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Effect of land use change on water discharge in Srepok watershed, Central Highland, Viet Nam

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Abstract

Srepok watershed plays an important role in Central Highland in Viet Nam. It impacts to developing social-economic conditions. Therefore, it is necessary to research elements which impact to natural resources in this watershed. The Soil and Water Assessment Tool (SWAT) model and Geography Information System (GIS) were used to simulate water discharge in the Srepok watershed. The objectives of the research were to apply GIS and SWAT model for simulation water discharge and then, we assessed land use change which impacted on water discharge in the watershed. The observed stream flow data from Ban Don Stream gauge station was used to calibrate for the period from 1981 to 2000 and then validate for the period from 2001 to 2009. After using SWAT-CUP software to calibration, NSI reached 0.63 and R square value achieved 0.64 from 2004 to 2008 in calibration and NSI gained good level at 0.74 and R square got 0.75 from 2009 to 2012 in validation step at Ban Don Station. After that, land cover in 2010 was processed like land cover in 2000 and set up SWAT model again. The simulated water discharge in scenario 1 (land use 2000) was compared with scenario 2 (land use 2010), the simulation result was not significant difference between two scenarios because the change of area of land use was not much enough to affect the fluctuation of water discharge. However, the effect of land cover on water resource could be seen clearly via total water yield. The percentage of surface flow in 2000 was twice times more than in 2010; retard and base flow in 2000 was slightly more than in 2010. Therefore, decreased surface flow, increased infiltration capacity of water and enriched base flow resulted in the growth of land cover.

Key Words: Water discharge, Land use change, GIS, SWAT model, Simulations

1 Introduction

Nowadays, many basins are retrograded because of population's increasing and using natural resources too much to developing economy. Land and water are two important resources to social life and they are elements which affect the perseverance and degeneration of watershed. Srepok River basin has an area of 30,900 square kilometers, among which an area of 18,200 square kilometer belongs to Viet Nam and flows through Gia Lai, Dak Lak, Dak Nong and Lam Dong provinces; 12,700 square kilometers belong to Cambodia. Srepok river system in Viet Nam composes two main streams, Srepok and EaH'leo watersheds. The area of main Srepok in Dak Lak Province is 4,200 square kilometer, with 125 kilometer length. Srepok basin has potential to develop power stations and most of power stations were planned on the river. However, Srepok basin is bearing many problems like flood, sediment, erosion watercourse, destroying power and irrigation building in rain season and drought, lack of irrigation and domestic water in dry period. It affects the human life seriously. In many reasons which were examined, land use change was noticed the best. Therefore, it is necessary to assess the effect of land use change on water discharge in Srepok watershed, Central Highland, Viet Nam.

There were many approaches to assess the natural resources over the world, in which, models were used the

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most because of their qualification. SWAT model was one of them and it was applied in many fields. For example, it was used to assess the quality of water (Wilson and Weng, 2011; Panagopoulos el at, 2012); in addition, many studies were demonstrated that SWAT was useful in building an early flood warning system because it simulated discharge water clearly and quite exactly (Mohammad, 2006; Rivera et al., 2007; Demirel et al., 2009; Malutta and Kobiyama, 2011; Winai and Kobkiat, 2011). Moreover, SWAT also expressed its strength when this model was applied to assess the impact of climate change to water resource (Rivera et al., 2007) or to sustainable water resource (Mujumdar, 2008). The studies show the efficiency of the SWAT model and its applied ability. Therefore, SWAT model can be taken as a potential model for simulation of the hydrology of watershed.

Moreover, SWAT model was applied to simulate water discharge and sediment in Southern Krong Ana catchment, upstream of Srepok watershed. The authors found out the fitted parameters for Southern Krong Ana catchment. Although evaluated result of model was low, simulated result was accepted to calculate water quantity and quality in the catchment. Clearly that, water discharge had a relationship closely with forest cover. Compared with 2005, the area of forest decreased by 1,444.86 ha in 2008, maximum and minimum average runoff daily increased (Hanh, 2010). Another research assessed water quality on a branch of Srepok River which flew over Buon Ma Thuot City in 2004 and 2005. Five parameters including DO, NH_4^+, NO_2^-, NO_3^+, and PO_4^{3-} were used to assess for five tributaries number 17, 18, 56, 57 and 58. The simulated result showed that, quality of water in Srepok River just suited for traffic and irrigation purposes. However, simulated result of this research needs to estimate the accuracy because of lack of observed water quality data (Liem and Loi, 2011).

In summary, SWAT model was used in Srepok watershed in some of researches but most of them didn't calibrate and validated the model. Hence, the objectives of this research were to apply GIS and SWAT model with input data including: Digital Elevation Model (DEM), Land cover in 2000 and 2010, soil and weather for simulation water discharge during a period from 1980 to 2012 and then, we assessed land use change which impacted on water quantity in Srepok watershed.

2 Research methodology

2.1 *Approach*

First of all, we disposed input data as land use map, soil map, topography, climatic conditions…with supporting of ArcGis software version 10.0. After that, SWAT model version 2012 was applied to simulate water discharge and model was calibrated and validated by SWAT-CUP software. At least, land use in 2000 was replaced by land use in 2010 to assess the impact of land use change to water discharge and determine the SWAT model appropriate to simulating water discharge in Srepok watershed or vice versa (Fig. 1).

