Regional Groundwater Flow Modeling of the Geba basin, Northern Ethiopia

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Abstract

The Geba basin is located in a semi-arid mountainous region in the northern part of Ethiopia, in the Tigray Regional state. It is one of the most water-stressed areas of the country, with only a short rainy period from mid-June to mid-September. Because rainfall in this region has been consistently erratic in last few decades, both in time and space, rain-fed agriculture has become problematic. Hence, in order to supplement rain-fed agriculture with small to large scale irrigation, a detailed understanding of local and regional groundwater resources is important. However, information on the availability and distribution of groundwater resources is scarce as there has never been a systematic and detailed investigation in this region. Hence, the main objective of this study is to study the groundwater system of the Geba basin, using techniques as groundwater modeling and other tools, and to identify and quantify potential groundwater resources for exploitation.

An intensive field campaign has been undertaken from 2004 to 2008 to collect relevant information regarding geology, hydrology, and hydrogeology throughout the Geba basin. An inventory was made of groundwater levels, wells, discharge and water quality of springs, base flow of perennial streams, and interaction with reservoirs. Land-use was also investigated during field visits to be used as ground truth for supervised classification of satellite images. An extensive field campaign was also conducted for geological mapping.

Water samples collected were analyzed in the hydrochemistry laboratory of Mekelle University and results were compared with Ethiopian drinking water standards. For most of the chemical constituents, water samples are within the safety standards, except for SO_4 and NO_3 of which 15% and 19% of the samples fail to meet the standards. Further analysis of the water samples

using multivariate statistical analysis enable to cluster the water samples in two groups and five subgroups, which reflect differences in lithology and/or recharge-discharge conditions.

From the geological survey, it follows that the Geba basin is covered by metamorphic, sedimentary and volcanic rocks, most of which have been affected by different types of geological structures as folding, faulting, fracturing, and/or shearing by successive episodes of geological disturbances. A digital geological map of the Geba basin was prepared, which includes eighteen different types of lithological units as well as all major geological structures in the basin. This information, together with borehole lithological logs and pump test data, form the basis for building a regional groundwater flow model of the basin.

The WetSpass model was applied to simulate the hydrological water balance of the Geba basin. Seasonal and annual evapotranspiration, surface runoff, and groundwater recharge are the main outputs of the model. Accordingly, about 76% of the precipitation in the basin is lost through evapotranspiration, 18% becomes surface runoff, and only the remaining 6% is groundwater recharge. Results of the WetSpass model were calibrated against river flow measurements, which show that the predictions are within an acceptable range. From the WetSpass results additional maps can be derived as accumulated surface runoff, safe yield for groundwater abstraction, and water deficit for crop growth. Comparison of existing reservoirs with the accumulated runoff map shows that many reservoirs have failed because their design capacity is much higher than the actual inflow. Comparison of the safe yield map with the crop water deficit map shows that in most areas groundwater can be safely abstracted to supplement the water deficit for crop growth during the wet season. However, the crop water deficit in the dry season is too high to be supplemented by sustainable groundwater abstraction, except in some small parts of the basin

A groundwater flow model of the Geba basin was developed which accurately predicts the observed groundwater levels, and yields a groundwater balance with a small error (0.43%). A calibration graph using 340 observation points show a good fit with a normalized RMS of 0.8%. The obtained hydraulic conductivity values after model calibration range from 6×10^{-5} m/d for basement rocks to 0.023 m/d for Adigrat and Enticho sandstones. Other derived results of the model are a groundwater table map for the entire basin and piezometric maps for each formation,

which can be used for groundwater assessment. Comparison of the groundwater table map with topography indicates areas where the groundwater connects to the surface, and, hence, where discharge areas are located. These areas can be potential sites for groundwater abstraction by hand dug wells or shallow boreholes.