SWAT Hydrologic Model Parameter Sensitivity Analysis for Wang River Basin

การวิเคราะห์ความอ่อนไหวของพารามิเตอร์ทางอุทกวิทยาสำหรับลุ่มน้ำวังด้วยแบบจำลอง SWAT

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ABSTRACT

The purpose of this research is to study the proper parameter value for assessing accurate and reliable surface runoff at a daily time step, and parameter sensitivity analysis of the Wang River Basin by SWAT model. The amount of surface runoff was estimated by the model based on input data which are the digital elevation model (DEM), meteorological data, soil data and land use/-land cover. Parameter sensitivity analysis presents the most 3 sensitive parameters: 1) saturated hydraulic conductivity (SOL_K), 2) moist bulk density (SOL_K) and 3) average slope length (SLSUBBSN). The coefficient of determination (R^2) correlation between surface runoff observation value and simulation value was 0.52, the Nash-Sutcliffe coefficient (NSE) was 0.51 and PBIAS was 2.1 in calibration. R^2 is 0.31, NSE was 0.00 and PBIAS was -39.8 in validation.

บทคัดย่อ

การศึกษาครั้งนี้มีวัตถุประสงค์เพื่อหาค่าพารามิเตอร์ที่เหมาะสมต่อการประเมินปริมาณน้ำท่ารายวัน และวิเคราะห์ความอ่อนไหวของพารามิเตอร์ในลุ่มน้ำวัง โดยใช้พารามิเตอร์ 16 ตัว ด้วยการใช้แบบจำลอง SWAT ซึ่งเป็นแบบจำลองที่ประมวลปริมาณน้ำท่าจากข้อมูลนำเข้าได้แก่ แบบจำลองระดับสูงเชิงเลข ข้อมูลอุตุนิยมวิทยา ข้อมูลปฐพีวิทยา และข้อมูลการใช้ประโยชน์ที่ดิน ทำการวิเคราะห์ความอ่อนไหวของแบบจำลอง พบว่าพารามิเตอร์ที่มีความอ่อนไหวมากที่สุด 3 อันดับแรกได้แก่ ค่าสัมประสิทธิ์การนำน้ำของดินขณะอิ่มตัวด้วยน้ำ ความหนาแน่นมวลของดินรวมสภาพเปียก และ ความยาวความลาดชันเฉลี่ย ในขั้นตอนการสอบเทียบแบบจำลองให้ค่าสัมประสิทธิ์การตัดสินใจเท่ากับ 0.52 ค่าดัชนีความแม่นยำเท่ากับ 0.51 และร้อยละความลำเอียงเท่ากับ 2.1 สำหรับขั้นตอนการทดสอบความแม่นยำของแบบจำลองให้ค่าสัมประสิทธิ์การตัดสินใจเท่ากับ 0.31 ค่าดัชนีความแม่นยำเท่ากับ 0.00 และร้อยละความลำเอียงเท่ากับ -39.8

Keywords: SWAT model, Wang river basin, Parameter
คำสำคัญ: แบบจำลอง ลุ่มน้ำวัง พารามิเตอร์

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Introduction

The water is the natural resource that provides ecosystem and preserves the living organisms, it was concerned both quantity and quality. In hydrological system, surface runoff is an important parameter to human activities. The more surface runoff, the more causing of floods, and the more insufficient surface runoff, the more causing of drought.

At present, the math model is necessary to hydrological management. The Soil and Water Assessment Tool (SWAT) is a small watershed to river basin-scale model to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change (Arnold, J.G et al., 1998). SWAT is widely used in assessing soil erosion prevention and control, non-point source pollution control and regional management in watersheds (Arnold, J.G et al., 1998). Adequate simulation of the targeted watershed's hydrologic balance is foundational for all SWAT applications regardless of their ultimate objectives. Gassman P.W et al. (2007) review of 115 SWAT hydrologic studies, and concluded that their daily time step predictable results were generally poorer than monthly and annual time step predictions except in a few cases. They attributed the weaker results of some studies to inadequate spatial rainfall representation, inaccuracy in stream flow measurements, lack of model calibration, and relatively short calibration and validation periods. In the past few years, there had been much increase in using SWAT for daily hydrological simulations. Although the strongest results are still mostly reported by studies of annual and monthly time steps, there has been a trend of increase in the number of successful SWAT applications at the daily time step (Gassman P.W et al., 2014). In addition, the selection of suitable parameter is necessary to be evaluated by mathematical models to get accuracy value of surface runoff.

