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SWAT based hydrological assessment and characterization of Lake Ziway sub-watersheds, Ethiopia

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A R T I C L E I N F O

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A B S T R A C T

Study region: Lake Ziway watershed, Ethiopia.
Study focus: Lake Ziway and its watershed play a significant role in supporting the livelihoods of people in the region. However, the study region is currently under heavy human pressures mainly associated with the ever increasing of human population and the subsequent intensification of agricultural development activities. The present study therefore aims at quantifying and comparing water balance components, feeder rivers' discharge and evapotranspiration (ET) in the study region using SWAT (Soil and Water Assessment Tool) model. Flow data from 1988 to 2000 and from 2001 to 2013 were used for model calibration and validation periods respectively.
New hydrological insights for the region: Results show that infiltration, surface runoff, base flow and aquifer recharge were large in Katar sub-watershed while ET and lateral flow were large in Meki sub-watershed. However, surface and base flows showed decreasing trends in both sub-watersheds, yet Katar sub-watershed showed major contribution of water to Lake Ziway. The model estimated Lake Ziway and its watershed mean annual ETs as 1920 mm and 674 mm respectively, but plantation showed more ET than other land cover types in the watershed. If the current trends in irrigation development continue in the region, it is suspected that Katar and Meki Rivers are likely to cease to exist after seven decades, and so is then Lake Ziway to dry out.

1. Introduction

Water resources are one of the most critical resources needed to support the socioeconomic development of the human society (Huang and Cai, 2009). However, the degradation of these resources is among the many critical environmental problems (Vitousek et al., 1997; Ramankutty and Foley, 1999). The adverse impacts on water resources have occurred by human pressures, especially in developing countries due to the large demands of an ever-increasing human population, which are further aggravated by poverty (Olson and Maitima, 2006; Huang and Cai, 2009). Watershed degradation is also one among many critical environmental problems, mainly associated still with human interventions (Bach et al., 2011). However, many of the causes for these critical environmental problems arise at the local scale from these interventions. Roth et al. (1996), Brooks et al. (1997), and Tomer and Schilling (2009) asserted that land cover changes are important drivers of changes in watershed hydrology and processes, leading to a decreased availability of different products and ecological services (Moshen, 1999). Degradation of watersheds due to such land cover changes can have adverse impacts on water resources and associated biological communities (Brooks et al., 1997).

Watersheds serve as semi-closed systems for water whose single source is precipitation so that they provide a convenient logical

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unit for hydrologic analyses (Hwang et al., 2015). The physical processes of precipitation, evapotranspiration (ET), overland flow, infiltration, recharge or discharge, and groundwater flow and their interactions in the atmosphere, land surface and sub-surfaces are involved in water movement dynamics and distribution from one system to the other within the hydrologic cycle (Delfs et al., 2013; Niu et al., 2014). Thus, watersheds are balanced by all of the sinks in the system − stream flow at the watershed outlet, ET, and anthropogenic water consumption for urban and agricultural purposes (Frey et al., 2013; Condon and Maxwell, 2014; De Schepper et al., 2015).

Lake Ziway and its watershed play a significant role in supporting the livelihoods of approximately 2 million people (CSA, 2013). The watershed also inhabits 1.9 million livestock (Tsegaye et al., 2012). The lake is a source of drinking and domestic water for nearby towns, water for open and closed farm irrigation, and fish supply to huge market centers in the country. A large number of anglers, both in cooperatives and individually, depend on this lake for their livelihoods, including women and children involved in processing and selling the fish. According to Vuik (2008), Lake Ziway and its watershed support unique ecological and hydrological characteristics in addition to its economic and livelihood values.

However, Lake Ziway is currently under heavy pressures associated with the increasing population (Jansen et al., 2007), climate change (Zeray et al., 2006) as well as the intensification of agricultural development activities in the watershed. Thus, water abstraction from the lake feeder rivers for irrigation farming (Ayenew, 2004; Scholten, 2007) and land cover change in the upstream areas of the watershed (Hengsdijk and Jansen, 2006) have been affecting the lake hydrology. In recent years, the rivers flowing into Lake Ziway are being diverted into farmlands for irrigation. Such multiple problems have the potential for damaging the hydrological and ecological integrity of Lake Ziway.

