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Land use/land cover changes and their environmental implications in the Gelana sub-watershed of Northern highlands of Ethiopia

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Abstract

Background: Soil erosion in the Ethiopian highlands is considered to be one of the major problems threatening agricultural development and food security in the country. However, knowledge about the forces driving the long-term dynamics in land use is limited. Therefore, the aim of this paper was to analyse the spatial and temporal land use/land cover (LULC) changes and their environmental implications over the period 1964–2014 in the Gelana sub watershed, Northern highlands of Ethiopia. Two aerial photographs (1964, 1986) and a Landsat 8 image (2014) were the source of objective landscape data. The subjective supporting data was collected by group discussion, interview and field visits that include the collection of photographic evidence. Seven LULC types, namely forest, shrub land, cultivated and rural settlement, grass land, bare land, urban built up area, and wet land were identified.

Results: The result revealed that during the analysis period shrub land, cultivated and rural settlement, grass land, bare land, and urban built up area expanded at a rate of 0.48, 0.14, 0.62, 4.95, and 28.45% per year respectively. On the other hand, during the same period forest and wet land decreased by 1.28 and 1.09% per year respectively. The observed LULC changes were driven by population growth, growing demand for cultivated and rural settlement and forest for extraction of fuel and construction materials.

Conclusions: These aggravate soil erosion and biodiversity loss. This information on LULC changes and possibilities for their optimal use is essential for the selection, planning and implementation of land use schemes to meet the increasing demands for basic human needs and welfare. Therefore, there is an urgent need to design and implement appropriate land management options, coupled with population control and designation of protected areas to preserve natural resources.

Keywords: Land use, Land management, Soil erosion, Northern highlands of Ethiopia

Background

In developing countries where a large proportion of the human population depends almost entirely on natural resources for their livelihoods, there are competing demands for utilization, development and sustainable management of the land resources (e.g. natural vegetation), resulting in land-use and cover changes (Mwavu

and Witkowski 2008). Land use/land cover (LULC) change has important impacts on the functioning of socio-economic and environmental systems with tradeoffs for sustainability, food security, biodiversity and the vulnerability of people and global ecosystem impacts (Lesschen et al. 2005). The formation of a given land cover results complex processes and can be considered as the biophysical state of the earth's surface and immediate sub-surface (Turner II et al. 1995), while land use refers to the conversion or transformation of the land cover into the desired human purposes which are associated with that

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cover, e.g. cropping, conservation, or settlement (Meyer and Turner 1994).

Studies on LULC (for example, Turner II et al. 1993, 1995; Lambin et al. 2001) showed that socio-economic and biophysical variables act as the driving forces of land use changes. Driving forces are generally subdivided into two groups: proximate causes and underlying causes. Proximate causes are the activities and actions that directly affect land use, e.g. wood extraction or road building. Underlying causes are the 'fundamental forces' that underpin the proximate causes, including demographic, economic, technological, institutional and cultural factors (Geist and Lambin 2002).

In the highlands of Ethiopia, agricultural practices and human settlement have a long history and recently a high population pressure including unsustainable practices and depletion of the natural resources. As a result, significant land-cover changes have been observed since the last century (Gete 2000; Solomon 1994; Kebrom and Hedlund 2000; Gete and Hurni 2001; Woldeamlak 2002; Woldeamlak and Solomon 2013). These changes are caused primarily by anthropogenic activities, because increasing population has forced people to clear forest for cultivation and for forest products (Girmay et al. 2010).

In Ethiopia, previous studies reported that there have been considerable LULC changes in different parts of the country over the different time periods (Gete 2000; Kebrom and Hedlund 2000; Belay 2002; Woldeamlak 2002; Gete and Hurni 2001; Aklilu et al. 2007; Asmamaw et al. 2011; Mohammed 2011; Tsehay and Mohammed 2013; Kassa et al. 2014; Eleni et al. 2013). Kassa et al. (2014) reported that there was a strong decrease of the forest and bush land in favor of arable land and rangeland from 1965 to 1994 in Eastern Tigray. For the period between 1957 and 1995, there was a significant increase in cultivated land at the expense of forests in the Dembecha area of NorthWest Ethiopia (Gete 2000).

In contrast, some studies found an increase of forest cover in the country. For instance, Amare et al. (2011) reported that a substantial increase of shrub land and forest at the expense of cropland and grazing land since the late 1970s in the Eastern Escarpment of Wollo. Throughout the period 1958–2006, an increase in forest land was documented in Gerado catchment, northeastern Ethiopia (Asmamaw et al. 2011).

However, studies of LULC changes at sub watershed level are rare in Ethiopia and there have been no studies of LULC changes and their environmental implications in the study area, which is an important consideration in the design of integrated watershed management and of appropriate sustainable land management practices, strategies and policies that best fit to local conditions in

the country. Furthermore, during the study period, the three regimes occurred and set up different ideologies and differing land policies. So, this study could show the contribution of these regimes for LULC changes in the study area. Therefore, the objective of this study was to analyze LULC changes and their environmental implications in the Gelana sub watershed of Northern highlands of Ethiopia using the analysis of available panchromatic aerial photographs and satellite image. Attempts to combine the available heterogeneous spatial data sources could significantly alleviate the challenge faced by areas with inadequate geospatial database, but such endeavors are rarely employed in the Ethiopian context.

Methods

Description of the study area

The Gelana sub-watershed is situated in Wollo area, Amhara region of Ethiopia. Geographically, it lies between 11°34'44" and 11°45'4"N, and 39°34'11" and 39°45'2"E (Fig. 1). It is located 491 km north of Addis Ababa. It covers 24,972 ha of land. Its elevation ranges from 1365 to 3328 m above mean sea level. Physiologically, the study area is located in the western escarpment of Afar rift valley. The present complex topography has been formed by large scale tectonic and volcanic activity and covered by Cenozoic volcanic rocks (Mohr 1971) and subsequent fluvial erosion. It is composed of rugged topography incised by steep river valleys. The slope gradient of the study area varies from flat to very steep slopes. The sub-watershed drains eastward to the Awash River.

The study area falls into three agro-climatic zones: hot (Kolla), temperate (Woina Dega) and cool (Dega) climatic zone (MOA 1998). The mean annual temperature of 22 years (1992–2014) was 20.9 °C (NMSA 2015). The mean monthly temperatures ranging from 18.2 °C in December to 24.3 °C in June (Fig. 2).

The watershed is characterized by unimodal pattern of rainfall with a mean annual total of 1024 mm with a peak in August (Fig. 2). About 59% of the rainfall occurs between June and September.

The major soil types in the study area are Leptosols, Cambisols, Vertisols, and Regosols (ADSWE 2011). Gelana sub-watershed is densely populated with 64,965 people in 2007 (CSA 2008) and average density of 260 persons per km².

