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LAND USE/ COVER DYNAMICS AND ITS IMPLICATIONS IN THE DRIED LAKE ALEMAYA WATERSHED, EASTERN ETHIOPIA

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ABSTRACT

The objective of this study was to examine land use/cover dynamics and its implications in Lake Alemaya watershed through interpretation of aerial photographs (1965 and 1996) and satellite imagery (2007). The study showed that aquatic vegetation, urban built-up area, cultivated and rural settlement, forest, grass, open water, marsh and shrub land use/cover patterns of the watershed. A significant spatial – temporal expansion of urban built-up and cultivated and rural settlement lands was observed. The proportions of forest, grass and shrub lands decreased considerably. The lake dried-out and was replaced mainly by grass, aquatic vegetation and marsh. The number of rural dwelling units increased from 925 in 1965 to 1390 in 1996. Length of gullies increased from 93.88km in 1965 to 154.38 km in 2007. These have implications for environmental degradation in the form of soil erosion, decreasing available water and the subsequent drying-out of Lake Alemaya. To tackle problems, development of a watershed land-use plan and soil and water conservation methods is needed.

Key words: Change detection, land degradation, Expansion, Reduction

INTRODUCTION

Mankind's presence on the surface of the earth results in the modifications of landscape (Daniel & Steven, 2000). This modification largely occurs through land-use/cover (LUC henceforth) changes (Dwivedi, Sreenivas & Ramana, 2005; Hellden, 1997), and can have adverse impacts and implications on the local, regional and global environments (Brandon, 1998; Houghton, 1994). LUC is an endlessly changing process taking place on the surface of the earth (Mas, *et al*., 2004; Reid *et al.,* 2000). LUC is mainly caused by the processes of expansion of agricultural, settlement and grazing lands and the removal of vegetation. In the light of this, the modern world has faced massive changes in its land-use patterns in the past few centuries (Muttitanon, 2005; Paul & Mascarenhas, 1981; Richards, 1990). Forest lands, wetlands, grasslands and deserts have been modified and transformed both in space and time. The size of human settlement, agricultural land and other related land-use systems have increased enormously (FAO, 1976; 1993). Consequently, in the past few decades, conversion of grassland, woodland and forestland into cropland and pasture has significantly increased in the tropics (Williams, 1994).

Ethiopia is endowed with a variety of agro-ecological conditions (MoARD & World Bank, 2007). Its complex topography and wide altitudinal variations contribute to the presence of various types of LUC class. However, the LUC system is a very dynamic process in Ethiopia and various practices control the rate of this change. As a result, environmental degradation processes in the form of soil, vegetation, biodiversity and water degradation are the major environmental problems facing Ethiopia today.

The Lake Alemaya watershed is a typical environment of Ethiopia in that it is endowed with a large potential of natural resources. In the watershed, a series of LUC dynamics has largely occurred over the past few decades. These dynamics and associated factors have resulted in the degradation of resources of the watershed; amongst others, the drying-out of Lake Alemaya and its related consequences.

For understanding of such watershed level LUC dynamics and their environmental implications, information is needed on where and when changes occur; the rates at which they occur as well as their implications for the environment. This can be achieved through change-detection analysis approaches. Change-detection analysis of LUC is best done by interpreting images that show features of interest between two or more dates, using remotely sensed datasets (Mas, 1999). In such types of analysis, the geo-informatics technologies (Remote Sensing and GIS tools) have been used in the recent decades in diverse areas of applications (Aronoff, 1989; Burrough & McDonnel, 1998; Lellisand, Kiefer & Chipman, 2006). Remote sensing and GIS techniques provide vital information on the spatial distribution of various LUC classes over the years. Such type of information is important in environmental planning, monitoring and management strategies.

Therefore, the aim of the present study is to provide information on long-term LUC dynamics (over a period of 42 years), and their implications concerning environmental degradation in the dried-out Lake Alemaya watershed, by examining the available spatio-temporal datasets by means of an integrated approach of remote sensing and GIS technologies. The output of the analysis will give baseline information in devising an appropriate strategy for watershed-level resource management, aimed at reversing or reducing the problems of environmental resource degradation. This study will also serve as an example for the proper conservation and management of other endangered or incipiently drying lakes of Ethiopia.

MATERIALS AND METHODS

The study area

Lake Alemaya watershed is in the Eastern highlands of Ethiopia, between 9º23´45´´– 9º30´55´´ N lat. and 41º57´30´´–42º6´30´´ E long. (Figure 1), and covers 13,797.48 ha. It comprises naturally closed lakes, and was formed within an erosional depression constituted by Mesozoic sedimentary rocks and crystalline basements (Tamiru, Wagari & Dagnachew, 2007). The depression is aligned NE–SW direction and collects natural recharge exclusively from rainfall.

The L. Alemaya watershed is part of the low-lying plateau of the Hararghe highlands, E. Ethiopia. It consists of dissected topography and rugged terrain. The eastern and northeastern parts of the watershed contain hilly and steep landscapes. The remaining part is almost flat, mainly in the centre and close to the dried-out Lake Alemaya corridor. The elevation of the watershed ranges between 1980 m above sea level (m asl) on the lake basin floor, and 2420 m asl on the upper recharging hills. The slope gradient reaches 78%.

The primary granite rocks are exposed in pockets in the upper, hilly areas of the watershed. In the other parts, sandstones and limestones, together with the lacustrine deposits of the dry lake basin, form the main geological features (Brook, 1995). Current erosion processes remove materials from the upper slopes and deposit colluvial-alluvial materials in most parts of the lower slope, on cultivated fields and in the dry lake basin. It is evident that the present geology and topography of the study area are the result of past and present geomorphologic processes.

