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EVALUATION OF HYDROLOGICAL COMPONENTS USING SWAT HYDROLOGICAL MODEL FOR POKO RIVER BASIN

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ABSTRACT

In this study, Poko river basin is selected for evaluation of water resources in the basin, as there is a decline inflow due to reduced rainfall over years and also due to increased activities in the upstream areas of the catchment. The study focused on evaluation of hydrological components for Poko river basin using hydrological model known as soil and water assessment tool (SWAT). The model was implemented for Poko river basin using digital elevation model (DEM), land use, soil and meteorological data etc. The model performance was evaluated by calibration and validation approach. The model was first calibrated for the period from 2000 to 2005 and then validated for the period from 2006 to 2018 using the observed stream flow data from Dak Mot stream gauge within the watershed. It is found that the coefficient of determination (R^2) and Nash- Sutcliffe index (NSI), and Percent BIAS (PBIAS) during the calibration process was 0.81, 0.64 and 12.1 respectively and validation process was 0.74, 0.60 and 13.5 respectively. All coefficients are satisfying the model results and are used for evaluating the hydrological components for the basin. Finally, the values were evaluated for Poko river basin for different hydrological components like water yield, evapotranspiration, groundwater recharge, sediment yield and discharge. The results can be used for decision making purpose and further for the planning of water harvesting plan.

Keywords: *Hydrological model; water resource; calibration; validation; Poko river basin.*

1. INTRODUCTION

The water resources are most important for maintaining the ecosystem, health and all life activities of humans. In the world over, clean and safe drinking water supply is a challenge due to contamination of water from agricultural and industrial wastes, extreme events like floods and droughts, growing risks from climate changes that affect hydrology and water management [1].

Improper management of water resource leads to water scarcity threatening human survival [2]. According to a recent UN estimate, there is around 20% increase in water scarcity in the coming decades will be caused by climate change (UN 2006). Sustainable management of water resources can help hydrologists, water managers, and the public to understand and manage the water system more effectively [1]. Recently GIS/spatial analysis software's led to the development of hydrological models which can enable climate change assessment, management of water supplies, determining flooding areas, and to assess impacts of land management for larger areas at basin scale [3].

The present study carried out on the Poko river basin, one of the tributaries of the Sesan river has been the major source of water supply in the basin. With the increasing population, urbanization and unplanned agricultural activities, water quality and quantity of the river is degraded. The Poko river basin has been facing a severe water shortage for both irrigation and domestic purposes over the past few years. It is observed that every year in summer all surface water resources get dry up to maximum level, which leads to water shortages. Due to the unpredictable climate in the Poko basin, causes consequences.

SCOPE OF STUDY

Poko river basin (Fig.1) is one of the tributaries of the Sesan watershed, and has a catchment area of 3,210 square kilometers and 152 kilometers length, located in the western of Kon Tum province. The river originates from Chu Prong high mountain, Dak Glei and flows from North to South.

Po Ko catchment is in the heavy rainfall area with approximately 2,500 millimeters average annual rainfall. Particularly, the 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, respectively. 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 [4].