Agriculture has been practiced in the watershed for millennia and is the main economic activity and source of livelihood. The farming system is mixed crop-livestock production on a subsistence level. The major crops of the area are cereal crops including sorghum (*Sorghum bicolor*), teff (*Eragrostis tef*), maize (*Zea mays*), barley (*Hordeum vulgare*) and wheat (*Triticum vulgare*). Other major

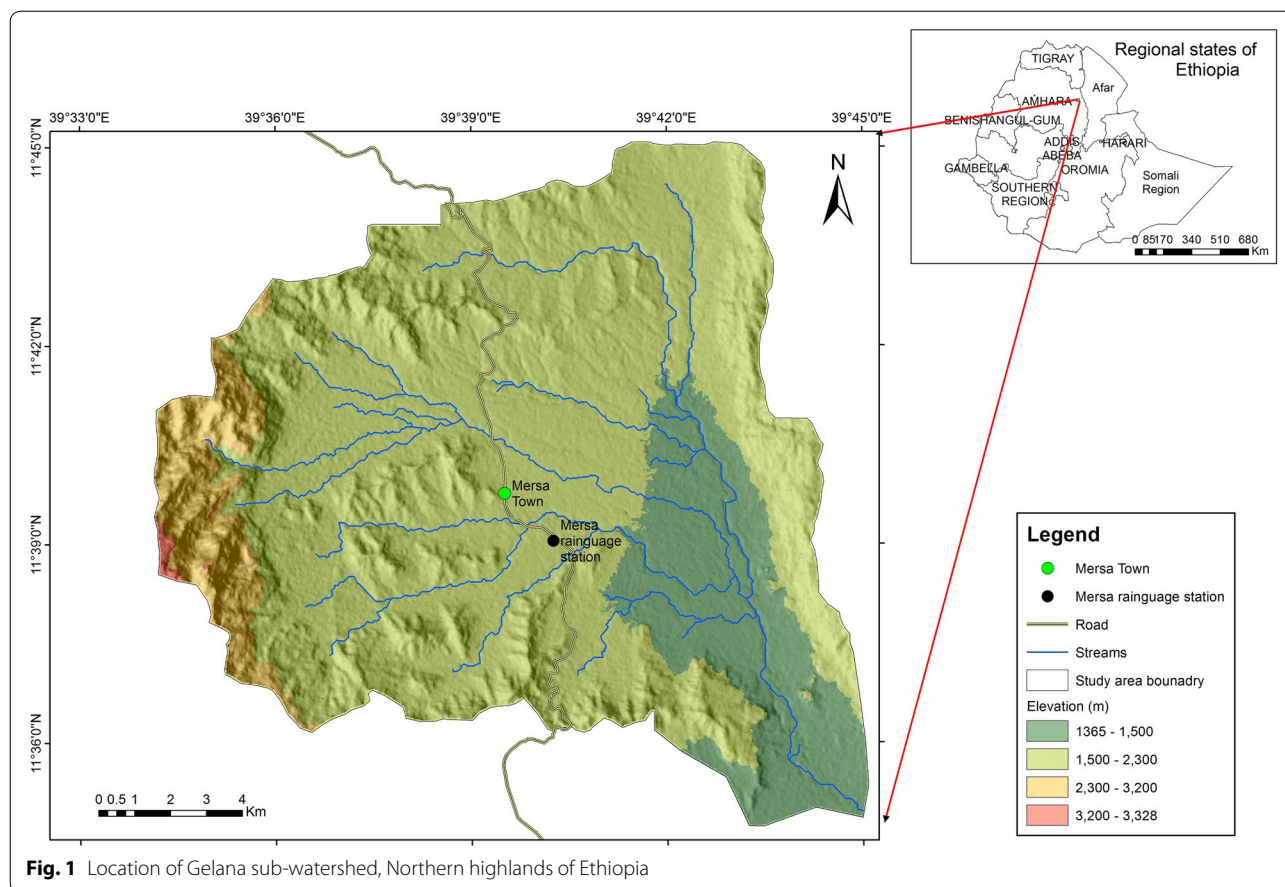


Fig. 1 Location of Gelana sub-watershed, Northern highlands of Ethiopia

crops are pulses such as Chickpea (*Cicer arietinum*), Field Pea (*Pisum sativum*), and Faba Bean (*Vicia faba*).

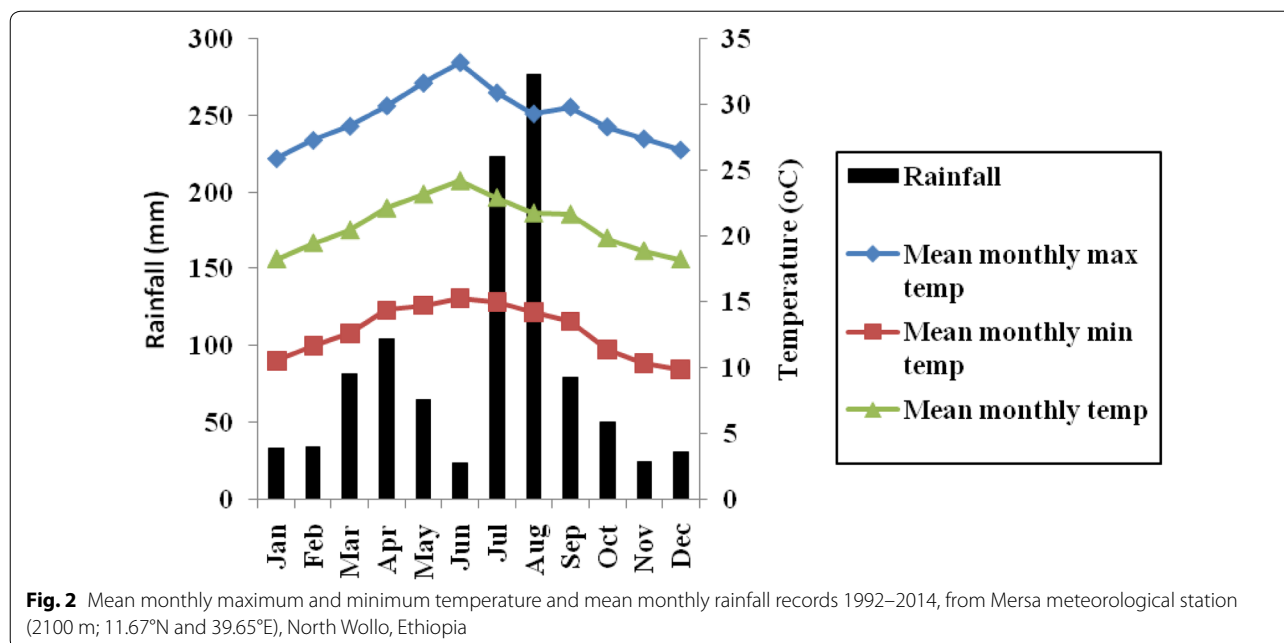
The farmers also cultivate fruits and vegetables. The most commonly cultivated fruits are orange, banana, papaya, mango, lemon, avocado and *Tirengo* (*Citron medica*). Livestock is closely integrated in the farming system and is used mainly for ploughing, threshing and transport. Livestock is also important sources of food and household income.

