Applied Geography 88 (2017) 130–143

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

Identifying sustainability challenges on land and water uses: The case of Lake Ziway watershed, Ethiopia

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ARTICLE INFO

Article history:
Received 24 January 2017
Received in revised form
12 September 2017
Accepted 13 September 2017
Available online 27 September 2017

Keywords:
LULC
Watershed
Water abstraction
Human impacts
Sediment yield
Lake Ziway

ABSTRACT

This paper firstly analyzes the land use - land cover (LULC) in Lake Ziway watershed (Ethiopia) and quantifies the changing patterns from 1973 to 2014 using Landsat images. Secondly, the paper estimates sediment yields using the Soil and Water Assessment Tool (SWAT model). It also assesses and estimates water abstraction from Lake Ziway using survey data. The study shows that the conversions from woodlands into agricultural lands and settlement areas are the major detected LULC changes. Of the total area of the watershed, agricultural lands and settlement areas together increased from 57% in 1973 to 75% in 2014 at the expense of woodlands whose areas decreased from 26.16% to 6.63% in the study periods. The study also shows that water abstraction and sediment loads are increasing at Lake Ziway watershed. The major driving forces behind these LULC changes and the impacts on the lake natural condition are anthropogenic factors such as population growth, land policy changes and deforestation. Increasing demands for more land and water resources, i.e., land for settlements and cultivation, wood for fuel and charcoals, and water for irrigation and municipal water supply, are the underlying causes for the observed changes on the watershed resources. Thus, if the existing scenarios of human pressures are left neglected without management interventions, severe watershed degradations will continue to further affect the watershed's resources including the hydrology. Therefore, responsible government institutions should start mobilizing the local communities along with providing financial and material supports for watershed rehabilitation through afforestation and soil and water conservation activities. Additionally, the free-access practices for water use should be replaced by user-charge policy to regulate water abstractions in order to adequately sustain the water level of Lake Ziway and its feeder rivers. In this respect, this study provides firsthand information to policy makers and planners to put in place a comprehensive land and water use plan and regulations against the unruly human actions in the watershed before irreversible losses might happen to Lake Ziway and its watershed resources.

1. Introduction

Fresh water lakes in Ethiopia are used for various purposes. Lake Alemaya, located in the Eastern parts of Ethiopia, was one of the freshwater lakes used for drinking (rural households and municipal water supply), irrigation, animal watering, etc. The lake was the only major source of water supply for the residents of Alemaya town, Alemaya University and for the communities living in its watershed. However, there were no regulation and monitoring mechanisms for water abstraction from this lake. Besides the excessive water abstraction for water supply and irrigation, water loss through increasing evapotranspiration (Brook, 1995), watershed's land use and land cover changes, i.e., increasing rural settlement and cultivated land areas from 1965 to 2002 (Setegn, Yohannes, Quraishi, Chowdary, & Mal, 2009), accelerated soil erosion and sediment accumulations via adverse effects of deforestation (Daba, 2003; Tamirie, 1981; Muleta, Yohannes, & Rashid, 2006), and change in the local climate and absence of sustainable resource management activities in the

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https://doi.org/10.1016/j.apgeog.2017.09.005

watershed (Setegn et al., 2009, 2011) were the major factors that aggravated the problems on the sustainability of Lake Alemaya. These multiple anthropogenic pressures and natural factors have made this lake continuously face a strong water budget deficiency and finally to a danger of disappearance in the mid- 2000s (Brook, 2003).

The human pressures observed at Lake Alemaya and its watershed has now been under similar practices in the Ethiopian Central Rift Valley (CRV) region where Lake Ziway and its watershed are located. Lake Ziway is the largest freshwater lake which provides large fish supply to many market centers in the country. The region exhibits a rich variety of flora and fauna species; encompassing, for example, about 50% of the country's bird species (Hengsdijk & Jansen, 2006; Tenalem & Degnachew, 2007). The lake and its watershed have also significant contributions in supporting the livelihoods of many people in the region. However, Lake Ziway watershed has currently become one of the massively degraded areas in the country and faced a range of degradation challenges mainly associated with human pressures (Feoli & Zerihun, 2000; Jansen et al., 2007). For example, the watershed's forest resources have been depleting at an alarming rate through deforestation (MoA, 2003; WBISPP, 2001).

According to Hengsdijk and Jansen (2006), such threatening practices are due to the multifaceted factors the cause of which is mainly associated with the on-going land use - land cover (LULC) change activities for livelihoods, and the establishment and expansion of large-scale investment projects such as irrigation-based agricultural development activities, floriculture industries, etc. These livelihoods and irrigation development activities have brought very high demand for water from Lake Ziway and its feeder rivers (Scholten, 2007; Tenalem, 2004). Associated with these problems of water abstraction from feeder rivers, discharge to Lake Ziway has correspondingly decreased (Jansen et al., 2007). All in all, Lake Ziway has now become vulnerable to excessive exploitation seemingly beyond its capacity due to a number of multiple challenges that have the potential for damaging the lake ecological integrity and its environs.

Sustainable land and water resource management is currently one of the priority agenda in many countries of the world. To ensure this sustainability, information about LULC changes is necessary (Cohen, Kuafman, & Ogutu-Ohwayo, 1996; Lambin et al., 2001; Xiaomei & Ronqing, 1999) as these changes have significant influences on watershed hydrology and processes (Brooks, Ffolliott, Gregersen, & DeBano, 1997; Roth, Allan, & Erickson, 1996; Tomer & Schilling, 2009). Therefore, the worst-case scenario of Lake Alemaya implies that any unsustainable land and water uses in Lake Ziway watershed will similarly make Lake Ziway face severe environmental degradations in the near future and finally dry out the lake unless the existing unplanned intensive utilization of the resources are properly managed in the watershed. Accordingly, taking into account the case of Lake Alemaya, the present study on land and water use management was conducted on Lake Ziway and its watershed with the aim to evaluate the possible trends of LULC changes, to estimate sediment yields in the watershed, and to estimate water abstraction from Lake Ziway. To this end, this study is fundamental to figure out the environmental changes occurring in the watershed in order to provide critical information for decision makers, planners and concerned citizens to understand these changes and form a sustainable land and water use plan and regulations before further degradation and irreversible losses might happen to Lake Ziway and its watershed resources.

2. Material and methods

2.1. Study area

Lake Ziway watershed falls between gradients 7°22′36″ - 8°18′21″ latitude and 37°58′57″ - 39°28′9″ longitude (Fig. 1). It covers an area of 7032.3 km^2. The watershed has two escarpment areas - northwestern and southeastern parts. The watershed stretches from the edges of the Gurage Mountains in the northwestern and Arsi Mountains in the southeastern escarpment, rising over 3500 m above sea level (masl). The central part of the watershed (Rift Valley floor) covers the Lake Ziway and its surrounding plains. The Rift floor is covered by sparse acacia trees, and extensive cultivated field crop. The entire watershed is located within two administrative reigns- Oromia National Regional State and Southern Nation Nationalities and People regions. The watershed inhabits millions of human and livestock population.

The watershed does not have uniform climatic conditions. As the intensity, duration and frequency of rainfall events vary in the watershed throughout the year, both dry (locally named as *Bega* from January—May) and rainy (locally named as *Kiremt* from June—September) seasons are distinguished. It has a tropical climate, with a mean annual rainfall between 136 mm and 139.5 mm (Fig. 2). The rainy season accounts for about 55% of the annual precipitation while the dry season contributes with 45% (Billi & Caparrini, 2006). The watershed mean annual temperature ranges between 17.2 °C and 18.5 °C (Fig. 2).