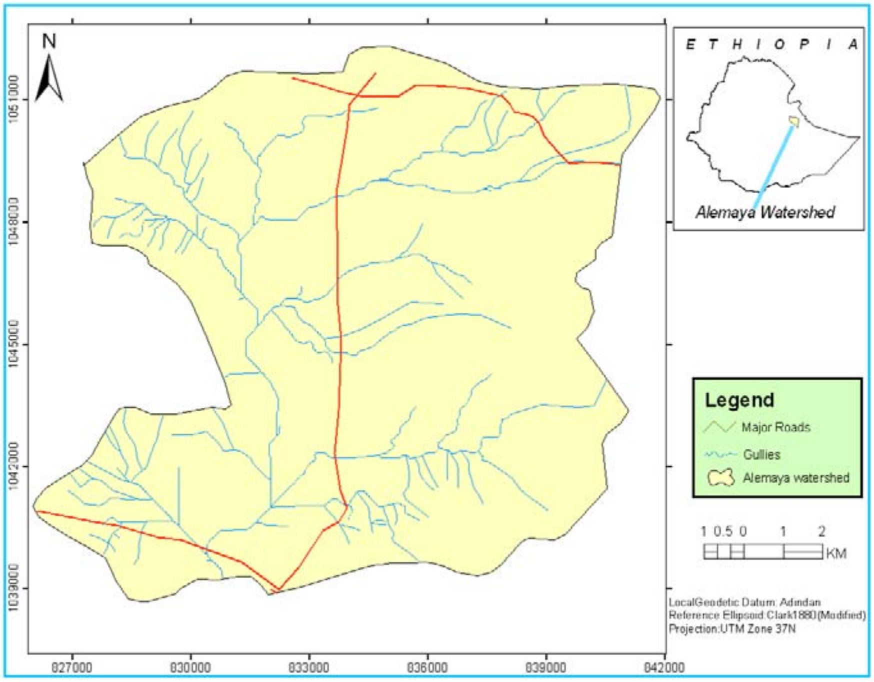

Figure 1: Location Map of Lake Alemaya Watershed

The climate type is warm-temperate (EMA, 1988). The rainfall pattern is bimodal, with a mean annual precipitation of 827 mm. Maximum precipitation occurs in April, August and September, with the highest peak in August (mean 149 mm), while the minimum is in December (mean 10 mm). The mean temperature of the area is 16 ºC (maximum in June, 19 ºC, and minimum in December, 13 ºC). The mean annual total potential evapo-transpiration (PET) is estimated at *ca*. 1227 mm (Brook, 1995).

In the watershed, the natural vegetation has been completely cleared for the expansion of agriculture, settlement and construction purposes. The surrounding hills consist of severely exposed and eroded parts of the local landscape. Patches of planted *Eucalyptus* tree species are found on the peripheral areas of farmlands, along roads and around homesteads. As may be inferred from old remnant trees scattered throughout the area, the climatic-climax vegetation may have consisted of the high-altitude forest trees of Ethiopia, such as *Juniperus procera*, *Hagenia abyssinica*, and *Ficus* spp. The major annual crops are sorghum (*Sorghum bicolor* L.) mixed with maize (*Zea mays*, L.), and horse bean (*Vicia faba*), sweet potato (*Ipomoea arabica* L.) and various horticultural crops. A woody stimulant species, *chat* (*Catha edulis*), forms the main perennial crop of the watershed.

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Data source and analysis

The required data for the study were acquired from a systematic analysis of remotely sensed data (at 1: 50 000 scale for 1965 and 1996 aerial photographs and the 2007 Spot-5 satellite imagery), the interpretation being supplemented by 1:50 000 topographic maps (0941D1_KERSA, 1999 and 0942C1_Harar, 2000) (EMA, 1999). The boundary of the catchment was determined on a 1:50 000 topographic maps. The same procedure was followed on 1:50 000 panchromatic aerial photographs and the 2007 Spot-5 satellite images, with the overlay of the demarcated topographic map. Contours at 20-m vertical interval, and the boundary of the study watershed, were digitized on-screen from the topographic maps. A Digital Elevation Model (DEM) was prepared from the digitized contours by means of '*3-D Analyst extensions' of* Arc GIS 9.3 software. Elevation and slope maps were derived from the prepared DEM.

Analysis of spatial and temporal LUC dynamics was carried out on the aerial photos and satellite images. The panchromatic aerial photographs of the years 1965 and 1996 were visually interpreted, using a mirror stereoscope. The Spot-5 satellite imagery (2007) was analyzed digitally by means of ERDAS Imagine 9.1 remote sensing software. Image rectification, re-sampling, interpretation and classification were the conventionally accepted image-processing techniques used. The output of the interpreted aerial photographs and topographic maps of the study area was scanned at 600 dots per inch (DPI) resolution, and exported to the Arc-GIS 9.3 software window for digitizing. The local geodetic datum of Adindan, the reference ellipsoid of Clark1880 (Modified) and the projection type UTM Zone 37 North, were the spatial reference coordinate systems applied to rectify and resample the scanned topographic maps, interpreted aerial photographs and the Spot image when using the ArcGIS software. From each sheet, six ground control points were digitized to register the data sets.

The geo-database was then created, and all spatial datasets were stored within a geo-database environment to facilitate further analysis. Three LUC maps were produced, corresponding to the 1965 and 1996 aerial photographs and 2007 satellite images (Figures 2, 3 & 4). To analyze the LUC change processes in relation to landscape attributes, the three periods of LUC map of the study area were cross-tabulated with slope classes, using the 'cross-tab' module with the support of the 'Spatial Analyst Extension' of ArcGIS 9.3 software.

For simplicity, before interpretation of aerial photograph and satellite images, preliminary LUC classes were set; in the course of the interpretation, some classes were deleted, while others were added. Because enrichment planting had been undertaken within the forest land, it was not possible clearly to distinguish plantations from natural forests on the aerial photographs and satellite images. Therefore, forest land cover was identified to include both natural and plantation forests. This was verified in the field in 2007. In the course of analysis of the available aerial photographs and satellite images, the number of rural dwelling units was counted. These dwelling units were scattered throughout the cultivated land, it was therefore not possible to map them separately. Thus, rural settlement land was included in the cultivated land. The LUC classes used in the final analysis and interpretation are given in Table 1. Measurement of gully was also carried out for the three periods of analysis.