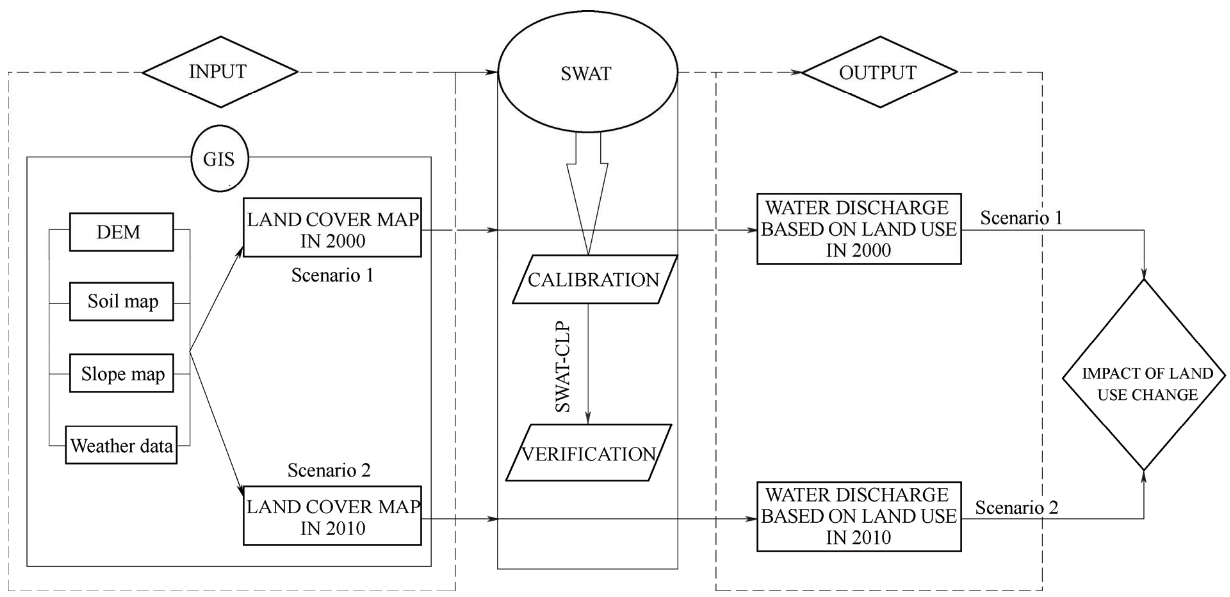

Fig. 1 The methodology of research

2.2 *SWAT model*

SWAT is a hydrologic quality model developed by United States Department of Agricultural-Agricultural Research Service (USDA-ARS) (Arnold et al., 1998). SWAT model is used to predict and assess the effect of land use, land management and climate change on water resource, sediment, crop growth and nutrient cycling. In addition, it allows modeling of different physical processes on the same basin. Moreover, the basin can be divided into many sub-basins depending on the number of reach outlets, after that, each sub-basin separated into HRUs *(Hydrologic Response Units)* by using the land cover, soil type and slope classification that have homogeneous hydrologic response. The applied process was presented by Fig. 2.

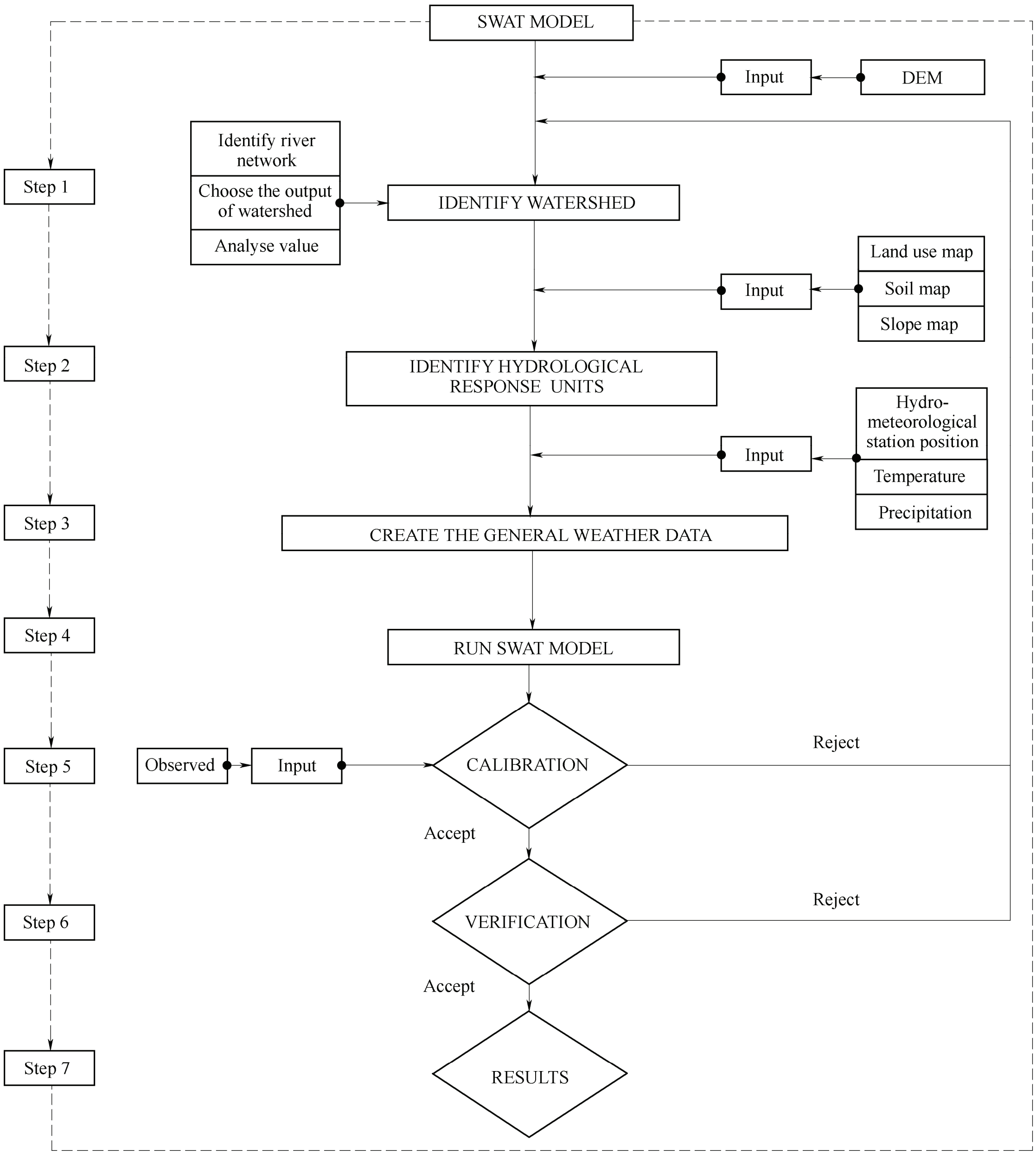

Fig.2 Application SWAT model in Srepok watershed

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

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

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), 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).

The inputs of SWAT model are arranged with detail level: basin, sub-basin, Hydrologic Response Units (HRUs), include (1) space data: DEM, soil map, slope map, land use map; (2) attribute data: weather data: max temperature, min temperature, rainfall…

2.3 *Collecting and processing data*

Data input of SWAT model in Srepok watershed was collected from local and global sources including digital elevation model (DEM), soil map, slope map, land use map, meteorological and hydrological data.

DEM data was collected from global digital elevation data ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer) - NASA with 30 meters resolution. The elevation separated five levels: 144–385 m, 385–617 m, 617–914 m, 914–1,318 m, 1,318–2,409 m (Fig. 3).

