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The Evaluation of Land Use Changes on Stream Discharge by SWAT Model and Remote Sensing in Agro-Forestry Watershed: A Case Study in Nghinh Tuong Subwatershed, Northern Vietnam

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Abstract: The purpose of this paper was to implement “Soil and Water Assessment Tool (SWAT)” model and Geographic Information System (GIS) to evaluate the impact of land use changes on stream discharge in Nghinh Tuong watershed (a brand of Cau River) in Northern Vietnam. The watershed was coverd by 56% forestry land, 30% agricultural land and the remain 14% for others. Stream discharge observed data from 2002 to 2007 were used for calibration period and from 2008 to 2012 for validation period. The result showed that two coefficients (*NSE* and *PBIAS*) to evaluate model performance were 0.76 and 6.54% for calibration period and 0.87 and 4.74% for validation period, respectively. Stream discharge strongly depends not only on quantity of precipitation but also on land use change. Through the scenario 1, agricultural land (corn, orchard and tea) increases 9,782.67 ha (2.45%), meanwhile forest (forest-mixed) decreases 1,091.77 ha (2.75%) as compared to baseline scenario. Additionally, precipitation increases 3.74% in mean wet season, but decreases 0.5% in mean dry season with respect to baseline period. SWAT model was able to simulate stream discharge and sediment yield for Nghinh Tuong watershed successfully not only for baseline scenario but also for scenario 1. In brief, SWAT proves its ability in simulation stream discharge in subwatershed level. It is a useful tool to assist water quantity and quality management process in Nghinh Tuong watershed. This work one more time indicated that SWAT is useful tool for resources and environment management.

Key words: Stream discharge, watershed, GIS, SWAT model, scenario.

1. Introduction

The research of “the application of Geographic Information System (GIS) and Soil and Water Assessment Tools (SWAT) to simulate and evaluate the characteristic of hydrology as well as the flow discharge on river watershed” is now being special concerned by domestic scientists and outside ones. The quantitative and qualitative of flow change due to the change of precipitation and vegetation on the river watershed is determined by hydrology model, such as SWAT model. SWAT model [1] is a physic model, which have been built since 1990s by Dr. Jeff Arnold in Agriculture Research Service (ARS), United States Department of Agriculture (USDA). The model is built to simulate the influence of land management on water resource, sediment and the organic content in soil on the watershed system in the period of time. In the world, many researches have been carried out, such as Arnold et al. [2] used SWAT to evaluate the flow discharge and sediment in Texas River with the watershed width from 2,253 km^2 to 304,260 km^2. The flow data have been collected from over 1,000 photogrammetry stations between 1960 and 1989, which was used for researches. The co-authors Van Lew and Garbrecht [3] evaluated the capacity of using SWAT model to forecast flow discharge with different weather conditions in three subwatershed in total area about 610 km^2 in Little Washita River to the

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Southwest of Oklahoma. They found that SWAT model has enough capacity to simulate the flow with different weather conditions. And, another author Gassman et al. [4] concluded the results of simulation in small watershed area (0.68 km^2) in South Africa with the correlation parameters between actual measures and simulation data by SWAT. In Vietnam, in 2009, Nguyen, K. L. [5] and Nguyen, D. B. et al. [6] successfully used SWAT model to evaluate the effect of agro-forestry system on flow discharge and sediment in Nghia Trung watershed in upstream of Dong Nai River. And Phan et al. [7, 8] published the research result with successfully using SWAT model to evaluate the influence of climate change and deforestation on flow discharge in watershed of Phu Luong River. The purpose of this paper was to implement SWAT model and GIS to evaluate the impact of land use changes on stream discharge in Nghinh Tuong watershed (a brand of Cau River) in Northern Vietnam (Fig. 1).

