Runoff Estimation Using Hydrological Models inPhee River Basin, Thailand

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Abstract

The objective of this research is to compare the results obtained from two hydrological models; Soil and Water Assessments Tool Model (SWAT model), andRainfall-Runoff Model (NAM model) for runoff estimation. These mathematical models had been applied to evaluate the characteristics of runoff in Phee River basin which was the sub-area of Yom basin in northern region of Thailand. The runoff events in 2002, 2004, and 1997 from the 20-year long term runoff data were selected to represent the highest, medium, and lowest flow respectively. The key performance indices; Efficiency Index (EI), Root Mean Square Error (RMSE), Nash Coefficient, and Correlation coefficient (r) ware used to evaluate and compare the accuracy of runoff estimation. The results showed that in wet year (2002), SWAT model gave the highest accuracy which had EI, RMSE, Nash Coefficient, and r equal to 0.45, 6.70 m3/s, 0.45, and 0.77 respectively. However, NAM Model requires more input data than SWAT model, which was an advantage of this model.

Keywords: SWAT Model, NAM Model,Phee River basin, Thailand

Introduction

Water resource management is the activity of planning,development and management of the optimum use of water resources.The water resource management is not a new concept: the stream flow simulating models become an important research topic, and hydrological models of instrument insurance are directly related for development and future planning of hydrologic cycle (Ghahraman, 2012). For this matter, comparing performance of Soil and Water Assessments Tool Model (SWAT model), and Rainfall-Runoff Model(NAM model). These hydrological models had been applied to evaluate the characteristics of runoff in Phee River basin which was the sub-area of Yom basin in northern part of Thailand. Thailand is located in the paths of the southwest monsoon and northeast typhoon. The country receives heavy rainfall; the amount varies according by months, especially during August-September of the year.

Main objective of this research is to compare the results obtained from twohydrological models; SWAT model and NAM model for simulate rainfall-runoff. Hydrological model has been applied to evaluate the characteristics of runoff. In this study, the models were applied for runoff estimation by using Phee River basin. The SWAT model was developed to applicable for long-term purposes such as land management practices on water, sediment yield, land useand management watershed (Jajarmizadeh, Harun, Ghahraman, & Mokhtari, 2012).The NAM model represents various components of the rainfall-runoff process by continuously accounting for the moisture content in various storages, which represent physical elements of the basin (Lipiwattanakarn, Sriwongsitanon, & Saengsawang, 2006). These researches select runoff events of the year 2002, 2004, and 1997 from the 20-year long term runoff data, there were selected to represent the highest, medium, and lowest flow respectively.

Study Area

Phee River is coverage an area of Chiang Muan district, Phayao province, and Ban Luang district, Nan province in the northern part of Thailand. The river basin has a total catchment area of 597 square kilometers; it has a total length of 66 kilometers; and an average runoff to 96 million cubic meters per year, the latitude 18°53´04´´N and longitude 100°17´24´´. Topography has high mountains terrain and flat narrow range and Phee River is sub-basin of the Yom River basin. It flows southwards, and joinsYom River flows southwards, and joins the Nan and the Ping rivers at NakhonSawan Province where the Chao Phraya River is formed. The Chao Phraya River is a major river in Thailand, as the centralized basin of the country(Chaibandit & Konyai, 2012). The location of Phee River basin is shown in Fig.1.

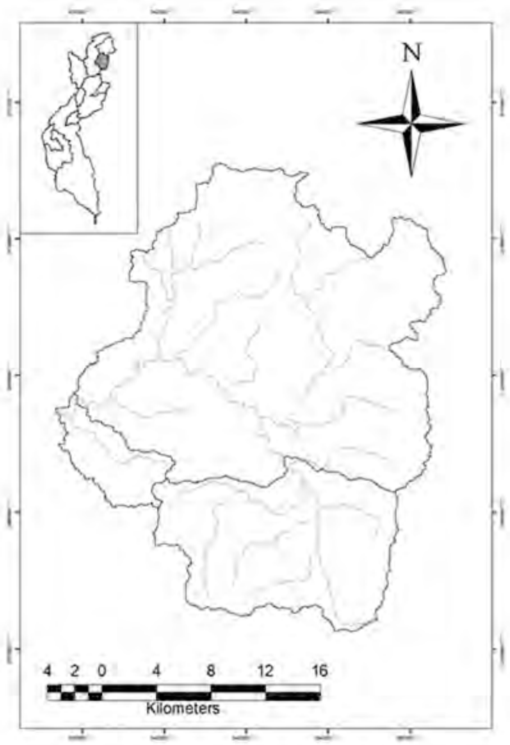


Fig.1: Location of Phee River basin

Methodology

SWAT Model

SWAT is the acronym for Soil and Water Assessment Tool, a river basin scale, spatially distributed rainfall-runoff model for continuous time simulation of river discharge developed by theUnited States Department of Agriculture (USDA), Agricultural Research Service in Texas. It was extended to predict the impact of land management practices on water, sediment and agricultural chemical yield, land use, and management watershed(Arnold et al., 2005).The SWAT model has been used worldwide and considered as a versatile model that can be used to integrate multiple environmental processes, which support more effective watershed management and the development of better informed policy decision (Gassman, Reyes, Green, & Arnold, 2007). The hydrologic cycle as simulated by SWAT is based on the water balance equation:

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

where SW_t is the final soil water content (mm), SW_o is the initial soil water content on day i(mm), *t* is the time (days), R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on dayi (mm), E_a is the amount of evapotranspiration on day i (mm), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm), and Q_{gw} is the amount of return flow on day i (mm).

The Soil Conservation Service (SCS) Runoff Curve Number method is developed by the United States Department of Agriculture (USDA) is a method of estimating surface runoff using daily rainfall, and SWAT simulates surface runoff volume. Surface runoff can estimate by SCS runoff equation, the retention parameter is defined as:

$$Q_{surf} = \frac{(R_{day}-0.2s)^2}{(R_{day}+0.8s)} \quad (2)$$

When, Q_{surf} is the accumulated runoff or rainfall excess (mm), R_{day} is the rainfall depth for the day (mm), S is the retention parameter (mm). The retention parameter by equation (3),

$$S = 25.4\left(\frac{100}{CN} - 10\right) \quad (3)$$

The SCS curve number is a function of the soil's permeability, land use and antecedent soil water conditions. SCS defines three antecedent moisture conditions: I – dry (wilting point), II – average moisture and III – wet (field capacity). The moisture condition I curve number is the lowest value the daily curve number can assume in dry conditions. The curve numbers for moisture conditions I and III are calculated with the equation. (4) and (5), respectively.

$$CN_1 = CN_2 - \frac{20\ x\ (100 - CN_2)}{\{100-CN_2+exp[2.533-0.0636\ x\ (100-CN_2)]\}} \quad (4)$$

$$CN_3 = CN_2\ x\ exp[0.00673(100 - CN_2)] \quad (5)$$

where CN_1 is the moisture condition I curve number, CN_2 is the moisture condition II curve number, and CN_3 is the moisture condition III curve number.

The Manning's equation is an empirical equation that applies to uniform flow in open channels and is a function of the channel velocity, flow area and channel slope for a given time step:

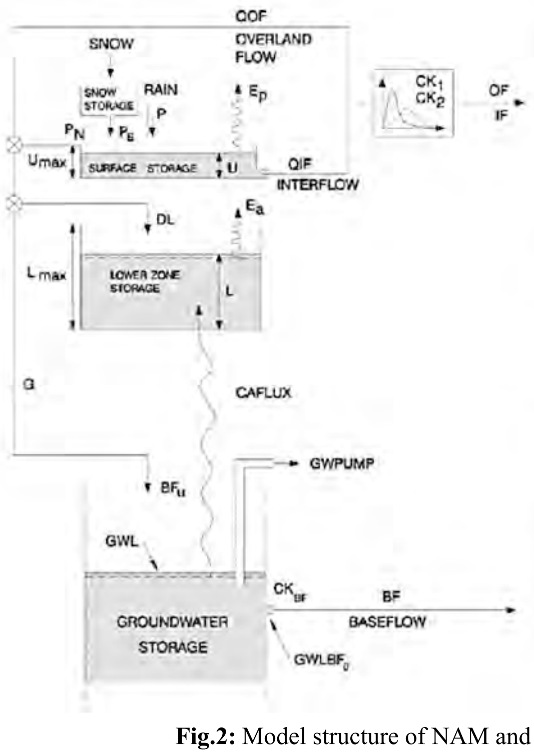
$$q_{ch} = \frac{A_{ch}R_{ch}^{2/3}slp_{ch}^{1/2}}{n} \quad (6)$$

$$v_c = \frac{R_{ch}^{2/3}slp_{ch}^{1/2}}{n} \quad (7)$$

where q_{ch} is the rate of flow in the channel (m^3/s), A_{ch} is the cross section area of flow in the channel (m^2), R_{ch} is the hydraulic radius for a given depth of flow (m), slp_{ch} is the slope along the channel length (m/m), n is Manning's coefficient for the channel and v_c is the flow velocity (m/s).

