Simulating surface flow and baseflow in Poko catchment, Kon Tum province, Vietnam

Vo Ngoc Quynh Tram, Nguyen Duy Liem and Nguyen Kim Loi

ABSTRACT

Estimating the volume of water resources has important significance in assessing water availability in a basin, particularly in mountainous areas. The Poko catchment, a sub-basin of Se San river basin, is located in the Central Highland of Vietnam with an area of about 3,210 km^2. This study focused on evaluating the performance of SWAT model and baseflow filtering algorithm in simulating surface flow and baseflow in Poko catchment. The model was calibrated and validated for the period 1996–2004 and 2005–2013, respectively, using the observed water discharge data at Dak Mot stream gauge. Statistical measures including R^2 (coefficient of determination), NSI (Nash–Sutcliffe index), and PBIAS (percent bias) indicated good performance of the model in simulating water discharge on monthly time step during the calibration and validation period. Using baseflow filtering algorithm with filter parameter (0.925), surface flow and baseflow were separated from water discharge. The results demonstrated good performance in capturing the patterns of surface flow and baseflow, which confirmed the appropriateness of the model for future scenario simulation. These findings provide useful information for water resources planning in Poko catchment, in particular, and other basins, which have a hydro-meteorological response similar to this catchment, in general.

Key words | baseflow filtering algorithm, Poko catchment, surface flow, SWAT model

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NOTATION

Variables	Description
R^2	Coefficient of determination
NSI	Nash–Sutcliffe index
PBIAS	Percent bias
Q_{sf}	The direct surface runoff (mmH_20)
Q_{lt}	The lateral flow from unsaturated soil profile (mmH_2O)
Q_{tl}	The drainage (mmH_2O)
w_{seep}	The total amount of water exiting the bottom of the soil profile (mmH_2O)
$w_{rchrg,sh}$	The recharge in the shallow aquifer storage (mmH_2O)
S_{sh}	The water storage in the shallow aquifer storage (mmH_2O)
$Q_{b,\ sh}$	The baseflow in the shallow aquifer storage (mmH_2O)
$w_{seep,dp}$	The total amount of water exiting the bottom of shallow aquifer storage (mmH_2O)
$w_{rchrg,dp}$	The recharge in the deep aquifer storage (mmH_2O)
S_{dp}	The water storage in the deep aquifer storage (mmH_2O)
$Q_{b,\ dp}$	The baseflow in the deep aquifer storage (mmH_2O)
Q_b	The total baseflow (mmH_2O)
Q_s	The total flow (mmH_2O)
DEM	Digital elevation model
r	The existing parameter value is multiplied by (1+ a given value)
v	The existing parameter value is to be replaced by the given value)

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r_HRU_SLP	Average slope steepness of hydrological response unit
v_GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)
r_ESCO	Soil evaporation compensation factor
r_SOL_AWC	Available water capacity of the soil layer
r_GW_DELAY	Groundwater delay (days)
r_REVAPMN	Threshold depth of water in the shallow aquifer for 'revap' to occur (mm)
v_PLAPS	Precipitation lapse rate
r_GW_REVAP	Groundwater 'revap' coefficient
r_CN2	Soil Conservation Service (SCS) runoff curve number
r_SLSUBBSN	Average slope length of subbasin
v_ALPHA_BF	Baseflow alpha factor (days)

INTRODUCTION

Poko catchment is one of three main basins located in Kon Tum province, Vietnam. It covers approximately 3,530 km^2, is 121 km in length and plays an important role in developing socio-economic as well as environmental aspects of the province. According to Cuong (2012), the water resource in Poko catchment is used for four sectors, including agriculture, industry, domestic, and environmental flow with the corresponding ratio, in turn being 81.24%, 1.98%, 3.74%, and 13.04%. Thanks to the large annual average rainfall, surface water contributes mainly to water discharge in the basin. However, under the pressure of socio-economic development and climate change, it is necessary to undertake a comprehensive assessment of the distribution of surface water as well as groundwater from a spatio-temporal perspective.

Water is essential to support humanity, and the understanding of water storage is indispensable to future use of water resources. As regards the hydrology aspect, many different approaches have been used in water resources management. Among them, mathematic modeling is a common method, such as HEC-HMS model (Kar *et al.* 2015), MIKE BASIN and ASM models (Ireson *et al.* 2006), SWAT model (Schuol *et al.* 2008; Liem 2011). Moreover, to separate surface flow and baseflow from water discharge, several filtering algorithms have been developed, such as exponential smoothing method (Tularam & Ilahee 2008), Lyne and Hollick filter (Ladson *et al.* 2013), automatic baseflow filtering (Luo *et al.* 2012). So far, no research has been found that focuses on applying the SWAT model and filtering algorithm to separate water discharge into surface flow and baseflow in Poko catchment.

This aims of the paper are the following objectives: (1) calibrating and validating the SWAT model for the simulation of water discharge from 1990 to 2013 in Poko catchment; (2) separating surface flow and baseflow from water discharge in the study area; (3) assessing the spatio-temporal distribution of surface flow and baseflow in the catchment.

