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Water balance of a lake with floodplain buffering: Lake Tana, Blue Nile Basin, Ethiopia

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SUMMARY

Lakes are very important components of the earth's hydrological cycle, providing a variety of services for humans and ecosystem functioning. For a sustainable use of lakes, a substantial body of knowledge on their water balance is vital. We present here a detailed daily water balance analysis for Lake Tana, the largest lake in Ethiopia and the source of the Blue Nile. Rainfall on the lake is determined by Thiessen polygon procedure, open water evaporation is estimated by the Penman-combination equation and observed inflows for the gauged catchments as well as outflow data at the two lake outlets are directly used. Runoff from ungauged catchments is estimated using a simple rainfall–runoff model and runoff coefficients. Hillslope catchments and floodplains are treated separately, which makes this study unique compared to previous water balance studies. Impact of the floodplain on the lake water balance is analyzed by conducting scenario-based studies.

We found an average yearly abstraction of 420×10^6 m^3 or 6% of river inflows to the lake by the floodplain in 2012 and 2013. Nearly 60% of the inflow to the lake is from the Gilgel Abay River. Simulated lake levels compare well with the observed lake levels ($R^2 = 0.95$) and the water balance can be closed with a closure error of 82 mm/year (3.5% of the total lake inflow). This study demonstrates the importance of floodplains and their influence on the water balance of the lake and the need of incorporating the effects of floodplains and water abstraction for irrigation to improve predictions.

1. Introduction

Lakes are very important components of the earth's hydrological cycle, and they contain approximately 90% of the world's available liquid surface freshwater (Shiklomanov, 1993). They provide a wide variety of ecosystem services. Lake Tana (Fig. 1), the largest lake in Ethiopia, is a typical example. Bahir Dar (largest city on the lake shore) and the other smaller villages and towns on the lake shore along with the 37 islands in the lake are enjoying the benefits of the lake as means of water transport, recreation, fishery, and sources of water supply for livestock (also for people in some rural towns), irrigated agriculture and industries. Above all, the lake and its basin are the focus of the Ethiopian Government to stimulate economic growth and to reduce poverty through the development of hydropower and a number of irrigation schemes. Being the source of the Blue Nile, this lake also contributes to the livelihoods of people in the lower Nile river basin (Setegn et al., 2009). The Lake Tana basin hosts a vast area of wetlands and floodplains, making it rich in biodiversity and endemic flora and fauna.

Despite the value of lakes outlined above, lakes are particularly vulnerable to stress (Ballatore and Muhandiki, 2002). According to Kira (1997), lakes face five major problems, namely lowering of water level, siltation, acidification, toxic contamination and eutrophication. To cope with such stresses impairing the value of lakes, many management responses have been triggered and a substantial body of knowledge on the processes occurring within lakes, their watersheds, and on lake management in general have been generated (Ballatore and Muhandiki, 2002). Accurate determina-

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tion of the water balance of lakes is one such instance of knowledge required for the management of lakes.

Several studies have been made to better understand the water balance of Lake Tana on a monthly basis (Kebede et al., 2006; Chebud and Melese, 2009) and on a daily basis (SMEC, 2007; Setegn et al., 2008; Wale et al., 2009; Rientjes et al., 2011). A major difference among the outcomes of these studies originates from the selected procedures they used to estimate inflows to the lake from ungauged catchments of the lake basin. For computational purposes (to indicate how ungauged river inflows to the lake have been quantified during the different water balance studies of the lake), the classification of the basin as gauged and ungauged catchments is made. For the gauged catchments, river discharges have been obtained from the discharge measurements.

Using a mean runoff coefficient of 0.22, computed for the larger Blue Nile Basin (Shahin, 1988), Kebede et al. (2006) estimated the lake inflow from the ungauged catchments and showed that most of the lake inflow results from the gauged catchments. Similar results are reported by Chebud and Melese (2009). Studies by Dessie et al. (2014a) show that the runoff coefficients for the upper catchments of the Lake Tana basin vary between 0.23 and 0.81, but these values are reduced by the downstream floodplain, indicating that runoff coefficients based on an assessment of actual and simultaneous measurements of both rainfall and runoff in the catchments should be used. Based on the principles of regionalization, Wale et al. (2009) and Rientjes et al. (2011) estimate that inflows to the lake from the ungauged catchments are 42% and 30% respectively. They did not differentiate between the hillslopes and the vast ungauged low-lying floodplain catchments. Regionalisation approaches rely on similarity of spatial proximity or on similarity of catchment characteristics (Merz and Blöschl, 2004).