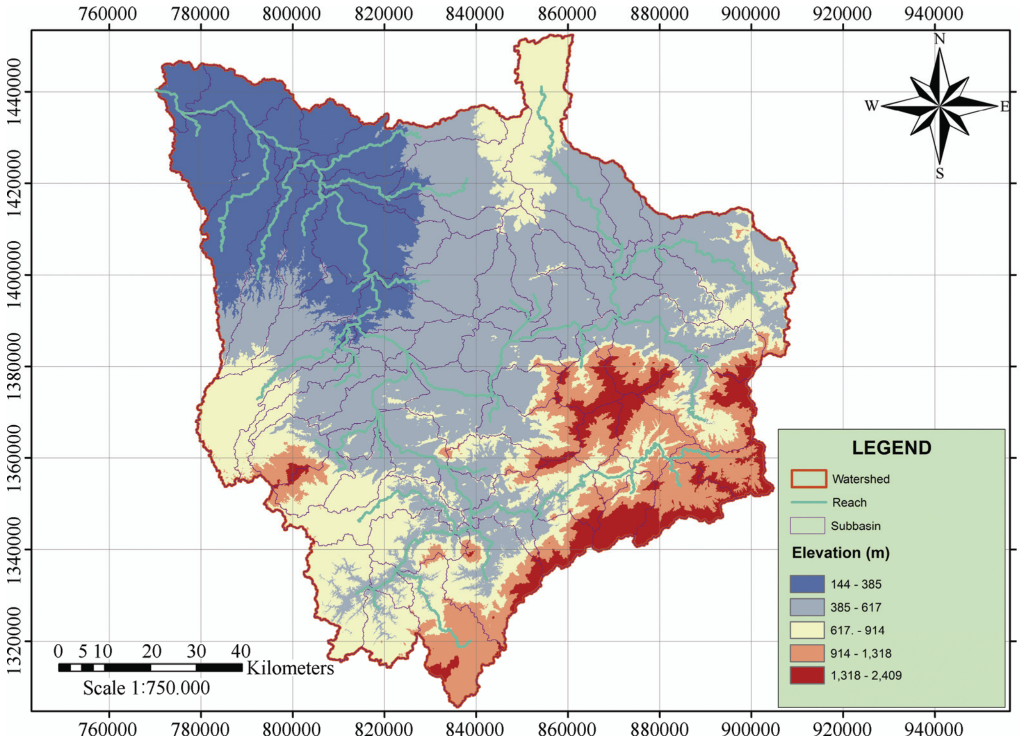

Fig. 3 Srepok Digital Elevation Model

Soil map was collected from The Digital Soil Map of the world, a product of Food and Agriculture Organization of The United Nations. This map is separated five main soil types due to SWAT code: Ferric Acrisol, Humic Acrisol, Orthic Acrisol, Rhodic Ferrasols, and Pelic Vertisols (Fig. 4).

Slope map was edited from SWAT model base on The Digital Elevation Model of Srepok watershed and it has five groups: under 5%, 5%–10%, 10%–15%, 15%–20%, and upper 20% (Fig. 5).

Meteorological data was bought from Central Highland Region Hydro-meteorological Centre throughout a period from 1980 to 2012. The model ultilized meteorological data from five local stations, including Buon Ho, M'Drak, Buon Ma Thuot, Dak Nong and Da Lat, and fifteen global stations in Srepok watershed and its neighborhood (Fig. 6).

Hydrological data at Ban Don station was used to calibrate and validate model. The period of calibration was from 1981 to 2000 and verification was from 2001 to 2009. Although study had observed data from 2010 till 2012, it was not used to validate because it has four reservoirs which have activated in this period on Srepok river (Fig. 6).