Methods and procedures

The study used aerial photographs of 1964 and 1986 at a scale of 1:50,000, and Landsat 8 image of 2014 to come up with the LULC map of Gelana sub-watershed. Selection of the 1964 year for LULC classification was based on availability of data for the study area. We selected 1986 aerial photographs because it was a period of localized Wollo drought. Finally, we selected 2014 satellite image to examine the current status of LULC changes and government land management practices; 2014 being the most recent satellite image available to the researchers.

The aerial photographs and satellite images were obtained from Ethiopian Mapping Agency (EMA). The

boundary of the study area was delineated by 1:50,000 topographic maps (EMA 1994). The aerial photographs were scanned with a high resolution of 1200 dot per inch (DPI) scanner and saved to Tag Image File Format (TIFF). The TIFF data were ortho-rectified in ERDAS 9.1 software using Digital Terrain Elevation data (DEM 30 m). The ortho-rectified photos were geo-referenced based on ground control points that were visible on topographic maps of the study area. Thus, image coordinates were transformed into map coordinates as per the local geodetic datum of Adindan, the reference ellipsoid of Clark 1880 (modified), and the Universal Transverse Mercator (UTM) projection Zone 37 North. From the geo-referenced aerial photographs, an ortho-photo mosaic was created (Fig. 3). On screen digitizing and editing of LULC types from the images was carried out using ARC GIS 10.2 software. Next visual interpretations of features on the aerial photographs were made based on the shade, shape, size, tone, pattern, texture and location of the features from aerial photos (1964 and 1986) using a mirror stereoscope (Ermias et al. 2013). Objects as small as 30 m x 30 m were identified on the aerial photographs and were classified.



The 2014 satellite image was corrected for atmospheric, sensor, and illumination variance through radiometric calibration procedures. The image was also corrected geometrically using a 1:50,000 scale map of the study area and was georeferenced following the above procedure used for ortho-rectifying the photos. For the classification of the satellite image, field work was conducted to establish ground truth data (reference data) for the verification of LULC types. A total of 1964 reference data points were collected using a Global Positioning System (GPS 60), of which 520 points were used for accuracy assessment and 1444 points were used for classification. Training sites were developed from the ground truth data collected to generate a signature for each land cover type. Supervised classification was made using ERDAS IMAGINE 9.1 software following Maximum Likelihood Classifier (MLC) procedure (Lillesand and Kiefer 2000) and exported to ArcGIS in vector format (Fig. 3). Then, GIS 10.2 software was used to produce LULC maps of 1964, 1986 and 2014. Accordingly, seven LULC classes were identified in the Gelana sub-watershed (Table 1). Finally, the rate of change and change detection matrix for each LULC between the different periods was computed.

After classification was performed, the accuracy of 2014 LULC map was assessed by computing the error matrix which compares the classification result with ground truth data (reference data) (Table 2). Stratified random sampling design was used to collect the aforementioned 520 reference data during field observations. The producer accuracy, user accuracy, overall accuracy, and Kappa coefficient were calculated for the classified

map of 2014 based on the formula given by Congalton and Green (2009).

$$\text{Overall accuracy} = \frac{\sum_{i=1}^k n_{ii}}{n}$$

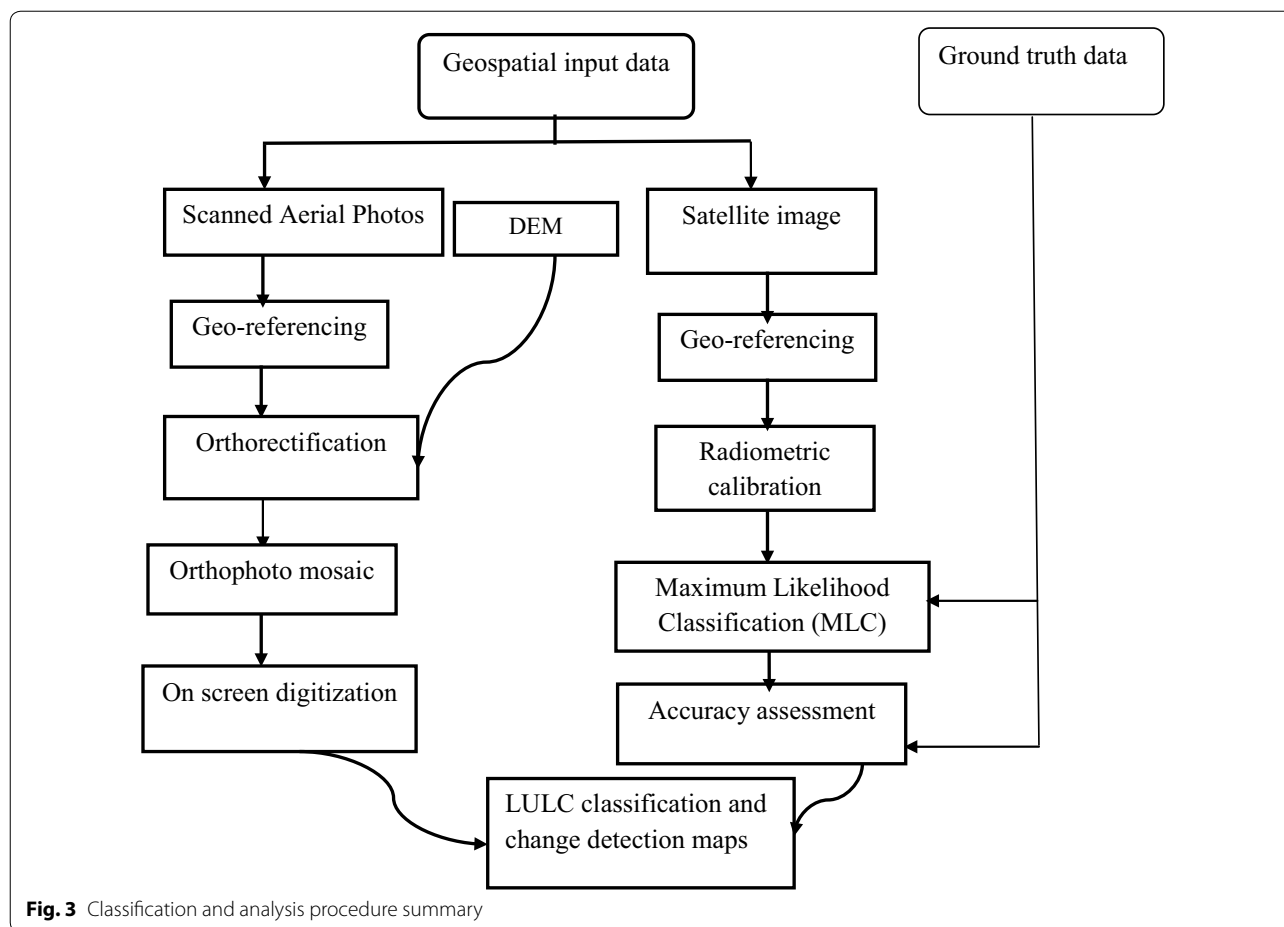
$$\text{Producer's accuracy } i = \frac{n_{ii}}{G_i}$$