STUDY AREA

Poko catchment, a tributary of the Sesan river basin, is located in the west of Kon Tum province with an approximately 3,210 km^2 area and 152 km length, as shown in Figure 1. The catchment flows through three districts including Dak Glei, Dak To, and Ngoc Hoi of Kon Tum province. Three major topography types in the catchment are mountain (average slope from 20 to 25 degrees), hills (average slope from 15 to 20 degrees), and valleys (average slope from 10 to 15 degrees). The highest elevation reaches about 2,000 meters in the upstream area and descends to the confluence between the Poko river and Dakbla river before flowing into Yaly lake. Average annual rainfall in the basin is approximately 2,500 mm, resulting in high-density river (1 km of river length per 1 km^2 area) and large flow module (approximately 40 liters/s/km^2). Total water volume reaches about 3.7 billion cubic meters per year. The quantity of surface water stored in Poko catchment is 3.8 times more than the total amount of groundwater (Cuong 2012).

METHODS

Water discharge modeling in SWAT model

In the SWAT model, water routed through a channel system to the outlet of the basin contains four components:

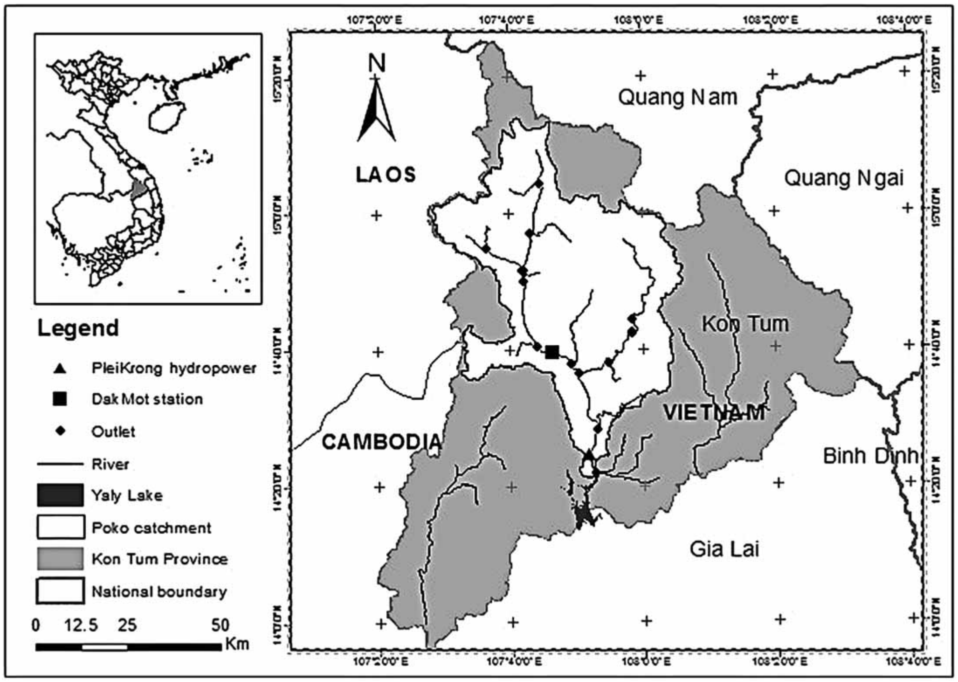

Figure 1 | Geographic location of Poko catchment, Kon Tum province.

direct surface runoff (Q_{sf}), lateral flow from unsaturated soil profile (Q_{lt}), drainage (Q_{tl}), and baseflow from underground storage (Q_b) including baseflow in the shallow aquifer storage ($Q_{b,sh}$) and baseflow in the deep aquifer storage ($Q_{b,dp}$) (Luo *et al.* 2012). All water components are described in Figure 2.

The formula used to estimate water discharge in the SWAT model is shown in Equation (1):

$$Q = \frac{\alpha Q_{sf} A}{3.6t} \tag{1}$$

where Q is water discharge (cms), α is the fraction of daily rainfall that occurs during the time of concentration, Q_{sf} is the surface runoff (mm H_2O), A is the subbasin area (km^2), 3.6 is a unit conversion factor, t is the time of concentration for the subbasin (hr).

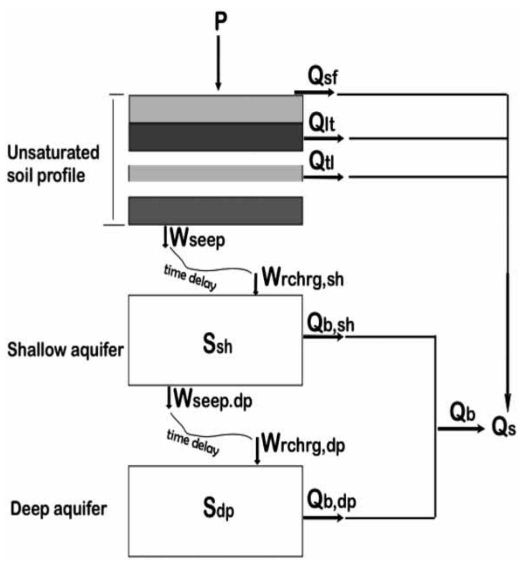

Figure 2 | Schematic of water discharge components in the SWAT model (Luo *et al.* 2012). *Note:* Q_{sf}: the direct surface runoff (mmH_2O); Q_{lt}: the lateral flow from unsaturated soil profile (mmH_2O); Q_{tl}: the drainage (mmH_2O); w_{seep}: the total amount of water exiting the bottom of the soil profile (mmH_2O); $w_{rchrg,sh}$: the recharge in the shallow aquifer storage (mmH_2O); S_{sh}: water storage in the shallow aquifer storage (mmH_2O); $Q_{b,\ sh}$: the baseflow in the shallow aquifer storage (mmH_2O); $w_{seep,dp}$: the total amount of water exiting the bottom of shallow aquifer storage (mmH_2O); $w_{rchrg,dp}$: the recharge in the deep aquifer storage (mmH_2O); S_{dp}: water storage in the deep aquifer storage (mmH_2O); $Q_{b,\ dp}$: the baseflow in the deep aquifer storage (mmH_2O);Q_b: the total baseflow (mmH_2O); Q_s: the total flow (mmH_2O).

