Journal of Environmental Science and Engineering, 5 (2011) 1063-1072

Impact of Climate Change and Deforestation on Stream Discharge and Sediment Yield in Phu Luong Watershed, Viet Nam

D.B. Phan[1], C.C. Wu[2] and S.C. Hsieh[2]

1. Institute of Tropical Agriculture and International Cooperation, National Pingtung University of Science and Technology, Pingtung 912, Taiwan

2. Department of Soil and Water Conservation, National Pingtung University of Science and Technology, Pingtung 912, Taiwan

Received: April 20, 2011 / Accepted: May 5, 2011 / Published: August 20, 2011.

Abstract: The purpose of this paper is to apply "Soil and Water Assessment Tool (SWAT)" model to assess the impacts of climate change and deforestation on stream discharge and sediment yield from Phu Luong watershed in Northern Viet Nam. Among the three climate change scenarios B1, B2, and A2, representing low, medium, and high levels of greenhouse gas emission, respectively were set up for Viet Nam, the B2 scenario was selected for this study. Two land use scenarios (S1-2030 and S2-2050) were formulated combination with climate change in WSAT simulation. In B2 climate change scenario, mean temperature increases 0.7 ºC (2030) and 1.3 ºC (2050); annual rainfall increases 2.1% (2030) and 3.80% (2050) respect to baseline scenario. The results show that the stream discharge is likely to increase in the future during the wet season with increasing threats of sedimentation.

Key words: SWAT, climate change, deforestation, sediment yield, stream discharge.

1. Introduction

Climate change and deforestation is one of the most significant challenges that all living matters on the Earth needs to face. It will affect living habitats, productions, and environment worldwide. The Intergovernmental Panel on Climate Change (IPCC) report reaffirms that the climate is changing in ways that cannot be accounted for by natural variability and that global warming is occurring [1]. The scientific consensus is that future increases of temperature will result in elevated global-mean temperatures with subsequent effects on regional precipitation, evapotranspiration, soil moisture and altered flow regimes in streams and rivers [2].

Land use change and deforestation is also becoming important and has attracted a lot of scientific interest due to the close correlation between land use change and flood disaster and water resources management along with climate change. Land use changes directly affect evapotranspiration, infiltration and soil water storage which change the dynamics of surface runoff, subsurface runoff and groundwater recharge. The accompanying spatial and temporal distributions of vegetation cover change the parameters of calculating evaporation from soil and transpiration from vegetation [3].

However, assessing the impacts of climate change and deforestation on water resource management is complicated by the spatial resolution of climate change predictions. Limited efforts have been carried out in Viet Nam regarding the potential impacts of climate change on water resource management systems.

Soil and Water Assessment Tools [4] known as SWAT has been used since 1993 mainly by hydrologists for watershed hydrology related issues. Muttiah and Wurbs [5] used SWAT to simulate the

Corresponding author: D.B. Phan, Ph.D. candidate, research fields: soil and water conservation, resources and environmental management. E-mail: binh_tuaf@yahoo.com.

impacts of historical climate trends versus a 2040-2059 climate change projection for the 7,300 km^2 San Jacinto River basin in Texas. They reported that the climate change scenario resulted in a higher mean stream discharge might induce greater flooding, but the frequency of the normal and low stream discharges decreased. Gosain et al. [6] simulated the impacts of a 2041-2060 climate change scenario on stream discharges from 12 major river basins in India, ranging in size from 1,668 to 87,180 km^2. Stream discharge was found to generally decrease, and the severity of both floods and droughts increased in response to the climate change projection. Nearing et al. [7] compared runoff and erosion estimates from SWAT versus six other models in response to six climate change scenarios for the 150 km^2 Lucky Hills watershed in southeastern Arizona. The responses of all seven models were similar across six scenarios.

They concluded that climate change could potentially result in significant soil erosion increases if necessary conservation efforts are not implemented. Therefore, the aim of this study is to apply SWAT model in Phu Luong watershed to assess the impact of climate change and deforestation on stream discharge and sediment yield in northern Viet Nam.