$$\text{User's accuracy } i = \frac{n_{ii}}{C_i}$$

$$\text{Kappa coefficient} = \frac{n \sum_{i=1}^k n_{ii} - \sum_{i=1}^k (G_i C_i)}{n^2 - \sum_{i=1}^k (G_i C_i)}$$

where *i* is the class number, *n* is the total number of classified pixels that are being compared to ground truth, *n_{ii}* is the number of pixels belonging to the ground truth class *i*, that have also been classified with a class *i*, *C_i* is the total number of classified pixels belonging to class *i* and *G_i* is the total number of ground truth pixels belonging to class *i*.

The authors conducted focus group discussions (FGD) in February 2014 in order to subjectively identify the major driving forces of LULC changes and their environmental implications of the study area. A total of 3 FGD were carried out, that is, 1 focus group in each of the upper, the middle and the lower sub watersheds. Each FGD had 7 participants from local elders, local community leaders and agricultural extension workers. In addition, the key informants (*n* = 15) from the local



community were interviewed to get additional information about how the LULC in their surrounding area evolved through time and about their observations of the causes of the changes. The key informants were elders who were older than 70 years and who were lived in the sub watershed more than 50 years.

Results and discussion

Accuracy assessment

Results of the image classification of 2014 were validated by creating an error (confusion) matrix from which different accuracy measures are derived. An error matrix compares information from reference sites to information on the map for a number of sample areas.

Table 2 shows an error matrix that was established using 520 ground control points which were not used in the classification of the 2014 image. According to the error matrix report (Table 2), the classification had an overall accuracy of 85.19% with a kappa coefficient of 0.82. The kappa coefficient values are a measure of agreement or accuracy between the reference data and land use/cover values in the classified image. The values can

range from +1 to -1 (Congalton and Green 2009). Landis and Koch (1977) suggested the possible ranges for kappa coefficient into three groupings: a value greater than 0.80 represents strong agreement; a value between 0.40 and 0.80 represents moderate agreement; and a value below 0.40 represents poor agreement. According to these ranges, the classification in this study had strong agreement with the reference data.

Land use/land cover changes since the 1964

The land use/land-cover maps of the Gelana sub watershed for the years 1964, 1986, and 2014 are presented in Fig. 4. Tables 3, 4 and 5 show the area coverage, trend and matrix of land-use and land cover types identified in the watershed. Descriptions of the changes in LULC over the period of analysis are as follow.

Forests

The forest cover of the study area had shown a gradual decline during the study periods (1964–2014). In 1964, forest cover was 3613 ha, i.e. 14.47% of the study area and decreased to 749 ha (3%) in 1986 (Table 3; Fig. 4a, b). It

Table 1 Description of LULC types identified in the Gelana sub watershed, Northern highlands of Ethiopia

LULC class	Description
Forest	Areas dominantly occupied both by planted and natural forests
Shrub land	Area covered by small trees, bushes, and shrubs mixed with grasses; less dense than forests
Cultivated and rural settlement land	Areas covered with annual and perennial crops and scattered rural settlements
Grass land	areas predominantly covered with grasses
Bare land	Areas with little or no vegetation cover consisting of exposed soil and/or rock outcrops
Urban built up area	Residential houses, administrative buildings, and small industrial areas
Wet land	Areas that are waterlogged and swampy in the wet season, and relatively dry in the dry season

Table 2 Error matrix (confusion matrix) for the 2014 classification map

Classified data	Reference data							Row total	User's accuracy
	BL	CL	FL	GL	SL	UA	WL		
BL	52	3	2	1	0	1	0	59	88.1
CL	6	97	4	3	5	3	3	121	80.2
FL	0	1	65	2	9	0	0	77	84.4
GL	2	5	2	56	3	0	1	69	81.2
SL	0	9	3	4	75	0	0	91	82.4
UA	0	4	0	0	0	52	0	56	92.9
WL	0	1	0	0	0	0	46	47	97.9
Column total	60	120	76	66	92	56	50	520	
Producer's accuracy	86.7	80.8	85.5	84.8	81.5	92.9	92.0		

Over all accuracy = 85.19%, kappa coefficient = 0.82

BL Bare land, CL cultivated and rural settlement land, FL forest land, GL grass land, SL shrub land, UA urban built up area, WL wet land

increased from 3.0% (749 ha) in 1986 to 5.4% (1351 ha) in 2014 (Table 2; Fig. 4b, c).

The annual rate of forest destruction was 3.6% per year in the first period (1964–1986), but the rate of forest expansion was about 2.87% per year in the second period (1986–2014). In general, for the whole study period (1964–2014), the forest cover was declined by 1.25% per year.

The study further shows that there were considerable conversions of one type of LULC into another one in the study area (Table 5). In 1986, about 48.46 (1751 ha), 31.17 (1126 ha) and 8.83% (319 ha) of forests were converted to shrub land, cultivated and rural settlement land and grazing land respectively. Focus group discussion (FGD) and key informant interviews (KII) confirmed that, this destruction of forest attributed to the rapid population growth and increasing demand of cultivable and grazing land as well as demand for construction and fuel wood in the study area.

In contrast, in the second period (1986–2014) the forest cover was increased due to the gains from shrub land (880 ha) and bare land (21 ha). FGD and KII the gains in the later period was due to rehabilitation (area closure)

and reforestation programmes (tree plantation by the local community) in order to meet the ever increasing demand for construction and fire wood of the society.

Shrub land

Shrub land occupied 10.82 (2703 ha), 18.87 (4713 ha) and 13.41% (3348 ha) of the study area in 1964, 1986, and 2014 respectively. During the first period (1964–1986), shrub land increased by 74.36%, whereas in the second period (1986–2014), it decreased by 28.96%. In this period, 18.67, 31.08, 6.43 and, 1.49% of shrub land converted to forest, cultivated & rural settlement, grazing land and bare land respectively. In general, for the whole study period (1964–2014), shrub land increased by 645 ha (Table 4). The results clearly revealed the occurrence of significant LULC transformation from one land use class to another. Hence, as it was confirmed in the group discussion, the scenario of these observed changes both spatially and temporally of shrub land cover was due to the increased demand for fire wood, charcoal and construction materials for subsistence as well as expansion of forest and cultivated and rural settlement land.