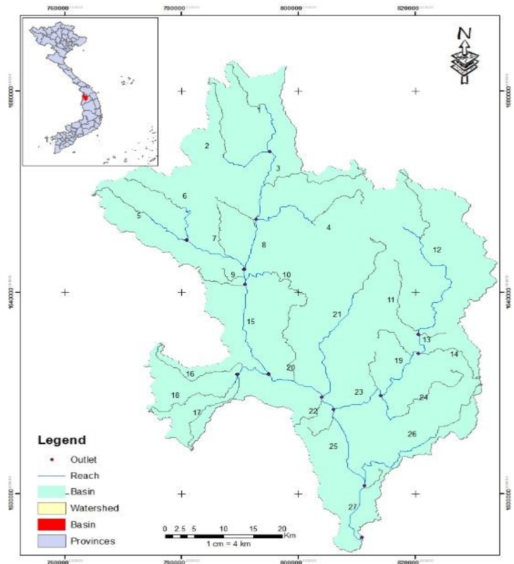

Fig. 1. *Location of PoKo river basin*

SWAT MODEL DESCRIPTION

The SWAT model is the free software and was developed at the USDA-ARS (Arnold et al., 1998) during the early1970's. SWAT model which is a physically-based model was developed for application to large and complex watersheds over long periods of time. Furthermore, it is a flexible framework that allows a simulation of a wide variety of conservation practices and other best management practices such as fertilizer and manure application rate and timing, cover crops, filter strips, conservation tillage, irrigation management, flood prevention structures, grassed waterways, and wetlands [5]. From topography data, the watershed is divided into the number of sub-catchments. The use of sub-catchments in simulation is particularly beneficial when different areas of the catchment are dominated by land-uses or soils dissimilar enough in properties to impact hydrology. Every sub-catchment is then subdivided into Hydrologic Response Units (HRUs). Every HRU is a unique combination of land-use, soil, and management practices in a sub-catchment. Input information for each sub-catchment is grouped into the following categories: climate; hydrologic response units or HRUs; groundwater; and the main channel or reach, draining the sub-catchment. The water balance in SWAT is given as follows:

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

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 (mm H_2O), R_{day} is the amount of rainfall 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 actual total evaporation on day i (mm H_2O), W_{seep} is the amount of water entering thevadose zone from the soil profile on day i (mm H_2O), and Q_{gw} is the amount of groundwater flow on day i (mm H_2O).

2. METHODOLOGY

2.1. Model Setup and Execution

In order to asess quantity of water in the river basin, a well-known semi-distributed basin-scale model, soil and water assessment tool (SWAT) (Arnold et al. 1998) was used. To setup the model (Fig.2), the following basic data are required: digital elevation model (DEM), soil, land use and meteorological data, which are to be collected and processed from different sources (see Table 1 and Fig 3a, 3b, 3c, 3d)).

First, the whole watershed was subdivided into 27 sub-watersheds, with a total area covering 3,210 km^2. In the second step, land use and soil were characterized and overlaid in each sub basin. Finally, the weather data was included in the model. The model was simulated for the period 2000 to 2018.

