

Analyse av endringer i arealbruk og arealdekke sett i lys av de underliggende drivkrefter i Lake Hawassa Watershed, Etiopia

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Lake Hawassa Watershed in the Main Ethiopian Rift Valley has experienced significant land use and land cover (LULC) changes over the last four decades. Challenges facing policy makers and resource managers are the insufficient or total lack of data on LULC changes both at local and regional levels. Accurate information about the extent and rates of LULC conversions is needed in order to avoid overuse and damage of the landscape beyond recovery. This research aims at quantifying the spatial and temporal extent of LULC changes and the underlying driving forces (UDFs) over the study period 1973–2011 using remotely sensed data and key informant interviews. A cross-tabulation matrix was used to quantify LULC conversions between successive dates, while key informant interviews identified five major UDFs: demographic, economic, institutional, technological, and biophysical factors. The study area is one of the most densely populated regions in Ethiopia. The result of remote sensing analysis revealed that built-up area expanded at a rate of 12.7% annually between 1973 and 2011 and in absolute terms the increase represents 1.7% of the total area. The highest rate of decline in forest cover occurred during the 1973–1985 temporal interval accounting for $-2.6\% \text{ yr}^{-1}$, while conversion in woody vegetation was the highest ($-2.1\% \text{ yr}^{-1}$) between 1985 and 1995. Cropland expansion, typical for the current study area, was estimated at 29.4% (183.8 km^2) between 1973 and 2011. On the other hand, cropland lost about 18 km^2 of its area to built-up between the same temporal instants indicating that the LULC conversions were multi-directional and significant in magnitude. Generally, LULC conversions are continuing to take place in the area, but a slight deceleration was observed in the expansion of cropland which could be explained either for shortage of land for further expansion or that the remaining land is not suitable for development.

Keywords: Land use land cover conversion, underlying driving forces, remote sensing, GIS, Ethiopia

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1. Introduction

Ethiopia is known as the cradle of humankind. For thousands of years people have been living in the area, interacting and transforming the natural environment (Brink et al., 2014). Humans have always depended on natural resources for deriving food, freshwater, timber, fiber, and fuel (Guler et al., 2007; Ramankutty and Foley, 1999). However, over the past decades such human

interventions have been largely affecting the LULC and its rate of conversion has been higher than in any preceding period in human history. Such human induced changes have caused adverse effects on both society and the environment.

Landscapes in the Lake Hawassa Watershed have undergone extensive LULC conversion. Vegetated areas have been overwhelmingly replaced by crop land. At the

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same time, some farmyards were converted into vegetation/perennial crops, bare land and built-up areas over the study period. It is not surprising to see the dominance of cropland, as agriculture at subsistence level is the mainstay of the economy. More than 85% of Ethiopia's population depends on agriculture. The country is economically underprivileged, basic resource need outstrips supply and nature is put under pressure by uncontrolled population growth (Wondafrash and Tessema, 2011). Around 2005 (DELTA, 2005) the average cultivable land size per household in the Lake Hawassa Watershed was about 0.58ha.

In the present study area, agricultural production did not keep up with population growth due to factors such as lack of technological know-how and the necessary inputs, land tenure systems, and regime changes following armed conflicts. These factors reduced the stewardship of institutions and individuals to protect natural resources including protected areas from destruction. Empirical evidence of LULC conversions obtained from multi-temporal image analysis can greatly contribute to a better understanding and management of available resources, especially in developing countries where other kinds of background data are limited or totally lacking (Tekle and Hedlund, 2000). However, to devise more appropriate mitigation strategies, studies on LULC conversions should be integrated with investigation of their UDFs.

Landscape changes are considered as one of the main research topics because changes in LULC are major factors in the global environmental processes (Imam, 2011). Since the advent of optical satellite based observation in the 1970s, remote sensing technologies have played a major role in analyzing and documenting changes in LULC at regional and local level.

Numerous case studies at multiple spatio-temporal scales have been conducted in different parts of the world to investigate LULC change dynamics. For instance, Abd El-Kawy et al. (2010), Guler et al. (2007), and Mendoza et al. (2011), analyzed LULC conversions in Egypt, Turkey, and Mexico, respectively using remotely sensed data. In all

cases, it was confirmed that expansion in agricultural land, urban areas, and decline in vegetated areas were prevalent with the only exception in Turkey. In Turkey, a slight decrease in agricultural land was reported owing to irrigation practices and shortage of suitable land for further expansion. Other investigations performed within Ethiopia have displayed a similar scenario. The LULC change analysis undertaken (Tekle and Hedlund, 2000; Zeleke and Hurni, 2001) in the northern and northwestern part of Ethiopia, respectively have indicated a widespread clearance of vegetation, including natural forests and expansion of cultivated land between 1957 and 1995. These are some of the areas with the highest land degradation in the country due to high population pressure and shortage of land. The farming community is compelled to cultivate marginal lands and steep slopes (>30%). Recent studies carried out in the central Rift Valley (*Arsi Negele* district) between 1973 and 2006 (Garedew et al., 2009), and at *Hare River Watershed* in the Southern Rift Valley (Tadele and Forch, 2007) from 1967 to 2004, estimated cropland expansions comparable to the results obtained in the current study. In the *Arsi Negele* district, a site adjacent to our study area, the cropland doubled between 1973 and 2006, while woodland cover declined from 40 to 9%. In the *Hare River Watershed*, farmland and settlement grew from 28.3% in 1975 to 52% in 2004, whereas vegetation cover declined from 28.4 to 16.2% from 1975 to 2004. Though it cannot be ascertained conclusively that these problems are nationwide with the limited number of reports, these are indications that the country's natural resources are at stake and that the biophysical resources need to improve in order to support millions of people. Classified image data (Wondrade et al., 2014) also indicated that the study area has undergone extensive LULC changes. However, current research was needed to quantify the pathways of LULC conversions and identify underlying driving forces that could serve as an input when developing mitigation strategies.

Remote sensing technologies are suited for capturing LULC conversions (Rogan and Chen, 2004) at a variety of spatial scales

with no information on what have caused the changes. The current study employed remote sensing and key informant interviews to quantify LULC conversions and their causative factors. Different views exist regarding the relationship between LULC changes and the UDFs in the tropics. Several authors (Castillo-Santiago et al., 2007; Mather and Needle, 2000) have concluded that population pressure is one of the major causes of deforestation and degradation of the land, while Mendoza et al. (2011) associated the main driving forces of LULC change in developing countries to the rapid population growth, poverty, and welfare condition. Rapid socio-economic development (Zhang et al., 2010), fire (Jones et al., 2011), and deforestation, large scale logging, firewood collection and charcoal burning, overgrazing, and fire (Jianzhong et al., 2005) have alternately been described as the main drivers of LULC change and forest decline. Deforestation and LULC changes are attributed to multiple factors (demographic, economic, technological, political/policy and institutions, biophysical, and cultural) acting synergistically rather than by a single factor (Burgi et al., 2004; Geist and Lambin, 2002; Lambin et al., 2003). Based on the interviews carried out with key informants in the watershed, the five most prominent UDFs of LULC change (demographic, economic, technological, institutional, and biophysical factors) were identified.

It is challenging to reverse land cover degradation while at the same time meeting the growing demands of people for more goods and better services, particularly in areas with land scarcity that are inhabited by resource-poor farmers. Thus, to sustainably manage natural resources, it is necessary to know the extent of changes and their causative factors. Literature review has not found published documentation on the state of LULC changes and the driving forces in the Hawassa area. That is why this research was undertaken in the Lake Hawassa Watershed to apply remote sensing and field survey techniques for the attainment of the following specific objectives: to (1) quantify the spatial and temporal dimensions of LULC conversions from the classified Landsat im-

ages extending over a period of 38 years, (2) identify the most prominent UDFs of LULC changes through key informant interviews, and (3) provide analysis of the identified driving forces with a particular focus on LULC conversions and deforestation. We believe that the analysis performed provides useful information for planning and management of the Watershed.

