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Using SWAT to Evaluate Climate Change Impact on Water Resources in the White Volta River Basin, West Africa

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Introduction

The freshwater resource of the White Volta river basin is a fundamental basis for the economic growth and social development not only within the basin but also in the riparian countries. However, due to high temporal and spatial variability in rainfall, prolonged dry season of 7 months, global environmental changes and population growth, there is serious pressure on the water resources with consequences for the many rural poor in the basin. The currently high annual population growth rate of 2.5 % (Andah et al., 2003) in the basin will lead to significant increase in water demand, particularly, for crops and livestock production in the near future. The ongoing global climate change puts further constraint on the already limited water resources in the basin. In equatorial Africa, the climate is expected to become warmer with an average temperature increase of 1.4°C by 2050 (IPCC, 2001). Predicted hydrological changes associated with the expected increase in temperature include (1) increase in precipitation of about 5 to 30 % from December to February and 5 to 10 % from June to August, and (2) greater runoff (Joubert and Hewitson, 1997; Arnell, 1999). In the Volta basin, Kunstmann and Jung (2003) among others have predicted mean annual increase of 1.2 ^{o}C in temperature and 5 % in rainfall between the present (1991-2000) and the future (2030-2039). Such increases will affect water availability for use by the different water sectors, particularly, agriculture with serious implications for many livelihoods since roughly 2 out of 3 basin inhabitants are employed in agriculture (Rodgers et al., 2007). Therefore, evaluation of water resources in light of future climate change is very important for sustainable planning and management of the resource. Within this study the Soil and Water Assessment Tool (SWAT) model is applied to simulate the water resources of the White Volta river basin and to evaluate the impact of future climate change.

Study Area

This study was carried out in the White Volta river basin, a major sub-basin of the Volta river basin in West Africa (Figure 1). The study basin is shared mainly by Burkina Faso and Ghana. The main channel of the river has a total length of 1,140 km and drains a total land area of about 106,000 km^2 (about 91,000 km^2 at Nawuni). The climate is semi-arid to humid with annual rainfall varying from 600 mm in the extreme north of the basin to about 1200 mm in the extreme south (VBRP, 2002). The mean annual temperature and evapotranspiration are 26 ^{o}C and 1650

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mm, respectively. The geology is mainly the basement crystalline rocks (Birimian category) of Precambrian age. The dominate soil types are Luvisols, Regosols and Lithosols (FAO, 1995). The land cover type is predominantly savannah, which consist of grassland interspersed with shrubs and trees (WRI, 2003).

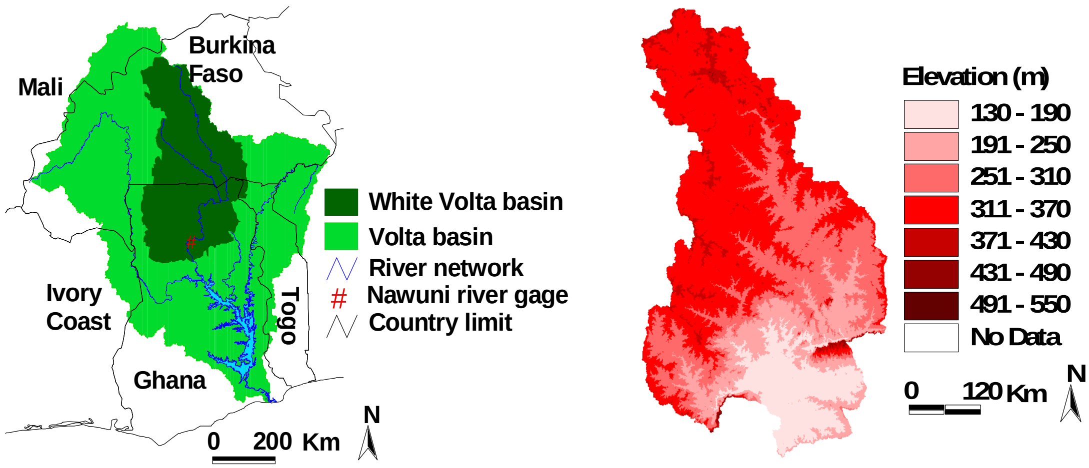

Figure 1. Location map and digital elevation model of the White Volta river basin, West Africa.

