Simulating soil moisture and climate change impacts in a watershed through application of the distributed hydrological WetSpa model

Mohsen Tavakoli

Abstract

This PhD research study consists of four parts: (1) Validation of soil moisture simulation with a distributed hydrologic model (WetSpa) in the Baron Fork river watershed, Oklahoma, USA, (2) Impact of climate change on stream flow and soil moisture in the Vermilion watershed, Illinois, USA, (3) assessment the spatio-temporal variation of soil moisture in the Bibeschbach watershed, Grand-duchy of Luxembourg, and (4) Impacts of climate change and urban development on extreme flow in the Grote Nete watershed, Belgium.

The application of the WetSpa model in the Baron Fork river watershed, Oklahoma, USA forms part of the second Distributed Model Intercomparison Project (DMIP2). The WetSpa model is calibrated and validated using hourly river flow observations for a 6 years period, and the ability of the model for simulating soil moisture is verified by comparing the model predictions to 4 years of daily soil moisture observations at WEST site soil monitoring station. A good match is obtained between observations and model predictions.

Potential effects of climate change on stream flow and soil moisture in the Vermilion watershed, Illinois, USA, are investigated using WetSpa. For future climate changes in the watershed, predictions of the HadCM3 general circulation model are downscaled using the SDSM software tool. The ability
of the WetSpa model to predict soil moisture is verified by comparison with observations at Stelle soil moisture monitoring station. The downscaled local climate variables are used as inputs to the WetSpa model and simulated river flows and soil moisture distributions in the 21st century are forecasted. The results show that stream flow in the Vermilion watershed may decrease substantially, especially in the summer as a result of less precipitation, but mainly due to increased evapotranspiration. Also soil moisture will decrease especially in the fall, which could have a negative impact on the natural vegetation and rainfed crop growth.

An improved WetSpa model for simulating surface soil moisture is tested in the Bibeschbach watershed, Grand-duchy of Luxembourg. In this small watershed, soil moisture variations have been monitored at different locations. The updated version of WetSpa is calibrated using hourly stream flow observations in 2009 and the predicted soil moisture at eleven locations is verified with observed data.

Effects of several climate change and urban growth scenarios in the Grote Nete watershed, Belgium are investigated with the WetSpa model. The WetSpa model is calibrated and validated with river flow observations. The regional climate change scenarios are generated with the CCI-HYDR Perturbation Tool and the urban development scenarios are taken from a previous study on extrapolation of historic urban development trends. The WetSpa model is used to predict the effects of three climate change scenarios (low, mean and high), three urban development scenarios (low, medium and high) and the nine combined climate–urban–change scenarios. It is concluded that in the future, peak flows in the watershed will increase and especially low flows will substantially decrease, which likely will lead to problems of more flooding in winter and more drought in summer.