2. Materials and methods

2.1. Study area description

The study area is located in the center of the Great East African Rift Valley, at times called the Afro-Arabian Rift. It is found 275km south of Addis Ababa, the capital city of Ethiopia, and covers a total of 1435km². Its extreme coordinates are 6°49' and 7°14' N latitude and 38°16' and 38°44' E longitude. The study area contains 77% of the Southern Nations, Nationalities, and Peoples Regions (SNNPR) and 23% of the Oromiya Region. Districts (*Weredas*) partly within the study site include *Hawassa zuria*, *Arbegona*, *Boricha*, *Shebedino*, *Siraro*, *Shashemene*, *Kofele*, and *Kokosa* (Figure 1), the first four being in SNNPR.

Hawassa and Shashemene cities, located at the center and northern edge of the study area, respectively, are the major urban centers and have a combined population of 432 445 (CSA, 2011). Based on the same source, this study area is one of the most densely populated regions in Ethiopia with estimated values ranging from 111 to 677 persons/km² for rural inhabitants and 1950 persons/km² for the Hawassa City. The average number of people living in the watershed in 1973 was estimated at 44 086 (CSA, 1975), a number which had increased to 1 103 507 by the year 2014 (BoFED, 2014). These figures were estimated based on the population density of provinces and districts for the year 1973 and 2011, respectively since there are no population data at watershed level. The sharp increase of the population in the watershed is an indication of the continuing influx of people to Hawassa, the region's capital city.

This area was rich in flora and fauna (Lemma, 2005) and has historically support-

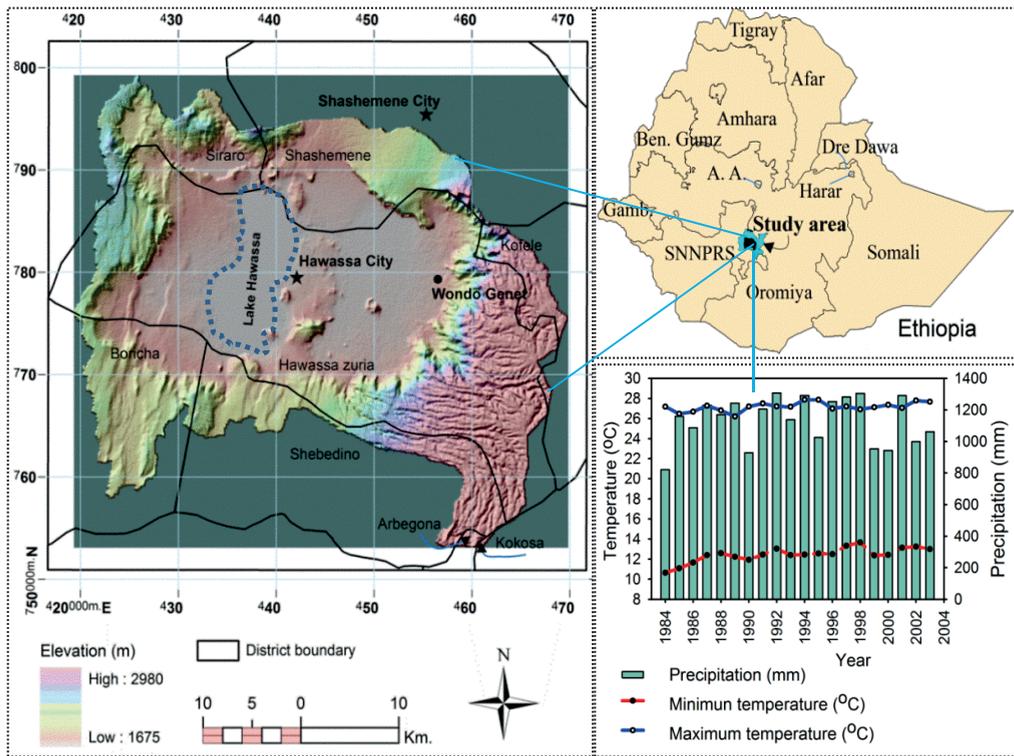


Figure 1. Maps showing location, climatic data, and administrative districts of the study area.

ed human related activities, such as agriculture, livestock grazing, fishing, recreation, extraction of wood for construction materials and household fuel. The average annual precipitation varies between 821 and 1307mm, the highest being in the Wondo Genet area. Average temperatures generally range between 12.5 and 27.2°C, but are as low as 10.6°C up in the Abaro Mountain. Both mean precipitation and temperatures were calculated from 20 years of meteorological data recorded from the stations within the site. According to reports from previous studies (DELTA, 2005; MWUD, 2006), there have been significant LULC changes in the Lake Hawassa Watershed since 1965. The topography of the watershed ranges from flatlands, gentle sloping land to dissected escarpments, and mountainous regions. The study area features altitudes between 1675 and 2980m above sea level and it is characterized by two complex calderas, volcanic

features formed by the collapse of lands following volcanic eruptions. The Hawassa caldera is a giant elliptical depression 30–40km wide (Esayas, 2010; Gebreegziabher, 2004) on the Rift Valley floor, while the Korbetti caldera which is found in *Siraro* and partly in *Hawassa zuria* districts, north west of Lake Hawassa, is a nested caldera within the Hawassa caldera. The eastern and north eastern highlands had more vegetation cover than areas at lower altitudes, while the western part of the watershed is poorly vegetated and severely affected by erosion. The soils are formed on volcanic sedimentary rocks and are predominantly sandy loam, loamy sand to sandy loam, heavy clay, and sandy clay loam (Lemma, 2005).

2.2. Datasets and image classification

The main sources of data in this study were multi-temporal satellite images and field surveys augmented by census reports, mete-

orological data, and documented facts. Population data were collected from the Central Statistical Abstracts of Ethiopia and Bureau of Finance and Economic Development.

Spatial analysis of LULC conversions relied on Landsat Multispectral Scanner (MSS) image data from 1973 and Thematic Mapper (TM) image data from 1985, 1995, and 2011 along with ancillary data such as topographic maps and aerial photographs. Considerable evidence is available (Love-land, 1999) demonstrating the use of Landsat data for investigating contemporary LULC conversions. The selected TM images have been geometrically corrected and georeferenced by the image provider to the UTM (Universal Transverse Mercator) projection with a processed spatial resolution of 30m. The MSS image was resampled to be comparable to TM images. Topographical maps were used as a reference to register all the Landsat images in ERDAS Imagine and the precision of spatial registration of MSS and TM images was less than one pixel. To aid classification and accuracy assessment, locations were determined using a Global Positioning System and visual interpretation. The overall accuracies were between 82.5 and 85%. The user's and producer's accuracies were all reasonable, but as expected there were some difficulties in discerning cropland and grassland covers. Upon completion of classification by applying a hybrid method, multi-date post classification comparison was performed to quantify the spatial distribution of LULC changes. A more comprehensive review of the image analysis and its accuracy assessment can be found in Wondrade et al. (2014).

2.3. Field survey to identify underlying driving forces

The advantage of using remote sensing was that it allows mapping and monitoring of LULC changes. However, this bio-physical approach gives no information on why changes occur (Garedew et al., 2009). A field survey was then combined with multi-date image data analysis in order to identify the UDFs of LULC conversions. In this research setting, key informant interviews were used as a tool to collect information about the dri-

ving forces. The interview questions were focused on identification of the major LULC types, changes that have occurred, and the possible UDFs of changes. The interviews were conducted with a total of 27 selected key informants within the Lake Hawassa Watershed. Of this number, 7.4 and 92.6% were female and male, respectively. The survey was conducted in January and February, 2012, involving farmers, forest technicians, GIS experts, forest guards, researchers, and experts from the regional bureau of agriculture, the forestry college, and the city municipality. During the selection of interviewees, purposive sampling focusing on their knowledge of the watershed's natural resources development was used. It was observed that the memory gaps of younger informants were higher for the time span that refers back to 1973 compared to older respondents. Previous reports, academic theses, and published papers were also used as supplemental sources to identify driving forces.

2.4. Land use land cover conversions

To derive the spatial distribution of LULC conversions in the Lake Hawassa Watershed, cross-tabulation matrices were created through a spatial overlay of successive thematic maps (Figure 2a-d), in ERDAS Imagine. Cross-tabulation matrices are tables with systematic arrays, composed of the LULC classes from the initial year in one axis and the same classes from the subsequent year in the other axis. Each cell of the main diagonal of the matrix contains the surface area (in km²) of each class that remained unchanged during the time period evaluated, while the remaining cells contain the estimated surface area of a given LULC class that changed to a different class during the same time period (Mendoza et al., 2011). The tables facilitated the determination of the quantity of LULC conversions taking the advantage of «from-to» change information for each of the nine established cover classes. Recent studies (IPCC, 2003; Zhou et al., 2008) have shown that remote sensing is the most direct and cost-effective tool that can be used for verification of LULC classes and conversions.