RESULTS AND DISCUSSION

LUC class and description

The interpreted aerial photographs of 1965 and 1996 and the Spot satellite imagery of 2007 identified eight LUC classes (Table 1).

Table 1: Identified LUC classes of the study area

LUC class	Description
Aquatic vegetation	this mostly grows in parts where the water table is at or close to the surface for a significant part of the year, and is largely found along the shore of the lake
Urban built-up area	is a portion of land used for urban settlement
Cultivated and rural settlement land	land covered with annual and perennial agricultural crops. Scattered rural settlements, gullies and homestead plantations are considered to be part of this LUC class
Forest land	represents both the natural and enhanced plantation forest areas that are stocked with trees capable of producing timber or other wood products.
Grassland	this includes areas predominantly covered with grasses. This class includes areas dominated by native or introduced grasses and forbs, including grass-like plants such as sedges and small flowering and non-flowering plants occurring on upland and flat land areas.
Open water surface	land completely covered with water and includes mainly the lake water
Marsh Area	is an area where the water table is at the surface for a significant part of the year
Shrubland	this includes bushes with open stands of short trees and shrubs.

RATE OF LUC DYNAMICS

Aquatic Vegetation

The proportion of aquatic vegetation showed a constant increase over the analysis period. It was 76 hectares (ha) (0.56% of the total area of the watershed) in 1965, 97 ha (0.7%) in 1996 and 103 ha (0.74%) in 2007 (Table 2). This implies an average increase of 26% between 1965 and 1996, 6.29% between 1996 and 2007 and an overall increase of 33.76% between 1965 and 2007. Aquatic vegetation largely grows around the lake shore. During the field visit, the growth of aquatic vegetation in shallow water depths, on wetter soils and/or frequently flooded parts of the dried-out lake basin, was observed. With a subsequent drying of the soil moisture of the lake basin, with time, the aquatic vegetation was transformed to other types of LUC classes (Tables 3 & 4). A large proportion of its transformation occurred to open water, followed by grassland and shrubland between 1965 and 1996, and marsh, grassland and shrubland between 1996 and 2007. Its transformation to open water (in 1965) and marsh area (in 1996) indicates the existence of seasonal inundations, which could remain on the surface for some more months after rain. The transformation to grass land suggests that, on further drying-up of the soil moisture, aquatic vegetation allows the growth of grasses and shrubs in the drier areas.

Most aquatic vegetation covered slopes of less than 4.55% (Table 5), indicating its relative position and its encroachment on the shore as the lake dries out.

Urban built-up area

This LUC class covered 190 ha (1.38%) in 1965, 364 ha (2.64%) in 1996 and 413 ha (3%) in 2007. This reveals that urban land expanded by 91.1% between 1965 and 1996, 13.8% between 1996 and 2007 and 117% over the whole analysis period. Thus much of the urban land expansion in the watershed took place between 1965 and 1996, and it more than doubled over a 42-year period. Urban land expanded to both cultivated and non-cultivated LUC. A significant proportion of cultivated land, shrubland, grassland and forest land was transformed into urban built-up land. This indicates expansion of urban land at the expense of significant areas of land for cultivation and rural settlement, grass-, forest- and bushland. Transformation of these LUC patterns to urban land means a loss in the available cultivable land, a decreasing area of cultivable land available *per capita,* and a decline in forest-, grass- and shrubland resources.

The urban built-up area expanded on almost all slope classes, but largely on slopes of less than 19.13%. This means that the expansion of urban land largely took place on relatively gentle slopes, which are considered as better land for cultivation. Hence, there was competition between urban land and cultivated and rural settlement land in the study watershed.

Cultivated and rural settlement land

The cultivated and rural settlement LUC class covered the major part of the watershed during the study period. It accounted for 10943 ha (79.31%) in 1965, 11806 ha (85.56%) in 1996 and 12048 ha (87.32%) in 2007. The average change between 1965 and 1996, 1996 and 2007 and overall between 1965 and 2007, was 7.9%, 2.05% and 10.09%, respectively. The counted number of rural dwelling units was 925 in 1965 and 1390 in 1996. This revealed an increase of rural dwelling units by over 50%, which may suggest an associated increase in size of the population by over half of the 1965 level. The expansion of cultivated and rural settlement land suggests that the demand for more crop production was satisfied by turning over more land to cultivation. It further reveals an increase in the demand for more rural settlement land, coupled with an increase in the size of the population of the study area. The expansion of cultivated and rural settlement land was obtained *via* transformation of grassland, forest land and shrubland. Expansion of cultivation and settlement onto the dried portion of the lake basin was observed (Figure 5). Also, cultivation took place within and peripheral to the urban land, indicating the practice of farming within open urban built-up areas. As observed in the field, much of this cultivated land was occupied by *Chat (Catha edulis)*, which was a major perennial cash crop of the watershed.

Cultivated and rural settlement land occupied almost all slope classes. However, almost 75% of this LUC category occupied slope classes below 19.13%, and *ca*. 90% occupied slope classes up to 33.41%. This suggests that cultivation expanded to steeper slopes susceptible to soil erosion, and could be a major reason for the occurrence of soil erosion in the watershed.

