Assessing Water Availability in PoKo Catchment using SWAT model

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ABSTRACT: To utilize water resources in a sustainable manner, it is necessary to understand the quantity and quality in space and time. PoKo Catchment, a tributary of Se San watershed, located in the Central Highland Region of Viet Nam with an area of about 3,210 sq. km, accounted for more than 33% of the total area of Kon Tum province. The PoKo river and its tributaries play a very important role to develop socio-economic as well as environment aspects in Kon Tum province. This study was initiated to evaluate the performance and applicability of the physically based Soil and Water Assessment Tool (SWAT) model in analyzing the influence of hydrologic parameters on the streamflow variability and estimation of water balance components at the outlet of PoKo watershed. The model was first calibrated for the period from 2000 to 2005 and then validated for the period from 2006 to 2011 using the observed stream flow data from Dak Mot stream gauge within the watershed. The determination coefficient of linear regression of the observed and simulated monthly stream flows (R^2) and Nash-Sutcliffe Index (NSI) was used to evaluate model performance. The calibrated SWAT model performed well for simulation of monthly streamflow. Statistical model performance measures, R^2 of 0.64, NSI of 0.63 for calibration and 0.78 and 0.72, respectively for validation, indicated good performance of the model simulation on monthly time step. Both calibration and validation results represented fluctuations of discharge relatively well, although some peaks were overestimated by SWAT. Mean monthly and annual water yield simulated with the calibrated model were found to be 109.87 mm and 1,317.63 mm, respectively. Overall, the model demonstrated good performance in capturing the patterns and trend of the observed flow series, which confirmed the appropriateness of the model for future scenario simulation. Therefore, SWAT model can be taken as a potential tool for simulation of the hydrology of unguaged watershed in mountainous areas, which behave hydro-meteorologically similar with PoKo watershed. Future studies on PoKo watershed modeling should address the issues related to water quality and evaluate best management practices.
Keywords: Water availability, PoKo catchment, SWAT model

Introduction

Water resources management has been a critical issue for many countries, not except in Vietnam, in which water availability is also a vital factor deciding water resource conservation in the future. Water availability is defined as the amount of water retained in the soil profile that can absorb on the surface of plants. Based on the evaluation results of the water balance components in river basins, we can determine the parameters of the total flow, the flow components (groundwater, surface water, base flow, etc.), permeability and the amount of evapotranspiration, etc. to approach newer aspects in the management and ultilization of water resources as well as to advance sustainable development in the future.

This paper studies in the Po Ko catchment which located in the province of Kon Tum, Vietnam. This catchment plays an important role in economic development - social associated with the environmental protection of this province. According to statistic in 2010, the total water there provided some principle sectors, including agriculture, environmental activities, domestry, and industry with the ratios accounted for 81.24%, 13.04%, 3.74%, and 1.98% respectively (Cuong et al., 2012).

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Currently, along with development of geographic information system, many hydrological models are applied to bring about convenience and accuracy for users. SWAT (Soil and Water Assessment Tool) model is one of them because its well performance for simulating of river basins where lack of monitoring data and relative impact from different input data in the long period. Many applicable studies in national and international about the SWAT model under various approaches for water resources such as assessment of water availability (Jurgen Schuol et al., 2009; Monireh Faramarzi et al., 2009); assessment of water discharge (Liem et al., 2011). However, the number of studies in Po Ko catchment is still limited.

Paper objective is using SWAT model with input parameters include: Digital elevation model (DEM), land use, soil and weather so as to assess water availability based on water balance components estimation during a period from 2000 to 2011 as well as provide the scientific basis for supporting the irrigated planning on river basins more reasonable and effective.

Study area characteristics

Po Ko catchment, where is a tributary of the Sesan river basin, located in the western of Kon Tum province with approximately 3,210 square kilometers area and 152 kilometers length. River originates from Chu Prong high mountain, Dak Glei and flows from north to south. Uptream area length is about 21.5 km which has characteristics of upstream flows into narrow valley with approximately 3.3% gradient. Middle – stream one, where is flatter than upland, has 144 km length and 1.8% gradient with 20 to 30 meters and 50 to 70 meters width in dry season and rain season, respectively. The highest elevation is about 2000 m in the upstream area and descends to the confluence of DakBla and Krong Po Ko rivers. The area from Yaly lake to estuarine had many rocks with mountain area characteristics, especially river-bed became more narrow suddenly at some position with around 15 – 20 m width.