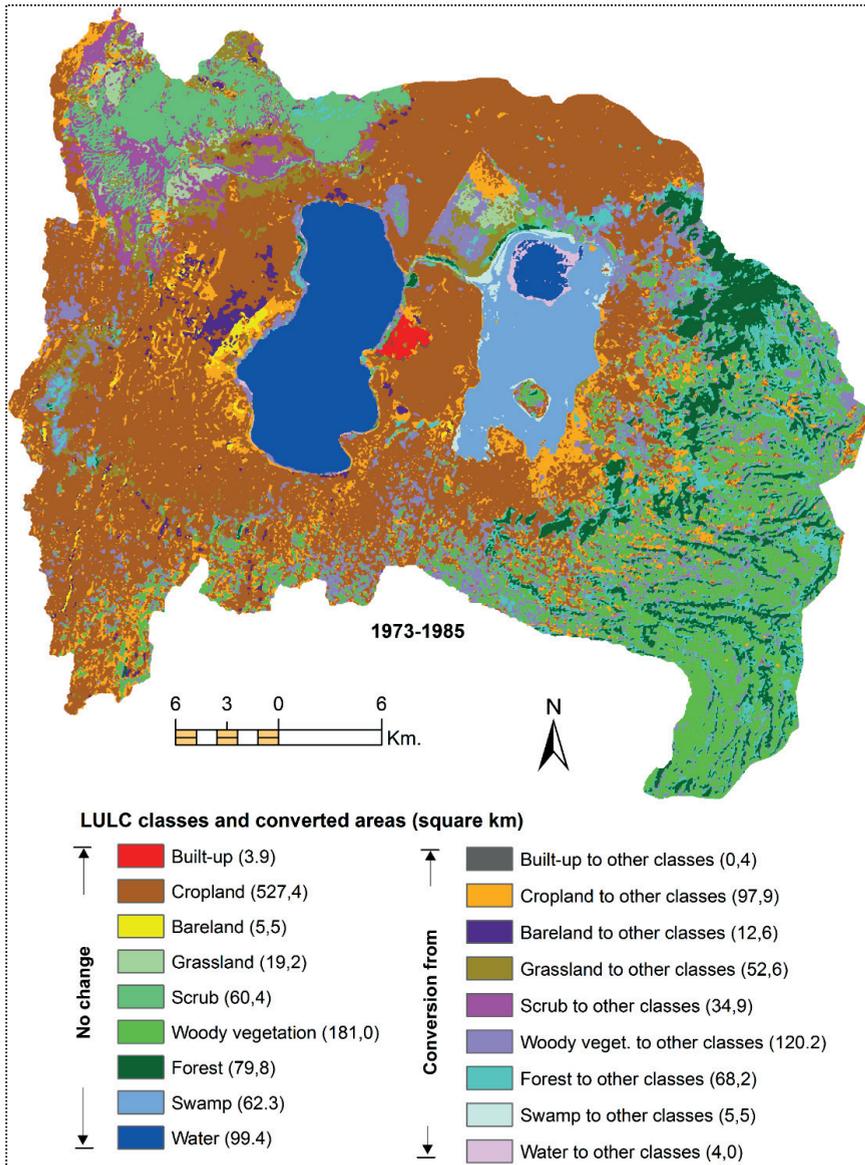


Figure 2a. Patterns of LULC conversions between selected dates. Modified based on Wondrade et al. (2014).

Due to unequal length of temporal intervals (12, 10, and 16) and undoubtedly uneven distribution of LULC conversions within each temporal interval, it was necessary to estimate the average temporal and annual rates of change of LULC type for the purposes of comparison. The annual rates of change were computed by dividing the temporal

rates of change by the number of years in the interval (Sleeter and Raumann, 2006; Zhang et al., 2010), which is calculated according to the following formula: $R_a = R_t / \Delta Y$, and $R_t = (A_c - A_p) / A_p * 100$, where R_a and R_t are the annual and temporal change rates of the target LULC type, respectively; $A_c - A_p$ are the area of the target LULC type at the

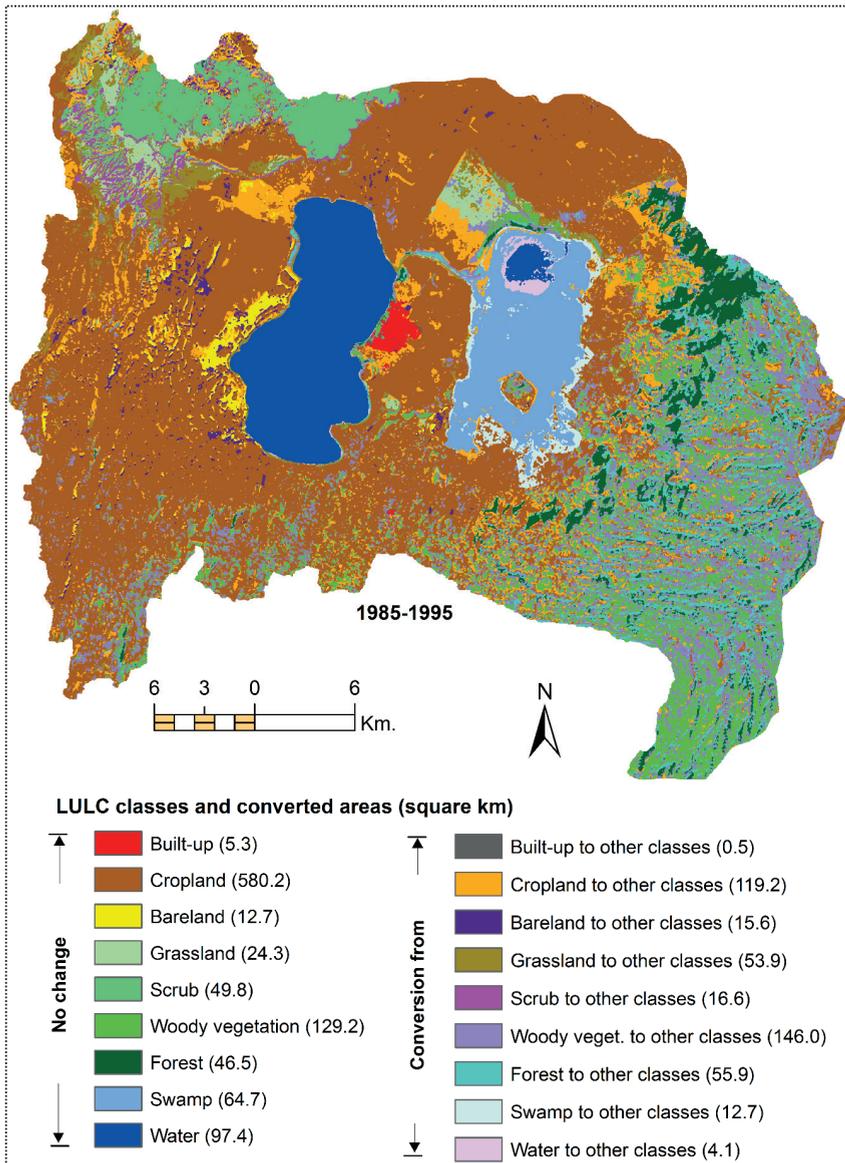


Figure 2b. Patterns of LULC conversions between selected dates. Modified based on Wondrade et al. (2014).

current and previous study points in time, respectively; and ΔY is the length of the study period measured in the unit of years. Calculating annual change rates by applying algebraic or geometric progression was not found meaningful owing to uneven distribution of LULC changes across each year and unequal temporal intervals.