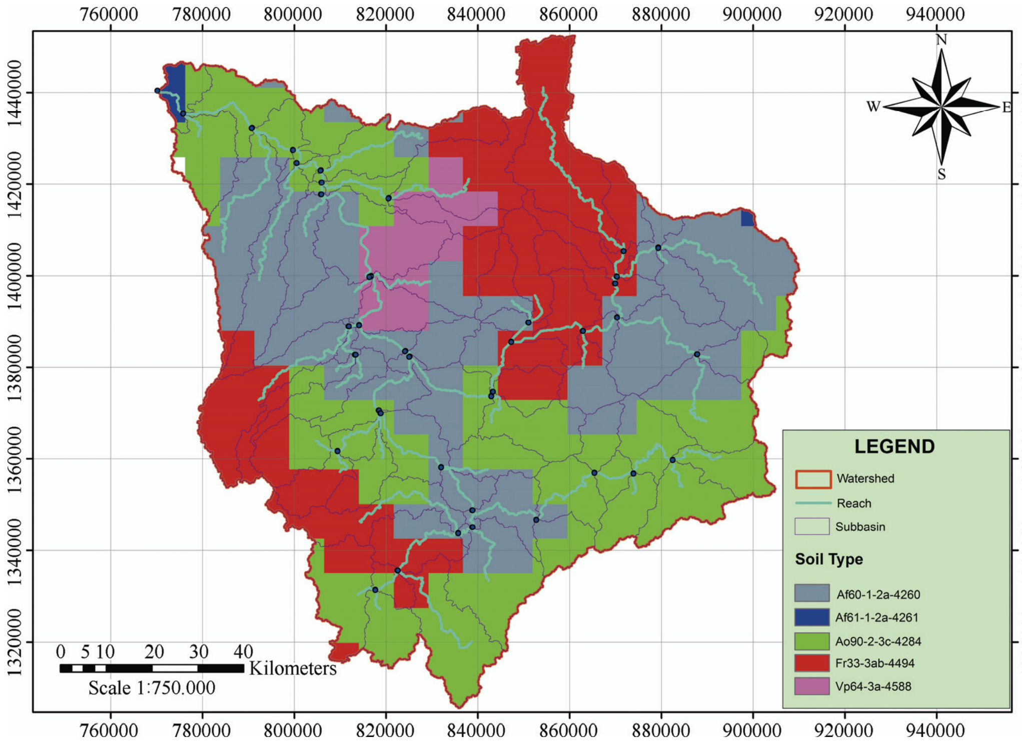

Fig. 4 Srepok soil map

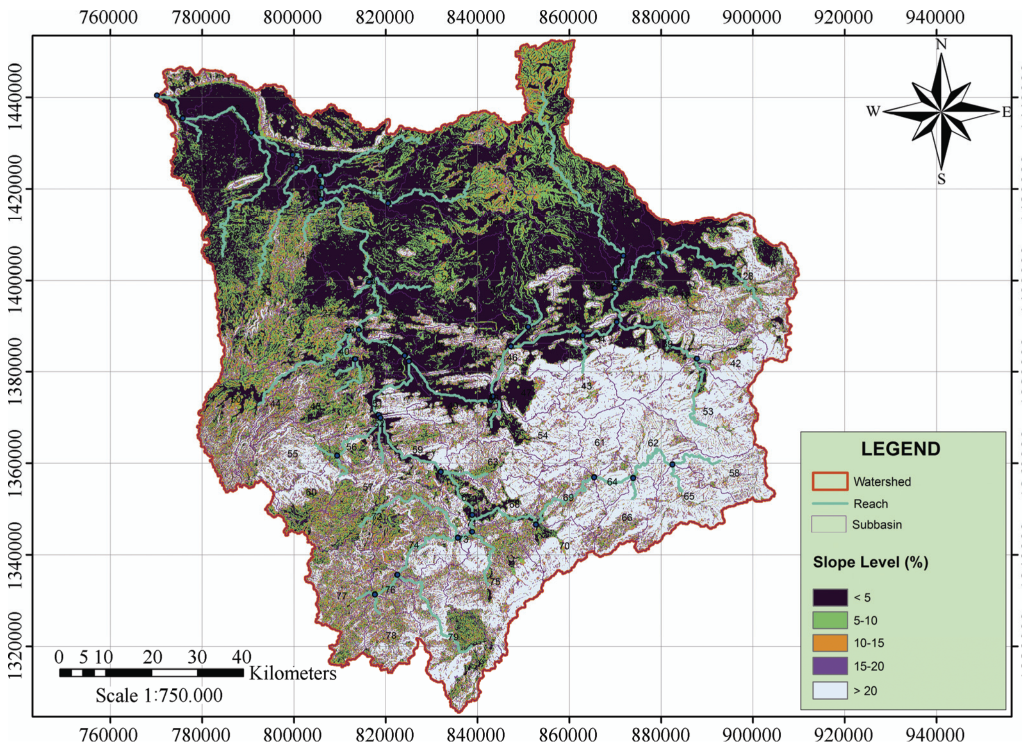

Fig. 5 Srepok slope map

Land use map of Srepok watershed in 2000 and in 2010 were collected from UMD land cover classification of Global Land Cover Facility. Similar to other map, land use map was divided into seven types based on SWAT code: Agricultural Land-Generic, Agricultural Land-Row Crops, Forest-Deciduous, Forest-Evergreen, Forest-Mixed, Residential-Medium Density and Water (Fig. 7 and Fig. 8).

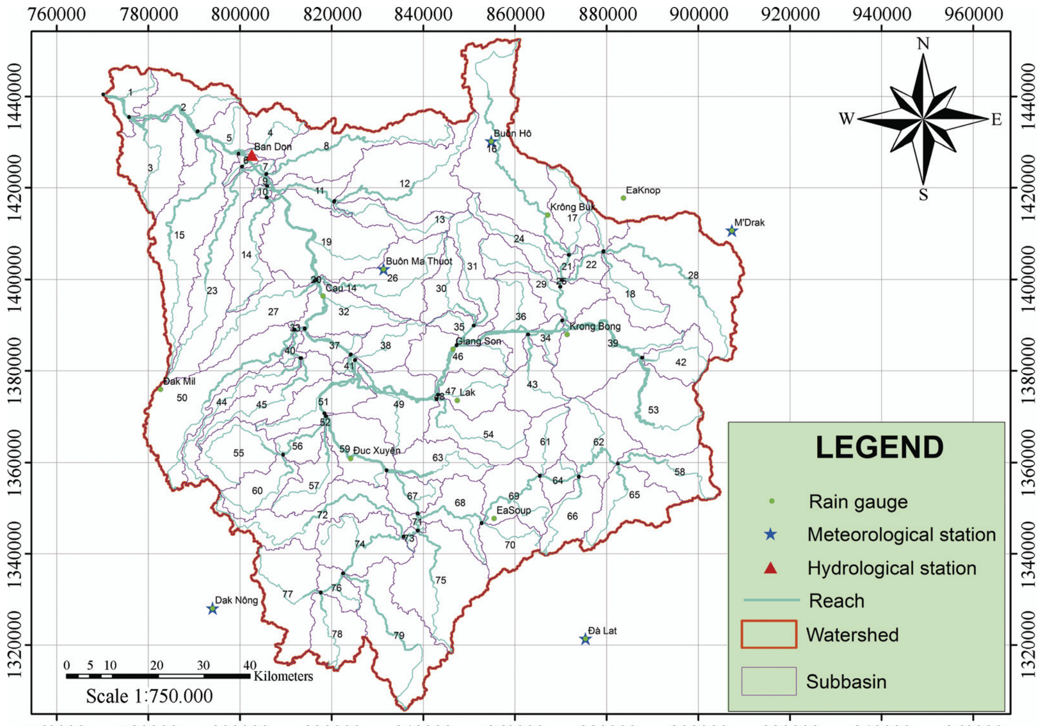

Fig. 6　Hydro-meteorological station position

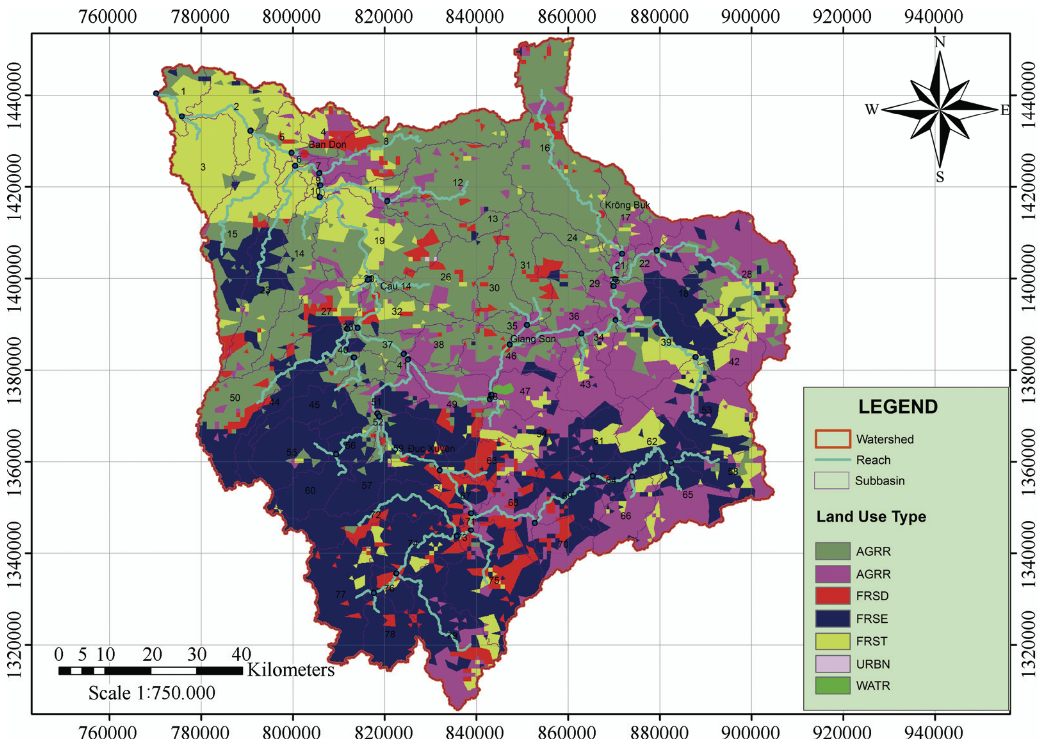

Fig. 7　Srepok land use map in 2000

2.4　*Estimation SWAT model*

Two statistical indexes include Nash-Sutcliffe index (NSI) and the coefficient of determination (R^2) which represented the correlation between the observed value and simulated value, were utilized to evaluate the simulated results of SWAT model.