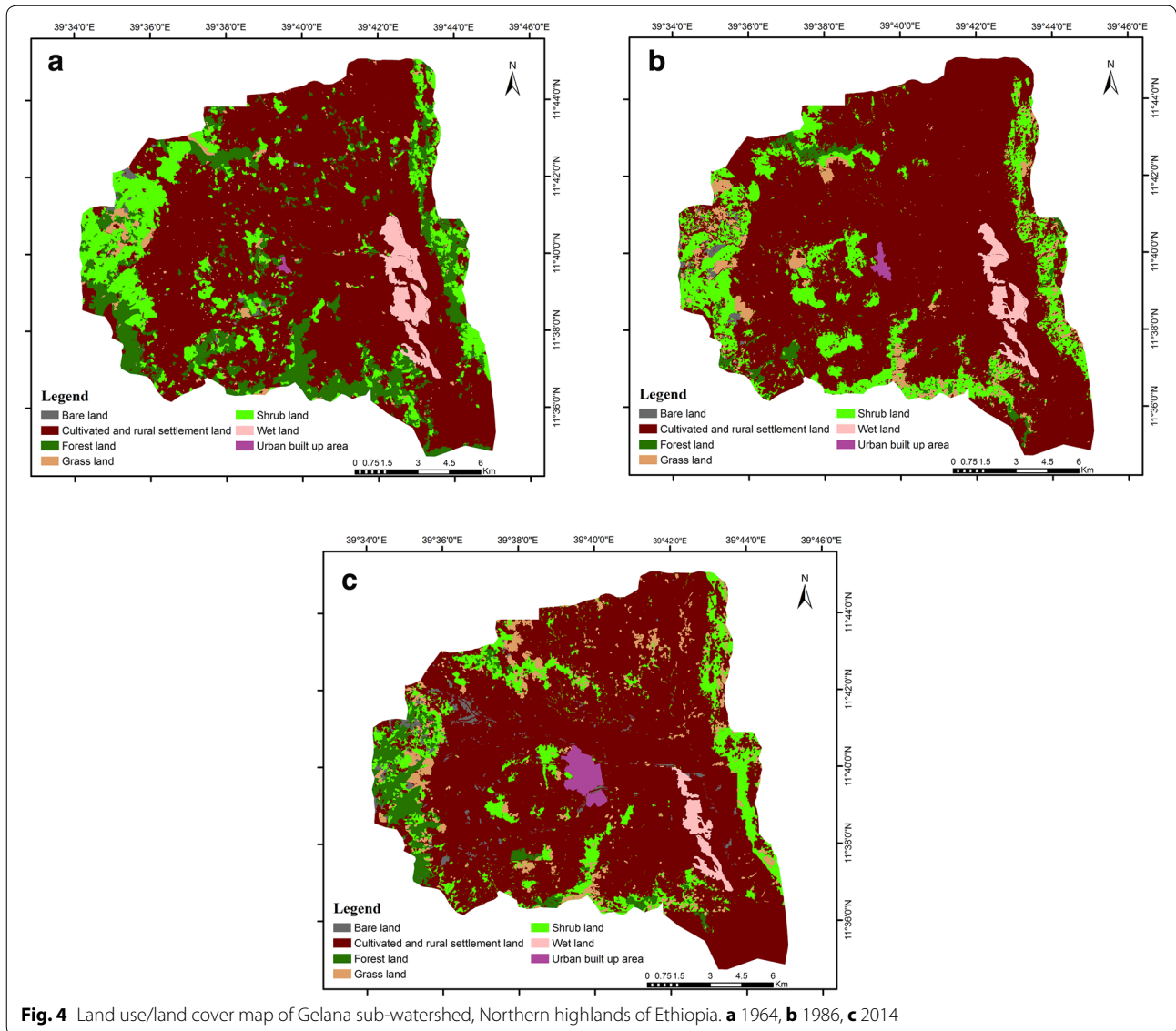


Fig. 4 Land use/land cover map of Gelana sub-watershed, Northern highlands of Ethiopia. **a** 1964, **b** 1986, **c** 2014

Table 3 Areal extent of LULC type of Gelana sub watershed in 1964, 1986 and 2014

LULC type	Areal extent of LULC type					
	1964		1986		2014	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Forest	3613	14.47	749	3.00	1351	5.41
Shrub land	2703	10.82	4713	18.87	3348	13.41
Cultivated and rural settlement	17,302	69.29	17,938	71.83	18,535	74.22
Grass land	568	2.27	890	3.57	744	2.98
Bare land	103	0.41	107	0.43	358	1.43
Urban built up area	22	0.09	73	0.29	335	1.34
Wet land	661	2.65	502	2.01	301	1.21
Total	24,972	100	24,972	100	24,972	100

Table 4 Trends of LULC changes in the Gelana sub watershed, Northern highlands of Ethiopia

LULC type	Trends of LULC changes								
	1964–1986			1986–2014			1964–2014		
	Area (ha)	% change	Rate of change (%/year)	Area (ha)	% change	Rate of change (%/year)	Area (ha)	% change	Rate of change (%/year)
Forest	–2864	–79.27	–3.6	602	80.37	2.87	–2262	–62.61	–1.25
Shrub land	2010	74.36	3.38	–1365	–28.96	–1.03	645	23.86	0.48
Cultivated and rural settlement	636	3.68	0.17	597	3.33	0.12	1233	7.13	0.14
Grass land	322	56.69	2.58	–146	–16.40	–0.59	176	30.99	0.62
Bare land	4	3.88	0.18	251	234.58	8.38	255	247.57	4.95
Urban built up area	51	231.82	10.54	262	358.90	12.82	313	1422.73	28.45
Wet land	–159	–24.05	–1.09	–201	–40.04	–1.43	–360	–54.46	–1.09

Cultivated and rural settlement

Cultivated and rural settlement land has remained the dominant form of land use, occupying about 17,302 ha (69.29%) of the study area in 1964, 17,938 ha (71.83%) in 1986 and 18,535 ha (74.22%) in 2014 (Table 3; Fig. 4a–c). This implied that a consistent increase of cultivated and rural settlement land. In addition, this LULC type increased by 3.68% (636 ha) between 1964 and 1986 at a rate of 0.17% per year and 3.33% (597 ha) between 1986 and 2014 at a rate of 0.12% per year. In 50 years period (1964–2014), cultivated and rural settlement land was increased by 7.13% with a rate of expansion of 0.14% per year (Table 4). The analysis also revealed that the expansion of cultivated and rural settlement land occurred mainly at the expense of forest, shrub land, grass land, bare land, and wet land and then it gains a total of 2503 ha of land during the first period (1964–1986). Similarly the expansion of this LULC type in the second period (1986–2014) was due to the conversion of 251 ha of forest, 1465 ha of shrub land, 308 ha of grass land, 35 ha of bare land and 193 ha of wet land to cultivated and rural settlement land (Table 5). This expansion of cultivated and rural settlement land may eventually result in soil erosion and biodiversity loss in the study area.