Po Ko catchment is in the heavy rainfall area with approximately 2,500 milimetres average annual rainfall. Particularly, annual average temperature is about 22.3 ^{0}C at Dak To, in which May and January had the highest and lowest average monthly temperature reached 24.5 ^{0}C and 18.7 ^{0}C in the order given (**Table 1**). PoKo also have high density streams (1km/km^2) and large flows (approximately 40l/s.km^2 modular flow). Total flow discharge (about 3.7 billion cubic meters/year) occupied for over 25% of the entire basin in Kon Tum province (Cuong et al., 2012).

Table 1 Average annual and average monthly temperature (^{0}C) at Dak To station in study area.

Station	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Year
Dak To	18.7	21.0	23.0	24.4	24.5	24.0	23.9	23.1	22.8	22.0	20.7	19.1	22.3

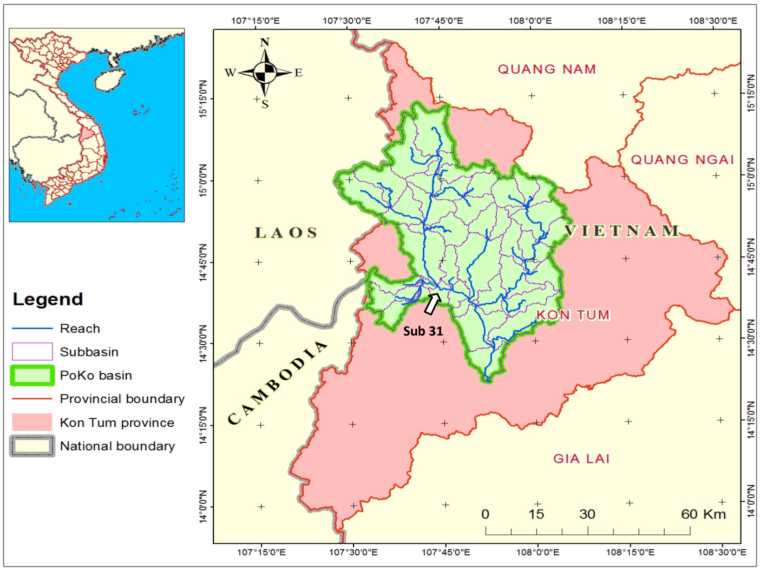


Figure 1 Location of PoKo catchment

As regards to soil, Po Ko area has seven major soil types, with the largest ones are Ferric Acrisol (56.0%) and Humic Acrisol (41.4%) classified due to FAO 74. According to land use map in 2005, this catchment also has 10 various land use types, in which protected and special-use forest predominated over (34.8%).

Study methodlogy

SWAT model

SWAT is the acronym for Soil and Water Assessment Tool, a river basin, or watershed, scale model developed by Dr. Jeff Arnold for the USDA Agricultural Research Service (ARS). SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. SWAT allows a number of different physical processes to be simulated in a watershed. A watershed may be partitiones into a number of subwatersheds or subbasins. The use of subbasins in a simulation is particularly beneficial when different areas of the watershed are dominated by land usesor soils dissimilar enough in properties to impact hydrology (Arnold et al., 2009).

The hydrologic cycle as simulated by SWAT model is based on the water balance equation:

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

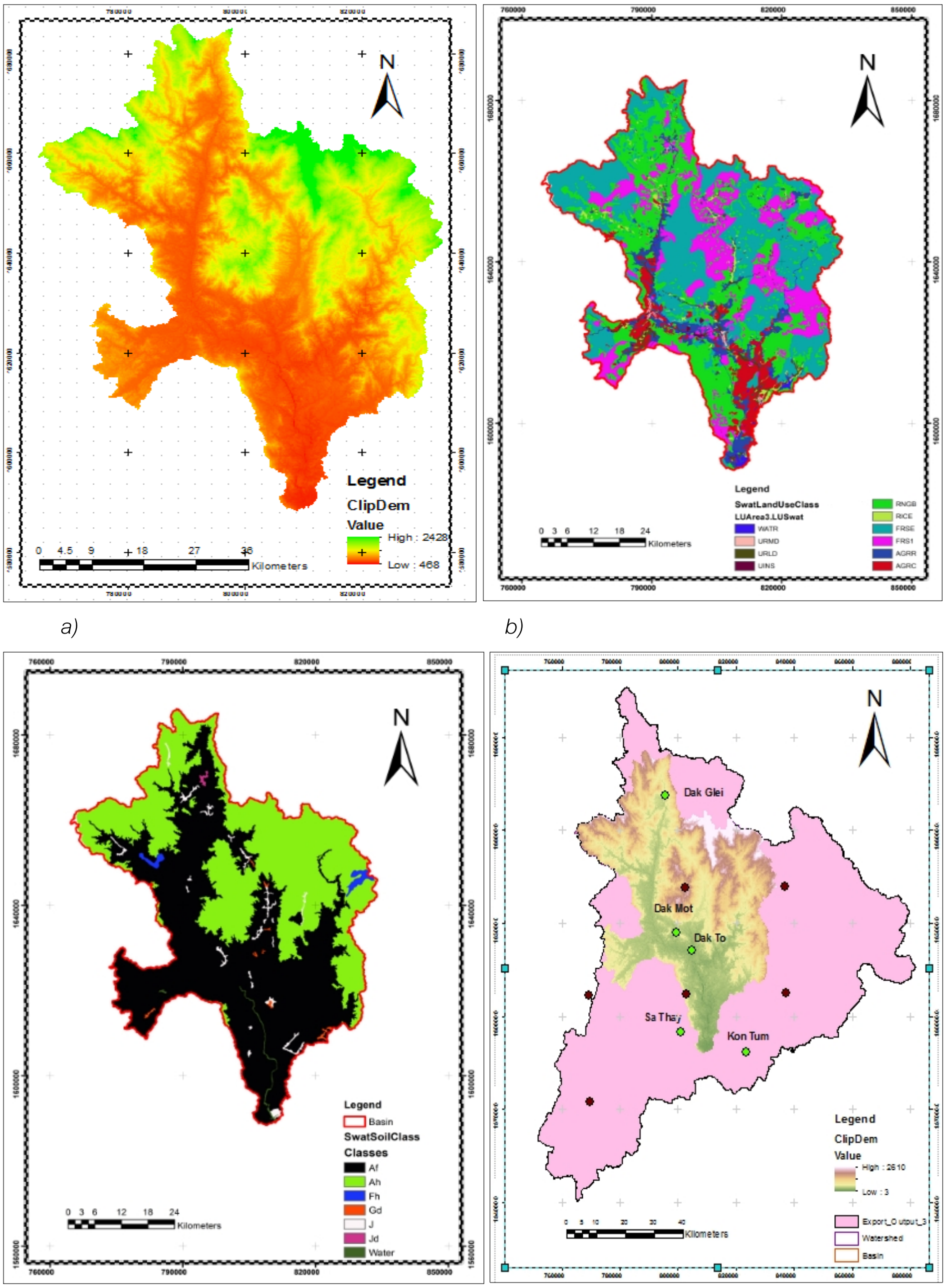
where SW_t is the final soil water content (mm H_2O), SW_0 is the initial soil water content on day i (mm H_2O), R_{day} is the amount of precipitation on day i (mm H_2O), Q_{surf} is the amount of surface runoff on day i (mm H_2O), E_a is the amount of evapotranspiration on day i (mm H_2O), W_{seep} is the amount of water entering the vadose zone from soil profile on day i (mm H_2O), and Q_{gw} is the amount of return flow on day i (mm H_2O).

Collecting and processing data

Data input of SWAT model was collected from local and global sources including digital elevation data (DEM), land use map, soil map and weather data.

