Modeling of hydrological processes in the Geba river basin, Northern Ethiopia

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Abstract

The Geba river, located in northern Ethiopia, is one of the major tributaries of the Tekeze (Atbara) river, which is a tributary of the Nile. The Geba basin covers an area of 5,150 km^2 and is characterised by a semi-arid climate and rugged topography. Water resources in the basin are scarce due to limited rainfall, high evapotranspiration, sparse vegetation and ongoing land degradation.

This PhD research study intends to determine and quantify the hydrological processes in the Geba basin through: (1) statistical analyses of historic climate trends and spatial patterns, (2) simulation of hydrological processes with a spatially distributed model, (3) assessment of the effects of soil data on hydrological model performance, (4) modeling of soil erosion and sediment transport, and (5) assessment of future climate change and potential impact on water resources.

To achieve these goals various techniques are applied. The Mann-Kendall test for climate trend detection shows that the Geba basin has experienced a significant increase in temperature in the last decades, while precipitation remained constant. Temperature and evapotranspiration are strongly correlated with altitude, while precipitation is independent of altitude. Geostatistical analyses, using correlograms and kriging interpolation, show that precipitation and evapotranspiration are only weakly spatially correlated over longer distances.

The hydrological processes in the basin are simulated with the WetSpa model using digital data of elevation, soil type and land-use in grid GIS form with a resolution of 90 m and daily time series from 1999 to 2004 of precipitation and potential evaporation interpolated with kriging to the same spatial resolution. The model results reveal that 90% of the precipitation is lost by evapotranspiration, while the main water resource in the basin is surface runoff which accounts for only 9% of the precipitation and the rest is groundwater recharge and drainage. Basin grid GIS maps of hydrologic parameters, such as run-off coefficient, flow velocity and travel time are developed that can be used for surface water harvesting.

The model is also applied to the Agulae (456 km^2) subbasin, in order to study the effect of soil data on model performance. Two soil maps are used: one derived from the FAO soil database and one obtained trough field reconnaissance and laboratory analyses. Results indicate that hydrological modelling with the FAO soil map may result in reduced model performance in small catchments.

Erosion and sediment transport in the basin are modelled with the WetSpa transport module. Observed daily discharges and suspended sediment concentrations of two summer seasons in 2006 and 2007 are used for model calibration and validation. The predicted sediment hydrographs compare favourably with the observations and simulated maps of soil losses are derived for erosion control planning.

A statistical downscaling approach is applied to synthesize present and future daily precipitation and temperature series in the Geba basin from the HadCM3 climate change predictor and A2 and B2 emission scenarios. The WetSpa model is calibrated with this data for the period 1961 to 1988 and independently verified from 1992 to 2010 using daily precipitation and temperature data observed at Mekelle (Quiha) airport. The downscaling results show that temperature will become gradually warmer in the forthcoming decades while precipitation will become less. The predictions with the WetSpa model indicate that this will results in significant changes in future stream flow and other hydrological parameters in the basin.