NAM model

The NAM model is an integrated and conceptual model of runoff-rainfall. NAM model simulates the rainfall-runoff process using the linkage rule between the four reservoirs which are connected together and each represent different physical specifications (Fig. 2). These four reservoirs are: snow storage, surface storage, groundwater storage and root zone storage(Lafdani, Nia, & Pahlavanravi, 2013). The required basic data for NAM model are: model parameters, initial conditions, meteorological data and data for hydrometric calibration; and validation of the model. Basic meteorological data include precipitation, potential evapotranspiration, wherein snowmelt also modeled, temperature and radiation data should also be added. In addition, NAM model has the ability of simulating the changes made by human in hydrologic cycle, meanwhile time series of irrigation and using rate of groundwater aquifers will be required (Taye, Ntegeka, Ogiramoi, & Willems, 2011).



Basic parameters	Description
U_{max} (mm)	Maximum water content in the surface storage
L_{max} (mm)	Maximum water content in the lower or root zone storage
CQ_{OF} (-)	Overland flow runoff coefficient
CK_{IF} (hours)	Time constant for interflow
$CK_{1,2}$ (hours)	The time constant for routing interflow and overland flow
CK_{BF} (hours)	The time constant for base-flow
TOF, TIF, TG (-)	Threshold value for overland flow, interflow and recharge
PN	Excess water from surface storage
QOF	The overland flow contribution
QIF	The inter flow contribution
Ea	Actual evapotranspiration
Ep	Potential evapotranspiration
BF	The base flow from groundwater
G	The amount of infiltrating water recharging the groundwater storage

Fig.2: Model structure of NAM and parameters description (DHI, 2008)

Model calibration and verification

These models were evaluated using observed and calculated discharges data. The coefficient of determination Efficiency Index (EI), Root Mean Square Error (RMSE), and Nash–Sutcliffe model efficiency coefficient were used to evaluate the model performance(P. Krause et al., 2005).

$$EI = 1 - \frac{\sum_{i=1}^{N}(Q_{mi}-Q_{ci})^2}{\sum_{i=1}^{N}(Q_{mi}-\bar{Q}_m)^2} \quad (8)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(Q_{mi}-Q_{ci})^2}{N}} \quad (9)$$

Where, Q_{mi} and Q_{ci} are, respectively, the daily observed and calculated discharge at time i, and $\bar{Q}_m$ and $\bar{Q}_c$ are the corresponding average values. N is thenumber of data points. The best fit between the calculated and observed discharges using these parametersoccurs when EI approaches 100 percent,RMSE approaches zero,andthe closer the Nash-Sutcliffe statistic is to one.

Results and Discussion

Development and application of the integrated SWAT and the NAM models was carried out by adjusting the model parameters in order to fit the measured and simulated flood hydrographs using both calibration and verification process. Table 1 showed the hydrological models output statistics.The result of both models can simulate flood hydrographs close to the observed hydrographs, as shown by the acceptable average statistical values for model parameters in Fig. 3 to Fig.5.Both models are unable to simulate flood hydrographs accurately for a few flood events. This could be due to the inaccuracy of daily rainfall data, which forms the most significant input data for model estimation. In addition, only a few rainfall stations are located within the catchment areas of some of the runoff stations.Despite the parameter was set to be zero to give the best fit between the observed and calculated flood hydrographs. This both modelswere used to simulate flood events that occur in the wet,normal and dry year. Thus, brings the number of SWAT parameters to compare with parameters of the NAM.

Table 1 : Hydrological models output statistics

Year	Hydrological Models Output Statistics							
	EI		RMSE		Nash Coefficient		r	
	SWAT	NAM	SWAT	NAM	SWAT	NAM	SWAT	NAM
Wet Year (2002)	0.45	0.43	6.70	6.83	0.45	0.43	0.77	0.79
Normal Year (2004)	0.60	0.54	5.84	6.35	0.60	0.57	0.78	0.79
Dry Year (1997)	0.68	0.63	5.68	6.16	0.68	0.63	0.83	0.84