Table 2: Extent of LUC classes of Lake Alemaya watershed

LUC class	Area of LUC class						Change (%)		
	1965		1996		2007		1965-1996	1996-2007	1965-2007
	ha	%	ha	%	ha	%			
Aquatic vegetation	76.78	0.56	97.03	0.7	102.57	0.74	26	6.29	37.76
Urban built-up	190.29	1.38	363.58	2.64	413.43	3.00	91.1	13.8	117.0
Cultivated & rural settlement	10942.7	79.31	11805.58	85.56	12048.28	87.32	7.9	2.05	10.09
Forest land	202.99	1.47	112.71	0.84	84.28	0.61	-44	-25.7	-58.62
Grass land	410.13	2.98	257.88	1.86	239.54	1.74	-37.1	-7.0	-41.64
Open water	563.62	4.08	402.47	2.91	0	0.00	-28.5	-10.0	-100.0
Marsh area	0	0	0	0.00	421.24	3.05	0	100	100
Shrub land	1410.99	10.22	758.19	5.49	488.14	3.54	-46.3	-35.6	-65.4
Total	13797.48	100	13797.48	100	13797.8	100	-	-	-

Forest land

Forest land occupied an insignificant proportion of the watershed, and showed a decreasing trend over the analysis period. It covered 203 ha (1.47%) in 1965, 113 ha (0.84%) in 1996 and 84 ha (0.61%) in 2007. It decreased by 44% between 1965 and 1996, 25.7% between 1996 and 2007 and overall by 58.6% between 1996 and 2007. Thus a significant decline in forest land was observed between 1965 and 1996. This was related to its significant transformation to the other land-use categories in the same period. It was largely transformed to cultivated and rural settlement land, followed by urban built-up areas between 1965 and 1996, and to cultivated and rural settlement land and grassland between 1996 and 2007. Hence, a conversion of forest land to cultivated and rural settlement land and urban built-up land was evident in the study area, the formation of these LUC classes being a major reason for the removal of forest.

Forest land covered almost all slope classes, except in 1996, when it was not found on slope class 33.41–77.45%. This suggests its presence in 1965, but its destruction in 1996 and its renewed existence in 2007. This reveals the presence of plantation activities in 2007 on this slope class and elsewhere in the watershed.

Grassland

The grassland LUC class covered a small proportion of the watershed, and continuously decreased over the 42-year analysis period. It covered 410 ha (2.98%) in 1965, 259 ha (1.86%) in 1996 and 240 ha (1.74%) in 2007. It thus decreased by 37.1% between 1965 and 1996, by 7.0% between 1996 and 2007 and by 41.6% over the whole analysis period. The decrease is associated with its transformation to other LUC classes, such as cultivated and rural settlement land, followed by urban built-up area between 1965 and 1996, and to cultivated and rural settlement land, marsh and aquatic vegetation between 1996 and 2007. This confirms the expansion of cultivated land, rural and urban settlement lands to uncultivated land-uses. The conversion of grassland to aquatic vegetation and marsh areas indicates floodwater accumulation in the dried-out portion of the lake basin. This in turn reveals the existence of a fluctuating hydrology in the watershed, which could be associated with change in local rainfall patterns. This may also suggest the existence of runoff on the upper slopes and accumulation on the flatter lands of the dried-out lake basin.

The grassland LUC occupied all slope classes, but over 85% of this LUC was found on slope classes below 10.93%. This confirms that, in the early phases of the drying-out of the lake, exposed land may have been covered by aquatic vegetation. With a continuous decrease in soil moisture, aquatic vegetation gives way to grasses.

Open water

The coverage of open water declined over the analysis period. It covered 564 ha (4.08%) in 1965, 403 ha (2.91%) in 1996 and 0 ha (0%) in 2007. On average, it decreased by 28.5% between 1965 and 1996, 100% between 1996 and 2007 and 1965 and 2007. Consequently, the lake dried-out completely in 2007. Much of the dry basin of the lake was transformed to all types of LUC, in various proportions. It changed significantly to cultivated and rural settlement, followed by aquatic vegetation, between 1965 and 1996 and to marsh, followed by aquatic vegetation and cultivated and rural settlement land, between 1996 and 2007. This indicates that cultivated and rural settlement land forms the major LUC class of the watershed. It further reveals that, upon the drying of the lake, a significant reduction in soil moisture occurred (implying rapid hydrological changes), which favored expansion of cultivation onto the dried-out lake basin (Figure 5). The newly cultivated land of the dried portion of the lake basin was cropped in short rooted crops such as potato (*Solanum tubersom*), onion (*Allium cepa*), cabbage (*Brassica oleracea*) and carrots (*Daucus carota*). Eventually, as the soil moisture further dried, field crops such as sorghum (*Sorghum bicolor* L) are cultivated. On the other hand, the transformation of open water to marsh area between 1996 and 2007, and aquatic vegetation throughout the analysis period, confirms the accumulation of floodwater in this part of the watershed. As a result, these LUC classes had a relatively high soil-moisture content, unsuitable for agricultural use.

Marsh

No marsh LUC class was identified in 1965 and 1996. Marsh covered 421 ha (3.05%) of the watershed in 2007. Thus, it increased by 100% over the study period. The presence of the marsh LUC class in 2007 was due to the significant transformation of open water, followed by grassland and aquatic vegetation, to a marsh LUC. This confirms that deep water, in the form of lake water, was completely absent in 2007. The lake also did not immediately dry-out, but underwent a stepwise transformation to marshland, then to aquatic vegetation, which in the end may be converted to grassland, cultivated and rural settlement land, or both.

Shrubland

The area of shrubland showed a decreasing trend throughout the analysis period. It covered 1411 ha (10.22%) in 1965, 758 ha (5.49%) in 1996 and 488 ha (3.54%) in 2007. On average, it decreased by 46.3% between 1965 and 1996, by 35.6% between 1996 and 2007 and showed an overall decrease of 65.4% between 1965 and 2007. This decreasing trend was associated with its transformation to other LUC classes. It was significantly transformed to cultivated and rural settlement land, grassland and urban built-up area. Shrubland occupied almost all slope classes, but much of it was found on slopes of less than 19.3%.