Lake Ziway (also referred to as Zwai or Zeway in the literature) is the largest freshwater lake located within the CRV with surface area of 420 km^2. It is a relatively shallow lake with a maximum depth of 9 m. It has five islands, namely, *Tulu Gudo*, *Tsedecha*, *Funduro*, *Gelila* and *Debre Sina,* including Birds' Island. All the islands are inhabited except *Debre Sina*. The lake and its watershed have significant contributions in supporting the livelihoods of many people in the watershed. The lake is a source of livelihoods for local communities, and a source of drinking and domestic water for Ziway (Batu) and Meki Towns, a source of water for open and closed farm irrigations, biological diversities such as fishes, birds, mammals e.g. hippopotamus, etc. The marshes around the lake support several bird species such as cranes, heron, ducks, geese, etc. The lake has great geochemical and hydrological significance to some CRV lakes, namely, Langano, Abijata and Shala, which are all found at lower altitudes southwards.

2.2. Data collection and analysis

2.2.1. Land use land cover (LULC) change analysis and pattern detections

Remote (satellite information) and human sensing are important sources of information for LULC change studies (Rodriguez Lopez, Heider, & Scheffran, 2017). In this study, remote sensing data such as Landsat Multispectral Scanner (MSS), Landsat Thematic Mapper (TM) and Enhanced Landsat Thematic Mapper Plus (ETM+) satellite imageries were used for the years 1973, 1989 and 2014 respectively (Table 1) to classify and detect LULC changes in Lake Ziway watershed. The same month of the year, i.e., January, was used for acquisition of these images considering the lowest moisture content and percent cloud cover in this month to minimize discrepancies in reflectance.

The classifications of LULC classes by satellite imageries were complemented with human sensing (ecological change complaints), Goggle Earth images and actual ground truthing (GPS) points for verification of each LULC change analysis following the mixed-method approach of Rodriguez Lopez et al. (2017). The human sensing in this study encompassed the perception of elders'

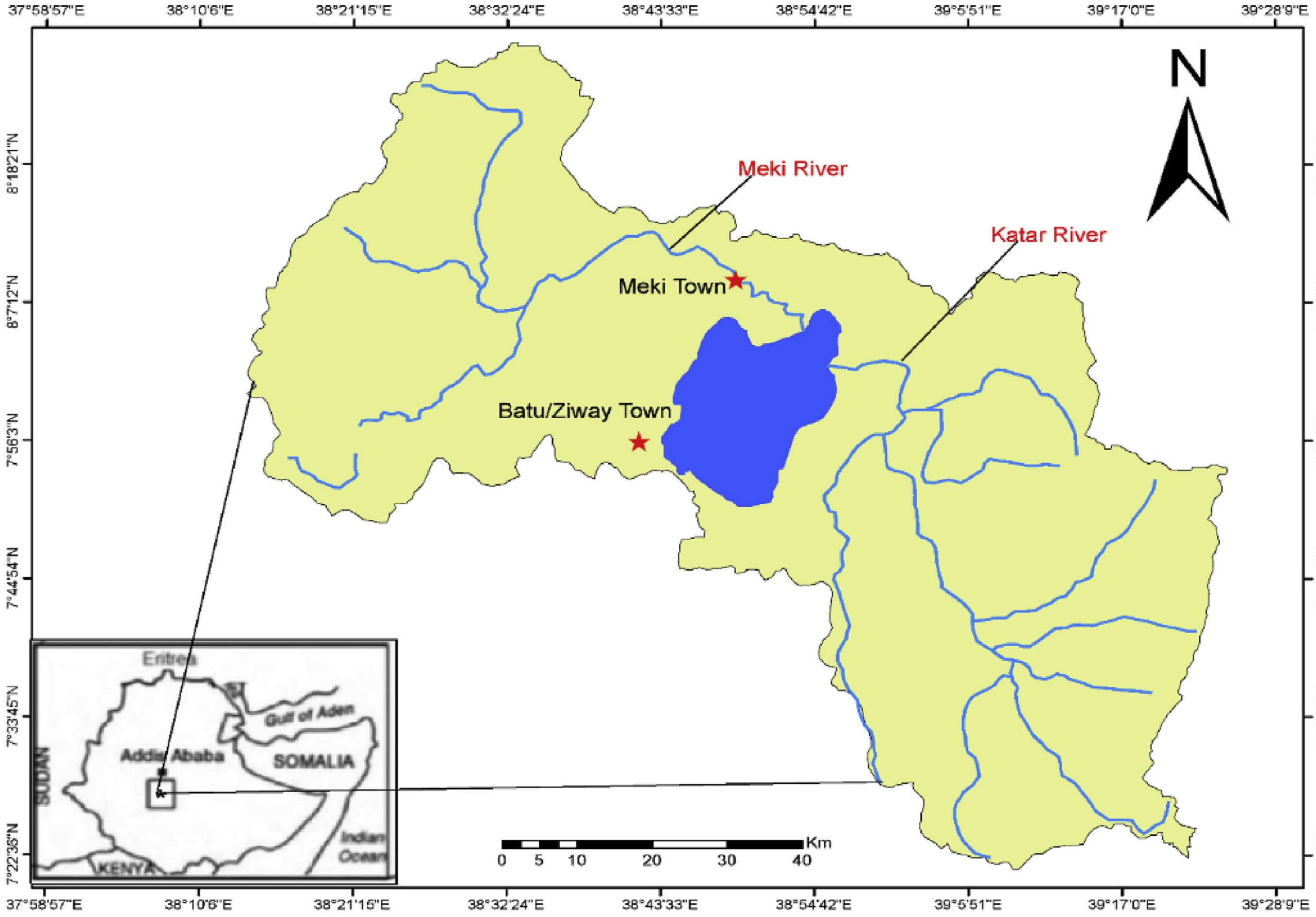

Fig. 1. Location of Lake Ziway and its watershed.

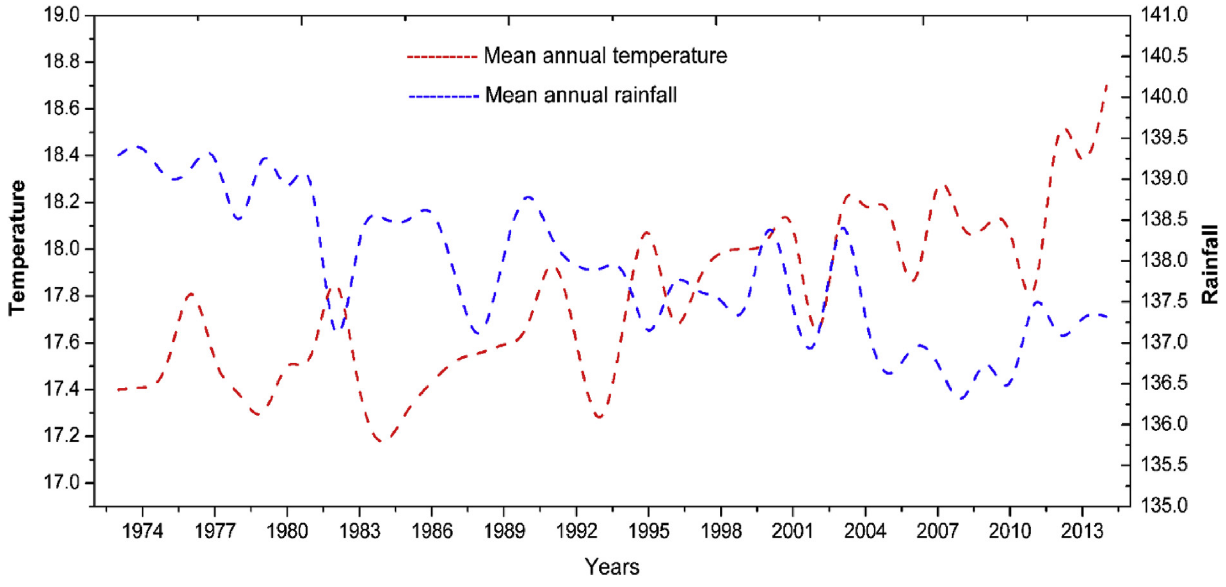

Fig. 2. Mean annual temperature and rainfall in Lake Ziway watershed (1973–2014).

people to investigate the past LULC types and identify their understanding of the reasons behind the past and present forms of LULC changes in their respective localities within the watershed. Elders were selected using purposive sampling on the basis that they were only born and raised in their present localities and were all over 65 years of age at the time of data collection, taking into

Table 1
Types of Landsat image scenes used for LULC change analysis.