- Digital elevation data of PoKo catchment (**Figure 2a**): Collected from global digital elevation data ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) – NASA with 30 meters resolution.
- Land use map of PoKo catchment in 2005 (**Figure 2b**): Collected from Department of Natural Resources and Environment in Kon Tum province. Land use map is divided into ten types based on SWAT code: Rice, agricultural land – row crops, agricultural land – close grown, protected or special – use forest, production forest, residential – medium density, residential – low density, institutional, water, and range brush.
- Soil map of PoKo catchment in 2005 (**Figure 2c**): Collected from Kon Tum Department of Information and Communication. Similarly to land use map, this map is seperated seven main soil types due to SWAT code: Ferric Acrisol, Humic Acrisol, Humic Ferralsol, Dystric Gleysol, Fuvisol, Dystric Fluvisol, and Water.
- Meteorological Data (**Figure 2d**): Collected from Central Highland Region Hydrometeorological Centre and National Center for Environmental Prediction (NCEP), Climate Forecast System Reanalysis (CFSR) of the United States throughout a period between 1990 and 2011. This model is ultilized meteorological data from four local stations (Dak Glei, Dak To, Kontum, Sa Thay) and six global stations in PoKo basin.

Besides that, model is also added more data from Dak Mot meteorological station to cater for calibration and validation stages over a period from 2000 till 2011.



c) d)

Figure 2 Input data of SWAT model

a) DEM; b) Land use map; c) Soil map; d) Hydrometeorological stations position.

Established and estimated SWAT model

Established SWAT model

Setting up SWAT model includes the six following steps: (1) Data collection, (2) Data processing, (3) Input SWAT model, (4) Run SWAT, (5) Calibration and validation. Flow simulation in SWAT is done under ArcGIS 10 software supporting.

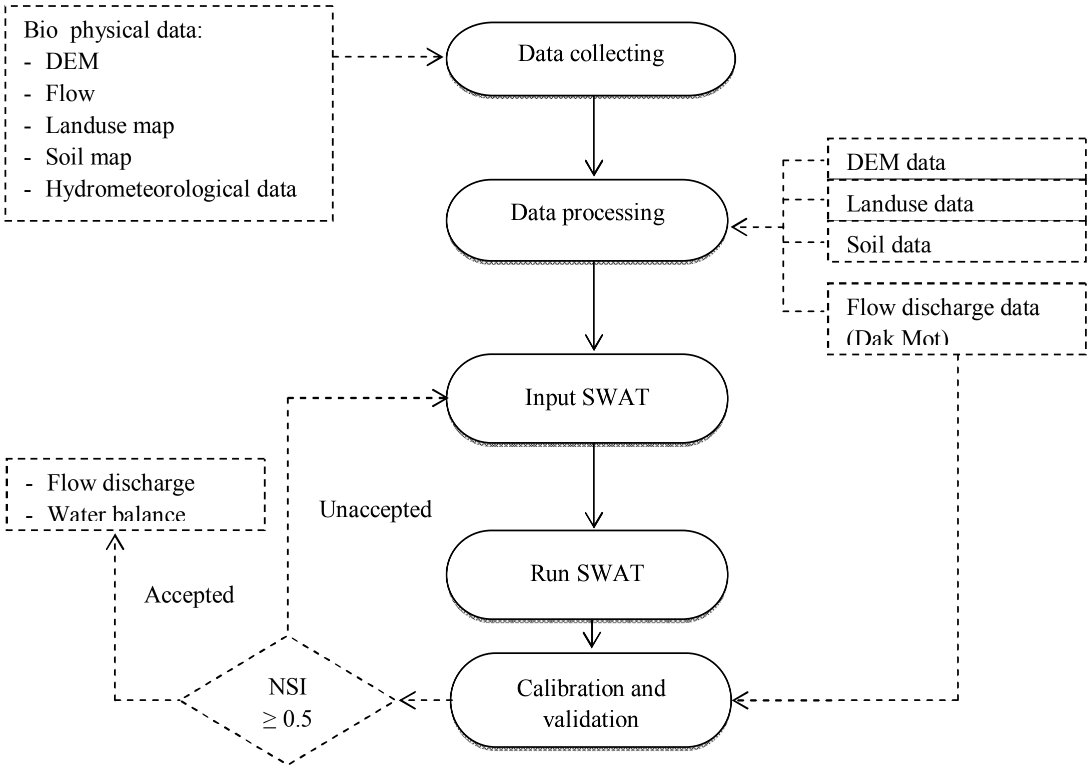


Figure 3 SWAT model in PoKo catchment

Estimated SWAT model

To evaluate the simulated results of SWAT model, this study is ultilized two statistical indicators included the coefficient of determination (R^2) and Nash-Sutcliffe index (NSI) as the following equation (1), (2). NSI and R^2 parameters represented the correlation between the measured value and simulated value. If the R^2 value is less than or very close to zero, the model prediction is considered “unaccepted or poor”. If the value is one, the the model prediction is “perfect”. However, there are no explicit standards specified for assessing the model prediction using these statistics (C. Santhi et al., 2001). Calibration and validation stages are done under SWAT – CUP software supporting.