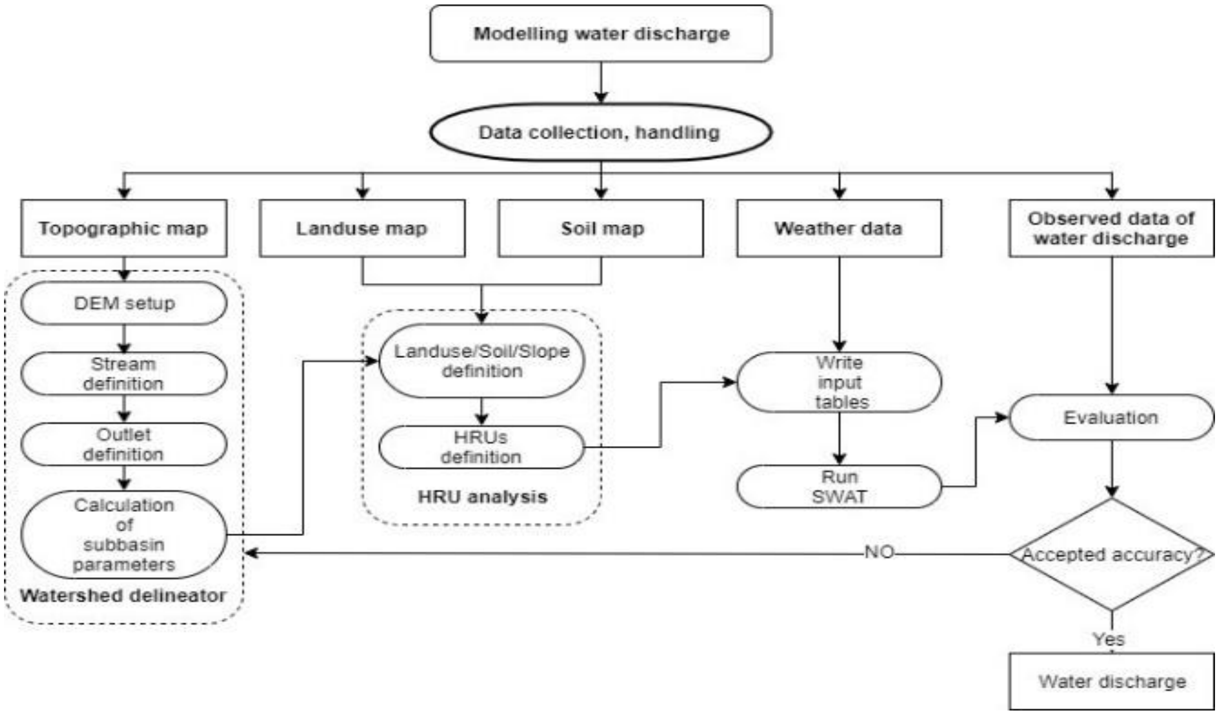

Fig. 2. *Work flow process for SWAT*

Table 1. *Data and its sources*

No.	Data	Source
1	Digital Elevation Model (DEM)	ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) – NASA with 30 meters resolution.
2	Landuse/land cover	Department of Natural Resources and Environment in Kon Tum province.
3	Digital Soil Map	Department of Information and Communication
4	Meteorological Data	Central Highland Region Hydrometeorological Centre from 1990-2018
5	Observed Discharge Data	Dak Mot hydrological station from 2000-2018.

2.2. Model Calibration and Validation

Calibration is an effort to fine tune a model parameter to a given set of boundary conditions, thereby reducing the uncertainty associated with the model prediction. Validation is an art to produce a sufficiently accurate model prediction to a given site specific boundary conditions. In this study calibration and validation of the model was achieved by using SUFI2 method in SWAT CUP. The observed discharge data of Dak Mot gauge station is used for calibration and validation of the model. Calibration and validation is achieved on monthly basis from period 2000 to 2005 and 2005 to 2018. The model performance results were checked by using coefficient of determination (R^2); Nash-Sutcliffe efficiency (NSE) and PBIAS, it is discussed below.

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

$$NSI = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \quad (3)$$

$$PBIAS = \frac{\sum_{i=1}^{n}(O_i - P_i) * 100}{\sum_{i=1}^{n}(O_i)} \quad (4)$$

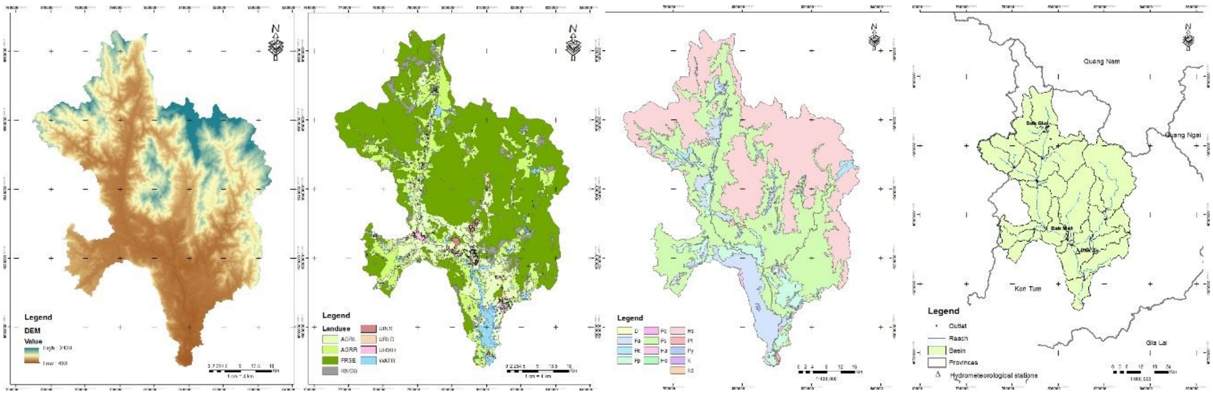

Fig. 3. *Input data of SWAT model a) DEM; b) Land use map; c) Soil map; d) Hydrometeorological stations*

3. RESULT AND DISCUSSION

3.1 Simulated discharge result

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

The correlation between the observed and simulated output from the model is used to check the model performances. In this study observed discharge data which is daily data and to check model performances the daily data were converted into monthly basis.