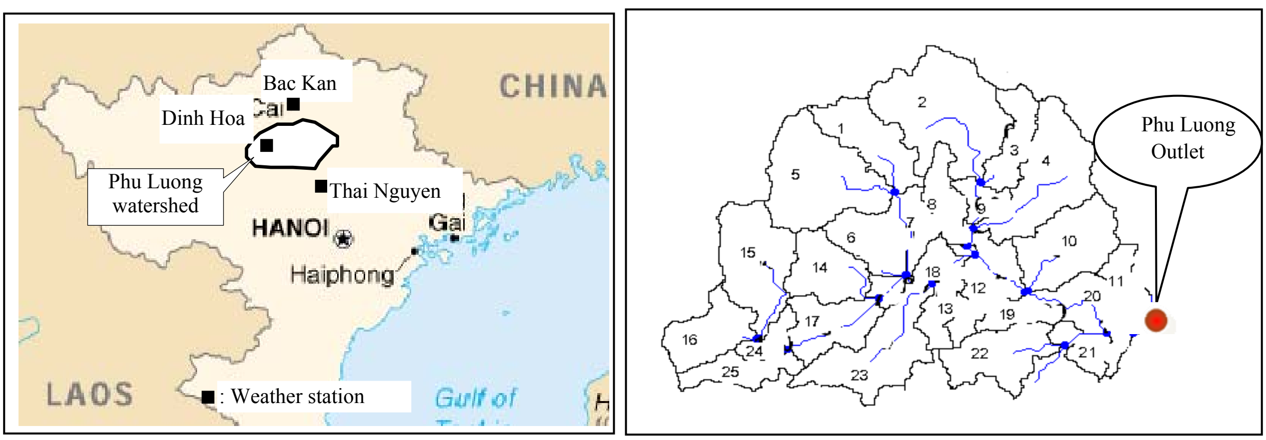
2. Methodology

2.1 Study Area

The Phu Luong watershed is located in northern Viet Nam, between 21°32'00"-22°58'00"N and 105° 34'04"-105°53'00"E. The watershed has an area of 338.81 km^2 and agriculture; mainly arable and pasture lands dominants the land use. The elevation ranges from 54 to 1498 m above sea level with the mean elevation of 284.8 m (Fig. 1). The length of the main stream is 45 km. High rainfall events in combination with less permeable soil formations caused significant runoff and subsequently high soil losses and sediment yield. Data from Thai Nguyen Meteorological and Gauging station show that the study area is influenced by tropical monsoon climate. The average annual rainfall and temperature is 2000-2500 mm and 22 °C, respectively, and the highest precipitation usually occurs from June to August which constitutes more than 70% total annual rainfall. The winter season, November-March, is mostly dry with the average temperature under 15 °C and the lowest temperature recorded in recent years is 3 ºC. The summer, April-October, is the hot rainy season with the average temperature of 26 °C, the highest temperature recorded so far is 39 °C [8].

2.2 Brief Descriptions of SWAT Model

SWAT is a physically based, continuous-time hydrologic model with an ArcView-GIS interface developed by the Blackland Research and Extension Center and the United States Department of Agriculture – Agricultural Research Service



(A) **(B)**

Fig. 1 (A)/Location, and (B)/sub-watershed and stream network of Phu Luong watershed.

(USDA-ARS) [9] to predict the impact of land management practices on water, sediment and agricultural chemical yields in large, complex basins with varying soil type, land use and management conditions over long periods of time. SWAT delineates watersheds into sub-basins interconnected by a stream network. Each sub-basin is further divided into hydrologic response units (HRUs) based upon unique soil and land class characteristics. SWAT sums the flow, sediment and nutrient loading from each sub-basin HRU and the resulting loads are then routed through channels, ponds, and reservoirs to the watershed outlet [10]. A single growth model in SWAT, based on a simplification of Erosion Productivity Impact Calculator (EPIC) crop model, is used for simulating all crops development [11]. Phenological development of a crop is based on daily heat unit accumulation. SWAT also uses WXGEN weather generator model [12] to generate climate data or to fill gaps in the measured records.

The hydrological processes of SWAT are divided into two phases [13]: (1) the land phase, which controls the amount of water, sediment and nutrients received by a water body; and (2) the water routing phase, which simulates water movement through the channel network. The hydrologic cycle of SWAT is based on the water balance equation:

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad (1)$$

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 (days), R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration on day i (mm), W_{seep} is the amount of water entering the vadoes zone from the soil profile on day i (mm), and Q_{gw} is the amount of return flow on day i (mm) [14].

Erosion and sediment yield are estimated for each sub-basin with the Modified Universal Soil Loss Equation (MUSLE). Sediment yield estimation in MUSLE [15] is written as:

$$Sed = 11.8(Q_{surf} \cdot q_{peak} \cdot area_{hru})^{0.56} \cdot K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE} \cdot CFRG \quad (2)$$

Where, Sed is the sediment yield on a given day (metric tons), Q_{surf} is the surface runoff volume (mm/ha), q_{peak} is the peak runoff rate (m^3/s), $area_{hru}$ is the area of the hydrologic response unit (HRU) (ha), K_{USLE} is the Universal Soil Loss Equation (USLE) soil erodibility factor (0.013 metric ton-m^2 -hr/m^3-metric ton-cm), C_{USLE} is the USLE cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor [16] and $CFRG$ is the coarse fragment factor.

The channel sediment routing equation uses a modification of Bagnold's sediment transport equation [17] that estimates the transport capacity of the streamflow as a function of flow velocity. The model either deposits excess sediment or re-entrains sediment through channel erosion depending on the sediment load entering the channel.