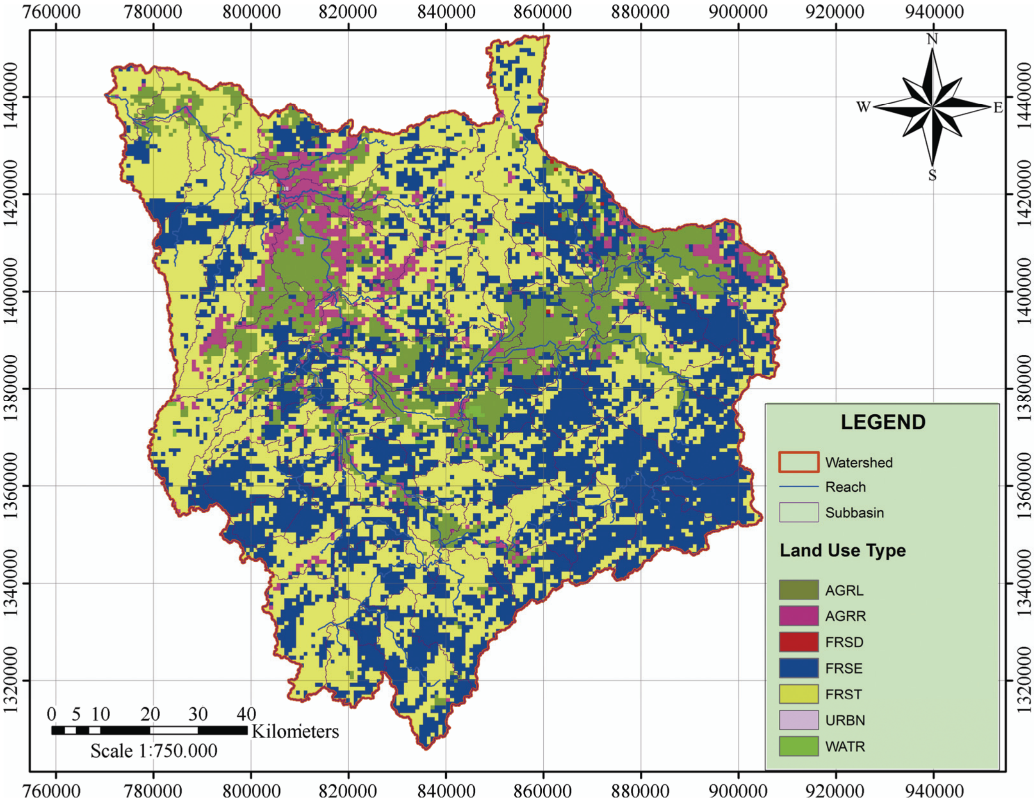

Fig. 8 Srepok land use map in 2010

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

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

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

The simulating quality of model is assessed with four levels (Moriasi et al., 2007)

- $0.75 < \mathrm{NSI} \leq 1$: very good.
- $0.65 < \mathrm{NSI} \leq 0.75$: good.
- $0.50 < \mathrm{NSI} \leq 0.65$: satisfaction.
- $\mathrm{NSI} < 0.50$: dissatisfaction, the factor of model need to consider clearly.

Moreover, 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 model prediction is "*perfect*". However, there are no explicit standards specified for assessing the model prediction using these statistics (Santhi et al., 2001). Calibration and verification steps were implemented under SWAT-CUP software supporting with Sufi-2 algorithm.

3 Results and discussions

3.1 *Calibration SWAT model in Srepok watershed*

Firstly, SWAT model was set up to simulate water discharge with land use in 2000 (scenario 1). It simulated water discharge at 79 sub-basins from 1980 to 2012 and the study used measured discharge at Ban Don station which was installed on Srepok river to calibrate the calculated runoff of model. In ArcGIS environment, we could see clearly that Ban Don station coincided with the outlet of sub-basin number 6. The period of calibration was from 1981 to 2000 (the observed data in 1980 was skipped to make model warm up).

It is difficult for researchers to find out the fitted parameters which base on the special characteristics and suit study area (Table 1). Fortunately, the processing was implemented quickly by the automatic calibration with Sufi-2 algorithm in SWAT-CUP software. After we analyzed the sensitivity of twenty six elements which affect surface flow, four parameters was determined which influenced water quantity best in Srepok watershed included Curve number (CN2), Base flow alpha factor (ALPHA_BF), Groundwater delay (GW_DELAY) and Threshold water depth in the shallow aquifer for flow (GWQMN). SWAT-CUP was set up to calibrate the model with four parameters and five hundred times iteration. The calibration result was showed in Table 2.

Table 1 The parameters in SWAT model

Parameter	Description	Value
CN2	Initial SCS curve number II value	35 – 98
Esco	Soil evaporation compensation factor	0 – 1
Gwqmn	Threshold water depth in the shallow aquifer for flow	0 – 5,000
Alpha_Bf	Baseflow alpha factor	0 – 1
Sol_Z	Soil depth (mm)	0 – 3,500
Sol_Awc	Available water capacity (mm H_2O/mm soil)	0 – 1
Ch_K2	Channel effective hydraulic conductivity (mm hr^{-1})	–0.01 – 500
Gw_Revap	Groundwater “revap” coefficient	0.02 – 0.2
Ch_N2	Manning’s n value for main channel	–0.01 – 0.3
Sol_K	Saturated hydraulic conductivity	0 – 2,000
Canmx	Maximum canopy storage (mm)	0 – 100
Gw_Delay	Groundwater delay (days)	0 – 500
Blai	Maximum potential leaf area index crop	
Epco	Plant uptake compensation factor	0 – 1
Surlag	Surface runoff lag time (days)	1 – 24
Revapmn	Threshold water depth in the shallow aquifer for “revap” (mm)	0 – 500
Biomix	Biological mixing efficiency	0 – 1
Slsubbsn	Average slope length (m)	10 – 150
Slope	Average slope steepness (mm^{-1})	
Sol_Alb	Moist soil albedo	0 – 0.25
Sftmp	Snowfall temperature (℃)	–5 – 5
Smfmn	Melt factor for snow on December 21 (mm H_2O/℃-day)	0 – 10
Smfmx	Melt factor for snow on June 21 (mm H_2O/℃-day)	0 – 10
Smtmp	Snow melt base temperature (℃)	–5 – 5
Timp	Snow pack temperature lag factor	0 – 1
Tlaps	Temperature lapse rate	0 – 50