Materials and Methods

SWAT is a medium- to large-scale river basin model that was developed to predict the impact of land management practices such as land-use and -cover changes, reservoir management, groundwater withdrawals, and water transfers on sediment, water, and agricultural chemical yields in complex watersheds with varying soils, land-use and management conditions over long periods of time (Neitsch et al., 2005). SWAT is a physically based and semi-distributed model that uses a GIS interface and readily available input data such as Digital Elevation Model (DEM), climate, soil and land-use data. For this study, the input data were obtained from the FAO, the GLOWA-Volta project of the Center for Development Research, Germany, the national meteorology agencies in Ghana and Burkina Faso, field research, and literature.
The model was calibrated and validated at Nawuni using observed river discharge time series obtained from the National hydrological offices in Ghana and Burkina Faso. Calibration was done for the period (1981-1991) with the first 5 years (1981-1985) used as a warm-up period which were not considered in the calibration analysis. Validation of the model was done for the period 1992-1999. The model performance was evaluated using goodness-of-fit statistics such as the Nash-Sutcliffe model efficiency (NSE), the coefficient of determination (R^2) and the index of agreement (IA).
The present (1990-2000) and future (2030-2039) water resources were simulated with the calibrated SWAT model and compared. The future water resources were simulated using climate series generated with the stochastic weather generator LARS-WG driven by monthly rainfall and temperature forecasted by the regional climate model MM5 (using the IS92a scenario and taking boundary conditions from the Global Climate Model ECHAM4).

Results and Discussion

Model calibration and validation

Results of the monthly and daily calibrations show good correlation between the simulated and observed discharge. The NSE, R^2 and IA were all higher than 0.90 for the monthly calibration and higher than 0.75 for the daily (Figure 2). The validation results also show good correlation between the simulated and observed discharge with the NSE, R^2 and IA, all higher than 0.90 for the monthly validation and higher than 0.60 for the daily (Figure 3). For both the calibration and validation periods, SWAT underestimated the baseflow. Generally, the SWAT model overestimated the high flows and underestimated the low flows. The underestimation of the low flows could be due to more than one aquifer contributing to baseflow in the basin, a situation not handled in SWAT at present.

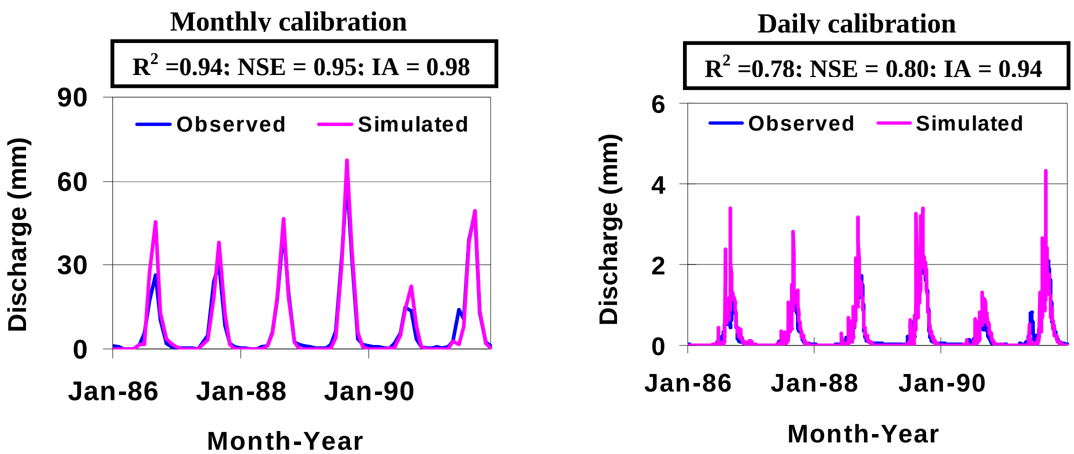

Figure 2. Calibration of SWAT-simulated discharge against observed values of the stream gage at Nawuni in the White Volta basin (about 91,000 km^2)