3. Results and discussion

3.1. Dynamics of land cover conversions

From the total study area, about 548km² (38.2%) has experienced change in LULC for the analyzed 38 year time period. Nearly 396km² (27.6%), 425km² (29.6%), and 465km² (32.4%) of land have been converted into other LULC classes for the 1973–1985,

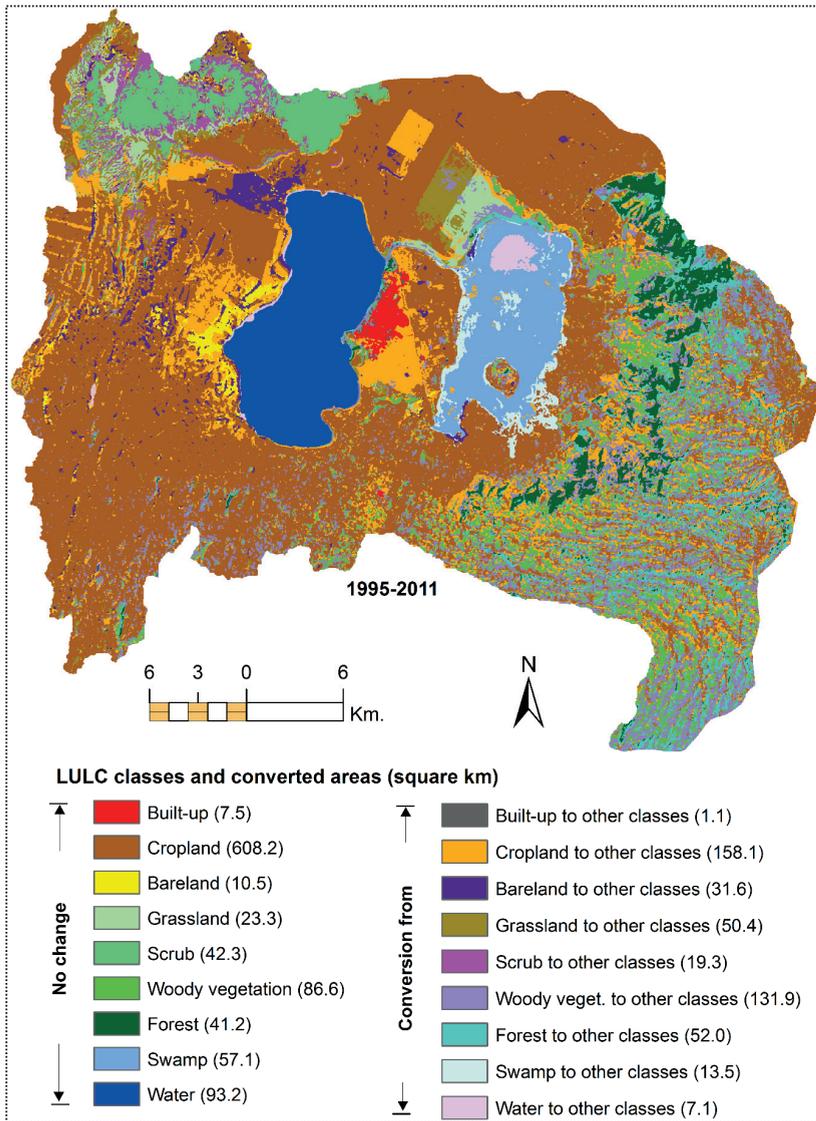


Figure 2c. Patterns of LULC conversions between selected dates. Modified based on Wondrade et al. (2014).

1985–1995, and 1995–2011 epochs, respectively. In the year 1973 vegetated area such as forest, woody vegetation, scrub, and grassland represented 10.3%, 21.0%, 6.6%, and 5.0% of the total LULC, respectively. However, several drivers had transformed the landscape with a predominant trend of vegetation cover being converted to cropland.

Cropland: This pattern of cropland expansion appears to be typical for the area and

was in agreement with the findings of Rembold et al. (2000) in the lakes region, north of our study site, between 1972 and 1994 and that of Fikir et al. (2009) in Eastern Tigray, Ethiopia between 1965 and 2005. As anticipated, the cross-tabulation matrices containing LULC conversions revealed a considerable increase (29.4%) in cropland between 1973 and 2011, the largest in spatial coverage. During 1973–1985, 86.9km² from woody

vegetation, 41.4km² from grassland, 14.1km² from forest, and 13.5km² from scrub LULC were transitioned to cropland. Likewise, during the interval from 1985 to 1995, 99.8km² from woody vegetation, 35.7km² from grassland, and 21.8km² from forest were converted to cropland.

Cropland also increased significantly during 1995–2011 gaining 101.8km² from woody

vegetation, 31.2km² from grassland, 27.1km² from bare land, and 22.2km² from forest land cover. On the other hand, cropland lost about 18km² of its area to built-up between 1973 and 2011 indicating that the LULC conversions were multi-directional and significant in magnitude. We estimated a yearly rate of change in cropland at 1.0% for the first two periods (Table 1). This was in agreement

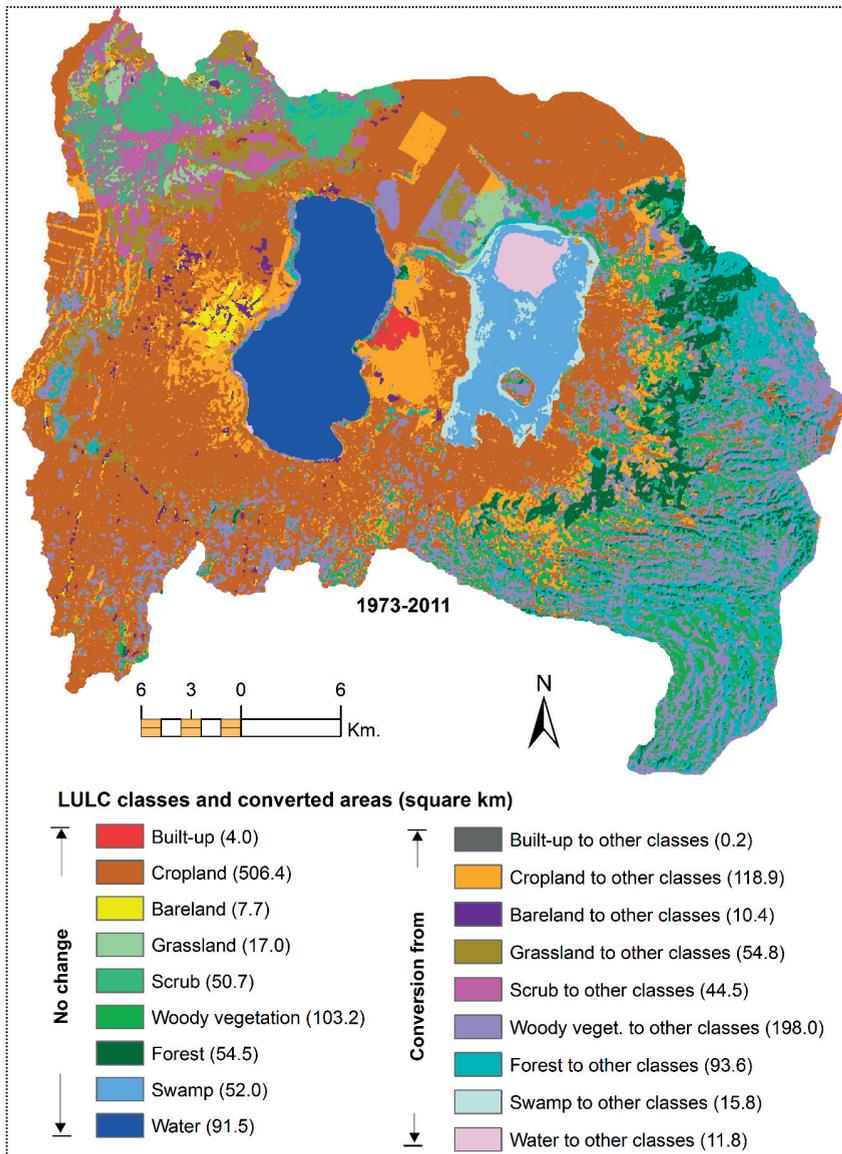


Figure 2d. Patterns of LULC conversions between selected dates. Modified based on Wondrade et al. (2014).

with reports from (Brink et al., 2014) with a yearly increase rate of arable land and permanent crops (0.9%) in the Intergovernmental Authority on Development in East Africa (IGAD) region during 1990–2000. However, the increase in cropland for 2000–2010 was much higher (1.87%) than the rate in our

study area (0.3%) for 1995–2011. This slight deceleration in the expansion of cropland could be attributed either to shortage of suitable land for further conversion or that the remaining area is not suitable for development.

