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Parameter uncertainty analysis for simulating streamflow in a river catchment of Vietnam

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ABSTRACT

Hydrological models play vital roles in management of water resources. However, the calibration of the hydrological models is a large challenge because of the uncertainty involved in the large number of parameters. In this study, four uncertainty analysis methods, including Generalized Likelihood Uncertainty Estimation (GLUE), Parameter Solution (ParaSol), Particle Swarm Optimization (PSO), and Sequential Uncertainty Fitting (SUFI-2), were employed to perform parameter uncertainty analysis of streamflow simulation in the Srepok River Catchment by using the Soil and Water Assessment Tool (SWAT) model. The four methods were compared in terms of the model prediction uncertainty, the model performance, and the computational efficiency. The results showed that the SUFI-2 method has the advantages in the model calibration and uncertainty analysis. This technique could be run with the smallest of simulation runs to achieve good prediction uncertainty bands and model performance. This technique could be run with the smallest of simulation runs to achieve good prediction uncertainty bands and model performance.

1. Introduction

Hydrological model is a useful tool in managing and planning water resources. In recent years, a large number of hydrological models have been developed and can be classified into lumped and distributed models. The distributed hydrological model is preferable, since it can realistically represent the spatial variability of catchment characteristics (Oeurng et al., 2011). In recent years, many such hydrological models have been developed such as AGNPS (Agricultural Non-Point Source) (Young et al., 1989), HSPF (Hydrologic Simulation Program—Fortran) (Bicknell et al., 2000), MIKE SHE (Refsgaard and Storm, 1995), and SWAT (Soil and Water Assessment Tool) (Arnold et al., 1998). Among these models, the SWAT is one of the choices because it is widely used to assess hydrology in small and large catchments around the world (see SWAT Literature database: http://www.card.iastate.edu/swat_articles/). The ability of the hydrological model to accurately simulate the hydrological process is assessed through a careful calibration and uncertainty analysis. Calibration of hydrological models is a challenging task because of uncertainties in hydrological modeling (Yang et al., 2008). According to Xue et al. (2014), the main sources of uncertainties are model inputs associated with measurement errors, from model structures due to assumption and simplification, and from model parameters related to approximations. Among these

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sources of uncertainty, the parameter uncertainty is inevitable but it is easy to control by using a suitable calibration method (Wu and Chen, 2015).

To account for that uncertainty, a number of uncertainty analysis techniques have been developed and applied to many hydrological studies. For example, Shen et al. (2012) used Generalized Likelihood Uncertainty Estimation (GLUE) method coupled with the SWAT model to estimate the parameter uncertainty of the streamflow and sediment simulation in the Daning River Watershed, China; Rostamian et al. (2008) used Sequential Uncertainty Fitting (SUFI-2) to perform model calibration and uncertainty analysis in the Beheshtabad and Vanak river catchments in the central Iran; van Griensven et al. (2008) applied Parameter Solution (ParaSol) method to estimate parameter uncertainty in the SWAT model of Honey Creek, a tributary of the Sandusky catchment in Ohio, USA; and Samadi and Meadows (2014) used Particle Swarm Optimization (PSO) method to investigate uncertainty analysis in the SWAT hydrological model at the Waccamaw River Catchment, USA. However, a few studies have been reported on comparison of different uncertainty analysis techniques. For instance, Wu and Chen (2015) evaluated uncertainty estimates in distributed hydrological modeling for the Wenjing River watershed in China by GLUE, SUFI-2, and ParaSol methods, and they indicated that the SUFI-2 method is able to provide more reasonable simulated results than the other two methods. Another similar study in a river basin of eastern India conducted by Uniyal et al. (2015) reported that both SUFI-2 and GLUE are the promising techniques for uncertainty analysis of modeling results and there is a need to conduct such types of studies in different catchments under varying agro-climatic conditions for assessing their generic capability.

From the above review of literature, it is apparent that the generality of using different uncertainty analysis techniques needs to be verified with more applications to different regions. In addition, the studies on uncertainty analysis of hydrological modeling in Vietnam has not been conducted yet. The objective of this paper is to apply the four uncertainty analysis techniques (i.e., SUFI-2, GLUE, ParaSol, and PSO) to perform parameter uncertainty analysis for streamflow simulation. A case study was conducted in the Srepok River Catchment in the Central Highlands of Vietnam, by using the SWAT distributed hydrological model. The results of this study provide a scientific reference based on uncertainty analysis to decision-makers in order to promote water resources planning efforts.

2. Study area

The Srepok River Catchment, a sub-basin of the Mekong River Basin, is located in the Central Highlands of Vietnam, and lies between latitudes 11° 45″–13° 15″N and longitudes 107° 15″–109°E (Fig. 1). The Srepok River is formed by two main tributaries: the Krong No and Krong Ana rivers. The total area of this catchment is approximately 12,000 km^2 with the population of 2.2 million (2009). The average altitude of the watershed varies from 100 m in the northwest to 2400 m in the southeast. The climate in the area is very humid (78%–83% annual average humidity) with annual rainfall varying from 1700 mm to 2300 mm and features a distinct wet and dry seasons. The wet season lasts from May to October (with peak floods often in September and October) and accounts for over 75%–95% of the annual precipitation. The mean annual temperature is 23 °C. In this catchment, there are two dominant soils: grey soil and red-brown basaltic soil. These soils are highly fertile and very consistent with agricultural development. Agriculture is the main economic activity in this catchment of which coffee and rubber production are predominant.

3. Methodology

3.1. SWAT hydrological model

The SWAT model is a physically based distributed model designed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds with varying soil, land-use, and management conditions over long periods of time (Neitsch et al., 2011). With this model, a catchment is divided into a number of sub-watersheds or sub-basins. Sub-basins are further partitioned into hydrological response units (HRUs) based on soil types, land-use types, and slope classes that allow a high level of spatial detail simulation. The model predicts the hydrology at each HRU using the water balance equation as follows:

$$SW_t = SW_0 + \sum_{i=1}^{t} \left(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw} \right) \quad (1)$$

where SW_t is the final soil water content (mm H_2O), SW_0 is the initial soil water content on day i (mm H_2O), t is the time (days), R_{day} is the amount of precipitation on day i (mm H_2O), Q_{surf} is the amount of surface runoff on day i (mm H_2O), E_a is the amount of evapotranspiration on day i (mm H_2O), w_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H_2O), and Q_{gw} is the amount water return flow on day i (mm H_2O). A detail description of the different model components can be found in the SWAT Theoretical Documentation (Neitsch et al., 2011).

The input data required for SWAT include weather data, a land-use map, a soil map, a Digital Elevation Map (DEM) (Table 1). Discharge data are also required for calibration of streamflow. Monthly flow data (2000–2005) measured at the Giang Son, Cau 14, and Ban Don stations were used for the calibration of streamflow. Streamflow data were provided by the Hydro-Meteorological Data Center of Vietnam.