Table 2 SWAT sensitive parameters and calibrated values

Parameter	Description of parameter	Calibrated value		
		Fitted-value	New min-value	New max-value
r_CN2.	Initial SCS CN II value	–0.38	–0.58	0.19
v_ALPHA_BF	Baseflow alpha factor	0.47	0.30	0.65
v_GW_DELAY	Groundwater delay	78.38	–31.20	187.96
v_GWQMN	Threshold water depth in the shallow aquifer for flow	1.63	1.07	2.19

Secondly, land use in 2000 was replaced by land use 2010 and other input data was steady (scenario 2). SWAT model ran again and simulated result was similar to scenario 1 with calculated water discharge in 79 sub-basins belong to Srepok watershed. Reach number 6 in scenario 2 was chosen to calibration with four parameters which were calibrated in scenarios 1. By this way, we could check the suitability of fixed parameters for both two scenarios. At the result, Nash-Sutcliffe index and the coefficient of determination reached very good level in both scenarios with 0.75 and 0.82, respectively. The correlation between the observed value and simulated value was represented via Fig.9 and Fig.10 as below.

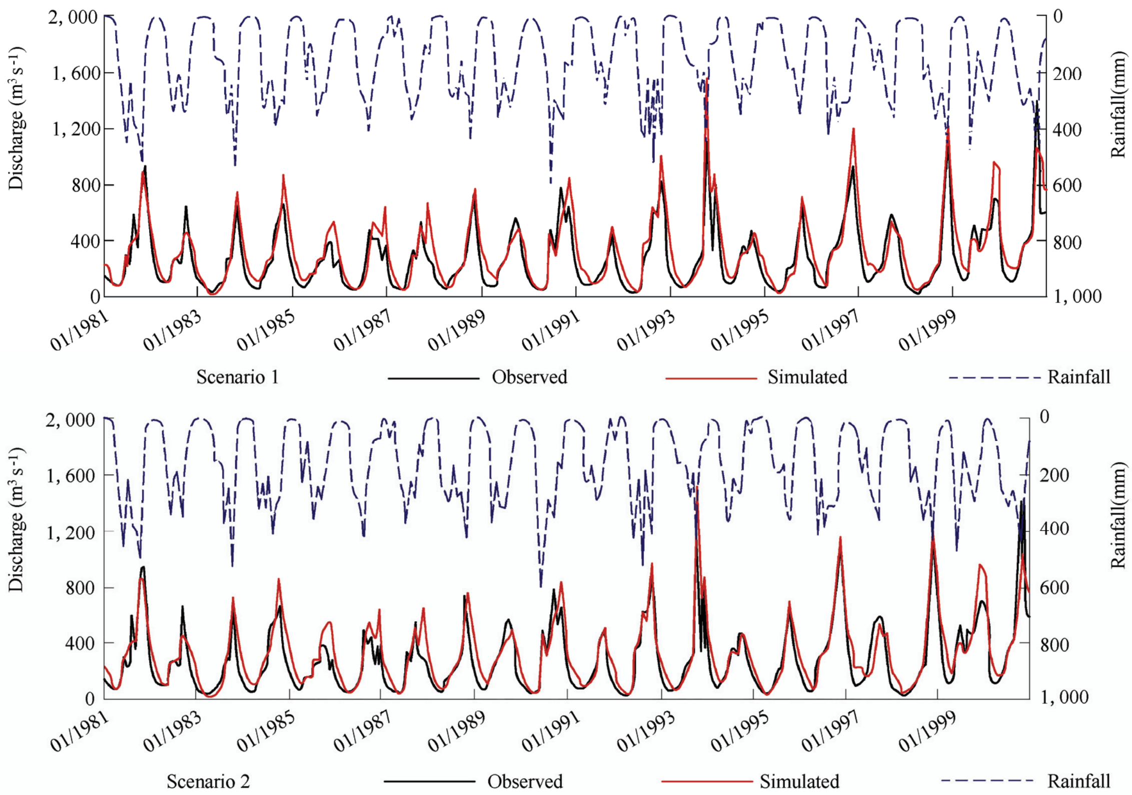

Fig. 9 Observed and simulated water discharge in calibration period for two scenarios at Ban Don station

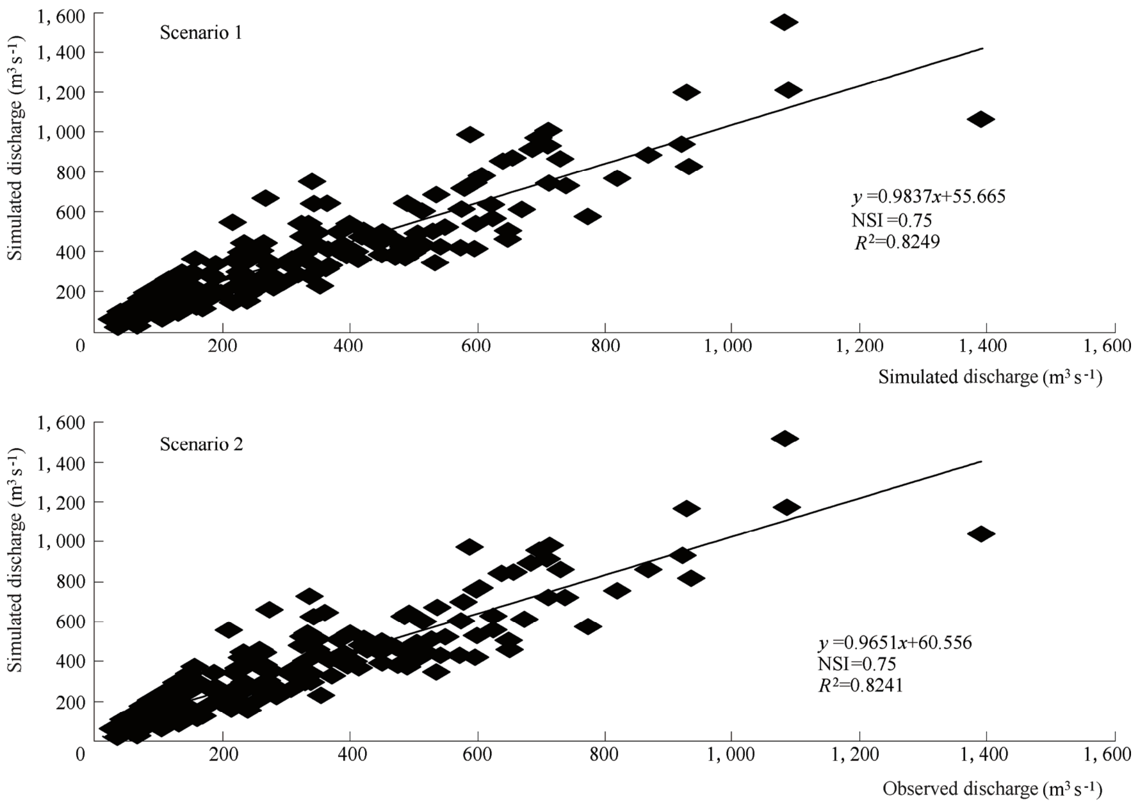

Fig. 10 The degree correlation between simulated and observed values in calibration period for two scenarios at Ban Don station

3.2 *Verification SWAT model in Srepok watershed*

After calibration, the model was validated to estimate the suitability of fixed values. Runoff simulation results were shown in Fig.11 and Fig.12.