Baseflow separation using filtering algorithm

The baseflow separation is a method to estimate baseflow under water discharge record. Many baseflow filters have been developed to separate baseflow from water discharge. The digital filter technique (Nathan & McMahon 1990) is used in this study because it is objective and reproducible. The formula of the filter is expressed as Equation (2):

$$q_t = \beta q_{t-1} + \frac{1+\beta}{2}(Q_t - Q_{t-1}) \quad (2)$$

where q_t, q_{t-1} is the filtered surface flow at the t, t − 1 time step (1 day, cm), Q_t, Q_{t-1} is the water discharge at the t, t − 1 time step (1 day, cm), and β is the filter parameter (0.925). The value of 0.925 determined by Nathan & McMahon (1990) gives more realistic results when compared to manual separation techniques. Baseflow is

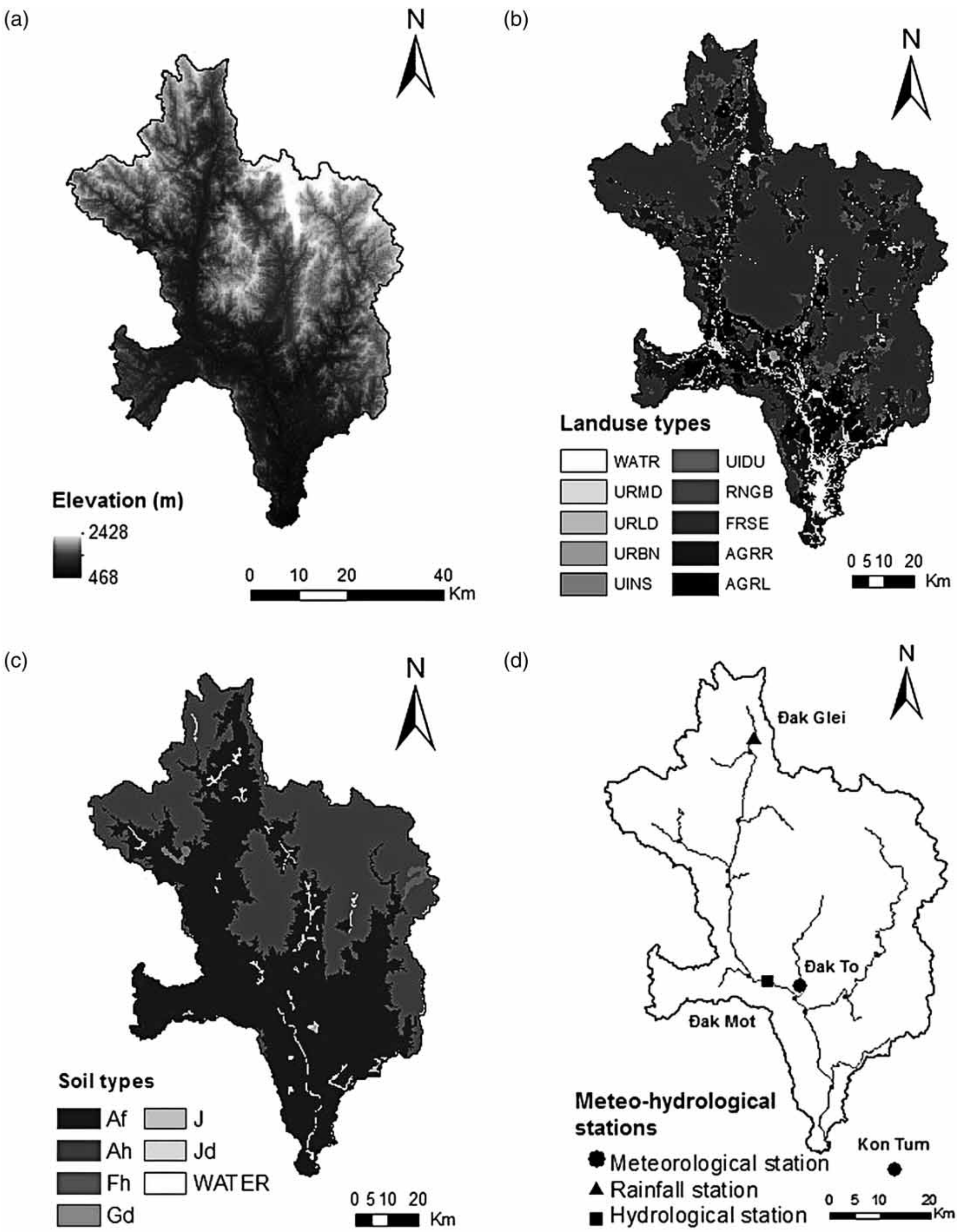

Figure 3 | Input data of SWAT model: (a) topographic map, (b) land use map, (c) soil map, and (d) meteo-hydrological stations.