2.3 Preparation of the SWAT Model Inputs

Spatial data required by the model include a digital elevation model (DEM), land use map and soil map. In this study, the DEM map was collected from Department of Information and Communication technology for Natural Resources and Environment, Ministry of Natural Resources and Environment. The DEM map was used to delineate the subwatersheds and generate the slope map of the test watershed for the SWAT simulations. The land use map was collected from the Department of Natural Resources and Environment of Thai Nguyen province, and field survey data in 2010. The soil map of the study area was extracted from the soil map of the Viet Nam prepared by Viet Nam Soil and Fertilizers Research Institute. Specific soil properties such as texture, organic matter content, soil erodibility, infiltration rate among others were compiled from literatures [18].

Time series of meteorological data such as rainfall, temperature, solar radiation, relative humidity, and wind speed were compiled into proper format required by SWAT from previous weather data obtained from Thai Nguyen, Bac Kan and Dinh Hoa weather station. Time series of stream flow (1996-2010) and sediment yield (2002-2010) measured was used to calibrate and validate the model.

2.4 Climate Change and Land Use Scenarios

The climate change is believed to be primarily dependent upon greenhouse gas emission level. Greenhouse gas emission has found to be correlated with human activities such as industry, agriculture, transportation, deforestation etc. Hence, grounds for determining greenhouse gas emission scenarios are: (1) economic growth at a global scale, (2) global population and consumption, (3) living standards and behavior, (4) energy sources and consumption, (5) technology transfer, and (6) land use change, etc.

In the Special report on emission scenarios in 2000, Intergovernmental Panel on Climate Change (IPCC) introduced 40 scenarios that reflect relatively diversified possibilities of greenhouse gas emission in the 21st century. These emission scenarios are classified into four families as A1, A2, B1 and B2 family [19].

Criteria of method selection for climate change scenario development in Viet Nam include: (1) plausibility of global climate change; (2) level of climate change; (3) inheritability; (4) updating; (5) local appropriateness; (6) completeness of scenarios; and (7) possibility of self updating [20]. Based on the analysis of the above mentioned criteria, the results from Stochastic Weather Generator (LARS-WG) software [21] and statistical downscaling method are selected for the development of climate change scenarios. Climate change scenarios for temperature and rainfall were developed for seven climate zones in Viet Nam. The resultant scenarios B1, B2, and A2 represents low, medium, and high level of greenhouse gas emission, respectively. In this study the northern zone and B2 scenario was selected with characteristics as shown in Table 1.

Table 1 Changes in annual mean temperature (℃) and annual rainfall (%) relative to those from 2000-2009 in northern Viet Nam for B2 scenario.

Scenario	Year	
	2030	2050
Rainfall		
Mean annual	2.1	3.8
Mean wet season	4.8	8.9
Mean dry season	-0.6	-1.3
Mean temperature		
Mean annual	0.7	1.3
Mean wet season	0.7	1.2
Mean dry season	0.8	1.4

The daily data was obtained and used together with observed data in LARS-WG to generate monthly rainfall and temperature changes. Three stations, Gia Bay, Bac Kan, and Dinh Hoa were chosen for climate change scenario generation.

Land use scenarios were formulated base on the social economic development and population growing within the watershed. The population and household were predicted for 2030 and 2050 (Table 2) and predicted of their land use demand (Table 3) to settle and maintain food security.

Table 4 shows 3 land use scenarios for Phu Luong watershed and the baseline scenario is the land use currently implemented. Scenario 1 (2030): converted 456.20 ha (1.24%) forest-mixed land into urban land and 1635.12 ha (4.43%) into agricultural land (Corn); the other land uses remained unchanged. Scenario 2 (2050): converted 2617.58 ha (7.10%) forest-mixed land into urban land and 4941.57 ha (13.40%) into agricultural land (Corn (1635.12 ha) and Agriculture land-row crops (3306.45 ha)); the other land uses

Table 2 Prediction of population and household for Phu Luong watershed.

Year	1990	1997	2000	2005	2010	Prediction			
						2030	Compare to 2010	2050	Compare to 2010
Population	88455	102450	109121	120356	130702	171377	+40675	253627	+122925
Household	19201	22421	23749	26754	29059	32657	+3598	49702	+20643

Table 3 Prediction of urban and agricultural land for Phu Luong watershed.

Land use type	2030		2050	
	Area (ha)	%	Area (ha)	%
Urban	+ 456.20[a]	1.24	+2617.58[b]	7.10
Agricultural	+1635.12[c]	4.43	+4941.57[d]	13.40
Total	+2091.32	5.67	+7559.15	20.50

(a and b = (Mean of urban land/household) × (number of household in 2030 and 2050 respectively); c and d = (Mean of agricultural land/person) × (population in 2030 and 2050 respectively)).

remained unchanged.