$$R^2 = \left(\frac{\sum_{i=1}^{n} (O_i - \bar{O})(P_i - \dot{P})}{\sqrt{\sum_{i=1}^{n} (O_i - \bar{O})^2} \sqrt{\sum_{i=1}^{n} (P_i - \dot{P})^2}} \right)^2 \quad (1)$$

$$NSI = 1 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - \bar{O})^2} \quad (2)$$

Where O_i is the observed flow discharge at time i, $\bar{O}$ is the average observed flow discharge, P_i is the simulated flow discharge at time i, $\dot{P}$ is the average simulated flow discharge, and n is the number of registered flow discharge data.

Performance ratings for NSI of this model are evaluated on different levels due to classification of Saleh et al. (2000) and Bracmort et al. (2006).
:

If NSI> 0.65: Simulation result is very well.

If 0.54 <NSI <0.65: Simulation result is adequate.

If NSI> 0.50: Simulation result is satisfactory.

Results and discussion

Simulated flow results

After running the SWAT model, the evaluation of simulated flow results based on two main stages named calibration and validation, in which ultilizing of monitoring flow data from Dak Mot station.

Calibration (from 2000 to 2005)

After evaluation and analysis some model sensitivity parameters, this result showed that the sensitivity parameters to influence the flow simulation results includes initial curve number (II) value (CN2), baseflow alpha factor (ALPHA_BF), groundwater delay (GW_DELAY) and threshold water depth in the shallow aquifer for flow (GWQMN). With the above parameters, using SWAT CUP supporting tool to search for appropriate values for each parameter led to results more accurate. These results are shown on **Table 2.**

Table 2 SWAT flow sensitive parameters and fitted values after calibration using SUFI-2.

Sensitivity ranking	Parameter name	Lower and upper bound	Fitted value
1	CN2	-0.2 – 0.2	-0.14
2	ALPHA_BF	0 – 1	0.71
3	GW_DELAY	30 – 450	61.50
4	GWQMN	0 – 2	0.53

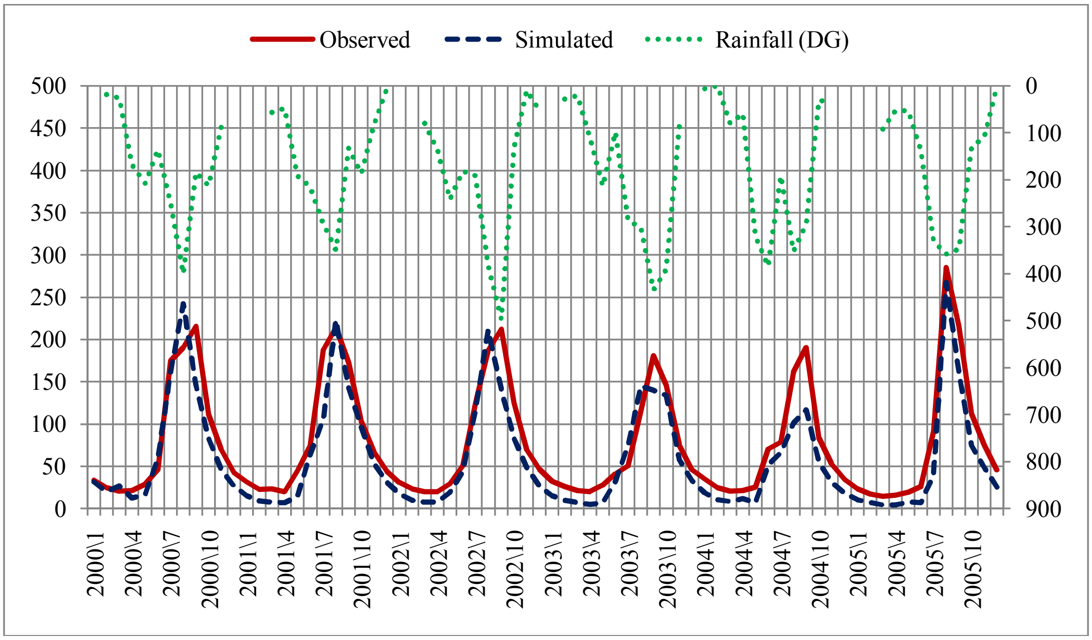


Figure 4 Comparison of observed and simulated monthly flow discharge during calibration period (2000 – 2005)