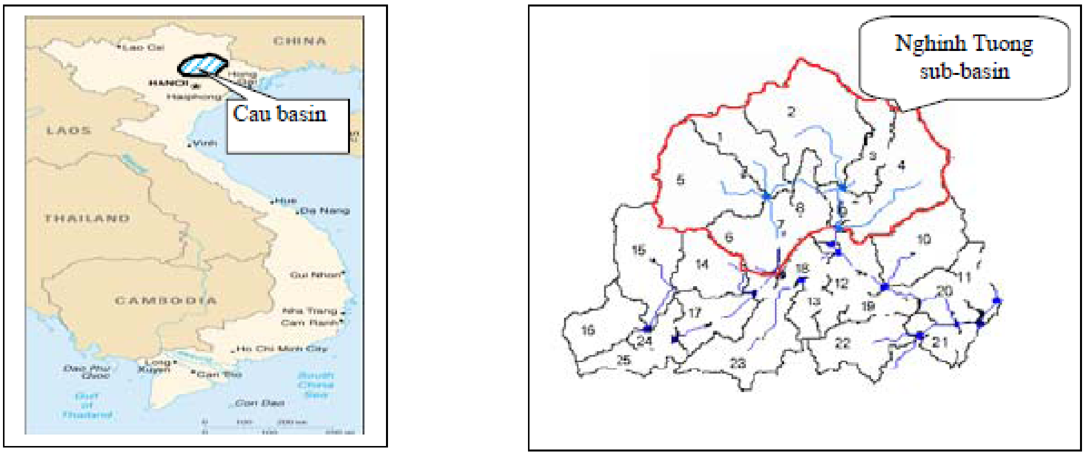
2. Methodology

2.1 Input Data for SWAT Model

Data requirements for the SWAT model are two forms: spatial database and characteristic database as Table 1.

2.2 Land Use Scenarios

Land use scenario is built on the basis of the current state of land use in the basin. The land use planning in conjunction with field surveys are shown in Table 2 and Fig. 2. Table 2 shows two land use scenarios for Nghinh Tuong watershed and the baseline scenario is the land use currently implemented (2012). Scenario 1 (2020): converted 2,617.58 ha (7.10%) forest-mixed



(a) (b)

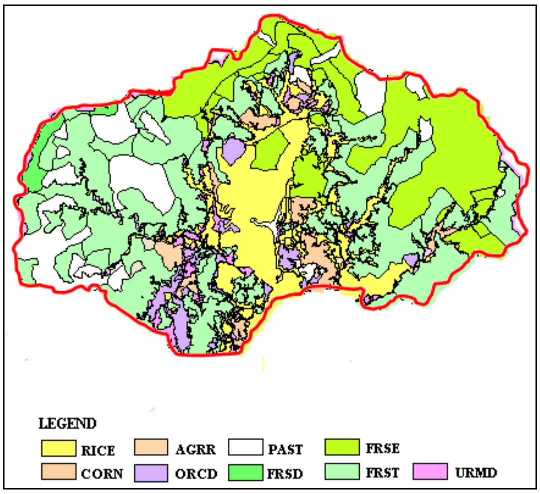
Fig. 1 Location (a) and Nghinh Tuong sub-basin (b) in Northern Vietnam.

Table 1 Input data for SWAT model.

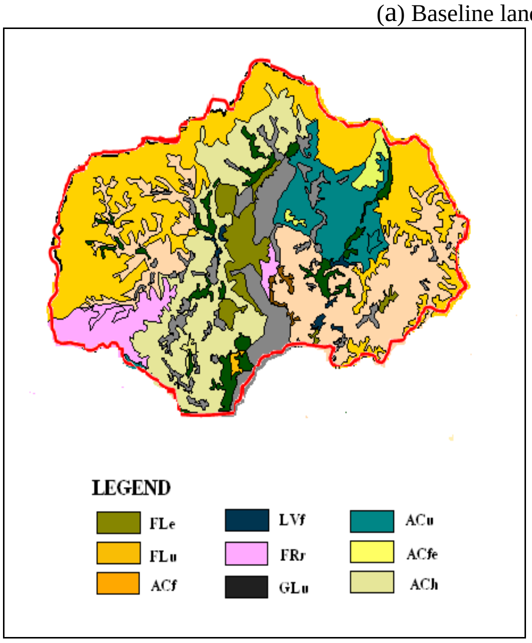
No.	Data	Sources
1	Precipitation	Thai Nguyen, Lang Son, Vo Nhai Meteorological Station
2	Temperature, humidity and other meteorological factors	
3	Discharge stream	Thai Nguyen Hydrological Station
4	Soil map	The Institute of Soils and the Department of Soil Science, Thai Nguyen University of Agriculture and Forestry
5	Map of slope	Department of Thai Nguyen Natural Resources and Environment Information Center
6	Map of land use	Department of Vo Nhai Natural Resources and Environment
7	Status area of land use	

Table 2 Land use scenarios and land use types in Nghinh Tuong watershed.