2.5 Model Performance Evaluation

This study uses Nash-Sutcliffe efficiency (NSE) [22], and percent bias (PBIAS) to evaluate model performance. The NSE value is calculated using the following Eq. (3):

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Q_{obs}^{i} - Q_{sim}^{i})^2}{\sum_{i=1}^{n}(Q_{obs}^{i} - Q_{obs-mean})^2} \quad (3)$$

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

PBIAS is used to determine if the average tendency of the simulated data is either larger or smaller than its observed counterparts [23]. PBIAS is calculated using Eq. (4):

$$\text{PBIAS} = \frac{\sum_{i=1}^{n}\left(Q_{obs}^{i} - Q_{sim}^{i}\right)}{\sum_{i=1}^{n} Q_{obs}^{i}} \times 100\% \quad (4)$$

All parameters in Eq. (4) shares the same definitions as that shown in Eq. (3).

2.6 Model Calibration and Validation

The entire Phu Luong watershed was divided into 25 sub-watersheds based on the similarity of land use to allow consideration of significant spatial detail for climatic, soil, topographic, and land cover variations within Phu Luong watershed (Fig. 1B). Table 5 presents a listing of the respective land cover types, and USLE C factors [24] for each land cover type delineated. The land use type and topography of each sub-watershed were both extracted from the GIS database. Soil parameters for the corresponding soil series extracted from the GIS system were obtained from the Soils database contained in SWAT.

Site-measured daily rainfall data were used for entire watershed stream discharge simulation. Measured daily maximum and minimum temperatures were obtained from Bac Kan, Dinh Hoa and Thai Nguyen station. Monthly stream discharge measured at the watershed outlet (Phu Luong station) for 8 years of record from 1996 to 2003 was designated for model calibration, and

Table 4 Land use scenarios and USLE C factor delineated for Phu Luong watershed.

Land use type	SWAT Code	Baseline Scenario		Scenario 1 (2030)		Scenario 2 (2050)		C factor
		Area (ha)	%	Area (ha)	%	Area (ha)	%	
Rice	RICE	4027.96	10.92	4027.96	10.92	4027.96	10.92	0.030
Corn	CORN	1093.17	2.96	2728.29	7.40	2728.29	7.40	0.200
Agri. land-row crops	AGRR	3925.60	10.64	3925.60	10.64	7232.05	19.61	0.200
Orchard	ORCD	1150.88	3.12	1150.88	3.12	1150.88	3.12	0.010
Pasture	PAST	4917.78	13.33	4917.78	13.33	4917.78	13.33	0.030
Forest-deciduous	FRSD	2891.26	7.84	2891.26	7.84	2891.26	7.84	0.001
Forest-evergreen	FRSE	4002.66	10.85	4002.66	10.85	4002.66	10.85	0.001
Forest-mixed	FRST	9604.40	26.04	7513.08	20.37	2045.25	5.55	0.001
Water	WATR	1584.34	4.30	1584.34	4.30	1584.34	4.30	0.000
Urban	URMD	3683.50	9.99	4139.70	11.22	6301.08	17.08	0.008
Total		36881.55	100	36881.55	100	36881.55	100	

records from 2004 to 2010 were designated for validation. For sediment, 5 years data recorded from 2002 to 2006 and 4 years from 2007 to 2010 were used for calibration and validation, respectively. To account for spatial variability in topographic, soil types, and land use factors in watershed, parameters governing stream discharge response in SWAT were calibrated in a distributed fashion.

3. Results and Discussion

3.1 Stream Discharge and Sediment Load Simulation

The daily simulated stream discharge in watershed was lumped into monthly total and compared with the measured stream discharge at the watershed outlet (Phu Luong). Fig. 2 shows that the stream discharge matched well with the measured values at watershed's outlet. Agreement between measured and simulated stream discharge at watershed was further indicated by a relatively high coefficient of coefficient of determination, R^2, were 0.85 and 0.68 (Fig. 3). 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 1996 to 2003, monthly NSE was 0.96, while PBIAS was 4.63. For the validation period (2004-2010) NSE and PBIAS were higher than those for the calibration period with respective values of 0.99 and 3.37 (Table 5). Moreover, the adequacy of the model was further demonstrated by its clear response to extreme rainfall events resulting in high stream discharge (Fig. 2).

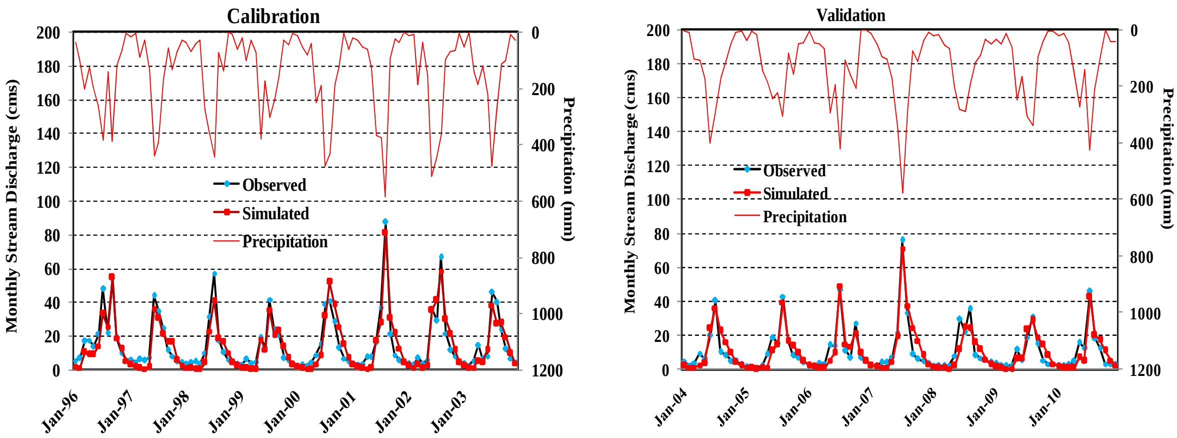


Fig. 2 Observed versus simulated monthly stream discharge and precipitation of Phu Luong during calibration and validation periods.

