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

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A B S T R A C T

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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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'