Table 1. Temporal and annual rates of LULC change between two dates.

LULC Classes ^c	(WR)	(BP)	(CL)	(WV)	(FT)	(GL)	(SP)	(BL)	(SB)
LULC Change (1973–1985)									
Difference (km ²)	-1.9	1.6	74.4	-25.3	-45.6	6.4	9.6	10.3	-28.8
Temporal change rate (%)	-1.8	37.0	11.9	-8.4	-30.8	9.0	14.2	56.9	-30.2
Annual change rate (%)	-0.1	3.1	1.0	-0.7	-2.6	0.7	1.2	4.7	-2.5
LULC change (1985–1995)									
Difference (km ²)	-1.2	2.8	66.9	-57.1	-9.3	-4.5	-6.7	13.7	-4.8
Temporal change rate (%)	-1.2	48.5	9.6	-20.7	-9.0	-5.7	-8.6	48.4	-7.2
Annual change rate (%)	-0.1	4.9	1.0	-2.1	-0.9	-0.6	-0.9	4.8	-0.7
LULC change (1995–2011)									
Difference (km ²)	-4.5	16.0	42.4	-23.8	-12.2	-7.9	-6.5	-2.2	-1.2
Temporal change rate (%)	-4.5	185.4	5.5	-10.9	-13.1	-10.7	-9.1	-5.2	-1.9
Annual change rate (%)	-0.3	11.6	0.3	-0.7	-0.8	-0.7	-0.6	-0.3	-0.1
LULC change (1973–2011)									
Difference (km ²)	-7.5	20.4	183.3	-106.3	-67.0	-5.9	-3.5	21.8	-34.7
Temporal change rate (%)	-7.3	480.9	29.4	-35.3	-45.3	-8.3	-5.2	120.9	-36.5
Annual change rate (%)	-0.2	12.7	0.8	-0.9	-1.2	-0.2	-0.1	3.2	-1.0

^cNote: For the description of abbreviated LULC classes, see Table 2.

Apparently, large area conversion from cropland to woody vegetation was evident in all temporal intervals in the cross-tabulation matrices (Table 2). These were not actually conversions to trees, bushes and other natural vegetation cover, but the conversions were to perennial crops which were challenging to discern from other woody vegetation due to similar spectral signatures of the image data used for classification. On the other hand, woody vegetation lost its area to other classes by 39.9% from 1973 to 1985, 53.0% from 1985 to 1995, and 60.4% from 1995 to 2011. The major conversions of woody vegetation were to cropland in all temporal intervals.

Forest: This was the third largest LULC class in 1973 and the major conversions observed were to woody vegetation and cropland throughout the study period, which shows the removal and degradation of forest cover. Forest experienced continuous decline, -30.8% from 1973 to 1985 and -13.1% from 1995 to 2011 period with a -1.2% annual rate of change during the whole study time. The forest cover transitioned to woody vegetation during 1973–1985, 1985–1995, and 1995–2011, were 51.2km², 30.6km², and 27.5km², respectively.

Table 2. Cross-tabulation matrices showing LULC conversions (in km²) between each two dates.

LULC Classes										
Year 1973	Year 1985									Total (1973)
	WR	BP	CL	WV	FT	GL	SP	BL	SB	–
Water (WR)	99.4	0.0	0.1	0.2	0.1	0.3	3.1	0.0	0.0	103.3
Built-up (BP)	0.0	3.9	0.2	0.1	0.0	0.0	0.0	0.0	0.0	4.2
Cropland (CL)	0.2	1.2	527.4	38.5	2.9	25.4	9.8	19.1	0.7	625.3
Woody vegetation (WV)	1.5	0.4	86.9	181.0	18.7	10.9	1.3	0.5	0.0	301.1
Forest (FT)	0.2	0.0	14.1	51.2	79.8	1.0	0.2	0.2	1.3	148.0
Grassland (GL)	0.1	0.2	41.4	3.2	0.2	19.2	0.8	2.7	4.0	71.8
Swamp (SP)	0.1	0.0	3.6	1.0	0.5	0.3	62.3	0.0	0.0	67.8
Bare land (BL)	0.0	0.1	12.0	0.0	0.0	0.5	0.0	5.5	0.0	18.1
Scrub (SB)	0.0	0.0	13.5	0.3	0.3	20.5	0.0	0.3	60.4	95.2
Total (1985)	101.5	5.8	699.4	275.6	102.4	78.1	77.3	28.4	66.5	1434.9

Year 1985	Year 1995									Total (1985)
	WR	BP	CL	WV	FT	GL	SP	BL	SB	–
Water (WR)	97.4	0.0	0.2	0.3	0.1	0.0	3.5	0.0	0.0	101.5
Built-up (BP)	0.0	5.3	0.2	0.3	0.0	0.1	0.0	0.0	0.0	5.8
Cropland (CL)	0.8	3.0	580.2	50.1	10.4	23.1	2.1	27.0	2.8	699.4
Woody vegetation (WV)	0.3	0.3	99.8	129.6	35.0	10.4	0.2	0.1	0.0	275.6
Forest (FT)	0.3	0.0	21.8	30.6	46.5	2.9	0.0	0.0	0.2	102.4
Grassland (GL)	1.2	0.0	35.7	6.3	0.8	24.3	0.2	1.4	8.3	78.1
Swamp (SP)	0.2	0.0	10.3	1.1	0.2	0.6	64.7	0.2	0.0	77.3
Bare land (BL)	0.2	0.1	13.8	0.0	0.0	1.1	0.0	12.7	0.6	28.4
Scrub (SB)	0.0	0.0	4.3	0.2	0.2	11.3	0.0	0.7	49.8	66.4
Total (1995)	100.3	8.6	766.2	218.5	93.2	73.7	70.7	42.1	61.7	1435.0

Year 1995	Year 2011									Total (1995)
	WR	BP	CL	WV	FT	GL	SP	BL	SB	–
Water (WR)	93.2	0.0	1.1	0.4	0.2	0.1	5.1	0.2	0.0	100.3
Built-up (BP)	0.1	7.6	0.1	0.6	0.1	0.2	0.0	0.0	0.0	8.6
Cropland (CL)	1.0	14.5	608.2	72.0	15.1	19.6	1.1	26.4	8.4	766.4
Woody vegetation (WV)	1.0	1.5	101.8	86.6	22.6	4.6	0.3	0.1	0.2	218.6
Forest (FT)	0.4	0.1	22.2	27.5	41.2	1.5	0.2	0.0	0.3	93.2
Grassland (GL)	0.1	1.0	31.2	5.8	1.6	23.3	0.4	1.7	8.7	73.7
Swamp (SP)	0.0	0.0	12.1	0.8	0.1	0.5	57.1	0.0	0.0	70.7
Bare land (BL)	0.2	0.1	27.1	1.0	0.1	2.4	0.1	10.5	0.6	42.1
Scrub (SB)	0.0	0.0	4.7	0.1	0.0	13.5	0.0	1.0	42.3	61.6
Total (2011)	95.8	24.6	808.6	194.7	81.0	65.8	64.2	39.9	60.5	1435.2

Year 1973	Year 2011									Total (1973)
	WR	BP	CL	WV	FT	GL	SP	BL	SB	–
Water (WR)	91.5	0.0	0.3	0.1	0.1	0.0	11.4	0.0	0.0	103.3
Built-up (BP)	0.0	4.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	4.2
Cropland (CL)	1.2	17.8	506.4	44.0	9.7	13.1	0.5	27.1	5.6	625.3
Woody vegetation (WV)	2.4	2.0	168.6	103.2	16.1	8.3	0.1	0.6	0.0	301.2
Forest (FT)	0.3	0.1	46.6	42.6	54.5	2.5	0.1	0.1	1.4	148.1
Grassland (GL)	0.3	0.4	44.7	2.6	0.4	17.0	0.3	3.2	2.9	71.8
Swamp (SP)	0.0	0.0	12.9	1.3	0.1	1.5	52.0	0.0	0.0	67.8
Bare land (BL)	0.0	0.4	9.4	0.1	0.0	0.5	0.0	7.7	0.1	18.1
Scrub (SB)	0.0	0.0	19.6	0.9	0.0	22.9	0.0	1.2	50.7	95.2
Total (2011)	95.8	24.6	808.4	194.7	81.0	65.8	64.2	39.9	60.5	1434.9

From our personal on-site observations and according to key informants, there were signs of forest closure at some locations, but due to low involvement of local people, the borders were violated by encroaching settlers at several sites. Limited area conversions from cropland to forest were observed as the result of farmers' initiative to grow

Eucalyptus trees on their farmstead to partially fulfill their wood demands for fuel and housing (Figure 3a).