Scene No.	Satellite Sensor	No. of bands	Ground resolution	Acquisition date	Path/rows
1	Landsat MSS	4	57 m*57 m	30/01/1973	180 and 181/54 and 55
2	Landsat TM	7	28.5 m*28.5 m	21/01/1989	168/54 and 55
3	Landsat Enhanced ETM+	7	28.5 m*28.5 m	10/01/2014	168/54 and 55

Table 2
Brief explanation of the major LULC patterns of Lake Ziway watershed (After Dagnachew et al., 2003).

Land use/cover categories	Brief description
Woodlands	Degraded Acacia land with cultivation/grazing
Wetlands	Non-forested wetlands
Water bodies	Permanent open water (lakes and reservoirs)
Plantation	Planted eucalyptus trees
Afro-alpine	Afro-alpine bushland, shrubs, and grasses
Cultivation	Intensively rain fed and irrigated cultivated lands
Agroforestry	Cultivated lands with vegetation/tree stands in between
Settlement	Build-up areas

account their age in 1973 - the beginning year of the LULC change analysis in this study. Finally, the LULC classes were mapped in eight categories (Table 2), after the modification of Dagnachew, Coulom, and Gassea (2003). Erdas Imagine Software Version 13 was used to process the image classification. An accuracy assessment was done to determine the quality of the information derived from the images.

The classified images were then exported to ArcGIS Software Version 10.2 to quantify the change matrices. Accordingly, areas were calculated in km^2 to identify the percentage change, and rate of changes between 1973, 1989 and 2014 against the resulting LULC types. The percentage changes were calculated to determine the trend of changes as shown in Equation (1).

$$Percentage\ \ change\ = \frac{observed\ \ change}{Sum\ \ of\ \ change} \times\ 100 \qquad (1)$$

2.2.2. Watershed characterization

Data such as 20 m by 20 m grid resolution Digital Elevation Models (DEM), LULC map, FAO digital soil map of Ethiopia, climate data i.e., daily precipitation, maximum and minimum air temperature, relative humidity, wind speed and solar radiation from 1984 to 2014, and rivers discharge data from 1984 to 2013 were used to characterize Lake Ziway watershed. However, the missing climate and discharge data were filled using linear regression equation. The percentage slope classes of the whole watershed area were classified into three slope classes, and the elevation variations into eight classes.

All processes were performed using a geographical information system (GIS) interface for SWAT (Soil and Water Assessment Tool), i.e., ArcSWAT 12.0 interface for ArcGIS 10.2 was used. The model calibration and validation was performed by SWAT-CUP software of the program SUFI-2 by manually adjusting the hydrologic parameters based on SWAT user manual and previous SWAT studies (Lenhart, Eckhardt, Fohrer, & Frede, 2002; Misgana & Nicklow, 2005; Moriasi et al., 2007; Santhi et al., 2001; White & Chaubey, 2005).

2.2.3. Sediment yield estimation

Sediment yield is calculated in SWAT using the Modified Universal Soil Loss Equation (Neitsch, Arnold, Kiniry, & Williams, 2011; Wischmeier & Smith, 1978).

$$Sed = 11.8^{*}(Q_{surf}\ {}^{*}q_{peak}{}^{*}area_{hru})^{0.56*}K_{USLE}{}^{*}C_{USLE}{}^{*}P_{USLE}{}^{*}L_{SUSLE}{}^{*}CFRG \qquad (2)$$

where sed is the sediment yield on a given day [metric tons], Q_{surf} is the surface runoff [mm], q_{peak} is the peak runoff rate [m3/s], $area_{hru}$ is the area of the HRU [ha], K_{USLE} is the USLE soil erodibility factor, C_{USLE} is the USLE cover and management factor, P_{USLE} is the USLE support practice factor, L_{SUSLE} is the USLE topographic factor, and $CFRG$ is the coarse fragment factor.

2.2.4. Assessment of water abstraction

Three districts share administrative border with Lake Ziway. Each of these districts has registered individual farmers, cooperatives, municipalities and private companies that abstract water from the lake along with data about their pump capacities. Data about the number of pumps being used along with their capacity were collected from Agriculture, Municipal Water Supply, and Water, Mine and Energy Offices of each three districts to estimate water abstraction from the entire lake surface. Abstraction was then estimated assuming six working hours per day as:

$$\mathrm{A} = \mathrm{P} \times \mathrm{C} \times \mathrm{H}$$

where:

A - Amount of water abstraction (liter/day),
P - Number of *pumps* being used,
C - Abstraction *capacity* of the pumps (liter per second), and
H - Abstraction *hours* per day.

3. Results and discussion

3.1. Confusion matrix

A confusion matrix of LULC types using ground control points revealed that the overall accuracy of land cover change analysis was 81% with a Kappa statistic of 0.704 (Table 3) as assessed in the Landsat Enhanced ETM+ 2014 image classification. User's accuracies ranged from 71% for woodlands to 100% for afro-alpine and producer's accuracies ranged from 62% for wetlands to 94% for water bodies.

3.2. LULC change detections

On the basis of the temporal and spatial datasets acquired, eight

Table 3
Error matrix for the classification accuracy assessment of Landsat Enhanced ETM+ 2014 image.

Reference										
LULC Class	Agroforestry	Cultivation	Afro-alpine	Plantation	Settlement	Water bodies	Wetlands	Woodlands	Total	UA (%)
Agroforestry	**64**	10	11	1	0	0	0	3	89	72
Cultivation	3	**94**	0	0	0	0	0	5	102	92
Afro-alpine	0	0	**25**	0	0	0	0	0	25	100
Plantation	0	1	0	**10**	0	0	0	0	11	91
Settlement	0	2	0	0	**8**	0	1	0	11	73
Water bodies	0	0	0	0	0	**17**	2	0	19	89
Wetlands	0	1	0	0	0	0	**8**	0	9	89
Woodlands	6	24	1	0	2	1	2	**90**	126	71
Total	73	132	37	11	10	18	13	98	392	
PA (%)	88	71	68	91	80	94	62	92		

Overall accuracy = 81%; Kappa statistic = 0.704 where, UA = user's accuracy; PA = producer's accuracy.