The group discussants and key informants in the Gelana sub watershed revealed that cultivated and rural settlement land increased in both periods due to increasing population pressure. As the growth of population increased, the demand for agricultural products in general increased and also increased the demand for rural settlement land, which resulted in the continuous expansion of cultivated land and rural settlement land. This expansion in cultivated and rural settlement land probably suggests that food crop supply was achieved through farm land expansion rather than intensification (Mohammed and Tassew 2009) as a result of high cost and limited access to agricultural inputs as it is true in the study area.

Its expansion during the first period (1964–1986) also associated with the 1975 land reform measure by the ‘Derg’ mainly abolished tenant landlord relationships in the nation with the aim of distributing land to the tillers, to increase agricultural production and provide a basis for expansion of agricultural land. Similarly, the increase of cultivated and rural settlement land in the second period (1986–2014) might be attributed to the 1991–1996 land redistribution programme of Amhara regional state in the study area. Hence, the farmers got “*Yewojede*” farmland which is those farmlands located near to the home of the farmer and “*Yeberha*” farmland refers to those farmlands located far from the farmers’ home during this period of land redistribution.

Grass land

The study area under grass land cover increased from 2.27% (568 ha) in 1964 to 3.57% (890 ha) in 1986 at a rate of 2.58% per year, followed by a decline to 2.98% (744 ha) in 2014 at a rate of 0.59% per year (Table 3, 4; Fig. 4a–c). The observed increase in the first period (1964–1986) was due to the conversion of 319 ha (8.83%) of the forest, 220 ha (8.14%) of the shrub land, 278 ha (1.61) of cultivated and rural settlement land and 7 ha (6.80%) of the bare land into grass land (Table 5). On the other hand, the decline in the area coverage of grassland during the second period (1986–2014) was as a result of about 86.74% of this LULC category converted into forest, shrub land, and cultivated and rural settlement land, bare land, and urban built up area. Hence, this conversion might be attributable to the rapid growth of population. The decline of grassland in the recent time leads to shortage of animal fodder and then declining of livestock. This is usually reflected in the availability of manure. According to Gete and Hurni (2001) manure is now in greater demand than ever not only because of the lower number of livestock but also because its use as a source of fuel has increased due to

Table 5 LULC transformation matrixes in the Gelana sub watershed between 1964 and 2014

Changed from	Changed to	1964–1986		1986–2014	
		Ha	%	ha	%
Forest	Forest	387	10.71	178	23.77
	Shrub land	1751	48.46	287	38.32
	Cultivated and rural settlement	1126	31.17	251	33.51
	Grass land	319	8.83	28	3.74
	Bare land	26	0.72	5	0.66
	Urban built up area	4	0.11	0	0
	Wet land	0	0	0	0
Shrub land	Forest	170	6.29	880	18.67
	Shrub land	1379	51.02	1995	42.33
	Cultivated and rural settlement	894	33.07	1465	31.08
	Grass land	220	8.14	303	6.43
	Bare land	39	1.44	70	1.49
	Urban built up area	1	0.04	0	0
	Wet land	0	0	0	0
Cultivated and rural settlement	Forest	154	0.89	157	0.87
	Shrub land	1368	7.9	725	4.04
	Cultivated and rural settlement	15,435	89.21	16,283	90.77
	Grass land	278	1.61	282	1.57
	Bare land	21	0.12	229	1.28
	Urban built up area	46	0.27	261	1.46
	Wet land	0	0	1	0.01
Grass land	Forest	37	6.51	114	12.81
	Shrub land	179	31.52	311	34.94
	Cultivated and rural settlement	266	46.83	308	34.61
	Grass land	66	11.62	118	13.26
	Bare land	20	3.52	38	4.27
	Urban built up area	0	0	1	0.11
	Wet land	0	0	0	0
Bare land	Forest	1	0.97	21	19.63
	Shrub land	36	34.95	30	28.04
	Cultivated and rural settlement	58	56.31	35	32.71
	Grass land	7	6.8	13	12.15
	Bare land	1	0.97	8	7.47
	Urban built up area	0	0	0	0
	Wet land	0	0	0	0
Urban built up area	Forest	0	0	0	0
	Shrub land	0	0	0	0
	Cultivated and rural settlement	0	0	0	0
	Grass land	0	0	0	0
	Bare land	0	0	0	0
	Urban built up area	22	100	73	100
	Wet land	0	0	0	0
Wet land	Forest	0	0	1	0.2
	Shrub land	0	0	0	0
	Cultivated and rural settlement	159	24.05	193	38.45
	Grass land	0	0	0	0
	Bare land	0	0	8	1.59
	Urban built up area	0	0	0	0
	Wet land	502	75.95	300	59.76

reduction of fuel wood. Unless appropriate land management practices are designed, it will have a huge impact on the fertility of the cultivated land.

Bare land

Bare land expanded in the Gelana sub watershed area during the study period. The proportion of bare land increased from 0.41% (103 ha) in 1964 to 0.43% (107 ha) in 1986 and to 1.43% (358 ha) in 2014. The rate of bare land expansion was about 0.18% per year and 8.38% per year between the first period (1964–1986) and the second period (1986–2014), respectively. In overall, it gains a total of 255 ha during 50 years (Table 4). This was due to the conversion of other LULC type into bare land. For instance, from 1986 to 2014, 5 ha of forest, 70 ha of shrub land, 229 ha of cultivated and rural settlement land, 38 ha of grass land and 8 ha of wet land was converted to bare land even though there was afforestation and reforestation efforts by the local government since 1991 in the study areas as it was reported from interview. However, in the second period (1986–2014), about 92.53% (99 ha) of the bare land was converted into forest, shrub land, cultivated and rural settlement land and grass land (Table 5).