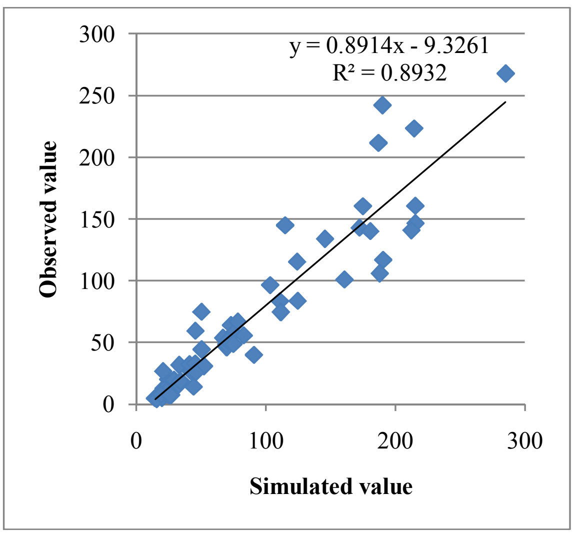


Figure 5 Relationship between observed and simulated monthly flow discharge during calibration period (2000 – 2005)

Comparison of observed and simulated flow discharge for relatively good results with $R^2 = 0.89$ and NSI = 0.82 at Dak Mot station' outlet (sub-basin 31) as shown in **Figures 4 and 5.** Accordingly, most of flow values in dry season distributed around the line y = x whereas ones in the flood season. This result illustrated that SWAT model is capable of flow simulation in the dry season better than in the flood season.

Validation (from 2006 to 2011)

Using the fitted values from calibration stage to simulate flow in validation one between 2006 and 2011. Flow simulation results shown in Figures 6 and 7.

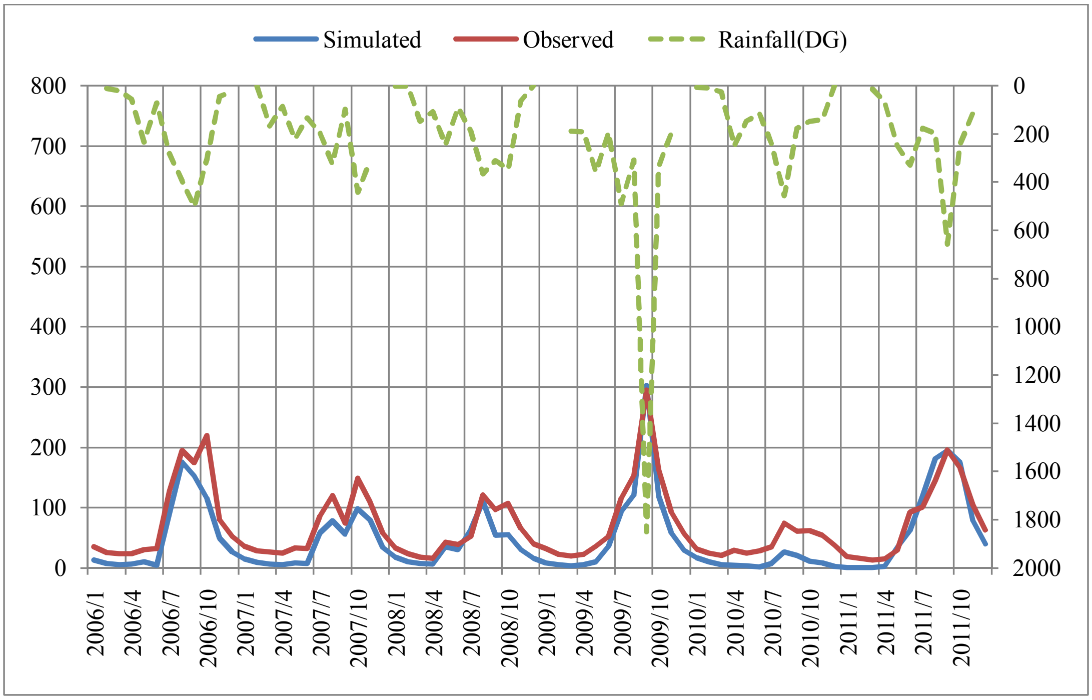


Figure 6 Comparison of observed and simulated monthly flow discharge during validation period (2006 – 2011)