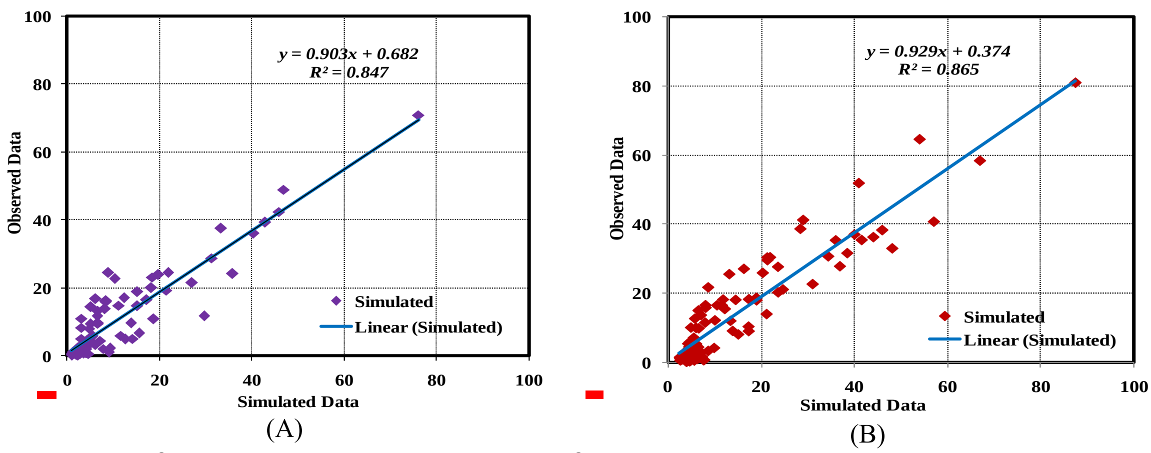


Fig. 3 Scatter plot of monthly simulated versus observed of stream discharge in Phu Luong outlet gauged station for (A)/calibration and (B)/validation.

Table 5 Monthly stream discharge and sediment load coefficient of Nash-Sutcliffe efficiency (NSE), and percent bias (PBIAS) of Phu Luong river.

Items	Simulation period	Period	Monthly NSE	PBIAS (%)
Stream discharge	Calibration	1996-2003	0.96	4.63
	Validation	2004-2010	0.99	3.37
Sediment load	Calibration	2002-2006	0.93	-13.77
	Validation	2007-2010	0.95	-11.91

These results indicate that important hydrologic processes such as runoff in tropical watersheds can be modeled realistically using the SWAT model.

Temporal variation of observed and simulated sediment yield at the outlet of watershed was shown in Fig. 4. The time to peak of sediment yield was adequately captured by the model. Moriasi et al., (2007) [25] concluded that a model performance of sediment is very good if PBIAS < ±15%; good if ±15% ≤ PBIAS < ±30%; satisfactory if ±30% ≤ PBIAS < ±55% and unsatisfactory if PBIAS ≥ ±55%. In this study the PBIAS values were very good (-13.77%) for calibration and (-11.91%) for validation period (Table 5). The negative value of PBIAS indicated that the sediment load was overestimated. SWAT tends to overestimate sediment loads for all months of year, except August and September of the validation period (Fig. 4). This behavior of the simulated sediment yields indicates high deposition of sediments as they travel along the channel. This was partly addressed during the calibration by adjusting the linear factor (SPCON) and exponential factor (SPEXP) for channel sediment routing to their maximum values of 0.01 and 2, respectively. The discrepancy between the simulated and observed sediment yield values may be attributed to channel erosion, especially during high flows, and other factors which the model could not adequately capture such as channel scouring and erosion and the presence of temporary channel embankment, which is used by the farmers to retard channel flow velocity. Nevertheless, the overall adequacy of the model to simulate sediment yields in the watershed indicates its usefulness as a management tool to predict the effects of land use changes in relatively small watersheds. It should be noted that most of the previous applications of SWAT dealt with large watersheds. This study has therefore provided additional evidence that the SWAT model can also generate reasonable hydrologic simulations even for relatively small watersheds and predict the effects of climate changes and deforestation in mid-size watersheds in Viet Nam. The SWAT model performance in this study, as NSE, is also comparable with the other SWAT model applications in equally small watersheds as reported by Gassman et al. [26].