Lake Tana basin is characterized by an extensive floodplain adjacent to the lake and its lowland tributaries (Fig. 1). Dessie et al. (2014a) show that the floodplain of Lake Tana abstracts a substantial quantity of water from overbank flooding of rivers, rainfall and the percolating groundwater from the upland catchments during the onset of the rainy season (May to Mid of July). This can result in the reduction of river flows to the lake due to abstraction by the extensive lacustrine floodplain on their way to the lake. In a similar study by Kebede et al. (2011), local rainfall and river overflows are the dominant sources of water for the floodplain and the effect of backwater flow from the lake is excluded. They indicated that the major error introduced into the water balance computation is related to evaporative water loss in the floodplains.

A review of the previous water balance studies of the lake reveals that most of these studies ignored this extensive floodplain and its impacts on the water balance of the lake, which is as an important research gap. Significant contribution in this perspective is attributed to Kebede et al. (2011). Floodplains are specific ecosystems, oscillating between terrestrial and aquatic phases (Junk, 1996), having different topography, soils and vegetation patterns. The water balance studies of the lake should address the floodplain hydrology properly and its impacts on the water budgets of the lake. Dawidek and Ferencz (2014) and Kummu et al. (2014) provide a detailed description of the hydrologic regime of the lake-floodplain system to obtain a meaningful assessment of the inflow and outflow contributions by the various hydrological and hydrometeorological components of the system in their water balance studies for a lake – floodplain system in Poland and Cambodia.

SMEC (2007) determined the inflow of the ungauged catchments from the water balance of the Lake Tana using observed lake levels and inflows from the gauged catchments. They obtained lower values of runoff from the ungauged catchments despite rainfall that is comparable with that of other similar gauged catchments; surprisingly, negative inflows were obtained for some months for the combined ungauged areas. How can such discrepancies be explained and what are the underlying causes? It remains necessary to revise the water balance of the lake and to

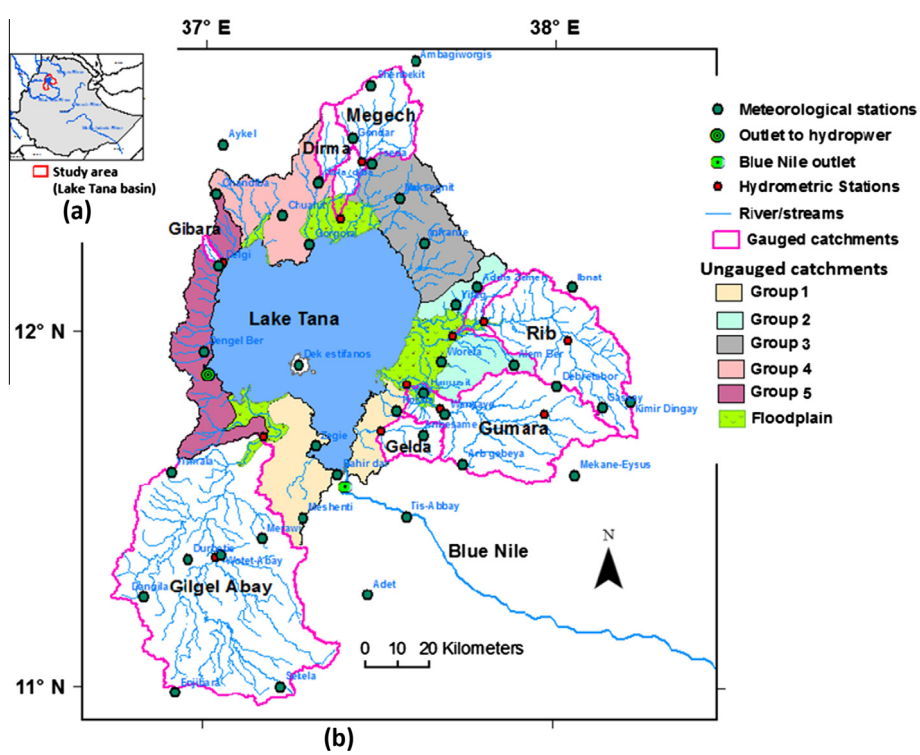

Fig. 1. (a) Location map of Lake Tana Basin in Ethiopia, (b) map of Lake Tana Basin with location of the floodplain, gauged and ungauged catchments, rainfall and hydrometric stations. Runoff discharge from the groups of ungauged catchments was predicted based on calibrated model parameters of observed runoff data from Gelda for Group 1, from Rib for Group 2, from Megech for Group 3, from Dirma for Group 4, and from Dirma for Group 5.