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Land use and land cover dynamics in Dendi-Jeldu hilly-mountainous areas in the central Ethiopian highlands

Muluneh Minta[a,b,*], Kibebew Kibret[b], Peter Thorne[c], Tassew Nigussie[d], Lisanework Nigatu[b]

[a] Ethiopian Institute of Agricultural Research, Holetta Research Center, Holetta, Ethiopia
[b] Haramaya University, School of Natural Resources Management and Environmental Science, Harar, Ethiopia
[c] International Livestock Research Institute, People, Livestock and Environment, Addis Ababa, Ethiopia
[d] Geomark System Plc., Addis Ababa, Ethiopia

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ABSTRACT

The central Ethiopian highlands where most human and livestock populations concentrated have experienced a drastic change in land use and land cover (LULC) of the landscapes. This study was aimed to define the rate and pattern of LULC changes in Dendi-Jeldu hilly-mountainous areas in the central Ethiopia. Aerial photographs of years 1957 and 1995, and Landsat images taken at 1995 and 2014 were used to analyze the historical land use and land cover (LULC) changes. The study covered an area of about 438 km^2. The analysis extracted from these remote sensing data revealed that, in 1957, the dominant LULCs were pastureland, cultivated land (cropland) and forestland covering 49, 25 and 20% of the total area, respectively. Remarkable LULC change dominated by cultivated land expansion (now covering 68% of the total area), however, claimed vast areas under pastureland (main), forestland and woodland. Deforestation in particular, would have been greater if Chilimo forest (remnant afro-montane forest) was not under state control. Plantation forestry exclusively dominated by eucalyptus species also showed substantial expansion into pastureland in the period between 1957 and 1995, and cultivated land between 1995 and 2014. In the period 1957 to 2014 cultivated land, plantation land and settlement were increased by 170%, 13,674% and 172% respectively, while pastureland, forestland and woodland declined by 67%, 73% and 100%, respectively. Change from natural habitat (pastureland, forestland and woodland) to other land uses (cultivated, plantation and settlement lands) is likely to have a large impact on biodiversity, land degradation and beyond.

1. Introduction

Since time immemorial, humankind has modified the natural environment to obtain food, fiber, freshwater, medical products and other essential materials. The extent and pace of human alterations of land surface increased rapidly over the last three centuries, and accelerated over the last three decades (Ramankutty et al. 2006; Lambin et al. 2001; Agarwal et al. 2000). Changes in land use (human purpose or intent applied to biophysical attributes of the earth's surface) and land cover (biophysical attributes of the earth's surface) are key forms of human impacts on the natural environment driven by multiple interacting factors including demographic, social, economic, political, economic, technological and institutional variables (Braimoh and Vlek 2008; Mather 2006; Brookfield 1999). Changes in any of these drivers (underlying factors) usually result in changes in one or more of the proximate factors (recurrent set of activities such as land clearing, cultivated land expansion, and urbanization) (Geist et al. 2006). The driving factors thereby LULC change varies in time and space depending on the specific human-environment conditions. Land use and land cover change is generally a concern due to its pervasive effects on loss of biodiversity, soil degradation and a reduced ability of the landscape to sustain natural resources and ecosystem services (Muriuki et al. 2011; Ellis and Pontius 2007; Chhabra et al. 2006).

Since the past few decades, significant LULC change has been taking place in the Ethiopian highlands (> 1500 m.a.s.l). Several studies pointed out that deforestation and expansion of cultivated land into marginal areas are the principal forms of LULC change in most upland areas of the country (Lemenih et al. 2005; Feoli et al. 2002; Zeleke and Hurni 2001). Despite some authors (Nyssen et al. 2004; Melaku 1992) are skeptical about often cited 40% forest cover of the Ethiopian landscape in 1900 (EFAP 1994) and estimates of forest cover are inconsistent (Pankhurst 1995; Von Breitenbach 1961), several research reports dealing with LULC changes and evidences from the local communities affirm widespread deforestation from the highlands in search

* Corresponding author at: Ethiopian Institute of Agricultural Research, Holetta Research Center, Holetta, Ethiopia.
E-mail address: mulumenta@gmail.com (M. Minta).

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of new cultivated and grazing lands.

It appears that, agriculture is the greatest forces of land transformation in the highlands. Due to favorable climatic and ecological conditions, the Ethiopian highlands (43% of the total area) have a long history of settlement and sedentary agriculture, thereby hosting and supporting the greatest proportion of the country's population (Pankhurt and Piguet 2009; Amsalu et al. 2007). Currently, agriculture occupies the majority of the land area in the highlands (FAO 2006; Sonneveld and Keyzer 2003). However, the growth of the sector is not keeping up with rapid population growth (CSA 2014; Minale 2013). Such a dynamic tension between the increasing population and agricultural productivity has forced the continued expansion of cultivated land into increasingly steeply sloping landscapes under natural habitats (Hurni 1993; EFAP 1994; Sanchez et al. 1997; Nyssen et al. 2009).

Despite concerns about LULC change emerged in the research agenda on global environmental change several decades ago (Lambin et al. 2003), in Ethiopia studies on LULC change has received research interest very recently. The evidence base is very limited and spatially concentrated in specific areas, mainly in the Northern highlands (Blue Nile river basin) and some in rift valley lake basins (Tefera et al. 2002; Muluneh 2010). However, resource availability, their dynamics and management vary considerably over time and from area to area (Veldkamp and Lambin 2001). In the study area, there is no previous data that would help to understand historical LULC change and related issues with the exception of a study made on deforestation of Chilimo forest (Melaku 2003). Several studies in the different parts of the country are required for a profound understanding of the dynamics in the human-environment interactions at different spatial and temporal scales (Veldkamp and Verburg 2004). This would be useful to make better "generalities" on patterns of LULC change and likely impacts on ecosystem functioning in Ethiopia. Therefore, this research addressed the rates and patterns of LULC change (1957–2014) in Dendi-Jeldu mountainous areas in the central Ethiopian highlands and provides information on the implications to environmental sustainability and the livelihoods of farming communities.