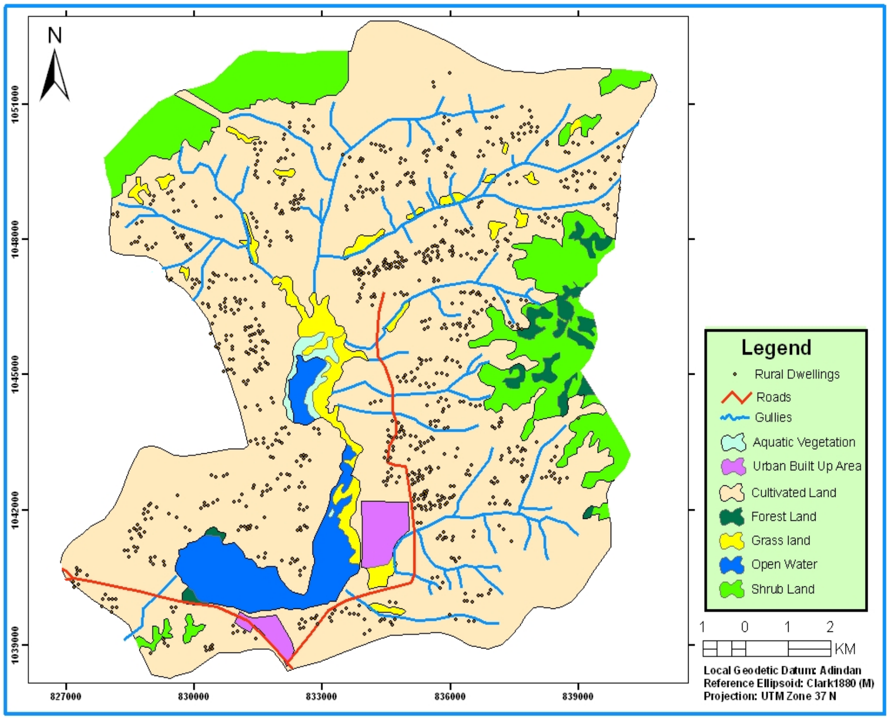

Figure 2: LUC Map of Lake Alemaya Watershed, 1965

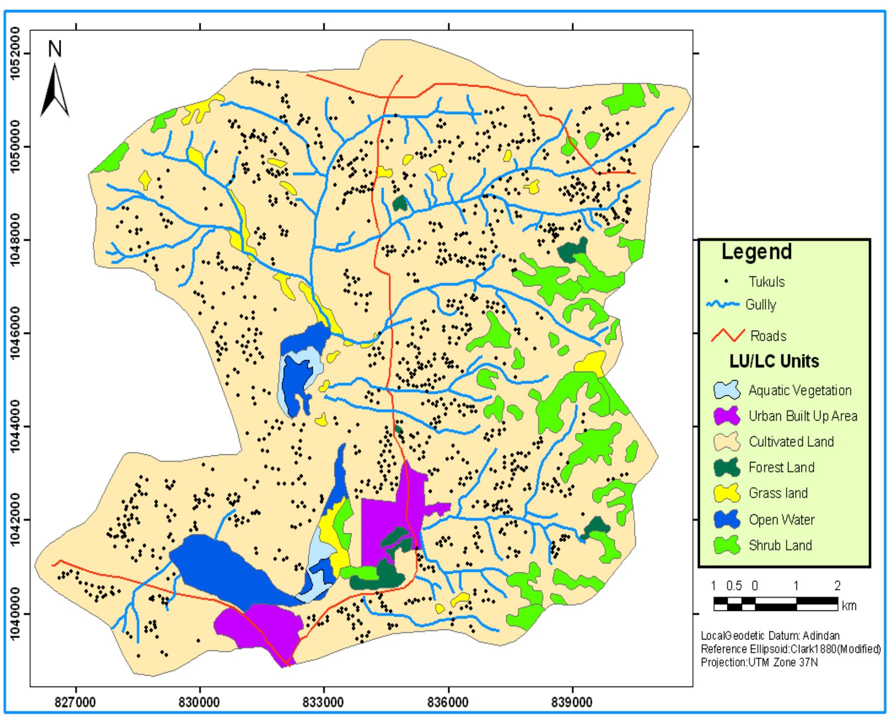

Figure 3: LUC Map of Lake Alemaya Watershed, 1996

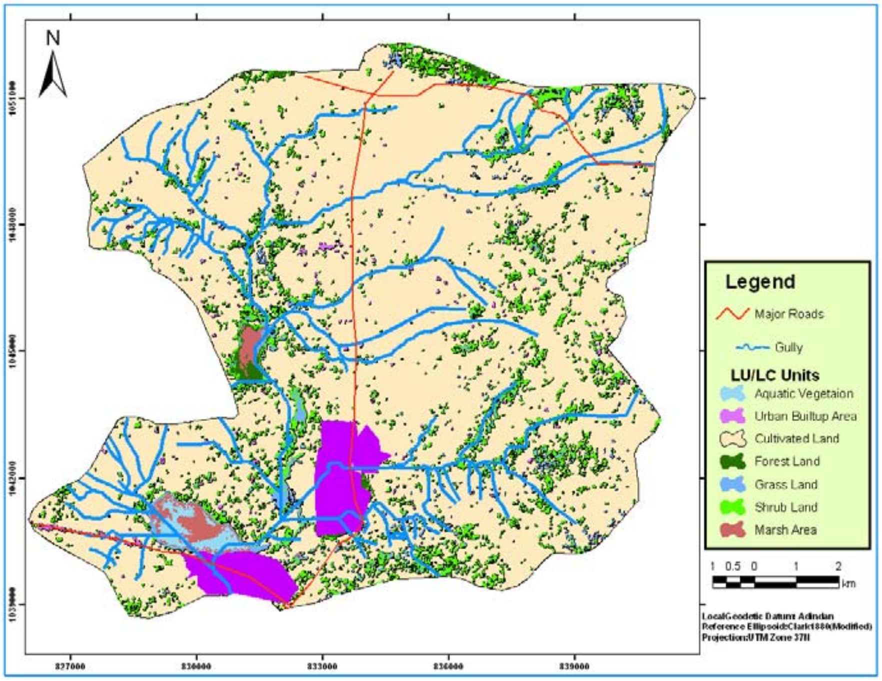

Figure 4: LUC Map of Lake Alemaya Watershed, 2007

Table 3: LUC Changes Matrix between1965 and 1996 in Lake Alemaya watershed (ha.)