Therefore, the purpose of this research is to study the proper value of parameters for assessing accurate and reliable surface runoff at daily time step, and parameter sensitivity analysis of Wang River Basin as the Wang River Basin is located in the north of Thailand, the mountain range topography and the 1 of 4 main up-streams of Chao Phraya River.

Objectives of the study

This study aims to determine the proper parameter value and parameter sensitivity analysis of the SWAT model for daily hydrological simulations of the Wang River Basin.

Methodology

1. Preparation of data set

- Calibration data Set:

1.1 Meteorological data in 2009

- Daily precipitation
- Daily minimum and maximum temperature
- Daily relative humidity

1.2 Land use 1:50,000 in 2009

1.3 Digital Elevation Model (DEM), grid size 30x30 m.

1.4 Soil types soil properties

1.5 GIS data (river) L7018

1.6 Hydrological data in 2009

- Validation data Set:

1.7 Meteorological in 2015

- Daily precipitation
- Daily minimum and maximum temperature
- Daily relative humidity

1.8 Hydrological data in 2015

2. Data analysis by SWAT model

2.1 Watershed boundary

Digital Elevation Data (DEM) was used to delineate the watershed boundary.

2.2 Hydrological response units

By SWAT, watersheds were divided into sub-basins based on interior outlet points along the stream network. Each sub-basin has been divided into hydrologic response units (HRUs) which are slope, soil type, soil properties, land use/-land cover and soil management practices.

2.3 Parameter sensitivity analysis

The sensitive parameters were determined by Global Sensitivity analysis, calculating the follow multiple regression system (equation (1)):

$$g = \propto + \sum_{i=1}^{m} \beta_i b_i \quad (1)$$

A t-test was used to identify the relative significance of each parameter b_i. The larger absolute value of t-stat and smaller the p-value (p-value $\leq$ 0.05) are the more sensitive the parameter

3. The proper parameter value identified surface runoff estimation by SWAT model

The SWAT-CUP program using the SUFI2 (Sequential Uncertainty Fitting) algorithm was used for calibrating SWAT model. The model is a calibration between surface runoff observation and surface runoff simulation to decreases difference value among of them. The proper parameters value must be giving the surface runoff values form model calculation nearly with observation by consider form coefficient of determination (R^2) and the Nash-Sutcliffe coefficient (NSE). At the outlet of the watershed for equation (2) and (3):

$$R^2 = 1 - \left[\frac{\left[\sum_{i=1}^{n} (O - O_{avg})(P_i - P_{avg}) \right]}{\sqrt{\sum_{i=1}^{n} (O_i - O_{avg})^2} \sqrt{\sum_{i=1}^{n} (P_i - P_{avg})^2}} \right]^2 \quad (2)$$

Where O = observed water quantity value from station.

P = estimated water quantity value from model.

O_{avg} = average observed water quantity value from station.

P_{avg} = average observed water quantity value from model.

$$NSE = 1 - \frac{\left[\sum_{i=1}^{n} (q_f - q_m)_i^2 \right]}{\left[\sum_{i=1}^{n} (q_f - q_{avg})_i^2 \right]} \quad (3)$$

Where q_f = observed water quantity value from station.

q_m = estimated water quantity value from model.

q_{avg} = average observed water quantity value from station.

In this study, the standard coefficient of determination and the Nash-Sutcliffe in calibration step were does not less than 0.5 both.

Results

The sensitivity parameters of surface runoff were determined by Global Sensitivity Analysis using SWAT CUP in SUFI2 (Sequential Uncertainty Fitting) algorithm. SWAT CUP in SUFI2 was used for SWAT model calibration. The model calibration based on 16 parameters was calibrated the daily hydrological simulations and observation.

Parameter Sensitivity Analysis of Surface Runoff

In this study, 16 parameters were used to calibrate and validate the surface runoff. Parameters were consisted as follows: 1 parameter relate to land management (CN2), 3 parameters relate to soil (SOL_AWC, SOL_K and SOL_BD), 5 parameters relate to hydrological response unit (ESCO, EPCO, OV_N, HRU_SLP and

SLSUBBSN) and 7 parameters relate to ground water (ALPHA_BF, GW_DELAY, GWQMN, GW_REVAP, SHALLST, DEEPST and RCHRG_DP).