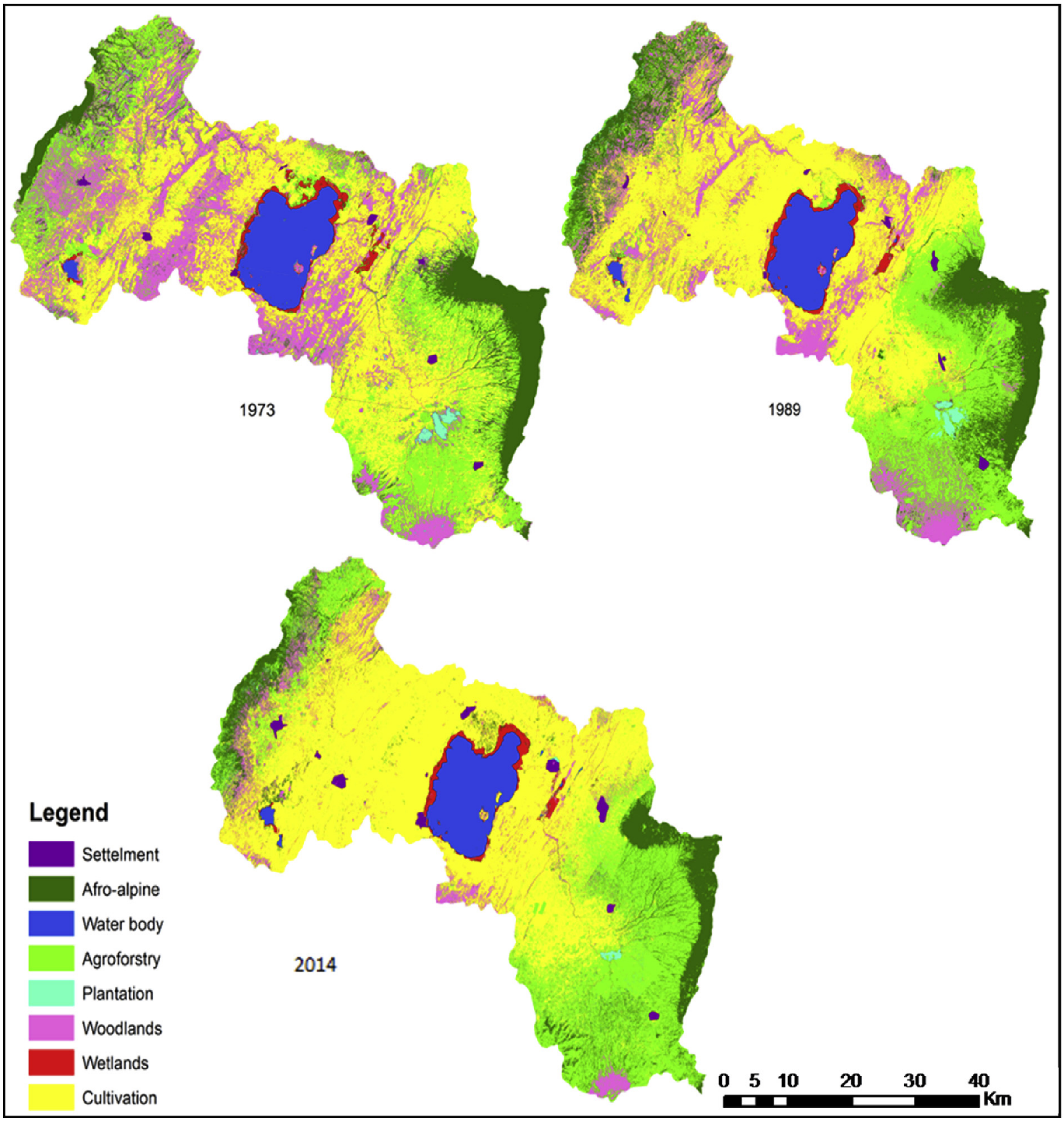

Fig. 3. LULC in the study area between 1973 and 2014.

land-cover classes were identified in Lake Ziway watershed (Fig. 3). The results confirm that a change trend in LULC was observed within the watershed with different intensity between the time-periods - 1973–1989, 1989–2014 and 1973–2014. Details of their statistics and the extent of LULC changes are shown in Table 4.

The LULC in Lake Ziway watershed is predominantly covered by agricultural lands (cultivation and agroforestry) (Fig. 4). However, settlement, plantation, and wetlands occupy the least class with just below 2% of the total classes in each study periods (Table 4). The spatial expansion of agricultural lands is clearly visible as shown in Figs. 3 and 4. Like cultivation, settlement areas had shown consistent increasing trends since 1973. However, in quantitative terms, settlement areas increased from 25 km^2 (0.34%) in 1973 to 59 km^2 (0.81%) area in 2014, thus representing an increase of 34 km^2 (136%) in land area (Table 4). Such an increase in settlement areas can be due to the watershed population growth over the time periods (1973–2014). Li, Zhao, Zhao, Xie, and Fang (2006) supported the fact that urban expansion targets woodland and forest areas by affecting the land cover characteristics of these LULC types.

Similarly, cultivated lands had shown a significant increase from 2547 km^2 (34.89%) in 1973–2863 km^2 (39.22%) areas in 1989. When the period of 1989–2014 is taken into consideration, cultivated lands have increased to 804 km^2 (11%) from its 1989 area. However, between 1973 and 2014, cultivated land class increased by a total of 1120 km^2 (44%) (Table 4). When the period of 1973–2014 is considered for agroforestry areas, it also showed an increase from 1590 km^2 (21.78%) in 1973 to 1759 km^2 (24.1%) in 2014. Thus, it was found out that agricultural land areas (agroforestry - 10.6% and cultivation areas - 44%) together showed an increase of about 55% in the last 4–5 decades. In 1973, the area under these land covers was 56.67% of the total, which increased to 60.59% by 1989 and to 74.33% by 2014. This shows that agriculture is currently the major practices in Lake Ziway watershed. Makin, Kingham, Waddams, Birchall, and Teferra (1975) and Coulomb, Dagnachew, Gasse, Travi, and Tesfaye (2001) strengthened the fact that such changes in this watershed have commenced since the early 1970s.

However, unlike the continuous increase of cultivated lands in the watershed, woodland areas had shown continuous decreasing trends since the beginning of the study periods. About one fourth of the study area was covered by woodlands (26%) in 1973, which later became the third largest cover (17.8%) in 1989 and the fourth in 2014 (6.6%) (Table 4). This clearly indicates that human impacts are the major reasons for these changes because of deforestation for land demands for agriculture. The demand for fuel wood and charcoal could also place additional burden to the woodlands which were dense in Lake Ziway watershed up until 1970s (Friis, 1986; McCann, 1995; Mohammed & Bonnefille, 1991). In quantitative terms, a decrease of 608 km^2 and 818 km^2 woodland areas were observed between 1973 - 1989 and 1989–2014 respectively (Table 4). This indicates that woodlands decreased significantly during 1989–2014. However, in general, woodland areas decreased by 1426 km^2 (74.7%) in the last four decades (Table 4).

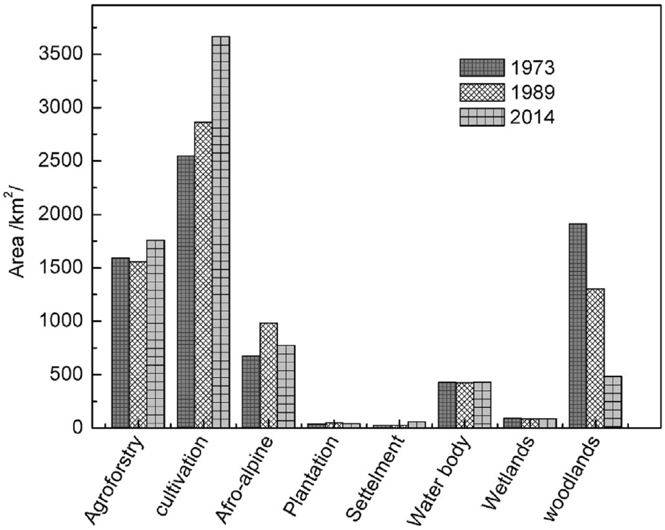

Fig. 4. LULC classes by area (km^2) for the period 1973, 1989, and 2014.

Unlike woodlands and agricultural lands, plantation and afro-alpine bush and shrub lands showed inconsistent change patterns. They showed increasing trends from 1973 to 1989, but the increasing trend was entirely reversed for both land covers from 1989 to 2014 periods. However, the changes in water bodies and wetland areas were not significant in the two-time periods (1973–1989 and 1989–2014). An increase in surface areas of the water bodies in the watershed between 1989 and 2014 might be due to the increase in soil erosion in the watershed and the subsequent sediment loads to water bodies, particularly to Lake Ziway (Badege, 2001; Aklilu, Stroosnijder, & Graaff, 2007; MoW, 2008; Derege, Tsunekawa, & Tsubo, 2012). Altogether, 18.2% of the surface area of the Lake Ziway watershed was transformed from natural to anthropogenic LULC types in the study periods.

The highest net change between 1973 and 2014 was observed for woodlands (loss) followed by cultivation (gain) and Agroforestry (gain). Consequently, the expansion of anthropogenic LULC types such as agricultural lands and settlement areas at the expense of altering woodland and wetland areas leads to the destruction of

Table 4
Statistical distribution of LULC classes in Lake Ziway watershed by years and their change areas in km^2.