Table 1 | Input data types of SWAT model

TT	Data types	Source	Description
1	Digital elevation model (DEM)	NASA & Japan ASTER Program (2009)	30 meters spatial resolution
2	Land use map (2010)	Department of Environment and Natural Resources of Kon Tum Province	10 types
3	Soil map	Central Sub-National Institute for Agricultural Planning and Projection (Soil Map of Kon Tum Province, Vietnam 2005)	7 types
4	Weather data (1990–2013)	Central Highland Region Hydro-Meteorological Centre	2 meteorological stations, 1 rainfall station
5	Water discharge data (1996–2013)	Central Highland Region Hydro-Meteorological Centre	1 hydrological station

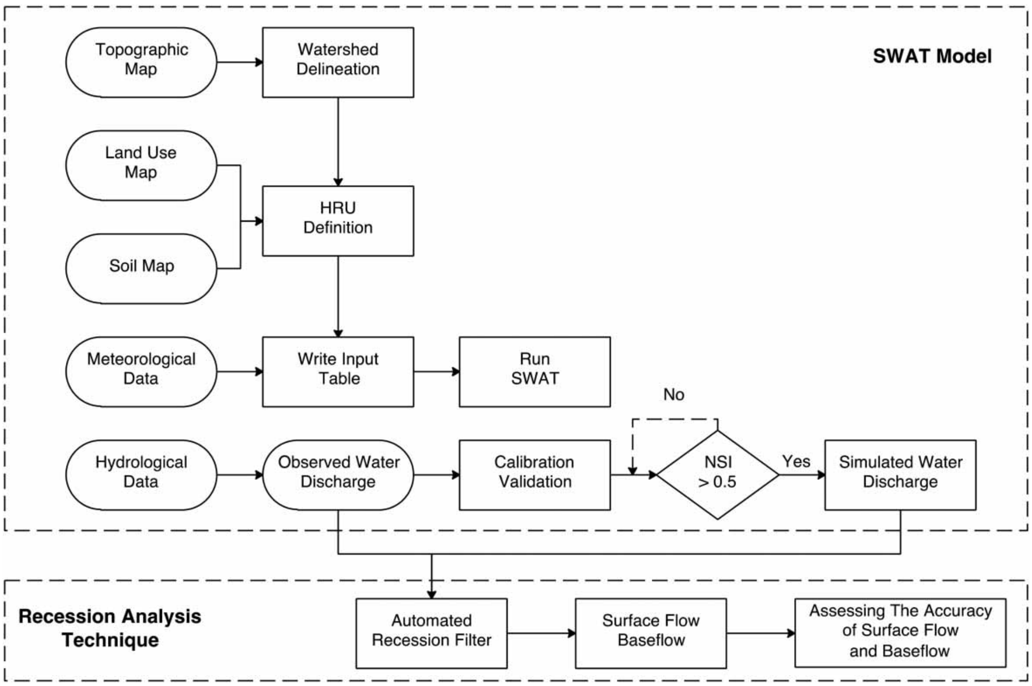

Figure 4 | Flowchart of steps in simulating surface flow and baseflow in Poko catchment.

Table 2 | Performance ratings for statistics quantitative indices

	Performance rating		
Index	**Satisfactory**	**Good**	**Very good**
NSI	$0.50 < \text{NSI} \leq 0.65$	$0.65 < \text{NSI} \leq 0.75$	$\text{NSI} > 0.75$
PBIAS (%)	$\pm 15 \leq \text{PBIAS} < \pm 25$	$\pm 10 \leq \text{PBIAS} < \pm 15$	$\text{PBIAS} < \pm 10$
R^2	$0.50 \leq R^2 \leq 0.65$	$0.65 < R^2 \leq 0.81$	$R^2 > 0.81$

Sources: Saleh *et al.* (2000), Bracmort *et al.* (2006) and Moriasi & Arnold (2007).

calculated with Equation (3):

$$b_t = Q_t - q_t \quad (3)$$

where b_t is the filtered baseflow at the t time step (1 day, cm).

Establishing the SWAT model

The SWAT model requires daily meteorological data (precipitation, maximum air temperature, minimum air temperature, relative humidity, wind speed, and solar radiation) and spatial datasets (digital elevation model (DEM), land use/land cover, and soil maps). Water discharge data are used for calibration and validation of water discharge simulation. The descriptions of input data are shown in Figure 3 and Table 1.

The implementation process of the study was divided into two parts (see Figure 4): (1) calibration and validation

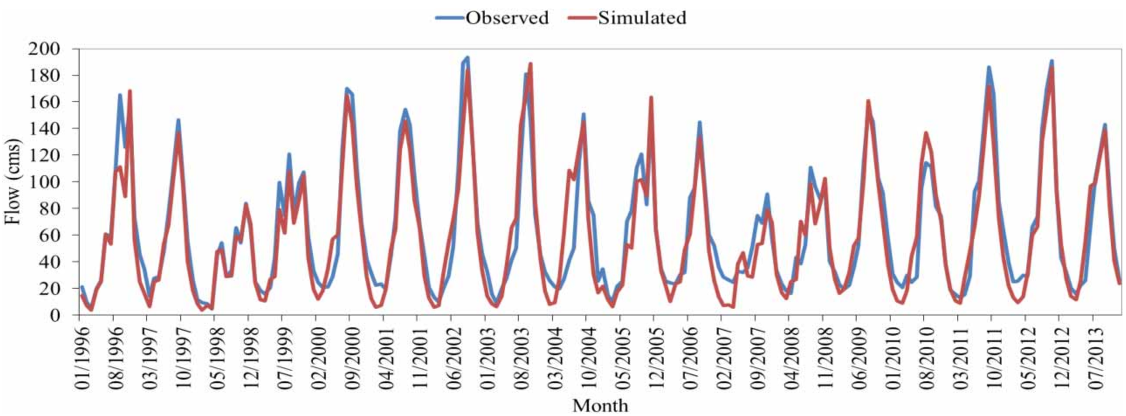

Figure 5 | Simulated and observed water discharge on monthly timestep at Dak Mot stream gauge (1996–2013).