		From LUC Class in 1965							
		Aquatic Vegetation	Urban Built-up Areas	Cultivated Land	Forest Land	Grass -land	Open water	Shrubland	Total
To LUC Class in 1996	Aquatic Vegetation	41.46	0	0.21	0.81	3.16	49.11	2.32	97.07
	Urban Built-up Area	0.37	190.29	70.23	20.52	32.52	0.28	49.37	363.58
	Cultivated Land	0.35	0	10638.9	140.0	308.9	122.59	594.8	11805.58
	Forest Land	0.19	0	79.14	27.15	2.19	0.5	3.54	112.71
	Grassland	8.97	0	94.57	4.74	59.79	11.23	78.58	257.88
	Open water	20.71	0	3.11	1.01	0.41	377.06	0.17	402.47
	Shrubland	4.73	0	56.53	8.75	3.18	2.85	682.15	758.19
	Total	76.78	190.29	10942.7	202.99	410.1	563.62	1410.98	13797.48

Table 4: LUC Changes between1996 and 2007 in Lake Alemaya watershed (ha.)

		From LUC Class in 1996								
To LUC Class in 2007		Aquatic Vegetation	Urban Built-up Area	Cultivated Land	Forest Land	Grass-land	Open water	Marsh	Shrub-land	Total
	Aquatic Vegetation	42.35	0	0.41	0.51	22.06	35.12	0	2.12	102.57
	Urban Built-up Area	0.17	363.04	38.12	5.32	4.41	0.15	0	2.22	413.43
	Cultivated Land	0.06	0	11679.8	42.19	156.67	15.17	0	154.41	12048.3
	Forest Land	0.24	0.54	49.36	21.22	4.09	0.14	0	8.69	84.28
	Grass Land	12.87	0	28.57	14.72	21.42	14.3	0	147.66	239.54
	Open water	0	0	0	0	0	0	0	0	0
	Marshy	39.59	0	0	0	45.97	335.4	0	0	421.24
	Shrub Land	1.79	0	9.34	28.75	2.96	2.21	0	443.09	488.14
	Total	97.07	363.58	11805.6	112.7	257.58	402.5	0	758.49	13797.48

Figure 5: Expansion of cultivation on the most dried-out portion of the lake basin (Photo by Author, 2010)

IMPLICATIONS OF LUC DYNAMICS

Implications for soil erosion

Land cover is among the major factors involved in soil erosion (Wishmeier & Smith, 1978). Removal of the vegetation cover exposes land to the impact of raindrops. This accelerates the detachment and removal of soil particles (Wishmeier & Smith, 1978; Morgan, 1986). The problem becomes worse when steeper slopes are cultivated under conditions of high erosivity, particularly in the absence of effective soil conservation measures. As in the other watersheds of Eastern Ethiopia (Thomas, 1998), water erosion forms the predominant form of land degradation in the dried-out Lake Alemaya watershed. This is evident from the existence of gullies, mainly in cultivated and rural settlement land (Figures 6, 7 & 8). The formation of gullies could be considered as an occurrence of severe water erosion (Morgan, 1986).

Thus, considering the LUC status of the watershed, the cultivated and rural settlement LUC were more vulnerable to soil erosion. Accordingly, the proportion of land prone to soil erosion increased from 79.31% in 1965, to 85.56% in 1996 and to 87.32% in 2007. The problem could become severe where grassland, forest land and aquatic vegetation LUC were transformed to cultivated and rural settlement land (Tables 3 & 4). Therefore, over 26 ha of land (forming 0.23% of land prone to erosion in 1965, or 0.19% of the total watershed area) were annually exposed to soil erosion.

Moreover, both the length and density of gullies increased over time, and showed significant spatial variations within the watershed. The length of gully was 93.88 km in 1965, 109.52 km in 1996 and 154.38 km in 2007 (Figures 6, 7 & 8). This showed an average gully length increase of 17% between 1965 and 1996, 41% between 1996 and 2007 and 64% over the 42-year analysis period. Correspondingly, gully density showed spatial variation over the analysis period, varying from 0 to 8.72 m km^{-2}. Most gullies were on cultivated and steep slope areas and alongside the natural drainage routes. This implies that in Ethiopia, cultivated land, and in particular the cultivation of steep slopes, are the major source of soil erosion (Hurni, 1983). In consequence, the presence of rugged and steep topography in the eastern and northeastern parts of the watershed is the major factor in gully formation in the study area. This substantiates the existence of spatial variability of soil erosion within the watershed. It also implies that cultivation in the watershed took place without appropriate soil-conservation measures, and expanded to marginal lands unfavorable for cultivation.

Table5: Distribution and area of LUC class with respect to Slope Class in the Lake Alemaya watershed