Comparing the observed and simulated discharge during the period 2000-2018 shows that the simulation results were relatively well. In the calibration stage (2000-2005), the R^2, NSI and PBIAS at Dak Mot station outlet (subbasin 20) were 0.81; 0.64 and 12.1 and in the validation stage (2005-2018) were 0.74, 0.60 and 13.5, respectively (see Fig. 4).

The results of evaluation and analysis some model sensitivity parameters showed that the sensitivity parameters to influence the flow simulation results includes initial curve number (II) value (CN2), threshold water depth in the shallow aquifer for flow (GWQMN), groundwater delay (GW_DELAY) and baseflow alpha-factor (ALPHA_BF). 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.

Based on Fig 4, obviously, the overall pattern of discharge variation at Dak Mot is determined by fluctuation of precipitation. During months of heavy rain, the discharge is usually greater. General model of water discharge of subbasin reaches the peak during the rainy season, the rest (especially during the dry season), the discharge is very small. However, flow discharge vakues differ for each year. In particular, during the simulation stage (2000-2018), there are 3 years when the flow reaches maximum, including August 2005, August 2009 and August 2018, the values were 429.7; 489.7 and 451.9 m^3/s, respectively.

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	r_CN2	(-2) – 2	-0.11
2	v_GWQMN	0 – 2	0.47
3	r_GW_DELAY	30-450	69.4
4	v_ALPHA_BF	0 – 1	0.65

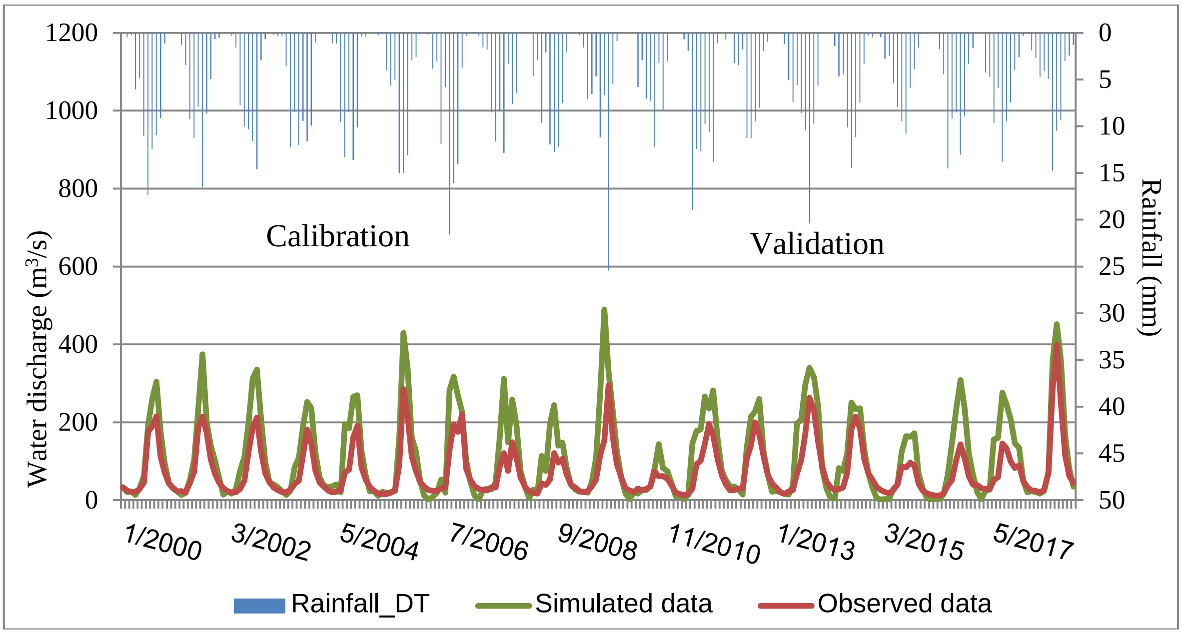

Fig. 4. *Comparison observed and simulated monthly discharge during calibration and validation periods*