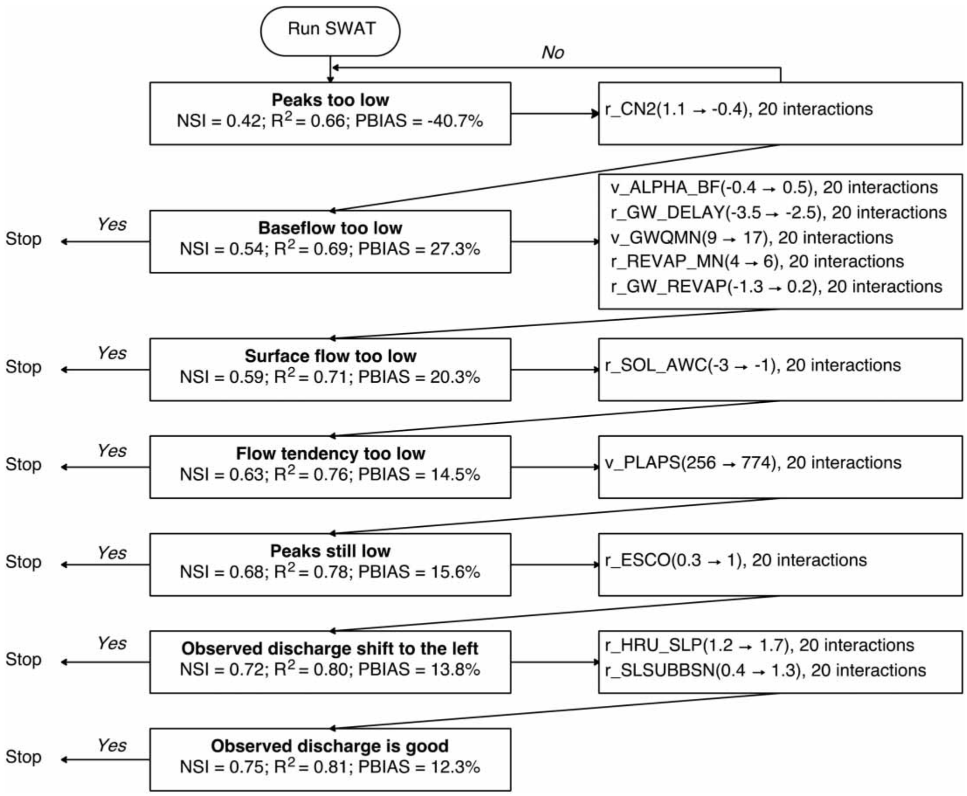

Figure 6 | The steps of SWAT model calibration. *Note:* r: the existing parameter value is multiplied by (1+ a given value); v: the existing parameter value is to be replaced by the given value).

of water discharge simulated in the SWAT model; (2) assessing the accuracy of the baseflow filtering algorithm in separating water discharge into surface flow and baseflow.

The performance of the SWAT model and baseflow filtering algorithm was evaluated by using three statistics: quantitative indices including Nash–Sutcliffe index (NSI), percent bias (PBIAS), and coefficient of determination (R^2). The performance ratings for these indices are shown in Table 2.

RESULTS AND DISCUSSION

Evaluating the accuracy of water discharge simulated in SWAT model

The results of comparing simulated water discharge in the SWAT model with observed water discharge data in monthly timestep from 1996 to 2013 at Dak Mot stream gauge (Dak To District, Kon Tum Province) (see Figure 5) showed that simulated values were underestimated in both non-flood season and flood season with $R^2 = 0.61$, NSI = 0.38, and PBIAS = −43.74. Most simulated flood peaks were lower than observed ones, except for flood peaks in 2009 and 2010 which were overestimated. In brief, the accuracy of simulated water discharge in the SWAT model was unsatisfactory, resulting in the need for calibration and validation.

Calibration and validation of water discharge simulated in SWAT model

The SUFI-2 algorithm in the SWAT-CUP software was used for SWAT model calibration, validation, and sensitivity analysis. A total of 220 interactions were done sequentially for 11 parameters related to surface flow, baseflow, flood peak, and flow tendency to capture most of the observed data within the 95% prediction uncertainty (95PPU) of the SWAT model as shown in Figure 6. The optimal range and sensitivity ranking of these parameters are described in Table 3. t-stat provides a measure of sensitivity (larger absolute values are more sensitive), while *p*-values determined the significance of the sensitivity (a value close to zero has more significance).

