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Recharge variability and sensitivity to climate: The example of Gidabo River Basin, Main Ethiopian Rift

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ABSTRACT

Study region: Gidabo River Basin, located in the south eastern Main Ethiopian Rift (MER).
Study focus: The focus is to characterize the spatial and temporal variability of groundwater recharge, identify the drivers that govern its distribution, and to improve the understanding of its sensitivity to precipitation and temperature in the MER by applying the semi-distributed hydrological model, Soil and Water Assessment Tool (SWAT).
New hydrological insights for the region: The average annual recharge for 1998–2010 reveals a remarkable decrease from the highland (410 mm/year) towards the rift floor (25 mm/year). Both the spatial and temporal recharge variability is mainly controlled by the climate. In the rift floor, recharge is found to occur only when annual precipitation exceeds a threshold of approximately 800 mm. A sensitivity analysis reveals that annual recharge is very sensitive to variations in precipitation and moderately sensitive to temperature changes. The relative sensitivity increases from the highland to the rift floor across the watershed. Increases in both precipitation and temperature, as suggested by climate change projections for Ethiopia, appear to have an overall positive impact on recharge in the majority of the catchment. These findings have implications also for other catchments where recharge is spatially nonuniform and provide a basis for further investigations into the assessment of groundwater resources and their vulnerability to climate change at the watershed and sub-watershed scale.

1. Introduction

For long Ethiopia's groundwater potential is believed to be of limited extent when compared to surface water resources, yet compared to other countries the total exploitable groundwater potential is high (Awulachew et al., 2007; Kebede, 2013). However the distribution, availability and accessibility of this groundwater are erratic both in space and time (Calow et al., 2010). This variability is directly linked to recharge, the entry of water into the saturated zone (Freeze and Cherry, 1979). The total annual recharge for the entire Ethiopia is estimated to be 36 billion m^3/year (Kebede, 2013). The distribution of this recharge however significantly varies spatially and temporally as it depends on a wide variety of factors such as climate, topography, vegetation, soil, and geology. Therefore, understanding the spatial and temporal variability of groundwater recharge is critical for sustainable development and management of groundwater resources. Although groundwater research has been done at a variety of different scales in Ethiopia, there have been few attempts (Chernet, 1993; Tilahun and Broder,

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2009) to quantify the spatial and temporal variability of recharge. As a result the fundamental aspects of groundwater recharge such as its timing, magnitude and distribution have not been well defined.

Likewise, the potential impact of future climate change on groundwater recharge is almost ignored in Ethiopia, although the potential effects of climate change on water resources, in general, have been of great concern. The existing assessments of climate change impacts (e.g. Legesse et al., 2003; Bates et al., 2008; Abeye et al., 2009; Elshamy et al., 2009; Beyene et al., 2010; Taye et al., 2011; START, 2013; Mengistu and Sorteberg, 2012; Faramarzi et al., 2012; IPCC, 2007, 2013; Kebede et al., 2013; Tekle and Tadele, 2014; Aich et al., 2014; Taye et al., 2015) have mainly focused on surface water and comparatively little is known about the potential impacts on groundwater recharge. Yet, the impacts on groundwater recharge are far reaching and need to be investigated, particularly in Ethiopia, where most people rely on groundwater as a source of potable water for drinking and other domestic uses. Changes in groundwater recharge due to climate change might cause decreasing groundwater levels in shallow unconfined aquifers and thus potentially can cause the drying up of springs and shallow boreholes. Similarly, groundwater recharge has immense importance for sustaining baseflow and therefore for the existence of many surface water resources such as lakes and rivers, e.g., in the Ethiopian Rift. A first water balance estimation indicates that around 50% of the total inflow to terminal lakes is groundwater coming through large open faults (Ayenew, 1998). However, fissured aquifers are highly vulnerable to variations in recharge, due to their low storativity, which may represent only three years of average infiltration (Wyns et al., 2004). Groundwater is a vital water resource and awareness needs to be raised on its vulnerability to overexploitation, pollution and climate change.