Woody vegetation: In a similar scenario, woody vegetation cover constantly declined, the highest loss being -20.7% between 1985 and 1995. The midpoint of this interval coincides

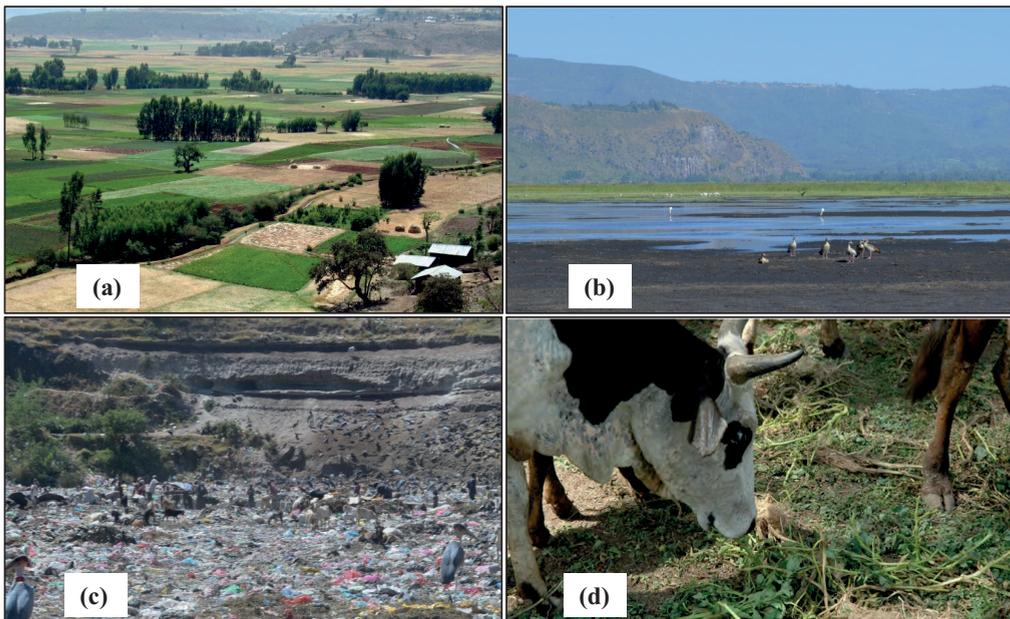


Figure 3. (a) Farmers' initiative to grow *Eucalyptus* tree on their farmstead (photo by Dessie, 2009), (b) Lake Cheleleka transformed into mudflat and grassland (photo by the author, 2013), (c) Quarrying pit currently used as a disposal site (photo by the author, 2013), and (d) Destruction of vegetation by overgrazing (photo by Bishaw, 2013).

with the aftermath of the conflict that resulted in regime change in Ethiopia where control over natural resources was loose. Similar reports were published by Gebremariam et al. (2009) that 1991 precipitated in an unprecedented period of environmental destruction until full authority was restored in 1993.

The conversion of woody vegetation to forest in the area signifies the presence of managed forests and the area that once was covered by plantation forest could be changed to woody vegetation in the other temporal interval as grown trees are harvested and left with understories and coppices. Expansion of cropland, extensive livestock browsing, and unwise harvesting of fuel wood were some of the main causes for the deterioration of woodlands.

Built-up: Driven by a constantly accelerating urban population in recent decades, urbanization has become one of the most dynamic processes in the context of global land cover transformations (Bhandari, 2010). Built-up areas increased by 480.9% over the study period and grew at a rate of 37.0%, 48.5%, and 185.4% during the 1973–1985, 1985–1995, and 1995–2011 periods, respectively. These are the highest temporal growth rates recorded in each period, except in the first temporal interval. The largest proportion of land conversions to built-up area were from cropland in all intervals. The promotion of Hawassa City as a political center of the region and improvements in investments particularly since 1995 combined with rapid growth in the construction sector have contributed to the expansion of built-up area. A study conducted (Ayenew and Gebreegziabher, 2006) in the same watershed between 1965 and 1998 corroborated our findings that built-up area has shown similar spatial increase of 185.7%, while (Tekle and Hedlund, 2000) reported 192% of urban settlement increase between 1958 and 1986 in southern Wollo, Ethiopia. Unexpected conversions from built-up to other LULC classes, though it was very small (ca. 0.2km²), were observed owing to the effect of automatic classification and the coarse resolution of the images utilized.

Water: It is evident from the cross-tabulation matrices that the area occupied by water and swamp decreased by -7.3 and -5.2%, respectively between 1973 and 2011. Though the total coverage of water body had decreased due to the desiccation of Lake Cheleleka, the surface area of Lake Hawassa had increased by ca. 3.5km² owing to the loss of vegetation cover and subsequent increase in runoff in the watershed. During the years of abundant rainfall, a rise in the lake levels were recorded, the highest being 3.83m in November 1998 (MWUD, 2006), which caused inundation of the surrounding area. Such lake level rises are presumed to be a threat to Hawassa City, established at its eastern shore.

Grassland: The coverage of grassland decreased by -8.3% between 1973 and 2011, while an increase of 9.0% was noted during the 1973–1985 study period. This variation of temporal change rate in grassland can be accounted for the land management system – that means the land that once was covered by grassland has been converted to cropland (mechanized farm). This switching of farmland to grassland and then back to farm land again was observed in the northern part of the study area. This is demonstrated by the transition of farmland (mechanized farm) to grassland in 1973–1985 when most parts of the state farms were abandoned and then in the next two intervals, grassland lost the majority of its area to cropland as people started to occupy and cultivate those sites. It should also be noted that higher temporal change rates in grassland were observed during the period 1995–2011 (-10.7%) than during the wider interval 1973–2011 (-8.3%). This shows that wider interval change analysis may mask more change processes than short intervals and shows one limitation in LULC conversion analysis. We believe that the opening up of the Landsat archive and the launching of Landsat Data Continuity Mission will provide a good opportunity in future research to analyze land use land cover changes with a more dense time series.

Swamp: The study results indicated an increase (14.2%) in swampy area during 1973–1985, but in the next two intervals, 1985–

1995 and 1995–2011, it had continuously decreased by -8.6% and -9.1% , respectively. Between 1973 and 2011, about 19% of the swampy areas were converted into cropland as the result of siltation and continuous evacuation of water from the former lake Cheleleka (Figure 3b). The surface area of Lake Cheleleka was about 12km^2 in 1972, with an estimated average depth of 5m and a storage volume of $6 \times 10^7\text{m}^3$ (Ayenew, 2004). However, it has now been converted into mud-flat and grassland indicating that the transported sediments have gradually filled the lake bed.

Bare land: This LULC class occupied the smallest area in all the study years next to built-up, but changed with the highest rate (56.9%) in 1973–1985. As the loss of vegetation cover increased, the bare land cover also increased during the first two intervals, but since 1995 when the land for cultivation has become scarce due to population pressure, areas previously left as marginal lands have come under cultivation and two-third of its area turned into cropland. This in turn has aggravated land degradation and yield reduction which causes a demand for more land to cultivate, creating a vicious circle.

Scrub: Scrub was limited to the north-western part of the study area. The major conversions observed were mainly to grassland and cropland over the entire period evaluated. The annual rates of change of scrub were estimated at -2.5% , -0.7% , and -0.1% during 1973–1985, 1985–1995, and 1995–2011 temporal intervals, respectively. This LULC was conserved as Swayne's Hartebeest Sanctuary, but it has frequently been disturbed and still clearing for farming, construction materials, and firewood has continued by encroaching settlers.

3.2. Underlying driving forces analysis

The image analysis has revealed that in many parts of the study area, landscape transformations have taken place at a high rate, but the question of what forces have driven those changes needed further investigation. To understand the changes and associated UDFs, it was necessary to integrate

the use of remote sensing which captures the LULC conversions and the experience of key informants who have the knowledge about the watershed's natural resource usage to pinpoint the possible causes of the changes.