Slope (%)	1965 Area(ha)	1965 %	1996 Area(ha	1996 %	2007 Area(ha)	2007 %
Aquatic Vegetation						
<4.55	65.62	85.46	84.19	86.73	94.12	91.76
4.55-10.93	11.16	14.54	12.74	13.12	8.45	8.24
10.93-19.13	0	0	0.14	0.14	0	0
19.13-33.41	0	0	0	0	0	0
33.41-77.45	0	0	0	0	0	0
Total	76.78	100	97.07	100	102.57	100
Urban Built-up Area						
< 4.55	59.55	31.29	211.5	58.17	244.43	59.12
4.55-10.93	112.58	59.16	110.2	41.81	123.67	29.91
10.93-19.13	12.09	6.35	34	0.09	36.24	8.77
19.13-33.41	5.05	2.65	5.88	1.62	5.97	1.44
33.41-77.45	1.02	0.54	2	0.76	3.12	0.75
Total	190.29	100	363.58	100	413.43	100
Cultivated Land with rural Dwellings						
<4.55	2948.27	26.94	2440.4	20.67	2497.24	20.73
4.55-10.93	5078.29	46.41	5459.14	46.24	4989.54	41.41
0.93-19.13	2288.52	20.91	2916.34	24.70	3337.73	27.70
19.13-33.41	559.08	5.11	647.82	5.49	846.89	7.03
33.41-77.45	68.54	0.63	341.83	2.90	376.88	3.13
Total	10942.7	100	11805.53	100	12048.28	100
Forest cover						
<4.55	74.98	36.94	14.58	12.94	7.67	9.10
4.55-10.93	84.69	41.72	35.85	31.81	22.55	26.76
10.93-19.13	12.15	5.99	56.52	50.15	32.21	38.22
19.13-33.41	27.43	13.51	5.76	5.11	17.98	21.33
33.41-77.45	3.74	1.84	0	0.00	3.87	4.59
Total	202.99	100	112.71	100	84.28	100
Grassland						
<4.55	180.98	44.13	113.26	43.92	89.9	37.53
4.55-10.93	154.35	37.64	113.66	44.07	102.11	42.63
10.93-19.13	53.18	12.97	14.91	5.78	34.74	14.50
19.13-33.41	11.61	2.83	9.34	3.62	8.23	3.44
33.41-77.45	10	2.44	6.71	2.60	4.56	1.90
Total	410.12	100	257.88	100	239.54	100
Open water						
<4.55	289.98	51.45	291.43	72.41	0	0
4.55-10.93	215.73	38.28	105.66	26.25	0	0
10.93-19.13	57.19	10.15	4.66	1.16	0	0
19.13-33.41	0.72	0.13	0.72	0.18	0	0
33.41-77.45	0	0.00	0	0.00	0	0
Total	563.62	100	402.47	100	0	100
Marsh						
<4.55	0	0	0	0	261.68	62.12
4.55-10.93	0	0	0	0	115.64	27.45
10.93-19.13	0	0	0	0	43.49	10.32
19.13-33.41	0	0	0	0	0.43	0.10
33.41-77.45	0	0	0	0	0	0.00
Total	0	0	0	0	421.24	100

			Shrubland			
<4.55	123.39	8.74	110.67	14.60	89.62	18.36
4.55-10.93	434.97	30.83	210.6	27.78	212.61	43.56
10.93-19.13	557.37	39.50	310.41	40.94	98.4	20.16
19.13-33.41	105.03	7.44	119.16	15.72	79.15	16.21
33.41-77.45	190.23	13.48	7.35	0.97	8.36	1.71
Total	1410.99	100	758.19	100	488.14	100