The spatial distribution of groundwater recharge and also the potential impact of climate change on groundwater recharge are likely to be most diverse in regions with highly variable physiographic characteristics such as the Main Ethiopian Rift (MER) (Fig. 1). In particular, climatic parameters such as precipitation and air temperature vary strongly from the rift floor towards the escarpment and the highland. Tilahun and Broder (2009) obtained an estimated average recharge of 28 mm per year for the Dire Dawa basin, a semi-arid area at the eastern margin of the northern MER. However, 80% of this recharge was found to occur in the escarpment, where local recharge rates were estimated to be up to 200 mm per year. Runoff generation and recharge mechanisms vary greatly within the different physiographic regions of the MER. Consequently, the sensitivity of groundwater recharge to climate change is also likely to show high spatial variability.

The goal of this study is (i) to characterize the spatial and temporal variability of recharge and identify the various drivers that govern its distribution and (ii) to improve the understanding of the response/sensitivity of groundwater recharge to changes in precipitation and air temperature in the MER. For this purpose, the Gidabo River Basin, which is located in the southern MER, is considered as the study area.

To account for the spatial heterogeneity of the watershed in terms of soil, land-use and slope characteristics, the semi-distributed hydrologic model SWAT (Arnold et al., 1998; Neitsch et al., 2011) is employed. Besides other water balance components, the spatial and temporal distribution of groundwater recharge is obtained from the model output. While other, more direct methods for recharge estimation are available (for an overview see e.g. Scanlon et al., 2002; Sophocleous, 2004), their application at the watershed scale appears to be impracticable in the given case. In addition, the model-based estimation of groundwater recharge allows examining the sensitivity of groundwater recharge to changes in air temperature and precipitation. This represents a first step towards an assessment of the aquifers' vulnerability to climate change. Scenario-based assessments, where a hydrological model is driven by climate change scenarios derived from downscaled GCMs have been found to result in high uncertainty of the projected recharge (Kurylyk and MacQuarrie, 2013). Motivated by the "alternate approach" suggested by Brown and Wilby (2012) the focus of this work is shifted to the hydrological system and its general sensitivity to changes in climatic parameters. The results from this sensitivity study will then be discussed in the light of existing projections of climate change.

2. Study area

The Gidabo River Basin is located in the south-eastern MER (Fig. 1). The River Gidabo winds through forested and agricultural land of escarpment and rift floor, finally terminating in Lake Abaya, the largest lake in the rift valley. The river is approximately 120 km in length with an estimated 3302 km^2 contributing source area. It originates on the north-eastern mountains of Soka Sonicha.

The area is covered by a variety of volcanic rocks (basalt, ignimbrites, rhyolites, trachytes and pyroclast) and to a minor part by lacustrine sediments (AG consult, 2004; Mechal, 2007; Halcrow, 2008; GSE, 2012). These rocks are highly affected by the late tertiary rifting activity and erosional processes (Wolde Gabriel et al., 2000) which resulted in a wide range of elevations from 1175 m a.s.l. at Lake Abaya in the west to about 3200 m a.s.l. at the Gelala summit in the north east. As a result of typical rift morphology the three major physiographic regions, rift floor, escarpment and highland are obvious.

Climate in the Gidabo River Basin ranges from semi-arid in the rift floor to humid in the mountains of the escarpment (Fig. 2). In the highlands and escarpment bounding the rift floor precipitation exceeds 1600 mm/year, whilst at the lowest altitude in the rift floor precipitation is often below 800 mm/year. Precipitation is characterized by a bimodal pattern with maximum peaks during April and May ("small rainy" season) and during September and October in the "main rainy" season. Like in most parts of Ethiopia, the diurnal variation of air temperature in the basin is more visible than its seasonal variation. Average monthly temperature varies from 21 °C to 25 °C in the rift floor to less than 11.5 °C to 13.5 °C in the high altitude plateau (highland).