Urban built up area

This LULC category occupied 22 ha, which account for about 0.09% of total study area in 1964. In 1986 it occupied 73 ha which constitute 0.29% and in 2014 it occupied 335 ha and account for 1.34% of the total sub watershed area. This indicated that urban built up area expanded by 231.82% (51 ha), which is a rate of 10.54% per year between 1964 and 1986, 358.90% (262 ha) at a rate of 12.82% per year from 1986 to 2014. The overall expansion of urban built up area has been 313 ha (1422.73%) during the analysis period (Table 4). The town of Mersa, which is located within the study area, gained 51 ha of land from forest, shrub land and cultivated & rural settlement land during the period 1964–1986. Similarly, during the second period 261 ha from cultivated and rural settlement and 1 ha from grass land converted into urban built up area (Table 5). This large conversion from cultivated and rural settlement land (261 ha) revealed that the expansion of this LULC consumes more cultivated land and leads to decline of crop production as increasing of cultivated land to compensate yield increase is a characteristics of farmers in the watershed. The major reason for the expansion of urban built up area was natural population increase and in-migration as it was confirmed during the group discussion and interview. Increased in migration from the rural areas in order to get more employment opportunity in the Mersa town, gave rise to more residential area to be built on the periphery of the town.

Wet land

The study area under this LULC category showed a decreasing trend throughout the study period. It declined from 2.65% (661 ha) in 1964 to 2.01% (502 ha) in 1986 and to 1.21% (301 ha) in 2014 (Table 2; Fig. 4a–c). In period of 1964 and 1986, the wet land decreased by 24.05% which is a rate of decline of 1.09% per year while between 1986 and 2014, it declined by 40.04% at a rate of decline of 1.43% per year (Table 4). The analysis also revealed that from 1964 to 1986, about 159 ha (24.05%) of the wetland was converted to cultivated & rural settlement land. Similarly, during the second period (1986–2014) 1 ha of wet land to forest, 193 ha to cultivated and rural settlement, and 8 ha wet land to bare land and 300 ha of wet land remain unchanged. In both period conversion of wet land to cultivated and rural settlement land was the largest. The decline in wetland area could be attributed to increased cultivation activities in wetland. Therefore, this implies that wetland degradation and its ecological importance was lost.

Implications of land use/land cover changes to soil erosion, biodiversity and the need for sustainable land management (SLM) options

Implications for soil erosion/SLM

Land cover is one of the factors that determine the rate of soil loss due to erosion (Woldeamlak 2002). Removal of vegetation cover means exposing the land to soil erosion (Tsehaye and Mohammed 2013). This process accelerates removal of soil particles and increased sheet, rill and gully erosions by reducing the protection of soil cover. Considering the observed LULC changes in cultivated and rural settlement and bare land, the study area could be prone to soil erosion. As a result, 69.7, 72.26 and 75.65% of the total area of the study area in 1964, 1986 and 2014 respectively (Table 3), was potentially exposed to soil erosion. The slight increase in forest cover during the second period in the study area does not indicate minimum soil erosion because most of the planted trees were eucalyptus trees. In addition, as it was observed during the field survey, the formation of deep and wide gully erosion is common effects of soil erosion in the study area. It was extended from upper watershed to the lower watershed and at the same time it was observed in the cultivated land. Hence, soil erosion is still a major problem in the Gelana sub watershed. Therefore, it is time to prioritize and design an environmentally friendly land management strategy for integrated and sustainable development of the study area.

Implications for biodiversity

As it was confirmed during the group discussion and interview, Gelana sub watershed was originally the home

of many indigenous tree species such as *Ziziphus spina-christi*, *Acacia abyssinica*, (*Derot*) *Acacia lahai*, *Ficus sur*, *Cordia Africana*, *Ficus vasta*, *Croton macrostachyus*, *Acacia lahai*, *Acacia albida*, *Olea Africana*, *Dodonaea viscosa*, *Euclea racemosa*, *Allophylus abyssinicus*, *Carissa spinarum*, *Rhus retinorrhoea*, *Pouteria altissima*, *Acacia seyal*, *Schinus molle*, and *Dichrostachys cinerea*. The study area was also the home of many wildlife such as antelope, leopard, boar, echidna, fox, rabbit, Menilik bush buck. Forests, shrub land, grassland and wet land were important habitats for these species study area. The LULC analyses have already revealed that these land use categories have significantly changed over the last 50 years. For instance, tree species like *Ficus sur*, *Cordia Africana*, *Ficus vasta*, *Croton macrostachyus*, *Olea Africana* and *Dodonaea viscosa* and wildlife such as antelope, leopard, boar, echidna, fox, rabbit and Menilik bush buck were significantly reduced or totally lost over the analysis period. Hence, these changes contribute to the loss of biodiversity in the study area. Therefore, integrated participation of the local community and alternative livelihood options for the people inhabiting in the Gelana sub watershed have to be designed and implemented.

Implication of LULC changes on hydrological regimes

Land cover changes interfere with the land phase of the hydrological cycle. As is well known, land under little vegetative cover is subject to high surface runoff and low water retention (Woldeamlak 2002). During group discussion and interview, we realized that the deforested slopes of the study area are less capable of absorbing and holding the rainfall and consequently, the large part of the rainfall runs down from the fragile steep slopes, devastating the lower part of the sub watershed by recurrent floods. Moreover, there is an obvious increase of sedimentation in the lower part of the Gelana sub watershed. Therefore, as a result of LULC, the hydrological regime of the study area has changed in terms of runoff magnitude and distribution. This suggests the need for conservation investments in the upper sub watershed in order to regulate the hydrological disturbance occurring in the area.

Conclusions

The quantitative evidence obtained through interpretation of aerial photographs and satellite image indicated that the study area has undergone significant LULC changes since 1964. During the analysis period (1964–2014), cultivated and rural settlement land constituted the largest coverage in the study area. Of the total area of the Gelana sub watershed, cultivated and rural settlement land accounted for 69.29% in 1964, 71.83% in 1986 and 74.22% in 2014. The results revealed that shrub land,

cultivated and rural settlement, grass land, bare land, and urban built up area have expanded over a period of 50 years while forest and wet land have declined during the same period. For the whole study period (1964–2014), the forest covers and wet land declined by 1.25 and 1.09% per year respectively.

The observed changes are associated with increasing human population and associated livelihood of most of the rural population that is dependent on a mixed farming system of crop production and livestock management. At the same time, the growing demand for cultivated and rural settlement and forest for extraction of fuel and construction materials compounds the changes. These changes aggravate soil erosion, biodiversity loss and disturbance of hydrological regimes.

The significant changes in LULC have the potential to affect natural resources and reduce agricultural productivity on which the livelihood of the local community depends for subsistence. Moreover, this article has emphasized that integrated use of Remote Sensing and GIS advances quantification, mapping and improved understanding of the process of land use/cover changes. Therefore, there is a need for forestation of hillsides and degraded lands, tillage along lines of constant elevation, regulating expansion of cultivated land and land use planning for this sub watershed in particular and the country at large for sustainable natural resources management.