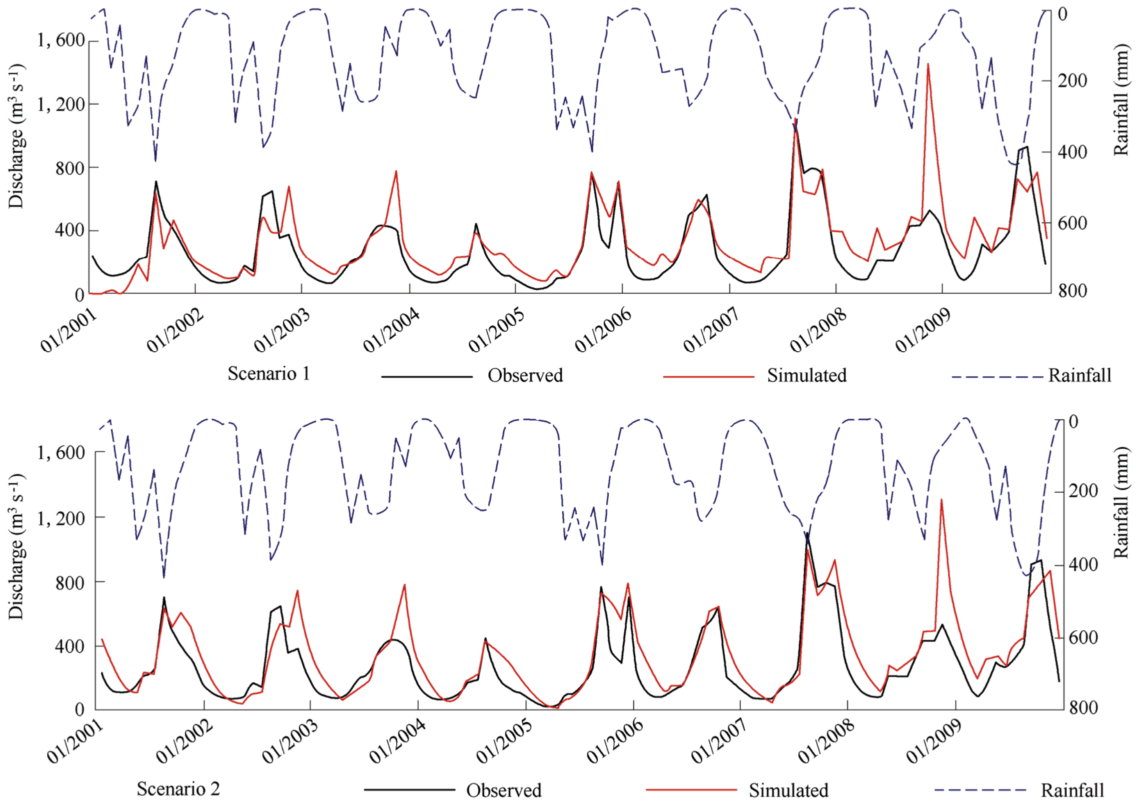

Fig. 11 Observed and simulated water discharge in verification period for two scenarios at Ban Don station

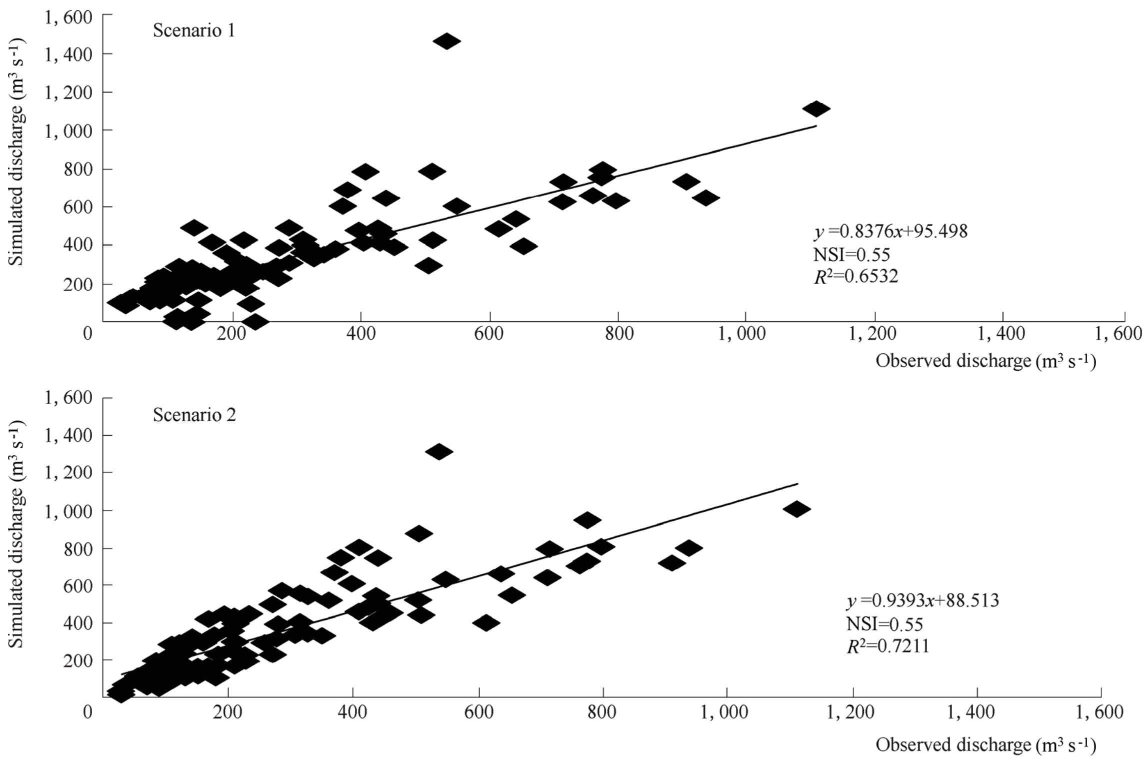

Fig. 12 The degree correlation between simulated and observed values in verification period for two scenarios at Ban Don station

Table 3 showed the simulated water discharge were calibrated against monthly observed data from 1981–2000 and it was validated from 2001 to 2009 at Ban Don station. The fit between simulated and observed water got very good level with 0.75 for the NSI and 0.82 for *R* square in calibration period in both scenarios. In validation period, the NSI and *R* square value was acceptable at 0.55, 0.65 in scenario 1 and 0.55, 0.72 in scenario 2, respectively. Therefore, this study could determine that SWAT model was one of the potential tools to simulate the water discharge in Srepok watershed.