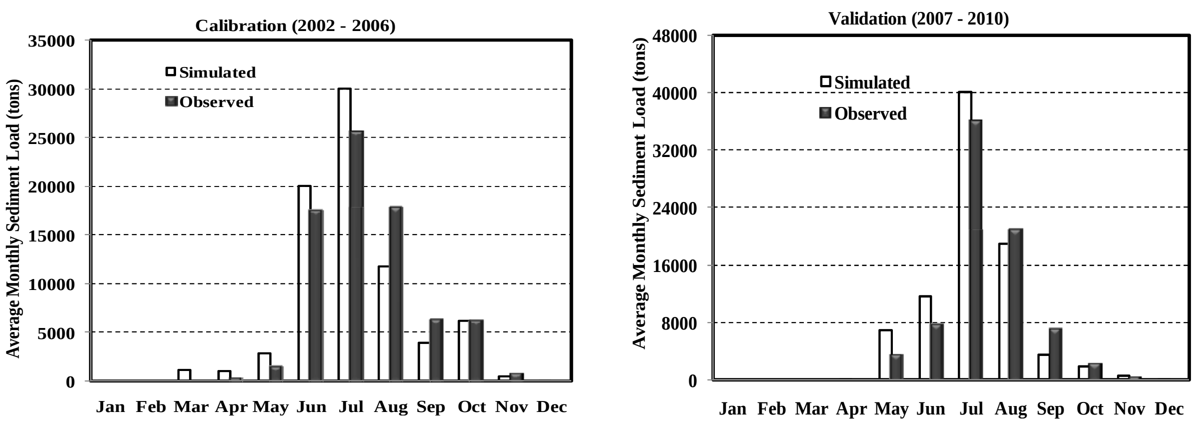


Fig. 4 Observed versus simulated average monthly sediment load during the calibration and validation periods of Phu Luong watershed.

3.2 Impact of Climate Change and Deforestation on Stream Discharge and Sediment Yield

The climate change data including percentage change of rainfall and absolute change of temperature were processed for the time slices of 2030s, and 2050s. The period of 2000-2009 was chosen as the baseline. The monthly changes of rainfall in terms of percentage change and absolute change of temperature for each time slice were then imposed in SWAT. Monthly averages were then calculated for these times slices and superimposed in SWAT to represent changes in climate. The changes of rainfall and temperature are given in Table 2. Rainfall changes are highly variable with the highest changes in wet season showing increases in the 2030s, and 2050s. Increases in rainfall in wet season could result in high surface runoff and that could aggravate the existing problem of flooding in lower Phu Luong watershed. Mean annual temperatures increase 0.7 ºC in 2030 and 1.3 ºC in 2050s.

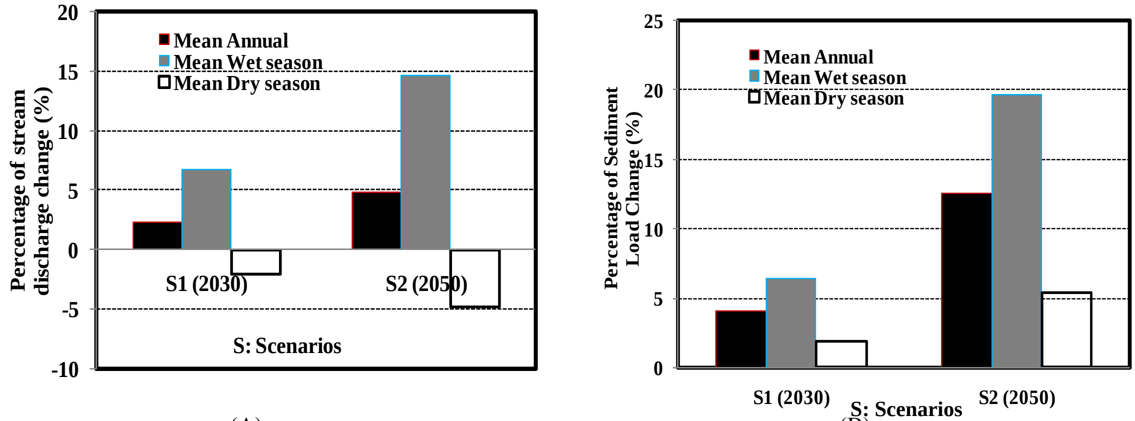
To assess the effects of climate change and deforestation in the study area, the calibrated model was run to simulate land use changes on stream discharge and sediment yield. Results of the simulations (Table 6 and Fig. 5A) indicate that: in combination of climate change and deforestation, stream discharge increases or decrease is directly proportion to rainfall increases or decreases. For instance, in scenario 1 (2030) (converted 456.20 ha (1.24%) forest-mixed land into urban land and 1635.12 ha (4.43%) in to agricultural land (Corn)), in wet season when rainfall increase 4.8%, the stream discharge will increase 6.72% compare to baseline scenario. Meanwhile in dry season, rainfall decrease 0.6% yields a reduction of stream discharge of 2.07%.