Parameters of the larger absolute value of t-stat and smaller the p-value (p-value $\leq$0.05) were the most sensitive parameters. The W25 hydrological station ~~is~~ was a lead number 3-flow-out in ArcSWAT model, three parameters (SOL_K, SOL_BD and SLSUBBSN) were not significantly sensitive at the 0.05 level in the daily model. They are presented in table 1 and the global sensitivity analysis using SWAT CUP in SUFI2 is presented in figure 1.

Table 1 Parameters sensitive with surface runoff at station W25

Station	Parameter	File	t-stat	p-value
W25	SOL_K	.sol	-45.236	0.000
	SOL_BD	.sol	-22.507	0.000
	SLSUBBSN	.hru	7.041	0.000

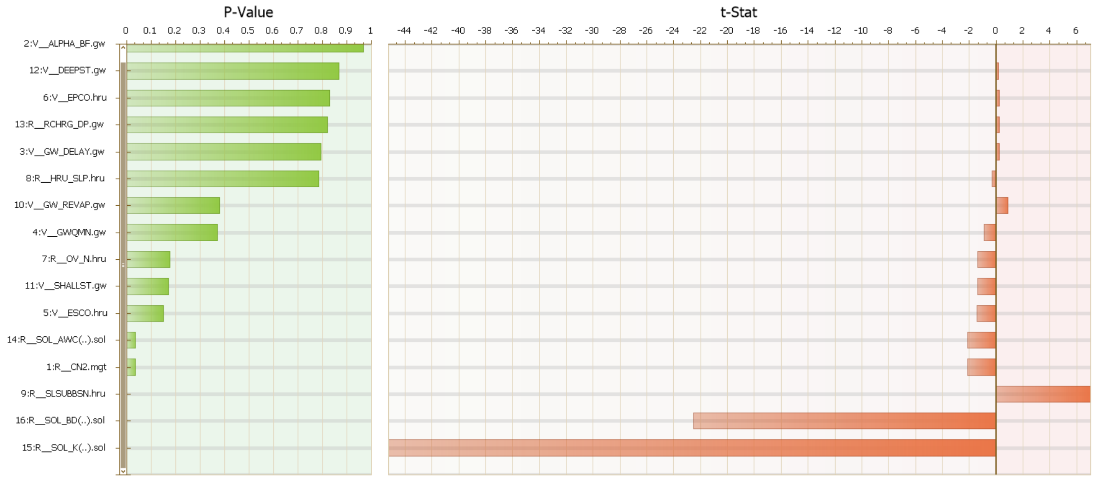

Figure 1 The global sensitivity analysis using SWAT CUP in SUFI2 at W25

The Result of Calibration and Validation model

The daily values of surface runoff in 2009 were used for calibration model. 16 parameters were calibrated by SWAT CUP SUFI2, the initial value and fit value are presented in table 2, the statistics of daily time step calibration and validation at W25 stations are presented in table 3, calibration and validation graph is presented in figure 2.

Table 2 The initial value and fit value parameters in SWAT CUP SUFI2

Parameters	Initial Value	Fitted Value
CN2	-45--20%	-38%
ALPHA_BF	0-1	0.44
GW_DELAY	30-450	265.83
GWQMN	2,100-2,500	2,322.60
ESCO	0.85-0.95	0.87
EPCO	0.3-1	0.77
OV_N	10-30%	16.27%
HRU_SLP	5-20%	15%
SLSUBBSN	-20-15%	14.95%
GW_REVAP	0.15-0.2	0.16
SHALLST	500-3,000	1,803.75
DEEPST	3,000-5,000	4,923
RCHRG_DP	-20--10%	-17%
SOL_AWC (1)	7-20%	11.10%
SOL_K (1)	-50-500%	32.78%
SOL_BD (1)	-20-30%	17.78%

Table 3 Model evaluation statistics for the calibration and validation period at W25 hydrological stations

Calibration period (2009)			Validation period (2015)		
R^2	NSE	PBIAS	R^2	NSE	PBIAS
0.52	0.51	2.1	0.31	0.0	-39.8