LULC Classes	Years[a]			Net change (1973–1989)	Net change (1989–2014)	Total Net change (1973–2014)	Percent Change in LULC area (1973–2014)
	1973	1989	2014				
Agroforestry	1590 (21.78)	1560 (21.37)	1759 (24.1)	−30 (−0.41)	199 (2.73)	169 (2.32)	10.6
Cultivation	2547 (34.89)	2863 (39.22)	3667 (50.23)	316 (4.33)	804 (11.01)	1120 (15.34)	44.0
Afro-alpine	672 (9.21)	984 (13.48)	773 (10.59)	312 (4.27)	−211 (−2.89)	101 (1.38)	15.0
Plantation	37 (0.51)	49 (0.67)	40 (0.55)	12 (0.16)	−9 (−0.12)	3 (0.04)	8.1
Settlement	25 (0.34)	28 (0.38)	59 (0.81)	3 (0.04)	31 (0.43)	34 (0.47)	136.0
Water bodies	427 (5.85)	426 (5.84)	430 (5.89)	−1 (0.01)	4 (0.05)	3 (0.04)	0.7
Wetlands	92 (1.26)	88 (1.21)	88 (1.21)	−4 (0.05)	0 (0)	−4 (−0.05)	−4.3
Woodlands	1910 (26.16)	1302 (17.84)	484 (6.63)	−608 (8.32)	−818 (−11.21)	−1426 (−19.5)	−74.7

[a] Figures in brackets are percentages.

wildlife habitats (Marino, 2003), loss of biodiversity (Spehn, Liberman, & Korner, 2006), loss of ecosystem service provisions (Aerts et al., 2002; Briner et al., 2013; Miehe & Miehe, 1994), increase pests (Primack, 1993), falling of groundwater levels and disappearance of natural wetland vegetation (Kilic et al., 2016), increase of soil erosion (Ruiz-Mirazo, Robles, & González-Rebollar, 2011); slope instability (Miehe & Miehe, 1994) and degrade watershed health (Booth & Jackson, 1997).

3.3. *Driving forces for LULC changes*

3.3.1. *Humans pressures*

The drivers for the majority of LULC changes could directly be related to the pressures exerted by the increase in human population in the watershed (Admassie, Adenew, & Tadege, 2008; Aklilu et al., 2007; Cropper & Griffiths, 1994; Deacon, 1994; FDRE, 2012; Henze, 1977; Kale et al., 2016; McCann, 1995; Zerihun & Mesfin, 1990). According to CSA (2013), human population in Lake Ziway watershed has almost increased by 50% since 1970s (Fig. 5). The Ethiopia's Climate-Resilient Green Economy Strategy (FDRE, 2012) stated that such population growth in the watershed demands for more new land for settlement and cultivation expansion, and more construction and fuel woods as energy sources - all of which accelerate deforestation and forest degradation. The rapid population increase along with mismanagement of land resources would negatively affect water resources (Huang & Cai, 2009) and biodiversity in a watershed.

3.3.2. *Livestock pressures*

Besides the expansion of agricultural lands in the watershed, the increase in livestock population (see Fig. 5) such as cattle, sheep, goat, horse, donkey, and mule appears to continue in the face of the growing human population in Lake Ziway watershed (Derege et al., 2012; Hengsdijk et al., 2008; Jansen et al., 2007), thereby creating extra pressure on the land resource such as overgrazing leading to soil erosion and land degradation (Tekalign & Gezahegn, 2003) and siltation on water resources especially on Lake Ziway, the final recipient of silts in the watershed, through its two major feeder rivers (Dagnachew et al., 2003). The overall changes will lead to irreversibly affect the biodiversity, water quality, wildlife habitats, and ecological systems of the watershed (Foley et al., 2005; Heistermann, Muller, & Ronneberger, 2006; Li, Jansson, Ye, & Widgren, 2013; Musaoglu, Tanik, & Kocabas, 2005; Rawat, Biswas, & Kumar, 2013; Sabr, Moeinaddini, Azarnivand, & Guinot, 2016; Vadrevu, Justice, Prasad, Prasad, & Gutman, 2015; Wijitkosum, 2016; Yu, Zang, Wu, Liu, & Na, 2011).

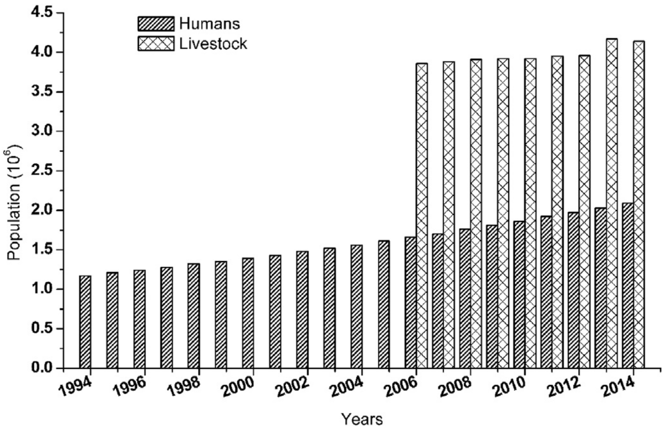

Fig. 5. Human population growth trends (in million) in the watershed.

3.3.3. *Land policy changes*

Changes in land policies that came along with the changes of government could also be the drivers for such shifts in LULC types in Ethiopia. Two land policy changes came along with government changes in the country in 1975 and 1991. During the emergence of the military socialist era in 1975, land was entirely transferred from individual ownership to the state throughout the country (PMAC, 1975). When the socialist era and its command economy came to an end, a new land policy was formulated in 1991 (FDRE, 1995). This policy still declares the state ownership of land, but attracts investment projects on land resources. However, these changes in land use policies have created open access mentalities for resources such as forests, water, etc., which make local communities compete for mindless exploitation towards the resources in the watershed with the absence of sense of ownership.

Discussions with elders of the watershed confirm that an extensive deforestation has taken place in their watershed with the aim to meet their demands for agricultural lands and settlement areas since the 1975 land policy change in the country. The expansion also includes on the upslope areas of the watershed by removing the natural vegetation. In support of the elders' views, Temesgen et al. (2013) also reiterated the reduction in vegetation cover and expansion of agricultural lands in the watershed since the mid-1970s.

3.3.4. *Topographic drivers*

Topographic drivers such as elevation and slope have also important roles in the distribution and dynamics of LULC types (Kale et al., 2016). Thus, the remaining vegetation cover is currently limited only to some less-accessible areas like the steep slopes of the mountains in the west and east part of the watershed (see Fig. 3).

3.4. *Current land use practices*

The slope classes in Lake Ziway watershed are spatially distributed as can be seen in Fig. 6. Thus, 89% (6306.02 km^2) of the total watershed area is found within the slope range of 0–30%, whereas the remaining areas possess >30% of slopes (Steep to very steep hills and mountains). Enactments of FDRE (2005) on the management of rural lands state that (i) cultivation of annual crops on rural lands having a slope gradient of 30–60% are allowed only by making the necessary terracing such as bench terraces; and (ii) the rural land with a slope gradient of >60% shall not be used for crop production and free grazing, but limited for plantation of trees. However, it is found out in this study that in the lake watershed, practically against the enactments, about 239 km^2 (54%)] of areas with slopes between 30 and 60% and about 50 km^2 (34%)] slopes >60% are generally under crop production neglecting the fact that such landscapes could easily be affected by land degradation impacts. This is an indication that cultivated lands are expanding in the upslope areas of the watershed whose natural land covers have been removed and the top soil exposed for all sorts of erosion forms. Thus, addressing them is fundamental on sustainable watershed management (Bach et al., 2011). Otherwise, these changes will have effects on water and sediment yields in Lake Ziway.