In scenario 2 (2050) (forest (forest-mixed) land reduces 2617.58 ha (7.10%) into urban land and 4941.57 ha (13.40%) in to agricultural land (Corn (1635.12 ha) and agricultural land-row crops (3306.45 ha)). An increase of about 14.57% of stream discharge occurs in wet season when rainfall increase 8.9%, while decrease 4.82% in dry season with a decrease 1.3% of rainfall respect to baseline scenario. Such conditions will cause significant soil erosion, depleting soil nutrients, sedimentation of reservoirs, and flooding of low lying areas at the downstream. The eroded sediment may also adsorb and transport agricultural contaminants such as pesticides, phosphate and heavy metals posing serious threat to aquatic life [27] and may create health problems for farm families and those living downstream. These results can impact the wildlife and fish in the streams and also the water supply of the watershed especially during dry periods.

A dramatic increase in sediment yield is predicted as rainfall increase and forest areas are converted to urban land and in to agricultural land (Corn). Simulation results show that the mean annual of sediment yield increases in both scenarios (Fig. 5B) The current mean annual sediment yield of the watershed is 6797 tons·yr^{-1}. Figures in Table 6 show that increasing in flow discharge will in general increase mean annual sediment load for all scenarios. For instance, in cenario 1, when converted 456.20 ha (1.24%) forest-mixed land into urban land and 1635.12 ha (4.43%) in to agricultural land (Corn) with rainfall of wet season increases 4.8%, the sediment load increases 6.45% in wet season and 1.82% in dry season. Scenario 2 produces significant increase in sediment loads during mean wet season by 19.63% and 5.41% in dry season

Table 6 Percentages of stream discharge and sediment load change (%) with respect to baseline period for mean annual, wet season and dry season.

Items	Scenario 1 (2030)	Scenario 2 (2050)
Stream discharge		
Mean annual	2.32	4.87
Mean wet season	6.72	14.57
Mean dry season	-2.07	-4.82
Sediment load		
Mean annual	4.13	12.52
Mean wet season	6.45	19.63
Mean dry season	1.82	5.41



(A) (B)

Fig. 5 Percentage of (A)/stream discharge and (B)/sediment yield change in mean annual, wet season and dry season with respect to baseline scenario.

when forest (forest-mixed) land reduces 2617.58 ha (7.10%) into urban land and 4941.57 ha (13.40%) in to agricultural land (Corn (1635.12 ha) and agricultural land-row crops (3306.45 ha)). Deforestation and cultivation corn in the slope land are the main reason of increasing the sediment load in Phu Luong watershed. Thus, rather than expanding the current agricultural areas to increase crop production, efforts should be exerted to improve present crop cultural management practices of farmers and train them to employ soil conservation practices to reduce soil erosion rate, thereby rehabilitating and sustaining the whole watershed.

Considering that Phu Luong watershed is a part of the Song Cau river basin (a biggest river basin in the northern Viet Nam), an increase in stream discharge and sediment yield will have serious environmental effects not only to the communities living in the study area but also those living downstream. Efforts should therefore be exerted to address forest conversion to agricultural crops. Policies addressing this problem should be done both at the local and national level. Likewise, an intensive information and education campaign on the consequences of forest conversion and ways of rehabilitating the watershed should be done.

4. Conclusions

The SWAT model was parameterized and calibrated in selected Phu Luong watershed in the northern Viet Nam with an aggregate area of 36881.55 ha to simulate the effects of climate change and deforestation on stream discharge and sediment yield. Results indicate that SWAT adequately predicted the stream discharge of the watershed with Nash-Sutcliffe Efficiencies ranging from 0.96 to 0.99. Likewise, the model adequately predicted the sediment yield with NSE ranging from 0.93 to 0.95. In the 2050s the percentages of stream discharge of mean wet season increase at 14.57%, meanwhile, mean dry season decreases 4.82% with respect to baseline scenario. That means more floods in wet season and draught in dry season may occur in the future. Consequently, this will increase sediment yield of 19.63% in wet season respect to baseline scenario. This study showed that SWAT model can be used as a management tool for modeling the impact of climate change and deforestation in Viet Nam watersheds.

Acknowledgement

The authors' sincere thanks go to Viet Nam Government Agencies for providing data on Phu Luong watershed and for preparing the detailed land use map. In particular, the corresponding author is especially grateful to Taiwan Scholarship Office for funding his Ph.D. programme.

References

[1] Intergovernmental Panel on Climate Change (IPCC), Climate Change 2007: IPCC Contribution of Working Group to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, 2007, pp. 145-147.

[2] N.W. Arnell, Climate-change impacts on river flows in Britain, J. Water Envir. Management 18 (2004) 112-117.

[3] G.A. Park, S.R. Ahn, Y.J. Lee, H.J. Shin, M.J. Park, S.J. Kim, Assessment of climate change impact on the inflow and outflow of two agricultural reservoirs in Korea, Trans. ASAE 52 (2009) 1869-1883.