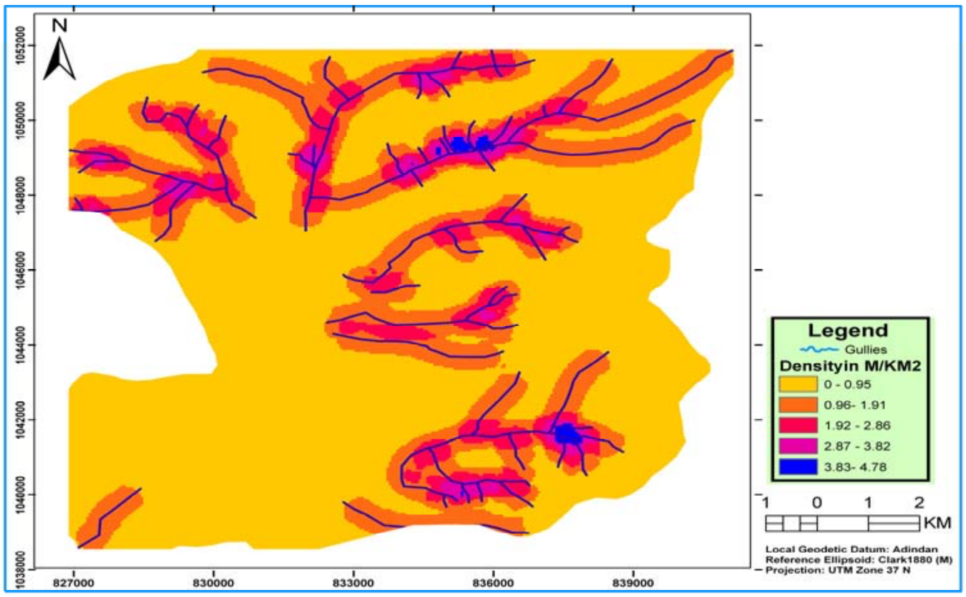

Figure 6: Gully Density Map, 1965

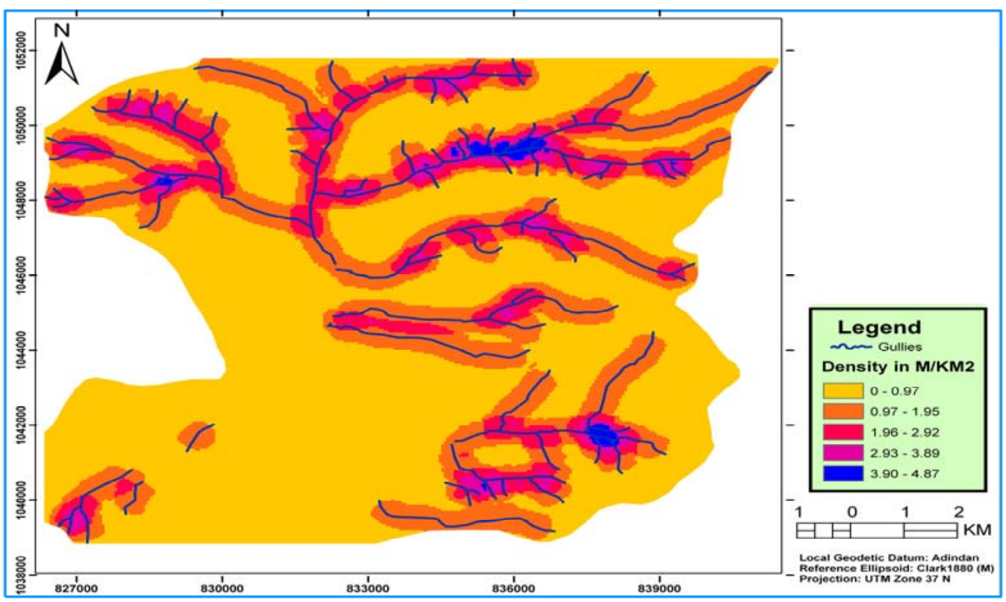

Figure 7: Gully Density Map, 1996

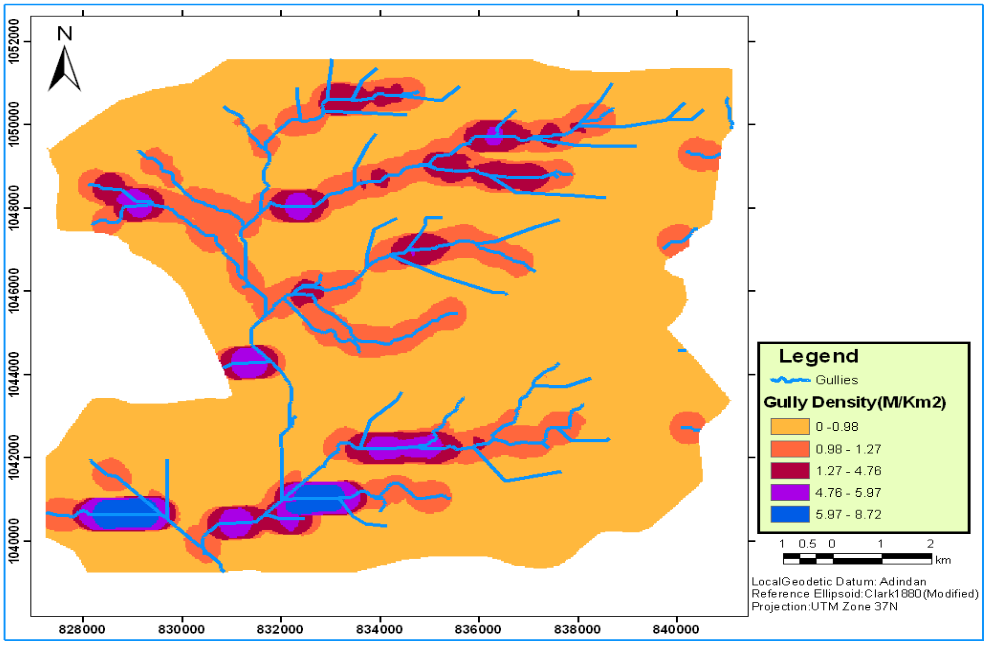

Figure 8: Gully Density Map, 2007

Implications for hydrology and water ecology

There is a direct interaction between LUC changes and the hydrological process, as well as the water ecology and quality of a given watershed. LUC change can cause floods, droughts, changes in surface and groundwater regimes, and reduce the quantity and quality of available water (Meyer & Turner, 1994). Land under little vegetative cover is subject to high surface runoff, and low infiltration and retention. The masses of sedimentary materials removed from the upper slopes accumulate on the lower slopes, and create the problem of water pollution and sedimentation of important agricultural lands (Woldeamlak & Ermias, 2009).

Continuous clearing of forest land, shrubland and grassland for farming could have increased the rate of siltation as well as of sediment accumulation in the Lake Alemaya watershed (Tamiru *et al.*, 2007). This may be a major cause of the complete drying-out of the lake. Hence, the surface water of Lake Alemaya may no longer be available for subsistence irrigation farming and domestic and industrial use after 2007.

As discussed above, the significant temporal increase of marsh, aquatic vegetation and flooding during the study period suggests the continual shrinkage and finally, drying-out of the lake water. Such processes have involved a change in the hydrological characteristics of the lake basin. As a result, these LUC classes contained a relatively high moisture content, unsuitable for agricultural land-use. With the continuous drying of these LUC classes, grasses grew, and in the drier parts of the basin, cultivation took place. This indicates spatio-temporal variations in the hydrology of the watershed. Moreover, the presence of severe soil erosion in the Lake Alemaya watershed could reduce the infiltration rate, thus making less water available for groundwater recharge, and leading to a new regime for the groundwater itself. As was observed from boreholes, the water table fell in many boreholes. In the light of this, the base flow of perennial rivers could in turn be seriously affected by a reduction in the groundwater returning to the river.

The drying-out of the lake has disrupted the lake ecosystems. As a result, the fish of the lake have been completely destroyed, and a variety of colored birds have migrated.

CONCLUSION

The study demonstrates that remote sensing and GIS tools were effective approaches for analyzing the direction, rate, and spatial pattern of LUC change. LUC change is a major environmental problem in the Lake Alemaya watershed. Moreover, the case study as presented here is, a vivid illustration of how rapidly cultivated land and settlements have expanded at the expense of forest, shrub- and grassland. Cultivation has expanded to the dried-out lake basin, to steeper slopes and marginal areas. This has in turn accelerated soil erosion, with the development of large and deep gullies. The complete drying-out of Lake Alemaya possibly resulted from LUC change in this watershed. LUC change thus aggravated land degradation and affected the hydrology of the area. The process resulted in shortages of available water and of trees for diverse uses.

Therefore, to exploit the potential of the watershed and for its sustainable use, land-use planning with integrated watershed management would be typical tools. In the first place, feasible soil and water conservation methods should be studied and practised in the watershed. In addition, an agro-forestry programme, *i.e.* an ecologically based natural resources management system which involves the integration of trees into farmland, needs to be introduced. To alleviate the current water shortage, attempts should be made to assess and exploit the groundwater potential, inter-basin water transfer and rainwater harvesting programmes. This probably will prevent further deterioration of the currently available groundwater potential of the watershed.

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