Authors' contributions

BA has made contributions in the design, data collection and analysis, interpretation of results and revisions of the manuscript. AA has contributed in sampling design, reviewing and writing the draft manuscript. Both authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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References

- Aklilu A, Stroosnijder L, Graaff Jd (2007) Long-term dynamics in land resource use and the driving forces in Beressa watershed, highlands of Ethiopia. *J Environ Manage* 83:448–459
- Amare B, Hurni H, Gete Z (2011) Responses of rural households to the impacts of population and land-use changes along the Eastern Escarpment

- of Wello, Ethiopia, Norsk Geografisk Tidsskrift—Norwegian. *J Geogr* 65:42–53
- Amhara design and supervision works enterprise (ADSWE) (2011) East Amhara development corridor integrated land use planning project soil survey thematic report, Bahir Dar, Ethiopia. Unpublished document
- Asmamaw L, Mohamed A, Lulseged T (2011) Land use/cover dynamics and their effects in the Gerado catchment, northeastern Ethiopia. *Int J Environ Stud* 68:883–900
- Belay T (2002) Land cover/land use changes in the Derekolli catchments of South Wello Zone of Amhara region. *East Afr Soc Sci Rev* 18:1–20
- Congalton RG, Green K (2009) Assessing the accuracy of remotely sensed data: principles and practices, 2nd edn. Taylor & Francis, Boca Raton
- CSA (Central Statistical Agency) (2008) The 2007 population and housing census of Ethiopia. Results of Amhara region: Population size of kebeles. Central Statistical Agency, Addis Ababa
- Eleni Y, Wolfgang W, Michael EK, Dagnachew L, Günter B (2013) Identifying land use/cover dynamics in the Koga catchment, Ethiopia, from multi-scale data, and implications for environmental change. *ISPRS Int J Geo Inf* 2:302–323
- Ermias T, Woldeamlak B, Uhlenbrooka S, Wenningera J (2013) Understanding recent land use and land cover dynamics in the source region of the Upper Blue Nile, Ethiopia: Spatially explicit statistical modeling of systematic transitions. *Agric Ecosyst Environ* 165:98–117
- Ethiopian Mapping Authority (EMA) (1994) Topographical map of Mersa. EMA, Addis Ababa
- Geist HJ, Lambin EF (2002) Proximate causes and underlying driving forces of tropical deforestation. *Bioscience* 52:143–150
- Gete Z (2000) Landscape dynamics and soil erosion process modeling in the North-Western Ethiopian highlands. *African Studies Series A16*. Berne: Geographica Bernensia
- Gete Z, Hurni H (2001) Implications of land use and land cover dynamics for mountain resource degradation in the Northwestern Ethiopian highlands. *Mt Res Dev* 21:184–191
- Girmay G, Bal Ram S, Øystein D (2010) Land-use changes and their impacts on soil degradation and surface runoff of two catchments of Northern Ethiopia. *Acta Agric Scand Sect B Soil Plant Sci* 60:211–226. doi:10.1080/09064710902821741
- Kassa T, Anton VR, Jean P, Simon VB, Jozef D, Kassa A (2014) Spatial analysis of land cover changes in eastern tigray (Ethiopia) from 1965 to 2007: Are there signs of a forest transition? *Land Degrad Dev*. doi:10.1002/ldr.2275
- Kebrom T, Hedlund L (2000) Land cover changes between 1958 and 1986 in Kalu District, South Wello, Ethiopia. *Mt Res Dev* 21:42–51
- Lambin EF, Turner BL, Geist HJ, Agbola SB, Angelsen A, Bruce JW, Coomes OT, Dirzo R, Fische G, Folke C, George PS, Homewood K, Imbernon J, Leemans R, Li X, Morano EF, Mortimore M, Ramakrishnan PS, Richards JF, Skånes H, Steffen W, Stone GD, Svedin U, Veldkamp TA, Voge C, Xu J (2001) The causes of land-use and land-cover change: moving beyond the myths. *Global Environ Change* 11:261–269
- Landis J, Koch G (1977) The measurement of observer agreement for categorical data. *Biometrics* 33:159–174
- Lesschen JP, Verburg PH, Staal SJ (2005) Statistical methods for analysing the spatial dimension of changes in land use and farming systems. LUCR Report Series No. 7. The International Livestock Research Institute, Nairobi, Kenya and Wageningen University, the Netherlands
- Lillesand TM, Kiefer RW (2000) Remote Sensing and Image Interpretation. Wiley, New York
- Meyer WB, Turner BL II (1994) Change in land use and land cover: global perspective driving force. Cambridge University Press, Cambridge
- MOA (Ministry of Agriculture) (1998) Agro-ecological zones of Ethiopia, natural resources management and regulatory department. Addis Ababa, Ethiopia
- Mohammed A (2011) Land use/cover dynamics and its implications in the dried lake Alemaya watershed, Eastern Ethiopia. *J Sustain Dev Afr* 13:96–109
- Mohammed A, Tassew N (2009) Land use/cover changes between 1966 and 1996 in Chirokella microwatershed, South Eastern Ethiopia. *East Afr J Sci* 3:1–8
- Mohr PA (1971) The geology of Ethiopia: Haile Sellassie I. University Press, Addis Ababa
- Mwavu EN, Witkowski ET (2008) Land-use and cover changes (1988–2002) around Budongo forest reserve, Nw Uganda: implications for forest and woodland sustainability. *Land Degrad Dev* 19:606–622. doi:10.1002/ldr.869
- National Meteorological Service Agency (NMSA) (2015) Temperature and rain fall data of Mersa. Unpublished document, Addis Ababa
- Solomon A (1994) Land Use Dynamics, Soil Conservation and Potential for Use in Metu Area, Illubabor Region, Ethiopia. *African Studies Series A13*. Berne, Switzerland: Geographica Bernensia
- Tsehaye G, Mohammed A (2013) Land use/land cover dynamics and their driving forces in the Hirmi watershed and its adjacent agro-ecosystem, highlands of Northern Ethiopia. *J Land Use Sci*. doi:10.1080/1747423X.2013.845614
- Turner II BL, Moss RH, Skole DL (1993) Relating land use and global land-cover change: a proposal for IGBP-HDP core project. IGBP Report 24, HDP Report 5. IGBP, Stockholm
- Turner II BL, Skole D, Sanderson S, Fischer G, Fresco L, Leemans R (1995) Land-Use and Land-Cover Change; Science/Research Plan. IGBP Report no. 35; HDP Report No. 7
- Woldeamlak B (2002) Land cover dynamics since 1950s in Chemoga Watershed, Blue Nile Basin, Ethiopia. *Mt Res Dev* 22:263–269
- Woldeamlak B, Solomon A (2013) Land-use and land-cover change and its environmental implications in a tropical highland watershed, Ethiopia. *Int J Environ Stud* 70:126–139

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