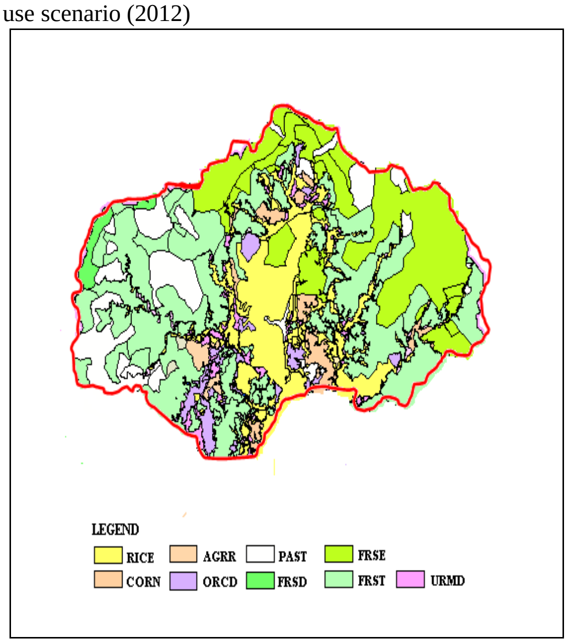
Land use types	SWAT code	Land use scenarios			
		Baseline (2012)		2020	
		Area (ha)	%	Area (ha)	%
Rice	RICE	4,335.30	10.92	4,335.30	10.92
Corn	CORN	1,175.13	2.96	2,147.80	5.41
Agriculture land-row crops	AGRR	4,224.14	10.64	4,224.14	10.64
Orchard	ORCD	1,238.65	3.12	1,052.06	2.65
Pasture	PAST	5,292.08	13.33	5,292.08	13.33
Forest-Deciduous	FRSD	3,112.52	7.84	3,112.52	7.84
Forest-Evergreen	FRSE	4,307.51	10.85	4,307.51	10.85
Forest-Mixed	FRST	10,338.03	26.04	9,246.26	23.29
Water	WATR	1,707.12	4.30	1,707.12	4.30
Urban	URMD	3,969.08	9.99	4,275.79	10.76
Total		39,700.58	100	39,700.58	100



(a) Baseline land use scenario (2012)



(b) Soil map



(c) Land use scenario1

Fig. 2 Land use scenarios (a, c) and soil map in Nghinh Tuong subwatershed (b).

land into urban land and 4,941.57 ha (13.40%) into agricultural land (corn 1,635.12 ha and agriculture land-row crops 3,306.45 ha); the other land uses remained unchanged.

2.3 Evalution Model

The *NSE* value is calculated using the following equation (Nash and Sutcliffe) [9]:

$$NSE = 1-\frac{\sum_{i=1}^{n}(Q_{obs}^{i}-Q_{sim}^{i})^2}{\sum_{i=1}^{n}(Q_{obs}^{i}-Q_{obs-mean})^2} \quad (1)$$

$$PBIAS = \frac{\sum_{i=1}^{n}\left(Q_{obs}^{i}-Q_{sim}^{i}\right)}{\sum_{i=1}^{n}Q_{obs}^{i}}\times 100\% \quad (2)$$

where, n is the number of registered data points; Q_{obs}^{i} and Q_{sim}^{i} are the observed and simulated data, respectively; on the i time step, $Q_{obs-mean}$ is the mean of observed data (Q_{obs}^{i}) across the n evaluation time steps.

3. Results and Disscussion

3.1 Run the Model and Calibrate the SWAT Model Index.

On the basis of the data set, for model testing and calibration of the model's sensitivity index, the ultimate sensitivity index was determined to run the model for the most accurate results as Table 3.

3.2 Stream Discharge Simulation by SWAT Model

After adjusting all sensitive parameters in SWAT, the set of sensitive parameter data was used for SWAT model run exactly. The daily simulated stream discharge in watershed was lumped into monthly total and was compared with the measured stream discharge at the watershed outlet (Nghinh Tuong). Fig. 3 showed that the stream discharge matched well with the measured values at watershed's outlet. Agreement

Table 3 The most sensitive parameters in SWAT and values used in this study.