Upon this backdrop, a study was necessary to assess the current status of Lake Ziway and its watershed from hydrological point of view using a mix of methods and tools. Accordingly, this study has been conducted using SWAT (Soil and Water Assessment Tool) model with the aim to quantify and compare water balance components, feeder rivers discharge, and ET in Katar and Meki sub-watersheds including Lake Ziway. In this respect, this article is timely to understand the current state of Lake Ziway watershed and the lake ET.

2. Materials and methods

2.1. Study area

Lake Ziway falls between 7° 22′36 longitude (Fig. 1). The watershed includes the rift floor, two escarpment are” and 8°18′21” latitude and 37°53′40” and 39°28′9”as, two major river inlets − the Katar and Meki Rivers − and one river outlet − the Bulbula River. Lake Ziway watershed has two sub-watersheds − Meki sub-watershed in the northwestern part and Katar sub-watershed in the southeastern part. The remaining part of the watershed covers the rift floor which is predominantly flat.

The watershed lies in two Ethiopian administrative regions − 73.6% in Oromia National Regional State (ONRS) and the remaining part in Southern Nation Nationalities and People Regions (SNNPRS) − rising over 3500 m above sea level (masl). Katar sub-watershed is entirely located within ONRS while Meki sub-watershed is scattered over ONRS and SNNPR. About 2 million human populations (CSA, 2013) and about 1.9 million livestock (Tsegaye et al., 2012) inhabit the Lake Ziway watershed.

Lake Ziway extends over an area of approximately 434 km^2 and has a maximum of 9 m depth with a shoreline length of 137 km (Hengsdijk and Jansen, 2006). It is the most upstream of the Central Rift Valley (CRV) lakes of Ethiopia. Runoff from the watershed drains into the lake through the two feeder rivers − the Katar and the Meki − which represent the opposing faces of the rift escarpments (Fig. 1). The lake is an important element of the Ethiopian Central Rift Valley region because it currently serves as the water source for closed and open farm irrigation, and as the only potable water supply for Ziway Town. It also supports the livelihoods of the fishing community. It is a habitat for biological diversity.

Lake Ziway sub-watersheds have tropical climate with no uniform spatial and temporal climatic conditions. According to the 30 years (1984–2014) average climate data, Katar sub-watershed has a minimum and maximum annual precipitation of 729.8 mm and 1227.7 mm respectively, and Meki sub-watershed with a minimum and maximum annual precipitation of 859.3 mm and 1088.1 mm respectively. The mean annual temperature is 16.3 °C and 18.5 °C respectively for Katar and Meki sub-watershed. The wet season − June to September − accounts for about 55 percent of the annual precipitation, while the dry season contributes 45percent (Billi and Caparrini, 2006).

The predominant land cover in the watershed is smallholder agricultural lands. The vegetation cover is characterized by extensively overgrazed Acacia Combretum in open woodland (Woldu and Tadesse, 1990), whereas deciduous woodlands occupy the escarpments (Mohammed and Bonnefille, 1991). The settlement pattern is typical of rural communities across Ethiopia (Stellmacher, 2015). Livelihoods largely depend on smallholder agriculture. Land cover change is massively and rapidly taking place, as elsewhere in the Ethiopian CRV (Dadi et al., 2016).

2.2. SWAT model

SWAT is a relatively recent model used to assess the watershed hydrology (Arnold et al., 1993; Arnold et al., 1998; Jha, 2011). According to Kannan et al. (2007) and Jha (2011), it is the best among the different hydrological models due to its capability for application to large-scale watersheds (> 100 km^2), interface with a Geographic Information System (GIS), continuous-time simulations performance, and generation of the maximum number of sub-basins and ability to characterize the watershed in enough spatial detail.