3.5. *Watershed characterization and sediment yield*

Sediment yield and its long-term transport have relationship with elevation in a watershed (Willgoose, 1994). The whole Lake Ziway watershed was delineated into two sub-watersheds, namely, Katar sub-watershed in the southeastern part with 3337.7 km^2 area and Meki sub-watershed in the northwestern part with

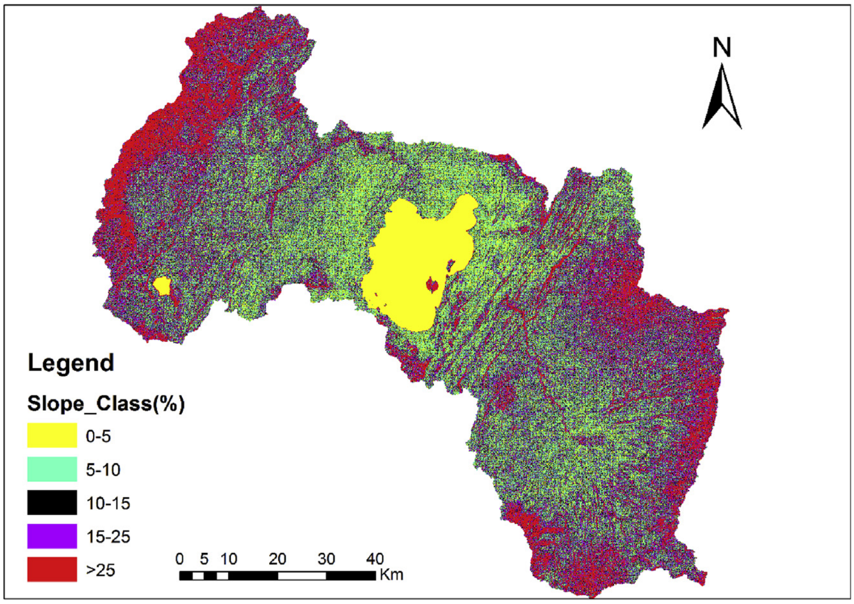

Fig. 6. Topography in Lake Ziway sub-watersheds.

2049.3 km^2; the remaining part of the watershed (1645.3 km^2) covers the Lake Ziway surrounding (SD) plains (Fig. 7).

The spatial distributions of elevation in whole watershed range from 1601 to 4213masl. Areas with higher elevation are located along the southeastern and northwestern ridge of the watershed whereas areas with lower elevation are located in the central portion of the watershed, all along the rift valley (see Fig. 8).

Thus, the lowest sediment yields were estimated along the lower reaches of Meki and Katar Rivers near to the rift floor (Fig. 9). The amount of the mean annual estimated sediment yield in Meki sub-watershed is 4.44 t/ha/yr and 4.42 t/ha/yr for Katar sub-watershed. The long term (i.e. 26 years) predicted total sediment yield and annual sediment yield rate for Meki sub-watershed was 23,657,385t and 909,899.4 t/yr (0.91 Mt/year) respectively whereas the long term predicted total sediment yield and annual sediment yield rate for Katar sub-watershed was 38,356,745t and 1,475,259 t/yr (1.48 Mt/year), respectively.

As estimated, Meki and Katar sub-watersheds have on average

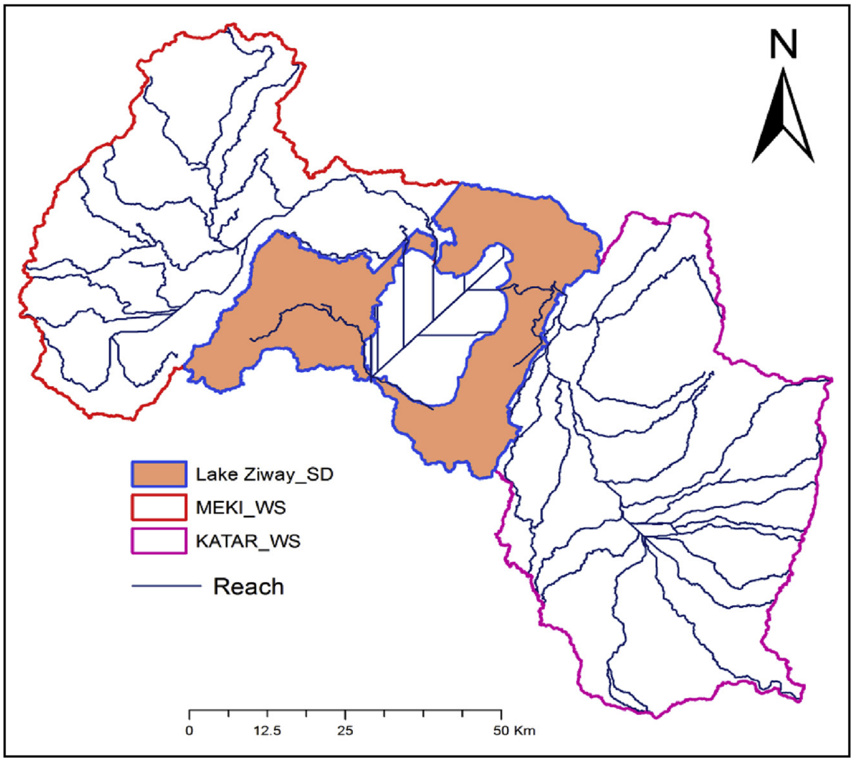

Fig. 7. Delineated Katar and Meki sub-watersheds (WS) in Lake Ziway watershed.

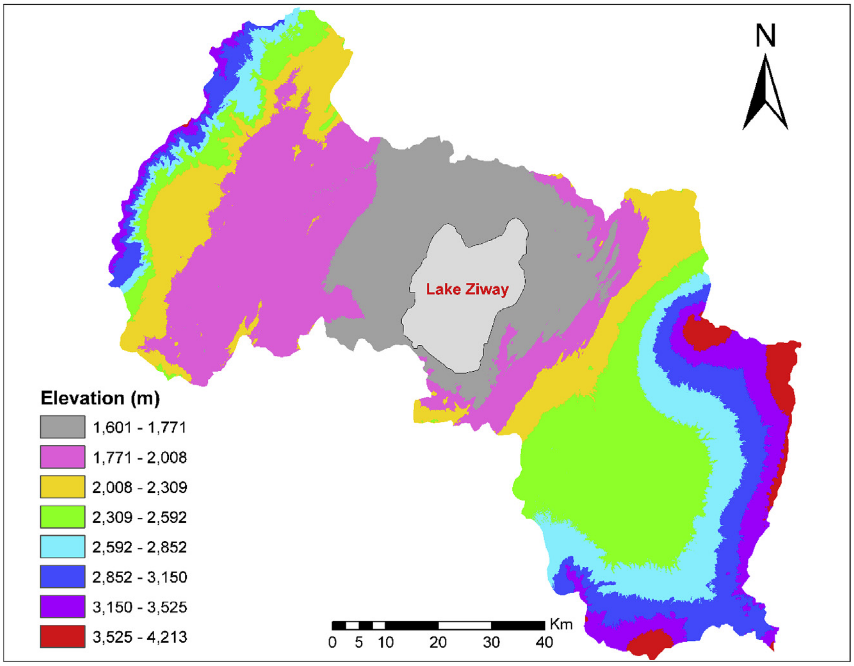

Fig. 8. Elevation in the Lake Ziway sub-watersheds.