3.2 Assessing hydrological components in PoKo river basin

After calibration and validation stages, the simulation results for hydrological components are necessary to statistic and evaluate. Most of water balance parameters in calibration were higher than in validation, except evapotranspiration (596.6 mm in calibration and 673.4 mm in validation) and potential evapotranspiration (1,365.5 mm and 1,518.2 mm, respectively). In view of the ratios between flow and rainfall in both stages are demonstrated flow availability in Po Ko catchment more abundant (over 50%) and the amount of evapotranspiration calculated for about 40%. Considering the contribution of the total flow in this catchment, groundwater (over 60%) is still exceeded than surface water in total flow.

Table 3. *Water balance ratios in PoKo river basin*

Water balance ratios	Calibration ratio	Validation ratio
Streamflow/ Precipitation	0.57	0.59
Baseflow/Total flow	0.63	0.65
Surface runoff/Total flow	0.45	0.43
Percolation/ Precipitation	0.27	0.24
Deep recharge/ Precipitation	0.01	0.01
Evapotranspiration/ Precipitation	0.34	0.35

For evaluation total water yield and sediment yield, Fig 5. shows that the evolution of flow and sediment transport depends on precipitation fluctuations. Monthly water yield and sed yield became larger during the rainy season while they are less large than in rest months (during dry season). Total water yield reaches a maximum with its value is 282.2mm and total sediment yield reaches a maximum with its value 32.1 ton/ha in August.

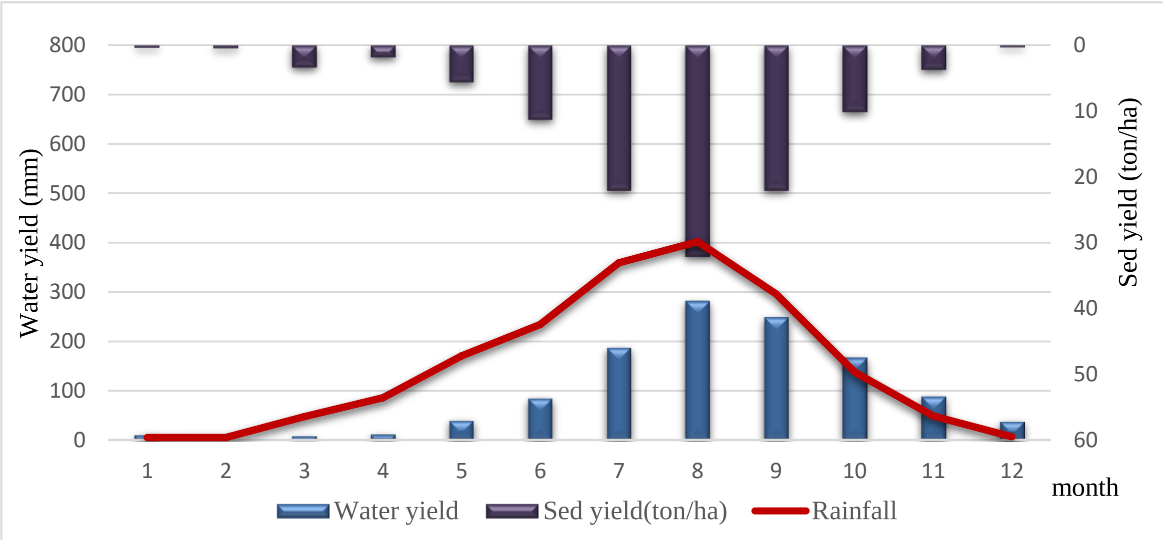

Fig. 5. *Relationship between rainfall, water yield and sediment yield in monthly over the entire basin*

4. CONCLUSION

During the period between 200 and 2018, the water discharge in Poko watershed was simulated with relatively well results (R2 và NSI > 0.6) by SWAT hydrological model. This result proved that this model is suitable to simulate water discharge more efficiently and accurately for Poko river basin and can be applied for other basins. Besides that, the assessment of hydrological components is one of the solutions to support the decide-makers in basin water-resource management.

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