Variable name	Involved processes	Description	Normal range	Value used
CN2	Flow	Curve number	± 5	± 4
ESCO	Flow	Soil evaporation compensation factor	0.00-1.00	0.55
EPCO	Flow	Plant uptake compensation factor	0.00-1.00	0.40
GW_REVAP	Flow	Groundwater "revap" coefficient	0.02-0.40	0.2

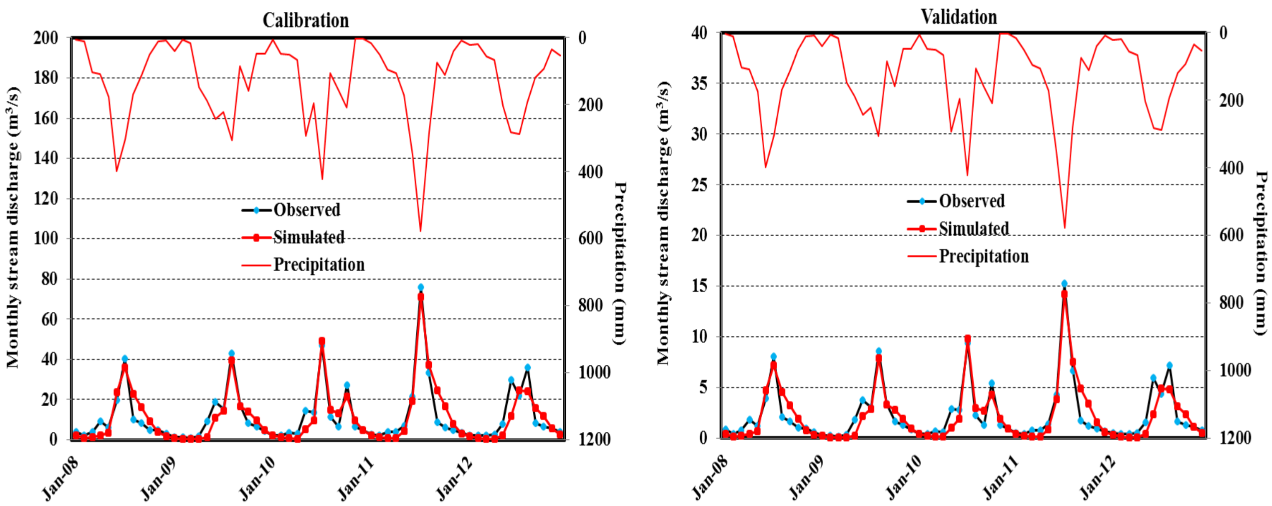


Fig. 3 Observed versus simulated monthly stream discharge and precipitation of Nghinh Tuong watershed during calibration and validation periods.

between measured and simulated stream discharge at watershed was further indicated by *NSE* and *PBIAS* index. The adequacy of the SWAT model to simulate the stream discharge was also indicated by a relatively high *NSE* values. For the calibration period from 2002 to 2007, monthly *NSE* was 0.76, while *PBIAS* was 6.54%. For the validation period 2008-2012, *NSE* and *PBIAS* were higher than those for the calibration period with respective values of 0.87 and 4.74% (Table 4). Moreover, the adequacy of the model was further demonstrated by its clear response to extreme rainfall events resulting in high stream discharge (Fig. 3). These results indicate that important hydrologic processes such as runoff in tropical watersheds can be modeled realistically using the SWAT model.

According to data in Table 5, the simulated data is lower than observed data for both mean wet (24.15 m^3/s) and dry season (4.65 m^3/s) for calibration period (2002-2012). For entire period (2002-2012), mean wet and dry season of observed data were 21.70 m^3/s and 4.23 m^3/s, while for simulated data were 21.24 m^3/s and 3.90 m^3/s, respectively.

3.3 Assessment the Impact of Land Use Change (in the Scenario) on Stream Discharge in SWAT Model

To assess the impact of land use changes on stream discharge , land use scenario 1 was built and run with the SWAT model parameters as the baseline. Results were as in Table 5 and Fig. 4.

In general, stream discharge strongly depends not only on quantity of precipitation but also on land use change [10, 11]; highly precipitation will lead to high stream discharge and land use change with increasing agricultural land will reduce stream discharge, especially in dry season. In mean wet season, precipitation increases 63.58 mm (4.57%) from 1,390.20 mm in 2012 to 1,453.78 mm in 2020. In this case, stream discharge in 2020 is 25.20 m^3/s and increases 1.05 m^3/s (4.35%) in comparison with baseline scenario period (Table 6). However, in mean dry season, stream discharge in 2020 decreases 0.05 m^3/s (1.09%) in comparison with baseline scenario period, from 4.65 m^3/s (2010) to 4.60 m^3/s (2020). Meanwhile, precipitation decreases 8.46 mm (2.77%) from 305.80 mm in 2010 to 297.34 mm in 2020. Therefore, mean annual stream discharge just increases 3.46% (from 14.42 m^3/s to 14.93m^3/s) with respect to baseline period. Another reason made stream discharge change in scenario 1 is that 2,617.58 ha (7.10%) forest-mixed land were converted into urban land and 4,941.57 ha (13.40%) into agricultural land (corn 1,635.12 ha and agriculture land-row crops 3,306.45 ha). Increase agricultural land for crop production need more water in the dry season and thus cause stream discharge decrease 1.09%.