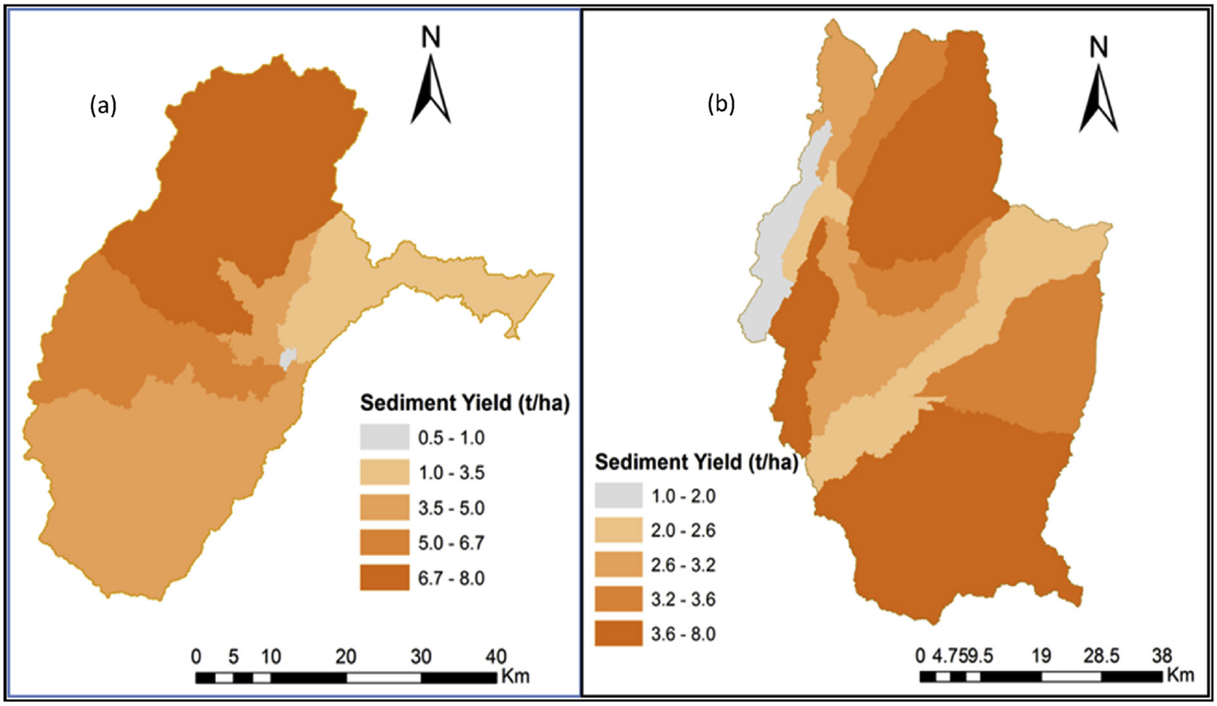

Fig. 9. Average annual sediment yield in (a) Meki and (b) Katar Sub-watersheds.

exported $\approx 0.91 \times 10^6$ t/year (4.44 t/ha/yr) and $\approx 1.48 \times 10^6$ t/year (4.42 t/ha/yr) of sediment yield respectively. The result for Meki sub-watershed is however lower than the one reported by MoW (2008) (6.1 t/ha/yr). The difference might be attributed to the levels of degradation, land use types, soil types and slope classes. The land use changes mainly due to deforestation in the past have contributed to severe soil erosion, and massive soil loss to this country (Tekalign & Gezahegn, 2003).

In Lake Ziway watershed, high amount of sediment load is exported in a given period of time, and then transported and finally deposited to Lake Ziway which is located at the lowest limit of the watershed (see Fig. 10) facilitated by feeder rivers (Meki and Katar) particularly at flow peak rainy seasons. This sediment transport from agricultural lands has major impact on water quality and quantity of Lake Ziway. The parts of the watershed that produce the most sediment yield are higher elevation areas with high

Fig. 10. Image showing sediment deposit in Lake Ziway.

percentage of slopes and degradation impacts and at the same time where there are high rainfall distributions that easily result rapid runoffs.

Human activities in a watershed contribute in changing the quantity and delivery of sediments to the receiving system (Bach et al., 2011). Like water abstraction, the sediment load into Lake Ziway is greater than what it was into Lake Alemaya, about 7928 m^3 per annum (Muleta et al., 2006) due to the large size of the Lake Ziway watershed and the large flow volumes of the feeder rivers. Generally, the sediment load to Lake Ziway can be attributed to (i) the expansion of cultivated lands upto the shores of the feeder rivers and Lake Ziway at the expense of loss of other land uses in the watershed (MoW, 2008), (ii) The absence of implementing soil conservation polices of the government (FDRE, 2005) (iii) the need for grazing land for livestock whose population is increasing (Derege et al., 2012), (iv) Sedimentation of Lake Ziway could also be associated with nutrient load that may impact its water quality, leading into eutrophication (Girum & Seyoum, 2012; Lenhart, Fohrer, & Frede, 2005). The uncontrolled land use changes could aggravate transport of nutrients and affect water quality within a watershed (Shi, Zhang, Li, Li, & Xu, 2017; Valle Junior, Varandas, Sanches Fernandes, & Pacheco, 2014), as they have significant positive correlation with water pollution due to fertilizer application entering lakes and rivers through runoff (Tu, 2011) and (v) the data thus collected suggest that the above-mentioned factors may contribute to the decreasing of the lake volume due to siltation and enhancing evapotranspiration. The cumulative impacts of these changes may lead to the drying out of Lake Ziway, if the present scenarios keep on going, as has been clearly observed on Lake Alemaya which ceased to exist due to excessive human pressures.

3.6. *Water abstraction*

The current water level abstraction from the lake is estimated about 612×10^6 l/day as calculated in this study (Table 5). The water is mainly used for water inefficient furrow type of irrigation and Batu Town water supply. As compared to Lake Alemaya's water abstraction, thousands of liters of water per day (Muleta, 2002), water abstraction from Lake Ziway is too much. Such excessive water abstraction has recently become a common practice. Irrigation using water abstraction from feeder rivers is increasing in both the lower and upper sub-watersheds. This has happened due to the fact that all water resources are common property that leads to free access to anyone (FDRE, 2000). Direct water abstraction mainly for irrigation from the lake and its feeder rivers could therefore be one of the reasons that can contribute to the reduction in the level of Lake Ziway, the view also shared in other earlier studies (Tamiru, Seifu, & Tenalem, 2006; Tenalem, 2001, 2004; Zinabu & Elias, 1989).

The recent agricultural developments being undertaken around Lake Ziway and the urban population increase in Batu town will further aggravate water abstraction for irrigation and municipal water supply. This could lead to the further lowering of the volume of lake level. Thus, one of the major challenges that could result in the deterioration of the lake water volume over time is free access for water abstraction as has been observed in Lake Alemaya. Though water abstraction is as high as that shown in Table 5, local communities and local administrators do not currently know the impacts of such practices on the lake ecosystem and its negative repercussions on local communities whose livelihoods are entirely dependent on this lake. But, the worst scenario of Lake Alemaya whose vanishing was not seen at a time can be a good example for Lake Ziway. Thus, Lake Ziway has started reducing its water level gradually as has been observed the gradual water level reduction of Lake Alemaya from its maximum depth of 8 m in mid 1980s to below 3 m in 2000 (Brook, 2003).

Besides these human impacts, evapotranspiration could also affect the water budget of a lake (Lentersa, Kratzb, & Bowserc, 2005). For example, the lost lake – Lake Alemaya annual rate of evapotranspiration showed increasing trends along with air temperatures and become about 1784 mm in the mid-1980s and 1990s (Setegn, Chowdary, Mal, Yohannes, & Kono, 2011), before it gets lost. Similarly, in this study, the Lake Ziway potential evapotranspiration was found high throughout the year, the maximum values being in February and March (Table 6). Although annual average evapotranspiration has been estimated by different authors as 1875 mm by Coulomb et al. (2001), 2023 mm by Tenalem (2003) and 1662 mm by Assefa, Wossenu, and Tibebe (2009), the long term (26 years) average annual actual evapotranspiration predicted for Lake Ziway in this study is 1920 mm (Table 6). This could consume nearly about 2.4 times the yearly contribution of rainfall to the lake water budget. This could likely be due to the changes occurred in climate patterns (Merz & Bloschl, 2009; Sriwongsitanon & Taesombat, 2011; Wang, Yang, Wang, Xu, & Xue, 2014; Zhang, Liu, & Sun, 2009).

Along with direct excessive water abstraction, the increment in evaporation ultimately results in the declining of the lake water level. If the current LULC change patterns and water abstraction from the feeder rivers in the upper part of the watershed continue

Table 5
Estimated amount of water abstraction (in liter) from Lake Ziway.