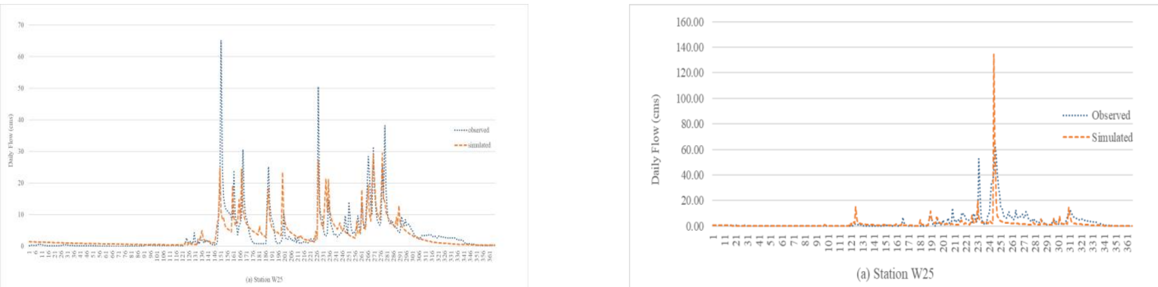

Figure 2 The calibration graphs (left) and validation graphs (right) in 2009 at W25 station

Discussion

The standard coefficient of determination (R^2) at W25 station was 0.52 and Nash-Sutcliffe (NSE) coefficient was 0.51 in the calibration period, the R^2 was 0.31 and NSE ~~is~~ was 0.00 in validation period. Linear regression analysis is presented in figure 3.

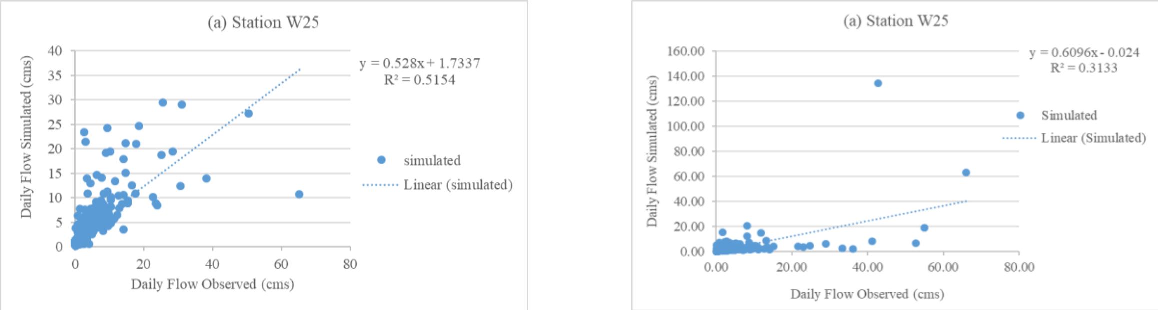

Figure 3 The linear regression analysis between surface runoff observation and surface runoff simulation of calibration period (left) and validation period (right) at W25 station

The standard coefficient of determination (R^2) of correlation between surface runoff observation and simulation and the Nash-Sutcliffe coefficient of the validation period at the daily time step was unsatisfactory because the NSE is lower than 0.36 (Krause P et al., 2005). The result was related with Akhavan S et al. (2010) that application of the SWAT to model the amount and dynamics of nitrate leaching from a typical crop was rotated in the watershed area 2,460 km^2. The calibration and validation with uncertain analysis using SUFI2 based on measurement of daily discharge data that presented the R^2 range 0.38 to 0.83 and the NSE range 0.27 to 0.77 in calibration period and R^2 range 0.27 to 0.75 and the NSE range -0.01 to 0.70 in validation period.

In addition, Yang X et al. (2015) applied the SWAT to simulate the daily stream flow at the Shakou hydrological station of the Upper Huai River Basin with a total drainage area of 5,803 km^2. Both daily and sub-daily rainfall observations were used as the model inputs to evaluate the impacts of the temporal resolution of rainfall on the daily simulation performance of the SWAT model for this large-sized basin. The result presents that the R^2 and NSE of daily stream flow was 0.47 to 0.93 both, in calibration period, 0.27 to 0.96 and 0.29 to 0.96 for R^2 and NSE in validation period.