The calibration result of water discharge at Dak Mot stream gauge from 1996 to 2004 was good with $R^2 = 0.81$, NSI = 0.75, and PBIAS = 12.3 (see Figure 7). Similar to the calibration period, during the validation period (2005–2013), water discharge was simulated well with $R^2 = 0.85$, NSI = 0.83, and PBIAS = 11.6 (see Figure 8). In general, the simulated values in the non-flood season

Table 3 | The sensitivity ranking of 11 parameters

Sensitivity ranking	Parameter	Meaning	Optimal range	t-stat	*p*-value
1	r_HRU_SLP	Average slope steepness of hydrological response unit	1.2 → 1.7	0.2	0.08
2	v_GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	9 → 17	−0.4	0.07
3	r_ESCO	Soil evaporation compensation factor	0.3 → 1	0.4	0.06
4	r_SOL_AWC	Available water capacity of the soil layer	−3 → −1	0.5	0.06
5	r_GW_DELAY	Groundwater delay (days)	−3.5 → −2.5	−0.5	0.06
6	r_REVAP MN	Threshold depth of water in the shallow aquifer for 'revap' to occur (mm)	4 → 6	0.6	0.05
7	v_PLAPS	Precipitation lapse rate	256 → 774	1.1	0.03
8	r_GW_ REVAP	Groundwater 'revap' coefficient	−1.3 → 0.2	−1.4	0.02
9	r_CN2	SCS runoff curve number	−1.1 → −0.4	1.6	0.01
10	r_SLSUBBSN	Average slope length of subbasin	0.4 → 1.3	−2.8	0.001
11	v_ALPHA_BF	Baseflow alpha factor (days)	−0.4 → 0.5	32.9	0.001

Note: r: the existing parameter value is multiplied by (1+ a given value); v: the existing parameter value is to be replaced by the given value.

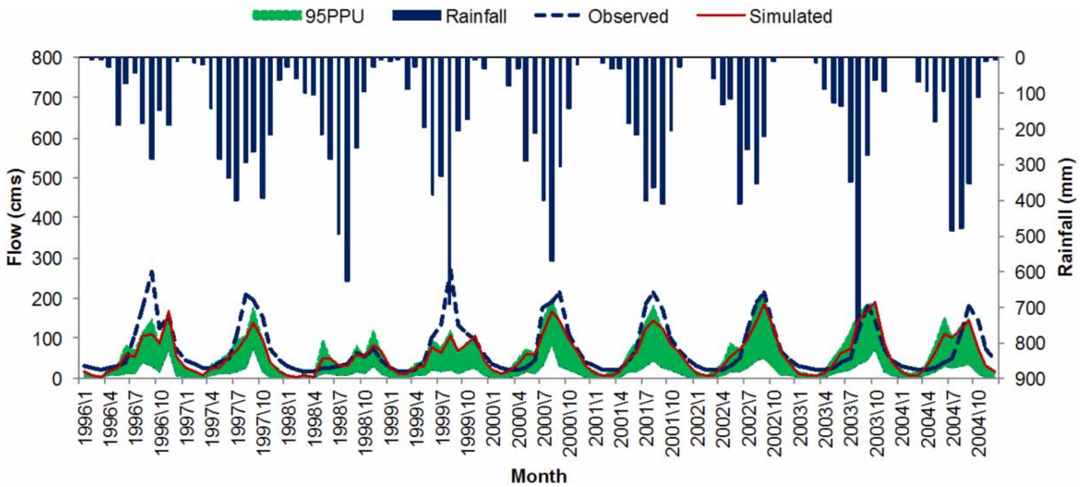

Figure 7 | Simulated and observed water discharge on monthly timestep at Dak Mot stream gauge in the calibration period (1996–2004).

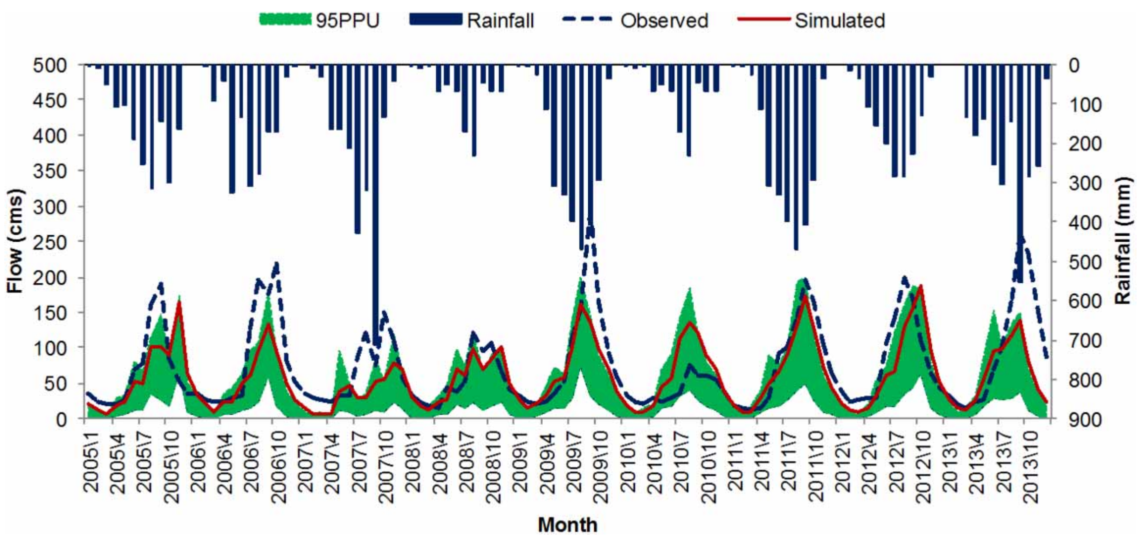

Figure 8 | Simulated and observed water discharge on monthly timestep at Dak Mot stream gauge in the validation period (2005–2013).

were estimated better than those in the flood season. To explain the above finding, besides the parameter uncertainty of the SWAT model, the impact of Plei Krong hydropower operation which began in August 2008 should be considered.