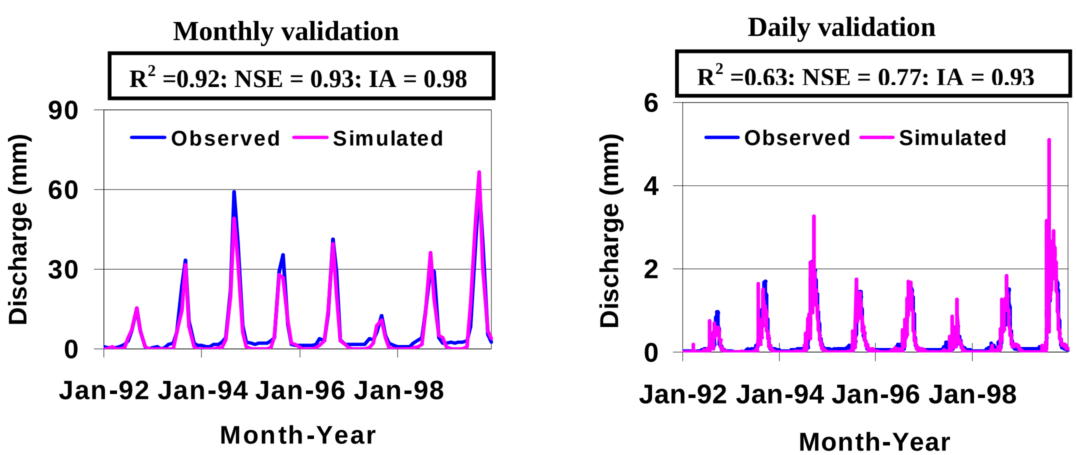

Figure 3. Validation of SWAT-simulated discharge against observed values of the stream gage at Nawuni in the White Volta river basin (about 91,000 km^2).

Impact of future climate change

The results of the simulated future mean annual discharge, surface runoff and baseflow show increases of 33 %, 37 %, and 29 % (Table 1). Such high increases in flows in response to a relatively small increase (6 %) in rainfall could be attributed to the non-linear response of discharge, surface runoff and baseflow to rainfall in the White Volta river basin and the fact that actual evapotranspiration is already high in the rainy season and only part of the additional rain is evaporated. Though the future annual water quantities show high increases, the annual coefficient of variation are also high. This means that water resources in the basin will be less reliable and more extreme events (e.g., flood and drought) can be expected.

Table 1. SWAT-simulated annual (mean over 95 years of stochastically generated climate data) water resources in the White Volta river basin under present and future climate scenarios. Figures in bracket are coefficients of variation.

Scenario	Simulation period	Rainfall (mm)	Discharge (mm)	Surface runoff (mm)	Baseflow (mm)
Present	1991-2000	851	89 (27%)	35 (31%)	55 (25%)
Future	2030-2039	904	118 (41%)	48 (46%)	71 (40%)
Percent change (%)		6	33	37	29

Conclusion and recommendation

The SWAT model is well able to simulate the hydrology of the White Volta River Basin. The future annual discharge, surface runoff and baseflow in the basin show importance increases over the present as a result of future climate change. However, water resources in the basin will be less reliable in the future.

This study used future climate series from one global climate model (ECHAM4) and based on one scenario (IS92a) for the impact analysis. Due to uncertainties in climate forecasting, the use of climate model ensembles and multiple scenarios will be useful for understanding the range of climate change impact that can be expected on water resources in the White Volta rive basin.

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