Table 3 **Model performance for the simulation of flow-out at Ban Don station**

Scenario	Before calibration		Calibration (1981–2000)		Verification (2001–2009)	
	R^2	NSI	R^2	NSI	R^2	NSI
1	0.79	0.28	0.82	0.75	0.65	0.55
2	0.81	0.37	0.83	0.75	0.72	0.55

3.3 *Relationship between land use change and water discharge in Srepok watershed*

To define the change of land use types between two different scenarios, we overlaid two land use map, one in 2000 and the other in 2010 by ArcGIS software.

Table 4 showed the change of area of land use types between 2000 and 2010. The area of Agriculture Land-Generic, Agricultural Land-Row Crops and Forest-Deciduous decreased by 181,785.68 ha, 177,414.83 ha, and 67,159.87 ha, respectively. On the contrary, the area of Forest-Evergreen increased by 60,597.67 ha, and 357,531.86 ha for Forest-Mixed, 926.75 ha for Residential-Medium Density and 7,304.1 ha for water.

Table 4 **The change of area of land use types between 2000 and 2010**

Number	Land use type	2000 Area (ha)	2000 Percentage (%)	2010 Area (ha)	2010 Percentage (%)	Compare to 2000
1	AGRL	349,710.21	29.03	167,924.53	13.94	–181,785.68
2	AGRR	244,710.25	20.32	67,295.42	5.59	–177,414.83
3	FRSD	67,710.70	5.62	550.83	0.05	–67,159.87
4	FRSE	365,496.28	30.35	426,093.95	35.38	60,597.67
5	FRST	174,360.53	14.48	531,892.39	44.16	357,531.86
6	URBN	163.00	0.01	1,089.75	0.09	926.75
7	WATR	2,295.85	0.19	9,599.95	0.80	7,304.1
	Total	1,204,446.80	100.00	1,204,446.80	100.00	

Note: AGRL: Agricultural Land-Generic; AGRR: Agricultural Land-Row Crops; FRSD: Forest-Deciduous; FRSE: Forest-Evergreen; FRST:Forest-Mixed; URBN: Residential - Medium Density; WATR: Water.

After calibration and validation model, we ran SWAT model in two different scenarios to assess the effect of land use change on the water discharge in Srepok watershed. To begin with, we kept DEM, soil map and weather data like fixed elements. Next, we changed land use map. We replaced land use map in 2000 by land use map in 2000. After model simulated water discharge at Ban Don Station in 2000, the last step, it was compared to simulated water discharge at Ban Don Station in 2010.

As the result, the simulation results of both scenarios about water discharge were not significantly different. It was covered in Fig. 13.

The main reason is that most of Srepok watershed locates in rural area where the process of industrialization and modernization has taken place strongly. Moreover, the overlay map result presented that, when the sum of AGRL, AGRR and FRSD area decreased by about 426,360.38 ha, the FRSE and FRST increased by 418,129.53 ha. Thus, the change of area of land cover was not much enough to affect the fluctuation of water discharge between two periods.

Although the chart didn't present meaningfully, the effect of land use change on water resource could be seen clearly via total water yield which flew to Srepok watershed. Table 5 indicated that, total water yield came to watershed in 2000 more than in 2010. In particular, the percentage of surface flow in 2000 was two times more than that in 2010; lateral and ground water flow in 2000 was slightly more than that in 2010. Following

Table 4 in the above, the area of Forest increased by over 41 ha in 2010 because of the afforesting policy of Vietnamese government in 1998. Clearly that, the growth of forest made surface flow decrease and increase the infiltration capacity of water and enriched base flow resulted in thicker layer of land cover. In summary, land cover has effect on water discharge in Srepok watershed.

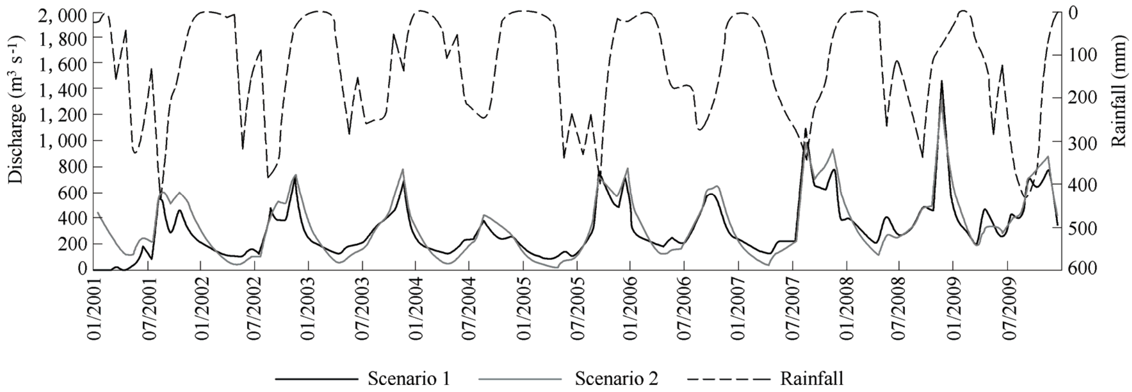

Fig. 13 Simulation of water discharge at Ban Don Station based on land use in 2000 and 2010

Table 5 The balance water ratio of scenario in 2000 and 2010 in Srepok watershed

	2000		2010	
	Value (mm)	Percentage (%)	Value (mm)	Percentage (%)
Surface flow	231.61	23.18	113.25	11.96
Lateral flow	89.63	8.97	94.55	9.98
Ground water flow	677.88	67.85	739.19	78.06
Total water yield	999.12	100.00	946.99	100.00

4 Conclusions

The paper points the prediction study of water discharge in Srepok watershed at Ban Don station in the period from 1980 to 2012 by SWAT model. The calculated result of two scenarios were evaluated by *R* square value and NSI index at 0.75, 0.82 in calibration and about 0.65 to 0.72, 0.55 in verification, respectively. In addition, the compared result of two land use scenarios could be seen that more land cover, the less surface flow and the more lateral flow and base flow. The conclusion presented that SWAT model could be applied at Srepok watershed. So that, the direction of study in the future needs to define the best of land cover ratio for Srepok watershed to guarantee sustainable development.

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