Evaluating the accuracy of baseflow filtering algorithm in separating water discharge into surface flow and baseflow

The result of separating water discharge into surface flow and baseflow at Dak Mot stream gauge from 1996 to 2013 is shown in Figure 9. In order to assess the accuracy of surface flow and baseflow, three statistical quantitative indices including R^2, NSI, and PBIAS were calculated for each year, then the statistical parameters (minimum, maximum, median, standard deviation) of these indices were defined for the whole period (see Table 4). It can be seen that the simulated values were almost lower than the observed values for both surface flow and baseflow. The correlation of surface flow ($R^2 = 0.64$) was lower than the correlation of baseflow ($R^2 = 0.90$). However, considering NSI and PBIAS, surface flow was more accurately simulated than baseflow.

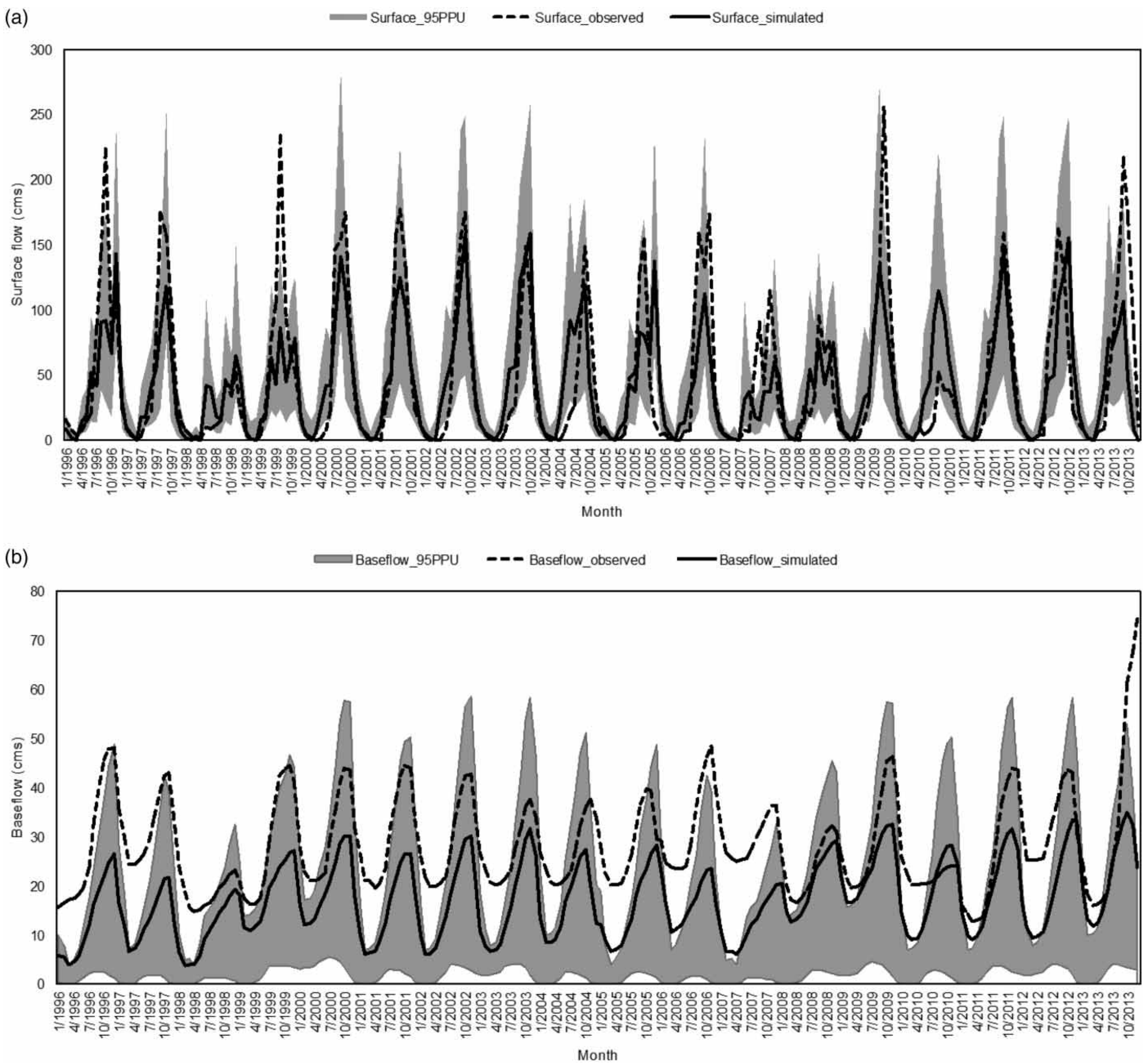

Figure 9 | Surface flow (a) and baseflow (b) separated from water discharge on monthly timestep at Dak Mot stream gauge (1996–2013).

