fencing, making farm tools and local bridges.

Besides being source of fuel wood and money, eucalypts became the stable source of construction tools and other means of livelihood sustenance (support) of the households in the region. Thus, the need of wood for construction purposes has its own impact on the expansion of eucalypts in the area.

3.2.6.3. Growing need for money. It seems that the cost and benefit on the use of eucalypts is known by farmers. For farmers, eucalypts mean "living bank account" (Turnbull, 1999; Teketay, 2000) that can be used when one is in need of money for different purposes, such as to pay land or agricultural taxes, yearly celebrations of *Meskel* and *Arafah*, and for supporting social institutions, such as *Mahiber* (religious shindig), wedding, *Zikir* (Holy memorial intake occasion), *Eekub* (rotating money funding system among individuals) and *Idir* (monthly money collection system for funeral service). Even when a farmer needs to cultivate own farmland, one has to have enough money so as to pay for daily laborers and to purchase food items such as *teff*, coffee, meat and local drinks. The money required for such and others expenses comes from the sale of eucalypt poles of different sizes (small, medium and big) in addition to selling cash crops, such as *Enset, Chat*, coffee, fruits, vegetables, cereals and pulses.

During the household survey, it was noted that some farmers in the study area collected about 80,000 Birr (= 3558.54 USD; exchange rate: 1 USD = 22.4811 Birr at 02/02/2017) in six years by selling eucalypt poles. Such farmers are not only boasting high prestige in the community because of their higher income, but are also socially more respected. Such farmers are also motivating other farmers to plant more eucalypts on their landholdings.

The income generated from selling eucalypt products supplements/compliments the household income (livelihood support) obtained from crops, livestock and non-farm activities. Eucalypt woodlots are also becoming strong coping strategy to ensure food security in addition to all other farm products as reported by focus groups and key informants. Thus, many households have started growing more trees than ever in the past, which ultimately accentuated expansion of eucalypt plantations.

4. Conclusions and recommendations

Land use and land cover dynamics is a common trend in all parts of the globe. There are several possible reasons for LULC transformation, such as economic, political, social or cultural motives. In Ethiopia, most of the rural and urban people are highly dependent on eucalypts for various purposes, particularly for fuel wood and construction materials. Plantations of eucalypts provide wood and other products, thereby, reducing the pressure on the natural forests.

Sample households from the three AEZs have clear understandings about the increment of their eucalypt wood lots since they started establishing eucalypt plantations. Planting more trees means creating varieties of opportunities in their livelihoods. Thus, all key informants and focus groups reported that they have continued planting eucalypts ever since they started. They have planted eucalypts almost in all types of landscapes found in their possessions, i.e. in flat, gently sloping and rugged areas. The trends in the study areas indicate a continuous increase in the total areas covered with eucalypt plantations.

The increase in planting of eucalypts is also attributable to price increment in eucalypt poles. As reported by key informants and focus groups, the main reason for its expansion is that the roles that eucalypts play in supporting the livelihoods of households tend to out ways by far the contributions generated from other cash crops. However, they also reported that there is fear that its competition with food crops, such as '*enset*', food crops and grazing land may shift the farming system of the Gurage Zone from *Enset* Culture to another system. This may threaten the livelihoods of communities and environmental sustainability in general. Hence eucalypt may not substitute *enset* for food security as a result of the presence of high population pressure and unless wise management on its planting practice is applied, it may also threat the environment.

Almost all studies agree that at the moment, there is no other genus or species as productive, well-adapted or requested like the *Eucalyptus*. The rate of adoption, amount of goods and services and level of socio-economic importance of this species are high. Eucalypts help local communities to diversify their farm income and increase their farming systems only when the wise planting practice is applied.

Ethiopia has been under severe wood deficit, and the gap between demand and supply of wood is widening enormously (EFAP, 1994; Teketay, 2000, 2001). Thus, eucalypts are needed to meet the ever-increasing demand for wood associated with rapid human population growth.

The areas of eucalypt woodlots increased with farm size since farmers have better opportunity to grow more trees once they have satisfied their subsistence and cash needs from food crops. Eucalypts are planted in the form of homesteads, farm woodlots, roadside plantations, degraded area plantations, riverside woodlots, gully side plantations and farm boundary plantations as first priority tree species in the study area.

The adoption of planting eucalypts has a history of more than a century. In the study area economic, social and environmental factors contributed for the expansion of agroforestry, in particular establishment of eucalypt plantations. Pressure from the ever-increasing population has encouraged people to be engaged in farm forestry practices, such as establishment of plantations of eucalypts. Thus, land use competition between eucalypt trees and food crops is becoming stronger in these areas. Also, road development in the study area has motivated farmers to plant eucalypts in flat areas adjacent to road sides instead of growing food crops. Increased access to markets, socioeconomic factors, such as *Meskel* and *Arafah* celebrations, which increased the demand and benefits from eucalypts, encouraged farmers to grow more eucalypt trees in their possessions.

Thus, farmers in the study area will continue growing eucalypts until other indigenous species that can substitute eucalypts are found. The divergent interests, scepticism and debate associated with eucalypts call for further scientific understanding that can inform decision making by concerned stakeholders.

In many parts of the world where eucalypts are cultivated as non-native species, they have spread from plantations to become invasive (i.e. forming self-sown populations sometimes far away from planting sites). In some countries, this is a growing problem that adds to the list of concerns expressed by stakeholders about the role of eucalypts in landscapes (e.g. see the review by Rejmanek & Richardson 2011). In the study area, and in Ethiopia as a whole, eucalypts are not seen as invasive species. However, farmers constantly expand it by converting other land uses.

In this paper a balanced review of the positive and negative roles of a eucalypt species is explored. Across diverse landscapes and contexts in other African countries, similar view is also seen (Hirsch et al. 2020). Perhaps a similar approach could be the course for sustainable use of the species into the future.

Based on the results from the present study and lessons drawn from the literature, the following recommendations are proposed:

- stakeholders should be capacitated with the knowledge about the environmental controversies and benefits of eucalypts;
- careful selection of appropriate species and matching of species with appropriate sites must be taken as prerequisites, and the right management practices should be employed;
- fewer trees per unit area should be planted, and existing plantations should be thinned to reduce the water consumption needed by eucalypts in areas where water is scarce or demanded by other crops;
- natural forests or even secondary growth should not be cleared to make way for eucalypt plantations;
- eucalypts could be tried in mixed species systems, using indigenous tree species and vegetation to minimize adverse impacts on biodiversity and wildlife;
- in order to solve the problem of land use competitioncompletion with food crops, shortage of fuel wood and construction materials, and sustain the environment in the studied watershed areas, there is a need to promote the planting of eucalypts in sites far-away from crop and grazing lands mixing with indigenous species;
- interventions should be explored and applied to address the unplanned land use/land cover change that may result in undesirable economic, social and cultural damage to the *Enset* culture in the study areas;
- representatives of households should get training on eucalypt tree plantations and their management;
- eucalypt plantations, which are becoming dominant in the watersheds, should be complimented with diversified alternative income generation horticultural ventures, such as cultivation of apple, avocado and mango based on soil and climate suitability;
- introduction and use of modern stoves, e.g. *Mirt Midija*, and indigenous technologies towards fuel energy consumption may lead to reduction in expansion of expansion of eucalypt plantations; and
- an in-depth community participatory research is needed aimed at overcoming problems of serious land use competition between eucalypt plantations and food crops.

Declaration of statement Interest

None.

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