Districts	No. of Pumps	Pump Capacity (l/s)	Abstraction (in 000 in liter)
Ziway Dugda	542	18	210, 729.6
Dugda Borra	367	18	142,689.6
	2[a]	764	33,004.8
Adami Tulu Jido Kombolcha	283	18	110,030.4
	7[a]	764	115,516.8
Total	1201		611,971.2

[a] Indicates Electric pumps, shown in Fig. 11.

Fig. 11. Electric pumps being used for irrigation at Meki.

Table 6
Mean monthly evapotranspiration for Lake Ziway.

Month	Solar Radiation (MJ/m^2)	Evapotranspiration (mm)
Jan	23.9	167
Feb	26.3	169
Mar	25.8	185
Apr	25.0	173
May	25.0	178
Jun	20.9	144
Jul	18.1	126
Aug	19.4	135
Sep	21.4	145
Oct	23.0	161
Nov	25.1	169
Dec	24.3	168
Annual		**1920**

as is, it is estimated that Meki River is likely to cease to exist after 67 years, and Katar River after 70 years (see Fig. 12). According to this scenario, within seven decades Lake Ziway may dry out, keeping other causes of lake volume reduction such as global warming, water abstraction, etc. constant. Such a phenomenon may be comparable to what has happened to Lake Alemaya of Eastern Ethiopia (Brook, 2002, 2003). Further, the contribution of surface water to downstream system of Abijata-Shalla System from Lake Ziway also seizes jeopardizing that part of the ecosystem. In general, demographic changes, climate variability and demands for water all influence the quantity and quality of water that has its origins in watersheds (Bach et al., 2011).

4. Conclusions

The study revealed that LULC changes have occurred in Lake Ziway watershed since the early 1970s. The conversions of woodlands to agricultural lands and settlement areas were the major observed changes. The decrease in vegetation cover through such changes has contributed to increase evapotranspiration and sediment loads in Lake Ziway. This might result the reduction in the water level of the lake. Moreover, more than half a million cubic meters of water are abstracted daily, free of charge, from the lake and its two feeder rivers, mainly for irrigation and domestic water supply. However, the users are not conservation oriented because they are not licensed and charged use fee. Besides other factors like sediment loads due to deforestation and soil erosion from the watershed, uncontrolled water abstractions from the lake and its feeder rivers can also be one of the major causes for the lake water level reduction. This might again lead in a long-term to the undesired effects on the hydrology of Lake Ziway by making it shallower and exposing it to increasing evapotranspiration. Therefore, free-access policy for water use should be replaced by user-charge policy along with setting rules and establishing regulations for enforcement mechanisms for those who do not accept or resist the legitimacy of the rules for water abstractions.

In conclusion, government body should in general play meaningful coordination roles towards achieving the sustainable use and management of land and water resources in the watershed. To this end, the responsible government institutions at both the federal and regional states should start mobilizing the local communities for watershed rehabilitation through afforestation and soil and water conservation activities along with providing them with financial and material supports. Otherwise, if the current scenarios

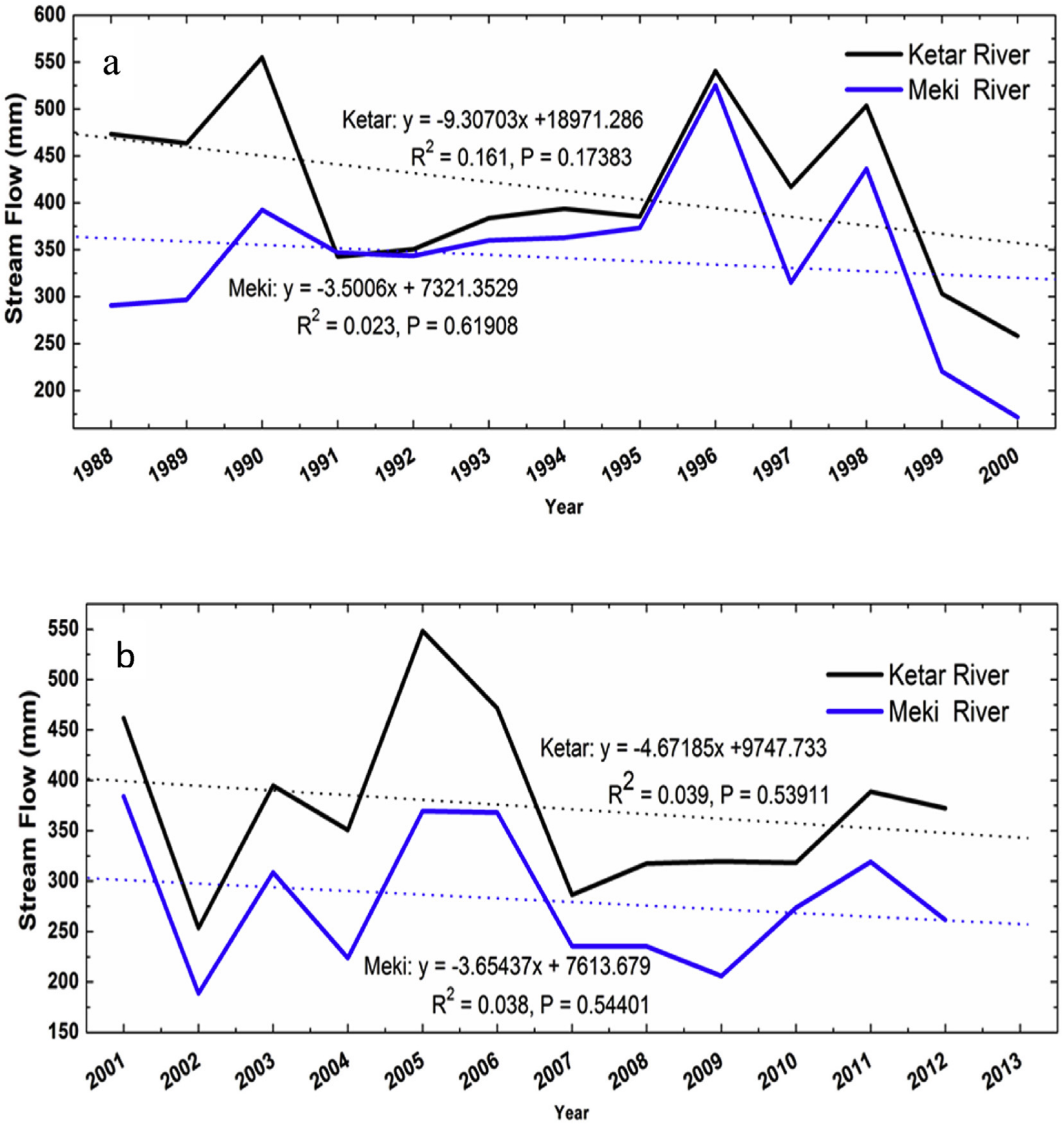

Fig. 12. Long-term mean annual discharge of Meki and Katar Rivers (a) calibration and (b) validation periods.

of unsustainable utilizations of land and water resources continue without any management interventions, Katar and Meki Rivers are likely to cease to exist, and so is then Lake Ziway to become the second lake to vanish in the country next to Lake Alemaya. This may in turn have negative repercussions on the socio-economic conditions of the watershed communities and beyond in the country. Accordingly, this study calls for all user groups - municipalities, fisher associations, farmers, private companies and all other users as well as concerned groups to make an urgent and comprehensive efforts for sustainable managements of land and water resources. In this respect, an authorized government body should setup effective land and water use management plan and regulations against the unruly users' actions before irreversible losses might happen to Lake Ziway and its watershed resources.

Acknowledgements

The Rachel Carson Center is gratefully acknowledged for granting the Carson Writing Fellowship to the first author. Financial support provided by Rufford Small Grants Foundation (Grant Number 12732-1) and Addis Ababa University was instrumental in successful completion of the study. Many thanks also go to Dr. Clive Nuttman, University of Cambridge, for his support and encouragement. The authors express their sincere thanks to the anonymous reviewers for their important comments and suggestions, which improved the quality of the paper.

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