[4] S.L. Neitsch, J.G. Arnold, J.R. Kiniry, J.R. Williams, Soil and Water Assessment Tool Theoretical Documentation, Version 2005, Temple, Tex.: USDA-ARS Grassland, Soil and Water Research Laboratory, Texas, USA, 2005.

[5] R.S. Muttiah, R.A. Wurbs, Modeling the impacts of climate change on water supply reliabilities, Intl. Water Resources 37 (2002) 407-419.

[6] A.K. Gosain, S. Rao, D. Basuray, Climate change impact assessment on hydrology of Indian river basins, Current Sci. 90 (2006) 346-353.

[7] M.A. Nearing, V. Jetten, C. Baffaut, O. Cerdan, A. Couturier, M. Hernandez, et al., Modeling response of soil erosion and runoff to changes in precipitation and cover, Catena 61 (2005) 131-154.

[8] General Statistics Office of Viet Nam, Statistical Year Book 2008, National Political Publishing House, Ha Noi, Viet Nam, 2008, pp. 367-380.

[9] J.G. Arnold, R. Srinivasan, R.S. Muttiah, J.R Williams, Large area hydrologic modeling and assessment part I: Model development, J. of Amer. Water Resource Assoc. 34 (1998) 73-89.

[10] J.G. Arnold, P.M. Allen, D.S. Morgan, Hydrologic model for design and constructed wetlands, Wetlands 2 (2001) 167-178.

[11] N. Sharpley, J.R. Williams, EPIC-Erosion Productivity Impact Calculator Model Documentation, U.S. Department of Agriculture, Agricultural Research Service, Tech. Bull, 1990, pp. 175-199.

[12] N.J. Rosenberg, D.L. Epstein, D. Wang, L. Vail, R. Srinivasan, J.G. Arnold, Possible impacts of global warming on the hydrology of the Ogallala aquifer region, Clim. Change 42 (1999) 677-692.

[13] S. Hiroaki, T. Ikuo, Numerical analyses on seasonal variations of nutrient salts and load discharges in Abashiri River Basin, in: 2009 International SWAT Conference Proceedings, 2009, pp. 241-248.

[14] J.R. Williams, Computer Models of Watershed Hydrology-Chapter 25: The EPIC Model, Water Resources Publications, 1995, pp. 909-1000.

[15] J.R. Williams, C.A. Jones, P.T. Dyke, A modeling approach to determining the relationship between erosion and soil productivity, Trans. of the ASABE 21 (1984) 129-144.

[16] W.H. Wischmeier, D.D. Smith, Predicting Rainfall Erosion Losses-A Guide to Conservation Planning, Agricultural Handbook No. 537, US Department of Agriculture, 1978.

[17] R.A. Bagnold, Bedload transport in natural rivers, Water Resources Research 13 (1977) 303-312.

[18] T.C. Ton, Vietnam Soils, 2nd ed, Agricultural Publishing House, Hanoi, Viet Nam, 2006.

[19] Intergovernmental Panel on Climate Change (IPCC), Working Group I, Climate change 2001: Contribution of Working Group I to the Third Assessment Report of the IPCC, Cambridge University Press, Cambridge, UK, 2001.

[20] Ministry of Natural Resources and Environment (MORE), Climate change, sea level rise scenarios for Viet Nam, Ha noi, Viet Nam, 2009.

[21] M.A. Semenov, E.M. Barrow, LARS-WG: A stochastic weather generator for use in climate impact studies, User Manual, 2002.

[22] J.E. Nash, J.V. Sutcliffe, River flow forecasting through conceptual models. Part I-A discussion of principles, J. Hydrology 10-3 (1970) 282-290.

[23] H.V. Gupta, S. Sorooshian, P.O. Yapo, Status of automatic calibration for hydrologic models: Comparison with multilevel expert calibration, Journal of Hydrologic Engineering 4 (1999) 135-143.

[24] A. Karaburun, Estimation of C factor for soil erosion modeling using NDVI in Buyukcekmece watershed, Ozean Journal of Applied Science 3 (2010) 77-85.

[25] D.N. Moriasi, J.G. Arnold, M.W. Van Liew, R.L. Bingner, R.D. Harmel, T.L Veith, Model evaluation guidelines for systematic quantification of accuracy in watershed simulations, Trans. ASABE 50 (2007) 885-900.

[26] P.W. Gassman, M.R. Reyes, C.H. Green, J.G. Arnold, The soil and water assessment tool: historical development, applications, and future research directions, Trans. ASABE 50 (2007) 1211-1250.

[27] V.B. Ella, Simulating soil erosion and sediment yield in small upland watersheds using the WEPP model, in: I. Coxhead, G.E. Shively (Eds.), Land Use Change in Tropical Watersheds: Evidence, Causes and Remedies, CABI Publishing, Wallingford, Oxfordshire, UK, 2005, pp. 109-125.