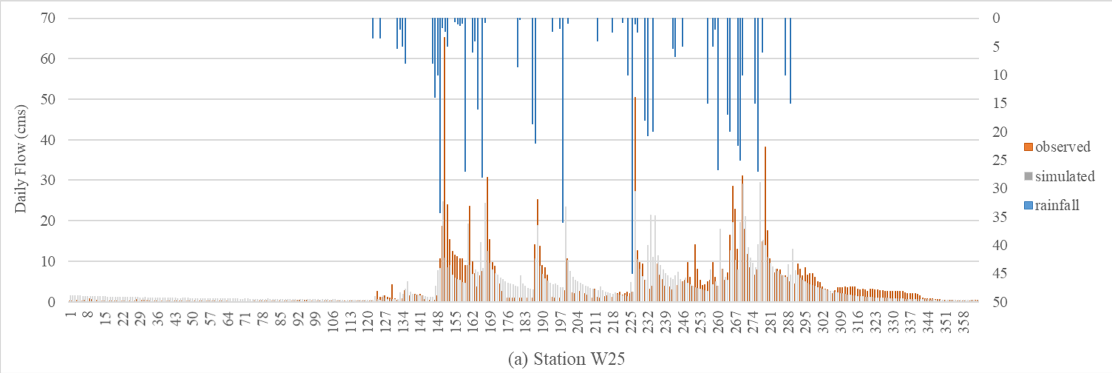

Figure 4 Rainfall, surface runoff observations and best simulation at station W25

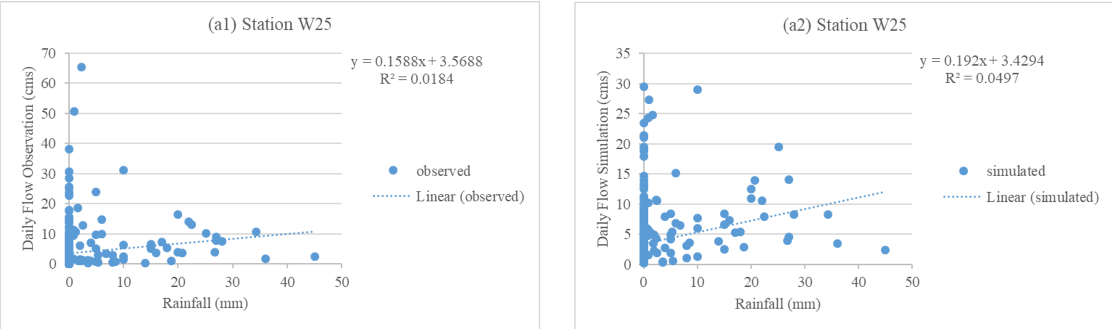

Figure 5 The linear regression analysis between rainfall and surface runoff observation (a1) and the linear regression analysis between rainfall and surface runoff simulation (a2) at station W25

Considering R^2 of correlation between rainfall and surface runoff observation at the daily time step was 0.0184, and 0.0497 of correlation between rainfall and surface runoff simulation at the daily time step because ~~of~~ they attributed the weaker results of validation period to inadequate spatial rainfall representation, inaccuracy in stream flow measurements which are presented in figure 4 and 5.

Conclusions and Limitation

At the W25 hydrological station, 16 parameters were used to ~~calibration and validation~~ calibrate and validate the surface runoff. Parameters were consisted as follows: 1 parameter relate to land management (CN2), 3 parameters relate to soil (SOL_AWC, SOL_K and SOL_BD), 5 parameters relate to hydrological response unit (ESCO, EPCO, OV_N, HRU_SLP and SLSUBBSN) and 7 parameters relate to ground water (ALPHA_BF, GW_DELAY, GWQMN, GW_REVAP, SHALLST, DEEPST and RCHRG_DP). The proper parameter value which presented the R^2 was 0.52, the Nash-Sutcliffe coefficient was 0.51 in calibration period, and R^2 was 0.31, NSE was 0.00 and PBIAS was -39.8 in validation period. Three parameters (SOL_K, SOL_BD and SLSUBBSN) are sensitive model that are significantly sensitive at the 0.05 level in the daily model.

Within the limitation of the present study, it could be concluded that the simulation of surface runoff at the daily time step of SWAT is not correlated with daily rainfall. In the future, the simulation at the daily time step by sub-daily rainfall should be studied to improve the result.

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