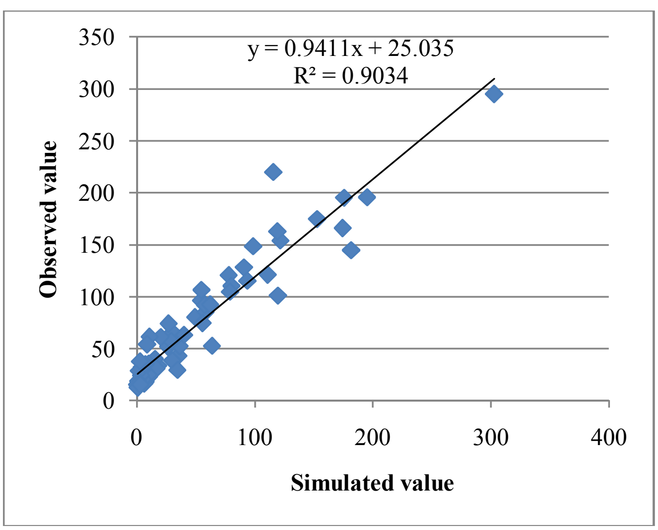


Figure 7 Relationship between observed and simulated monthly flow discharge during validation period (2006 – 2011)

Comparison of observed and simulated flow discharge for relatively good results with R^2 = 0.90 and NSI = 0.75 at Dak Mot station' outlet (sub-basin 31) as shown in **Figures 6, 7**. According to above results, the flow values distribution tendency in validation as same as in calibration, however, but values density around the line y = x in validation is better than in calibration.

As can be seen clearly, SWAT model simulated flow in validation more accuracy than in calibration. With the obtained results after calibration and validation, SWAT model may be applied to asess water availability in Po Ko catchment, which plays an important role in economic and social development, with the environment protection in Kon Tum province.

Assessing water balance in PoKo catchment

After calibration and validation stages, it is necessary to statistic some water balance components and ratios in PoKo catchment. Most of water balance parameters in calibration were higher than in validation, except evapotranspiration (739.2 mm in calibration and 740.6 mm in validation) and potential evapotranspiration (1,794.3 mm and 1,805.2 mm, respectively).

Considering the ratios between flow and rainfall in both phases are demonstrated flow availability in Po Ko catchment more plentiful (over 50%) and the amount of evapotranspiration accounted for about 40%. Regarding the contribution of total flow in this catchment, groundwater (over 60%) is still predominated than surface water in total flow.

Table 3 Water balance ratios in PoKo catchment

Water balance ratios	Calibration	Validation
	Ratio	Ratio
Streamflow/ Precipitation	0.58	0.56
Baseflow/ Total flow	0.62	0.63
Surface runoff/ Total flow	0.38	0.37
Percolation/ Precipitation	0.28	0.27
Deep recharge/ Precipitation	0.01	0.01
Evapotranspiration/ Precipitation	0.40	0.42

Assessing total water yield in PoKo catchment

Based on **Figure 8**, it can be seen the flow change in Po Ko catchment depend on precipitation fluctuations. During rainy season, monthly flow discharge became larger with reaching two peaks while flow is less large than in remaining months (especially in dry season).

Overall, flood season on catchment starts from May to October with total flow nearly 600 mm in August at time. Throughout dry season (from December to May in coming year), total flow is approximately 20 mm in January.