Several authors (Burgi et al., 2004; Jones et al., 2011; Zak et al., 2008) support the notion that land cover conversions are influenced by a variety of factors operating on more than one spatial and temporal level and acting not in isolation, but in an interconnected effect of several drivers. The interview results on the driving forces were in agreement with this notion and similar to the framework of Lambin et al. (2003) for tropical regions. Though it is difficult to analyze and represent all driving forces adequately due to their complexity, the assessment result indicated that the LULC conversions in the Lake Hawassa Watershed are mainly driven by a combination of demographic, low agricultural technology, institutional, economic, and biophysical factors.

3.2.1. Demographic factors

Historically, humans have increased agricultural output mainly by bringing more land into production by clearing vegetation cover (Lambin et al., 2003). The clearing of forest and other woody vegetation has taken place in Ethiopia for a long time and it continued at a rate of 141000 ha annually between 2000 and 2010 (FAO, 2011). This is mostly converted into cropland resulting in reduced vegetation cover and accelerated soil erosion (Berry, 2003).

According to the Census data (CSA, 1973; BoFED, 2014), the population of Lake Hawassa Watershed increased from 44 086 in 1973 to 1 103 507 in 2014 (Figure 4). Migration was one of the most important demographic factors that contributed to population increase. Based on interview results and own observation, most of the LULC conversions were population induced, such as agricultural land clearance and overstocking of grazing land. Similar interview results (Dessie and Christiansson, 2008) indicated that between 1974 and 1975, when the Revolutionary Derg took power, many farmers from the surrounding villages settled in the protected Wondo Genet forest which is part

of this study site. In 1991 during the most recent regime change, a large area of government owned forest in this protected area was extensively felled and converted to farm land. Increase in population, migration, and power vacuum all have the effect of increasing pressure on the existing natural resources. Particularly, population pressure, worsened by low agricultural technology, has significantly contributed to the expansion of agricultural land and excessive extraction of biomass. Earlier works of Nemani and Running (1995) have shown that increase in population and the associated pressures are major driving forces of land cover changes and contributes to natural resource degradation. Increase in population creates surplus labor force and the usual trend for this force has been to break from the extended family and start their own family life. However, this is seldom possible in the area due to shortage of land and thus, the nuclear family stays with the extended family for an elongated period. The recent trends show that this labor force migrates to other undisturbed areas in search of farm land or to the urban areas to look for jobs. Migration to urban areas in turn contributes to the expansion of built-up areas. Urbanization is causing deforestation and permanent soil degradation by re-

placing previously preserved green areas, parks, and lake side ecosystems. Some of the key informants noted that the combined effect of urbanization and soil degradation has been one of the causes for pollution of water sources through surface run-off.

The demand for fuel is critical in Ethiopia and it is one of the most severe causes of land degradation. A 1989–90 study (Berry, 2003) suggests that nationwide 18% of the energy in rural areas is supplied by dung and crop residues. Earlier, such residues were left in the field to serve as organic fertilizer to replenish soil fertility. A similar study conducted in our research area (Yigrem et al., 2008) indicated that 18.2% of the households used animal dung for fuel. Besides, the population increase has led to a shortage of land and following practice is becoming uncommon which in turn reduces soil fertility. It is evident from image interpretation that the 10–27km² area was converted from bare land to cropland in every temporal interval, indicating the use of more fragile marginal lands mainly accountable to the increase in population. Population growth has exerted more pressure on vegetated and bare land and this in turn has caused an increase in demand for more land and more forest products. As a result, forest resources have been continuously

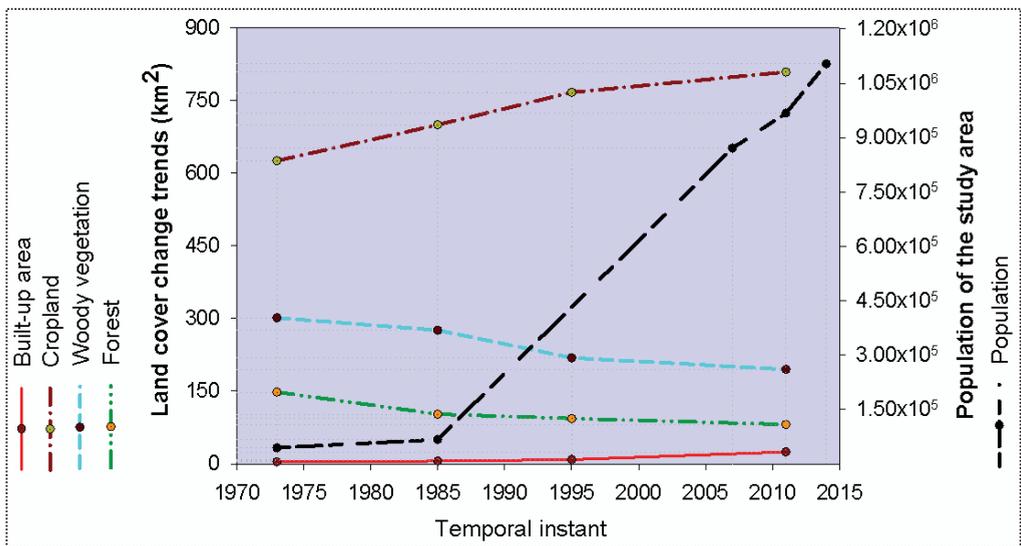


Figure 4. Trends of change in selected LULC classes and human population (1973, 1985, 1995, 2007, 2011 and 2014).

cleared during the study period. Poverty and scarcity of agricultural land, is widely considered as one of the most important precursors of deforestation (Castillo-Santiago et al., 2007).

In the current study area, the livestock population has undergone a parallel increase to that of human population. The increase in livestock population has contributed to a fragmentation of arable land and degradation of pasture areas. Arable land per capita declined significantly. In 1994/95, about 61 % of farming households cultivated less than one hectare of land and only 1 % of the farmers' own holdings were greater than 5 hectares (FAO, 2001) and these are likely to be concentrated in the sparsely populated areas with low agricultural potential. Agricultural sample surveys conducted by CSA (1985) and BoFED (2014) indicated that the livestock population (cattle, sheep, goat, donkey, horse, and mule) in the current study area increased from 74 810 to 1 136 670. These numbers refer to private peasant holdings only and livestock data of cities were not included due to unreliable sources.

According to respondents, the main source of feed for livestock was natural vegetation available in the field. As the common grazing land areas are gradually transformed into new farms, animals were freely roaming in the remaining pasture, woodland, and even in forested areas. The effects of overgrazing and trampling (Figure 3d) lead to vegetation removal. As confirmed by interviewees, scarcity of pasture for livestock coupled with difference in ethnic background and lack of well-defined boundaries between all forms of land resources are occasionally sources of conflict in the area.

3.2.2. *Technological factors*

The image analysis revealed that LULC conversion was multi-directional, the primary shift being from vegetated area to cropland. According to respondents, lack of technological know-how and necessary inputs have led the farming community to pursue rainfed horizontal expansion agricultural practices resulting in LULC conversions. Most agricultural practices have a traditional nature of farming system i.e. mixed type comprising

cultivation of crops and livestock production on a subsistence basis. This involves the use of traditional wooden farm implements which are extracted from the surrounding forests and woodlands, contributing to the deforestation and LULC conversions.

The mainstay of the farming community is agriculture, but the agricultural practices followed were not able to secure self-sufficiency in food, raw materials for agroindustry, and jobs for the growing population. A survey (Deininger et al., 2008) conducted in the SNNP Regional State indicated that 84% of households depend on agriculture and only about 6.1% and 2.5% of households are self-employed and salaried members, respectively. This shows the limited extent of economic diversity and the importance of land as a source of livelihood. According to respondents, farmers rely on horizontally expanding, labor-intensive and rainfed agriculture and sustainable intensification has not been possible due to the lack or high cost of agricultural inputs (fertilizer, seed, and secure land). The Wondo Genet area is endowed with abundant water resources and fertile soil where irrigation could have played a major role in food production.

The long existing state owned Shallo improved seed enterprise which is rainfed and the recently launched privately owned G2 irrigated farm, occupying about 3.0% of the study area, were formerly covered by woodland and pasture in a suburb of Hawassa City. However, farmers in the area are still practicing traditional agriculture on limited farmlands. Poor technological applications in the wood sector leading to wasteful logging practices (Geist and Lambin, 2002) are also contributing to the destruction of vegetation cover.