Table 4 Coefficients of monthly *NSE* and *PBIAS* as calibrating and validating stream discharge.

Simulation period	Period	Monthly *NSE*	*PBIAS* (%)
Calibration	2002-2007	0.76	6.54
Validation	2007-2012	0.87	4.74

Table 5 Observed and simulated stream discharge for each period in Nghinh Tuong watershed.

Items	Calibration (2002-2007)	Validation (2008-2012)	Entire period (2002-2012)
Observed (m^3/s)			
Mean annual	15.00	10.90	12.95
Mean wet season	24.85	18.55	21.70
Mean dry season	5.13	3.35	4.23
Simulated (m^3/s)			
Mean annual	14.42	10.71	12.55
Mean wet season	24.15	18.35	21.24
Mean dry season	4.65	3.10	3.90

Table 6 Seasonal stream discharge scenario 1 compared with baseline scenario (m^3/s).

Items	Precipitation (mm)		Stream discharge (m^3/s)			
	Baseline scenario	Scenario 1	Baseline scenario	Scenario 1	Difference	Change (%)
Mean annual	1,698.0	1,753.12	14.42	14.93	0.50	3.46
Mean wet season	1,390.2	1,453.78	24.15	25.20	1.05	4.35
Mean dry season	305.8	297.34	4.65	4.60	-0.05	-1.09

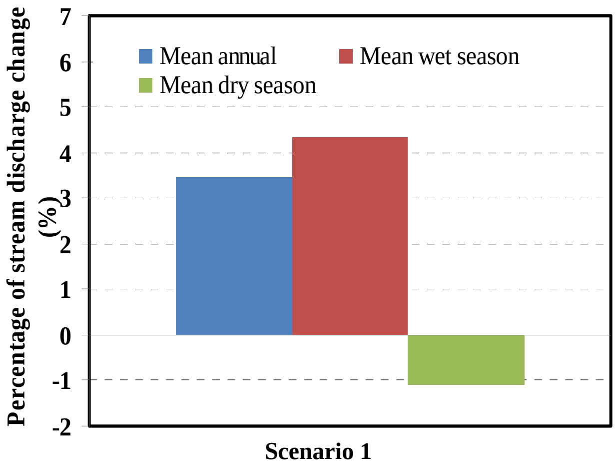


Fig. 4 The changes of stream discharge compares with baseline scenario in Nghinh Tuong subwatershed.

4. Conclusions

In this research, SWAT model was set up, calibrated and validated successfully at Nghinh Tuong watershed with the drainage area of 39,700.58 ha. In order to assess the impacts of land use change on stream discharge and sediment yield in Nghinh Tuong watershed, the land use scenarios were formulated combining with climate change in SWAT simulation. In scenario 1, agricultural land (corn, orchard and tea) increases 9,782.67 ha (2.45%), meanwhile forest (forest-mixed) decreases 1,091.77 ha (2.75%) as compared to baseline scenario. Additionally, precipitation increases 3.74% in mean wet season, but decreases 0.5% in mean dry season with respect to baseline period. SWAT was able to simulate stream discharge and sediment yield for Nghinh Tuong watershed successfully not only for baseline scenario but also for scenario 1. During calibration process, sensitive parameters were identified as: curve number (*CN2*), soil evaporation compensation factor (*ESCO*), plant uptake compensation factor (*EPCO*), cover and management factor (*C* factor). Simulation result for baseline scenario showed a good agreement between observed and simulated data. SWAT shows its high capability in stream discharge. Through this research, we have constructed characteristics database and spatial databases for SWAT model. The results of running the model calculated stream discharge for the period (2002-2012) shows that: annual stream discharge was 12.55 m^3/s; mean in wet season was 21.24 m^3/s; mean in dry season was 3.90 m^3/s; the results of the evaluation model through the *NSE* and *PBIAS* index were quite good. In brief, SWAT proves its ability in simulation stream discharge and sediment yield in watershed level. It is a useful tool to assist water quantity and quality management process in Nghinh Tuong watershed.

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