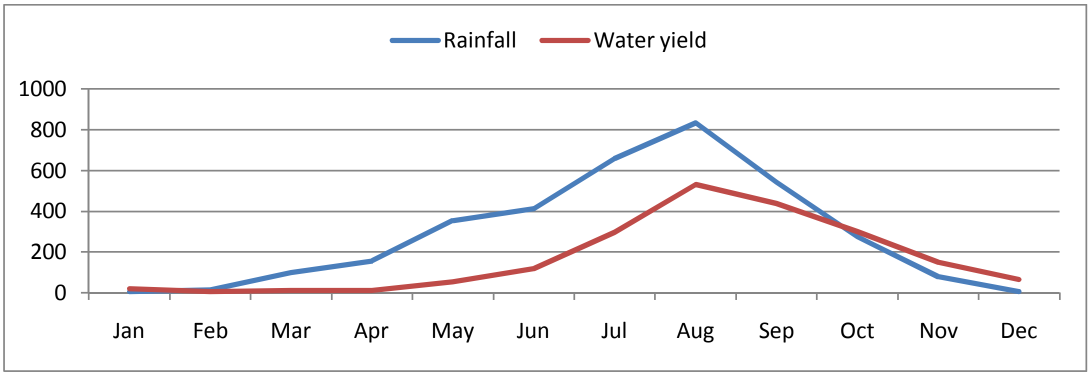


Figure 8 Relationship between water yield and rainfall in monthly over the entire basin

Besides that, Figure 9 illustrated total water (by year) at Po Ko catchment in the period from 2000 to 2011. In the first 6 years (from 2000 to 2005), total water tendency is decreased by time, however, a last 6 - year period had some significant changes compared to first period. From 2008 onwards, 2009 and 2011 had considerably fluctuations in total water discharge.

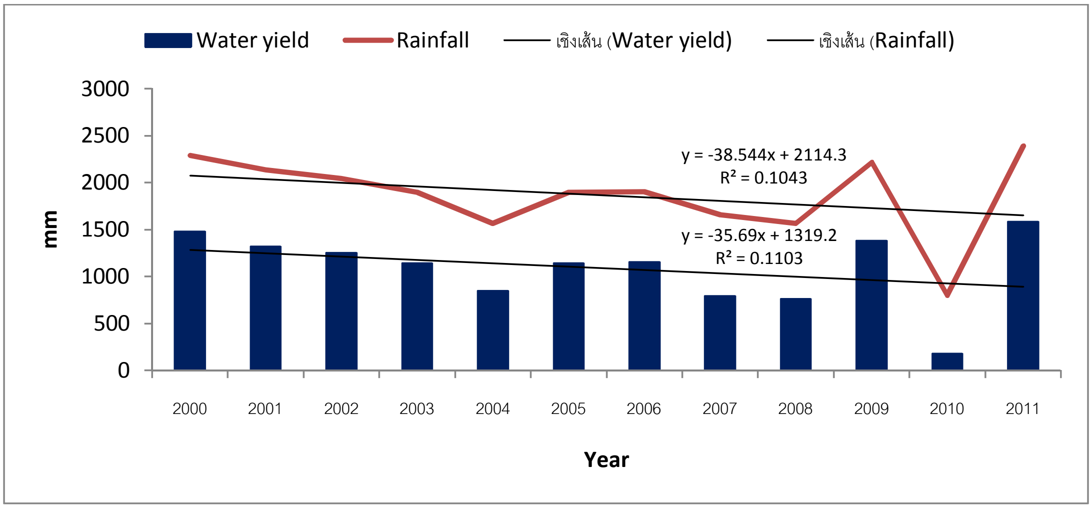


Figure 9 Relationship between water yield and rainfall in annual over the entire basin

Conclusion

This research was to simulate flow discharge in PoKo catchment over a twelve - year period between 2000 and 2011 with adequate results (R^2 và NSI > 0.75). With this result, SWAT model is one of the useful tools to simulate flow discharge more efficiency and exactly for PoKo river characteristics. Furthermore, using water balance diagram is also one of the key solutions to evaluate water availability in PoKo catchment as well as develop water resource more sustainable in the coming years of Kon Tum province.

However, in the coming study step, this study need to assemble more information of Plei Krong hydroelectric station (Kon Tum) and local stations to assess some impact on PoKo river and run SWAT model particularly. Considering water components, flow availability in Po Ko catchment is more plentiful (over 50%) and groundwater (over 60%) is still predominated than surface water. Total water of this basin had a decreasing tendency and only 2008 had the lowest water yield. Therefore, in coming years, it is need to assess some hydropower impact as well as climate change over Po Ko catchment combined with human'water use needs to run SWAT model more detailed and effective.

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