3.2.3. *Institutional factors*

There are several institutions with legal jurisdiction to administer land resources in Ethiopia. These include: the Ministry of Agriculture and Rural Development (MoARD) at a national level, Regional Agricultural Bureaus, the Environmental Protection Authority, and the Agricultural Research Organization among others. In Oromiya Regional State, authority over forests lies with the Ru-

ral Land and Natural Resources Administration Authority, while in SNNPRS jurisdiction falls to the Agriculture and Natural Resources Development Bureau under regional MoARD. Besides, institutions responsible for natural resource management have frequently been restructured to improve the protection of available resources. However, key informant interviews indicated that frequent restructuring and overlapping responsibilities among those institutions accountable for land resource management were considered barriers to halting the severe deforestation and land degradation in the area. Devolving of natural resource management responsibilities to lower administrative units, district level, where serious concerns exist over the capacity of officials to accurately demarcate the location of natural resources was shared by 75% of the respondents. Thus, inadequate capacity of institutions at district level to educate and involve local community in the management and conservation of the natural resources was one of the causes that led to the clearance of land cover and soil degradation.

Another pattern, seen mostly in Africa, comes from insecure ownership related to uncertainties of land tenure. In Ethiopia, ownership of land is with the state and people are entitled to inheritable use right which is in conflict with the goal of ensuring land users' tenure security. In their reports, Grover and Temesgen (2006) argued that restrictions on land ownership and land sales have caused insufficient land use, discouraged long-term investment in the land and thereby contributed towards increased land degradation. Key informants confirmed that people considered natural resources including forests as village commons and the environmental custodianship was gradually eroded among the newly emerging households. This situation makes the farming community both actor and victim of the land degradation.

From a study conducted by Dessie and Christiansson (2008) and feedback from key informants, it became evident that the power vacuum during the regime changes and weak institutional law enforcement exemplified by encroachment deep into vegetated ar-

eas, selective cutting, and illegal logging has also caused LULC conversions in the study area. During the regime changes, institutions often completely lose their stewardship to protect the natural resources. The weak law enforcement is sometimes linked with some level of undesired relationships among those engaged with resource management.

The Rural Land Administration and Land Use Proclamation (FDRE, 2005) was one of the institutional decisions perceived to reduce deforestation and land cover conversions in the region. This proclamation (456/2005) was issued in 2005 with the aim to increase tenure security, improve productivity and avoid expectations of land redistribution. However, forested areas were not mentioned until it was amended in 2007 and in most instances forests have yet to be mapped and registered. Rural households who knew this loophole in land law were able to clear land and stake a claim before the registration process began. Such was the case in SNNPRS where large areas of forest were cleared prior to the proclamation being issued (Gebremariam et al., 2009).

3.2.4. Economic factors

Agriculture is the predominant economic activity in Ethiopia and it contributes 53% of the GDP, 90% of the export earnings and 85% of the employment and livelihood (Bekele, 2001). Recent state investments in transportation and communication infrastructures improved access to local and regional markets and created opportunity for people to look for alternative livelihoods. An earlier study (Geist and Lambin, 2002) indicated that economic factors are prominent UDFs of tropical deforestation. According to our observation and feedback from key informants, soaring prices of timber and other wood products aggravated by overstocking of saw mill and joinery enterprises in the surrounding towns have negatively contributed to the LULC change in the area. Consumer prices for local and imported timber were reported to have reached USD 307/m³ (ca. 5 500 Birr) in 2009 for locally sawn wood and USD 386/m³ for imported timber (Bekele, 2011).

The other perspective is the introduction and prioritization of certain high-return

crops. Based on earlier reports (Dessie and Christiansson, 2008) and as confirmed by interviewees, the emergence of coffee, haricot beans, and khat (a mild stimulant plant) as economic crops, have intensified changes by promoting economic activities, establishment of new markets, and immigration and settlement, all of which are factors that have ultimately contributed to agricultural expansion and decline in wood lands.

We realized that forest protection was not a priority for the community, but an opportunity to benefit from forest resources. This is because not all members have knowledge of the impact of forests on the environment. Key informants also recognized that due to the limited off-farm employment opportunity, the majority of households need instant cash from other sources to pay for schooling, health care, and land taxes. This has increased the demand and pressure on natural resources by encouraging people to engage in illegal logging and clearing forest for charcoal burning to earn immediate income.

In connection with expanding built-up areas and associated construction activities, quarrying of building and road filling materials as a source of income has been extensive in the area. These include harvesting of sand, gravel, red ash, clay, surface and sub-surface earth materials. In suburbs of the cities and towns of the study area, people who are exploiting the resource may ask for permission for a given site, but dig anywhere they choose. In some areas the exploiters seldom bother to seek permission from anyone. On site observation and feedback from selected informants indicated that such quarrying activities have been huge sources of income since the 1990s resulting in a widespread clearance of vegetation and soil degradation. Exposed surfaces due to quarrying are vulnerable to erosion, and regrowth on such surfaces is rare or very slow. Besides, some of the quarrying pits close to Hawassa City are used as waste dumping sites. The quarrying pit in the new settlement area, commonly called «Diaspora», is a living example (Figure 3c). Some respondents interviewed around this site and from the municipality noted that there are many people involved in the flourishing waste disposal busi-

ness to generate income to support their families.

3.2.5. Biophysical factors

Biophysical attributes such as topography, local climate, soil type and availability of water (Briassoulis, 2000), generally play an important role in LULC conversions. According to accounts from key informants, suitability of land with flat-lying topography and availability of water for a range of use has contributed considerably to the expansion of agricultural land and livestock production. These conditions have served as a pull factor to the increase in the number of inhabitants and has led to cultivation of marginal lands. Areas with steep slopes and reduced vegetation cover are susceptible to erosion when short torrential tropical rain flashes. The result of image analysis and feedback from the interviewees demonstrated that the western part of the watershed was converted to bare land and some areas were exposed to gully formations due to erosion. Respondents also said that human-induced fires have played a significant role in the destruction of forest and dense bush on hillsides and steep areas where it is not easy to access and control the incidents. In the current study area, complete regeneration of vegetated areas was not possible given the increasing human and livestock population, expanding agricultural activities, and proximity to settlements and road networks.

The long term mean monthly rainfall of the watershed varies between January and September. According to summaries drawn by (Gebreegziabher, 2004) using meteorological data within the study area, the mean monthly rainfall in January was 26.7 mm while the highest recorded was in September amounting 133.1 mm. The rainfall data reveals the occurrences of high seasonal variability and recently irregular changes in the pattern have also been observed affecting the growth and regeneration of vegetation cover.

4. Conclusion

As the regions enclosing the study area do not have documented and harmonized land resource data, assessment of land conversi-

ons and driving forces at a local level is an important information layer that could be expanded to a regional level. The availability and analysis of remote sensing data coupled with field survey techniques was found effective to quantify LULC conversions and identify the UDFs of the changes. The result revealed a widespread clearance of vegetation cover, the primary conversion being to agricultural land. The current study area has undergone a rapid LULC conversion and more than 291 km² (20.3 %) of woody vegetation and forest cover has been permanently converted into other LULC classes over the study period 1973–2011. The quantified LULC conversions and interviews with key informants not only enabled us to identify the changes and UDFs, but also showed us direction about measures to be taken in order to minimize deforestation and land degradation. If the biophysical resources are to improve, mitigation strategies should be developed that are geared towards the UDFs. The need to transform low agricultural technology, enabling local community to influence resource management institutions through policies, and introducing secure land tenure system are some of the factors pinpointed to minimize the extent of resource degradation in the study area. Survey results and census data also indicated that the area is under population pressure and this trend is expected to grow in the future unless proper migration policy coupled with family and land use planning is formulated and implemented.

It is useful to create awareness that the use of coarse spatial and temporal resolution imagery may never completely be free of limitations. Using fine resolution image data in the future research should produce better results for planning and informed decision making in natural resource management. Particularly, analysis of high temporal resolution images will tend to avoid the masking of some sudden changes that have occurred within short temporal intervals.

The findings based on the analysis of the quantified LULC conversions and the response of key informants about the causal factors should provide useful information to planners and natural resource managers to

better understand the past and current change dynamics and subsequently manage biophysical resources in the future.

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