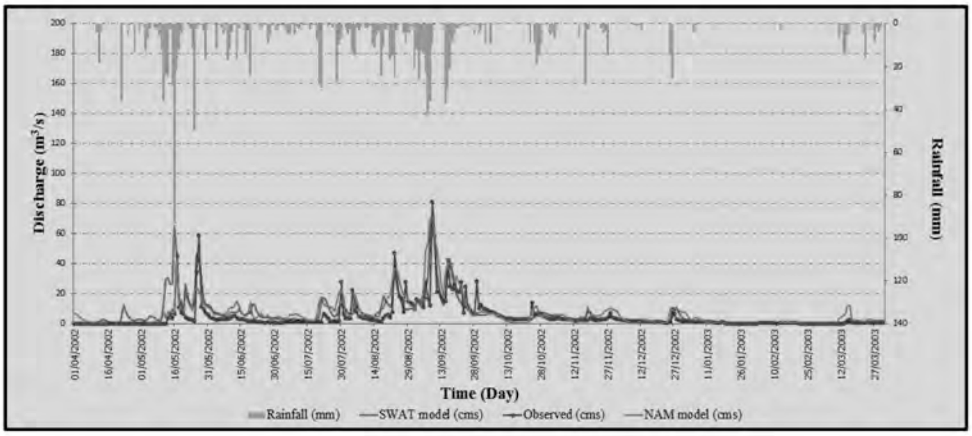


Fig.3: Hydrographs at the runoff station Y.24 in 2002

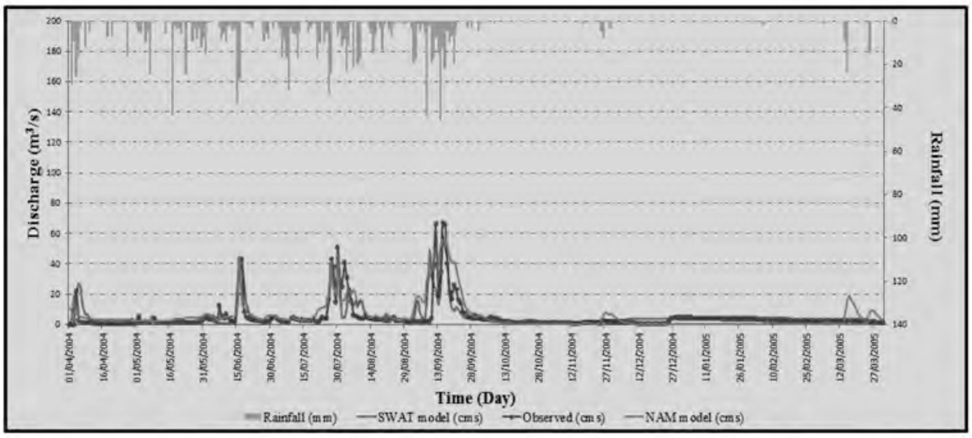


Fig.4: Hydrographs at the runoff station Y.24 in 2004

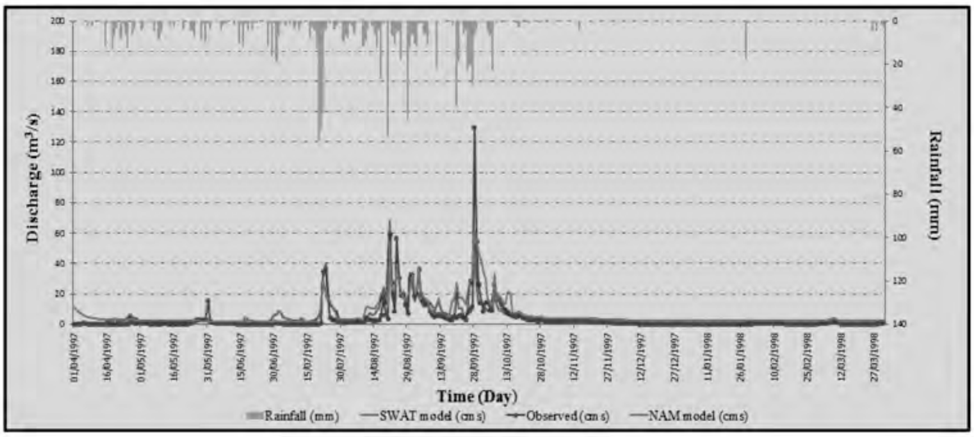


Fig.5: Hydrographs at the runoff station Y.24 in 1997

Conclusion

The objective of this research was to compare the results obtained from two hydrological models; Soil and Water Assessments Tool Model (SWAT Model), and Rainfall-Runoff Model (NAM Model) for runoff estimation on Phee

River basin in northern region of Thailand for a 20-year period. The impact assessment was performed based on SWAT and NAM model, lumped together to form the conceptual hydrological models. Models input were the combination daily rainfall data, climate data, land use data, and soil type data. The results of the study showed that both models had ability to execute runoff simulation. Meanwhile, the graphs show that the NAMModel has better simulation flood hydrographs than the SWAT model in term of observed hydrographs.The SWAT model gave the highest accuracy (2002) which had EI, RMSE, Nash Coefficient, and r equal to 0.45, 6.70 m3/s, 0.45, and 0.77respectively.The NAM model gave the highest accuracy (2002) which had EI, RMSE, Nash Coefficient, and r equal to 0.43, 6.83m3/s, 0.43, and 0.79respectively.

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