Table 4 | The statistics quantitative indices of surface flow and baseflow

	R^2		NSI		PBIAS (%)	
Value	**Surface flow**	**Baseflow**	**Surface flow**	**Baseflow**	**Surface flow**	**Baseflow**
Minimum	0.20	0.34	−4.11	−17.38	−137.42	14.02
Maximum	0.95	0.97	0.92	0.60	39.71	59.37
Median	0.64	0.90	0.56	−1.87	8.56	39.70
Standard deviation	0.22	0.22	1.13	5.47	42.77	13.01

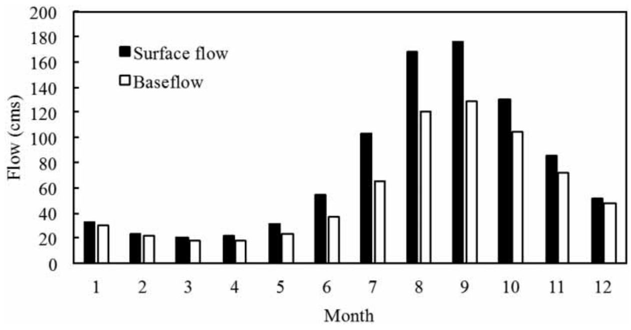

Figure 10 | The average monthly values of surface flow and baseflow at the outlet of Poko catchment.

Analyzing the distribution of surface flow and baseflow on a monthly basis

Based on Figure 10, it can be seen that the average monthly water discharge in Poko catchment during the period 1996–2013 ranged from 40 cm to 310 cm. Flow distribution shows a clear contrast between flood season and non-flood season. Total water discharge in the flood season accounted for over 60% of the total annual water discharge. Considering the flow components, surface flow prevailed at a contribution rate ranging from 51% to 58%.

CONCLUSIONS

The monthly water discharge in Poko catchment simulated by using the SWAT model gave good results at Dak Mot stream gauge in both the calibration period 1996–2004 (NSI = 0.75, PBIAS = 12.3) and validation period 2005–2013 (NSI = 0.83, PBIAS = 11.6). Based on baseflow filtering algorithm with filter parameter $\beta = 0.925$, surface flow and baseflow were separated from water discharge. The result showed that the simulated values were almost lower than the observed values for both surface flow and baseflow. Considering the contribution rate to flow, surface flow prevailed. These findings were expected to provide useful information for management, protection, exploitation, and use of water resources in Poko catchment. Further research should be undertaken to assess water resources availability of both surface water and groundwater in the catchment for four water use sectors including agriculture, industry, domestic, and environmental flow.

REFERENCES

Bracmort, K. S., Arabi, M., Frankenberger, J. R., Engel, B. A. & Arnold, J. G. 2006 Modeling long-term water quality impact of structural BMPs. *Transactions of the American Society of Agricultural and Biological Engineers* **49** (2), 367–374.

Cuong, L. V. 2012 *Irrigation Planning Kon Tum During A Period From 2011 to 2020 and Orientation to 2025*. Vietnam Academy for Water Resources, Hanoi City, Vietnam.

Ireson, A., Makropoulos, C. & Maksimovic, C. 2006 Water resources modelling under data scarcity: Coupling MIKE BASIN and ASM groundwater model. *Water Resources Management* **20** (4), 567–590. doi: 10.1007/s11269-006-3085-2.

Kar, K. K., Yang, S. K. & Lee, J. H. 2015 Assessing unit hydrograph parameters and peak runoff responses from storm rainfall events: a case study in Hancheon Basin of Jeju Island. *Journal of Environmental Science International* **24** (4), 437–447. doi:10.5322/JESI.2015.24.4.437.

Ladson, A. D., Brown, R., Neal, B. & Nathan, R. 2013 A standard approach to baseflow separation using the Lyne and Hollick filter. *Australian Journal of Water Resources* **17** (1), 25–34.

Liem, N. D. 2011 *Applying Remote Sensing, GIS and Mathematical Modeling for Water Balance in Be Watershed*. Nong Lam University, Ho Chi Minh City, Vietnam.

Luo, Y., Arnold, J., Allen, P. & Chen, X. 2012 Baseflow simulation using SWAT model in an inland river basin in Tianshan Mountains, Northwest China. *Hydrology and Earth System Sciences* **16** (4), 1259–1267. doi:10.5194/hess-16-1259-2012.

Moriasi, D. N. & Arnold, J. G. 2007 Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *American Society of Agricultural and Biological Engineering* **50** (3), 885–900. doi:10.13031/2013.23153.

NASA & Japan ASTER Program 2009 *ASTER Global Digital Elevation Model (GDEM)*. Available at: https://asterweb.jpl.nasa.gov/gdem.asp (accessed 12 July 2017).

Nathan, R. J. & McMahon, T. A. 1990 Evaluation of automated techniques for baseflow and recession analyses. *Water Resources Research* **26** (7), 1465–1473. doi:10.1029/90WR00136.

Saleh, A., Arnold, J. G., Gassman, P. W., Hauck, L. M., Rosenthal, W. D., Williams, J. R. & McFarland, A. M. S. 2000 Application of swat for the upper north Bosque river watershed. *Transactions of the ASAE* **43** (5), 1077–1087. doi:10.13031/2013.3000.

Schuol, J., Abbaspour, K. C., Yang, H., Srinivasan, R. & Zehnder, J. B. 2008 Modeling blue and green water availability in Africa. *Water Resources Research* **44** (1), 1–18. doi:10.1029/2007WR006609.

Soil Map of Kon Tum Province, Vietnam 2005 *National Institute for Agricultural Planning and Projection*. Hanoi, Vietnam.

Tularam, G. A. & Ilahee, M. 2008 Exponential smoothing method of base flow separation and its impact on continuous loss estimates. *American Journal of Environmental Sciences* **4** (4), 373–381. doi:10.3844/ajessp.2008.136.144.

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