2. Methods

2.1. Location

The study area falls in three districts (*Weredas*) of West Shewa Zone, namely Dendi, Jeldu and Elfata in Oromia National Regional State, central Ethiopian highlands. The location lies between 9° 00′ 54″–9° 15′ 18″ N latitude and 38° 02′ 10″–38° 13′ 35″ E longitude covering about 438 km^2 (Fig. 1). The altitude ranges between 2200 and 3100 m above sea level. Geographically the study area is characterized by extensive plateau of undulating landscape dissected by mountain ranges and incised river valleys highly vulnerable to land degradation (Mowo et al. 2006). The majority of the area represents tepid-cool highlands agro-ecological zones of Ethiopia most suitable for human settlement and livestock production (EIAR 2011). The rainfall is bimodal with an average annual rainfall of 1400 mm in high elevation areas while low elevation areas receive 1042 mm (Adimasu et al. 2012; Mekonnen 2007). Sixty five percent of the total annual rainfall occurs during the main rainy season (June–September), while the short rains (March–May) and dry-period (October–February) receive 24% and 10% respectively. The average minimum and maximum temperature of Dendi areas (southern parts of the study site) is 8.6 °C and 24.2 °C respectively, while that of high elevation areas is 4.9 °C and 19.9 °C respectively (Source: Holeta Agricultural Research Center/HARC).

The dominant soil type is Haplic Luvisols (Mekonnen et al. 2008) in association with Eutric Nitisols (FAO/UNESCO 1995). Rain-fed cropping, integrated with livestock production, is the mainstay of smallholder farmers. Barley (*Hordeum vulgare* L.) and potato (*Solanum tuberosum* L.) are crops widely cultivated in high elevation areas, while *tef*, wheat and chickpea are dominant crops grown in the lower elevation areas around Ginchi. Oat (*Avena sativa* L.) and enset[1] (*Enset ventricosum* (Welw.) Cheesman) are also grown in most areas of the study site. Cattle, sheep and horses are dominant livestock species used by the smallholder farmers. Forest encroachment has been the major problem (Mowo et al. 2006) and natural woodlands are almost extinct with the exception of the remnant dry afromountane Chilimo forest (about 2400 ha) and, on agricultural land. *Eucalyptus globulus* is the dominant tree species widely used for construction and to meet the energy needs of the rural community. Based on projected estimate (CSA 2013), population density in the study area is estimated to be 170 persons per square kilometer.

2.2. Land use and land cover classification and measure of changes

The spatial and temporal dynamics of the different LULC classes were investigated using remote sensing data (aerial photos and satellite images) of the period from 1957 to 2014, covering 57 years. The study period was divided into three time intervals, (1957–1980, 1980–1995, 1995–2004) based on the availability of reliable remote sensing data. These periods did not superimpose exactly on the three ruling regimes [monarchic (1930–1974), socialist *Derg* (1974–1991) and Ethiopian People's Revolutionary Democratic Front EPRDF (since 1991)] but there was a significant overlap between periods and regimes. The three regimes are distinct in their economic policies and land tenure system (Rashid et al. 2007).

For time series LULC change analysis, aerial photographs (1957 and 1980) and satellite images (1995 and 2014) were used in combination. The two sets of panchromatic aerial photographs taken during the dry seasons (December) of 1957 and (January) 1980 at a scale of 1:50,000 obtained from Ethiopian mapping authority (EMA); and multispectral satellite images (Landsat TM (1995) and ETM + (2014)) with a pixel size of 30 m × 30 m obtained from USGS.gov. Orthographic correction on the aerial photographs (scanned at 1016 dpi) was carried out using 90 m Aster DEM data. Aerial photos of 1980 were geo-referenced according to the Universal Transverse Mercator (UTM) system using a 1:50,000 topographic map (series: ETH 4; sheet: 0938 C3; edition: 1 EMA 1982) of the study area. The 1957 aerial photographs were geo-referenced using referenced 1980 aerial photos. Satellite images of 1995 and 2014 were also geometrically rectified and registered to a 1980 aerial photos.

Before classification, different LULC classes were extracted from the aerial photos. For satellite images, pre-processing was carried out using color composites in RGB transformation. To classify LULC types, a false color grid composite image was developed using ERDAS virtual Geographical Information System (GIS) analyzer. First, unsupervised classification was made to get the major land parcels which then used for supervised classification. Training sites and ground verification using Geographical Positioning System (GPS) were employed to verify the accuracy of the LULC map of 2014 with field points. About 750 random ground control (truths) points were used for verification of LULC classification outputs. Some inaccessible control points were taken from high resolution images of Google earth. The classification was done using the maximum likelihood classifier as described by Lillesand and Kiefer (1999). Finally, the LULC maps of the respective reference years (1957, 1980, 1995 and 2014) at a scale of 1:120,000 and temporal changes in LULC were determined and analyzed for interpretation. Due to quality problems in some aerial photographs and satellite images, six LULC classes were distinguished (see the LULC classes and their description in Table 1). These include: cultivated land, pastureland, forestland, woodland, settlement and plantation (eucalyptus) land. Others such as degraded/bare lands, long-term fallow

[1] Enset is an herbaceous monocot, large, banana like plant that grows 4–8 m in height (Tsegaye and Struik 2001). It is drought tolerant (Adimasu et al., 2012), and its leaves are often used as feed during the dry seasons.