

Response of Streamflow and Soil Erosion to Climate Change and Human Activities in Nam Rom River Basin, Northwest of Vietnam

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ABSTRACT

Change in climate and land use is the main cause of increasing streamflow and soil erosion. However, very few studies have investigated these changes on a basin scale. Thus, this study used the Soil and Water Assessment Tool (SWAT) method to evaluate the effects of both land use and climate change effects on streamflow, sediment yield, and soil loss in the Nam Rom River Basin, Northwest of Vietnam. The outputs of the SWAT model demonstrated it to be a strong tool in predicting catchment hydrology, sediment transport, and soil loss. Meanwhile, based on SWAT model simulation, it was found that reforestation and management practices executed between 1992 and 2015 strongly contributed to the decreased sediment yield. The potential for climate change clearly leads to an increase to sediment yield and significantly more soil loss. The combined climate and land use change analysis indicated that land use planning could be adopted to mitigate streamflow (16.9%) and sediment load (4.9%) in the future, in conjunction with the projected direct impact of climate change. In conclusion, the findings in the present study contribute useful knowledge, methods, and techniques that could be reapplied to other regions in Vietnam and the world in terms of land and water conservation.

1. INTRODUCTION

Global climate change in temperature and precipitation patterns are expected to alter water resource availability, sediment transport, and pollutants over the world (Duan et al., 2020; Krysanova and White, 2015; Ngo et al., 2015; Wu et al., 2012). Land use and land cover (LULC) change have disturbed overland flow generation and resulted in changing hydrological processes and the transport of pollutants (Van and Cochard, 2017; Van, 2007). LULC and climate change are recognized as the main elements in controlling the catchment hydrology, sediment yield and soil erosion (Boru et al., 2019; Shrestha et al., 2016; Alansi et al., 2009). Therefore, understanding hydrological responses, sediment transport, and soil loss plays a key role in developing long term LULC and water conservation and sustainable watershed preservation.

Recently, several studies have reported the impacts of LULC and climate change on hydrology and soil erosion in different spatial and temporal scale

(Ziegler et al., 2007; Nie et al., 2011; Phan et al., 2011; Khoi and Suetsugi, 2014; Ngo et al., 2015; Uniyal et al., 2015). Results of previous studies found that the increase in precipitation would likely increase changes of erosion by approximately 12% to 45% (Son and Binh, 2020; Van, 2007). In addition, change in climate and forest types has a significant impact on streamflow and sediment transport, however, no clear distinction was made between individual and combined effects of LULC and climate change on streamflow and sediment yield. Few research undertakings have also been conducted using the remote sensing (RS) and Soil and Water Assessment Tool (SWAT) to evaluate and predict hydrological responses and soil erosion in Southeast Asia due to a lack of data sharing and limited temporal and spatial data (Ngo et al., 2015).

The Nam Rom Watershed is a typical watershed located in Dien Bien Province which plays an important role in supplying freshwater for its locality. Forests and crops like rubber, rice, maize, and cassava are dominant in this area; however, under the pressure

impacts of population growth a dramatic decline in forest areas and increased cash crop (maize and cassava) and built-up areas have taken place since the last few decades (Huong et al., 2017; Do and Son, 2017). Aside from this, the Nam Rom Watershed is considered as one of the most disaster-prone regions, suffering from tropical storms, landslides, drought, soil erosion, and degradation (Do and Son, 2017). Therefore, a question needs to be explored, and is the motivation for the current study: Are human activities or climate variability the main causes of the increased streamflow and sediment load?

Currently, many hydrological models, such as LISEM (Jetten et al., 2003), ANSWERS (Bouraoui et al., 1996), AGNPS (Young et al., 1985), MIKE-SHE (Thompson et al., 2004), MMF (Morgan, 2001), WEPP (Flanagan et al., 2012), and SWAT (Arnold et al., 1998) are used to simulate the soil erosion and hydrological process involved in the hydrological cycle. Among these methods, the SWAT model was selected for the present study. SWAT represents the spatial distribution of hydrological properties using the fundamental concept of the hydrological response unit (HRU). SWAT is widely used to assess hydrological effects of environmental change around the world (see SWAT literature database: https://www.card.iastate.edu/swat_articles/). Besides, SWAT presents a user-friendly graphical interface facilitating the handling input data.

In addition, as we know so far, no clear distinction has been made between individual and combined effects of LUCCs and climate change on hydrology and sediment yield in previous studies (Son and Binh, 2020). Therefore, the present study aims at quantifying the historical and projected change in LULC and climate change on streamflow, sediment transport, and soil erosion in the Nam Rom Watershed. For doing this, we follow the spatially distributed hydrological model approach and implement the SWAT model using RS data and monthly hydrological data. The sub-objectives are: (1) to calibrate and validate the SWAT model in terms of flow and sediment yield; (2) to simulate responses of streamflow, sediment yield, and soil erosion to individual land-use change and climate variation; (3) to investigate the combined impact of land-use change and climate variation on streamflow and soil erosion; and (4) a deep understanding of hydrological processes can provide tools and methods that could be used to other river basins in Southeast Asia as well as long term soil conservation programs.

2. METHODOLOGY

The research content is distributed into two main parts corresponding to the past and future periods through the application of hydrological models (SWAT). The first part presents the steps in setting up the SWAT model, model running, model calibration and validation. Model application focuses on simulation of stream flow and sediment loads based on the variations in land use in the past. In addition, special attention is given to simulation streamflow for long term under projected land use and climate change scenarios. The principle impacts of hydrology are not only land use but also climate change. Therefore, the objective of this study is to assess individual and combined effects of land use and climate change on streamflow and soil erosion. It is very important to understand hydrology and soil erosion from these changes in order to develop strategies for land use planning and water management. The second part of the study is to predict land use scenarios based on the population growth and socio-economic development as well as land use demands and plans in the study area. SWAT modeling is selected to simulate the impacts of projected land use and climate scenarios in 2030 on streamflow and soil erosion considering the socioeconomic development and population growth in the study area. Figure 1 illustrates the detailed methodology applied in this research.

2.1 Study area

The study area is situated in the Nam Rom Watershed, Northwest of Vietnam (between 20°90' to 21°40' E and from 102°30' to 103°20' N). The drainage area of the Nam Rom Watershed covers 1,348 km² with elevation ranges from 2019 m to 436 m (Figure 2). Nam Rom is generally characterized by a tropical monsoon climate with high annual precipitation (1,600 mm), however, its precipitation is spatial and seasonal distributed unevenly with, rainy season accounting for 80% of total annual rainfall. Soils in this study area mostly located on slopes, and thus are major causes of severe soil erosion (Dien Bien People's Committee, 2015b).

LULC in the Nam Rom Watershed is predominantly forests (45.87% of the total area) and cash crop (35.23%). The major land use in the basin area includes lowland rice, rain-fed crops (upland rice, corn, bean, cassava, groundnuts, etc.) and perennial crops (10.57%) (fruit trees, acacia, rubber, etc.). The people's committee in Dien Bien Province indicated

that the characteristics of the study area are massive changes in LULC patterns and conservation practices

in the last few decades (Dien Bien People’s Committee, 2015a).

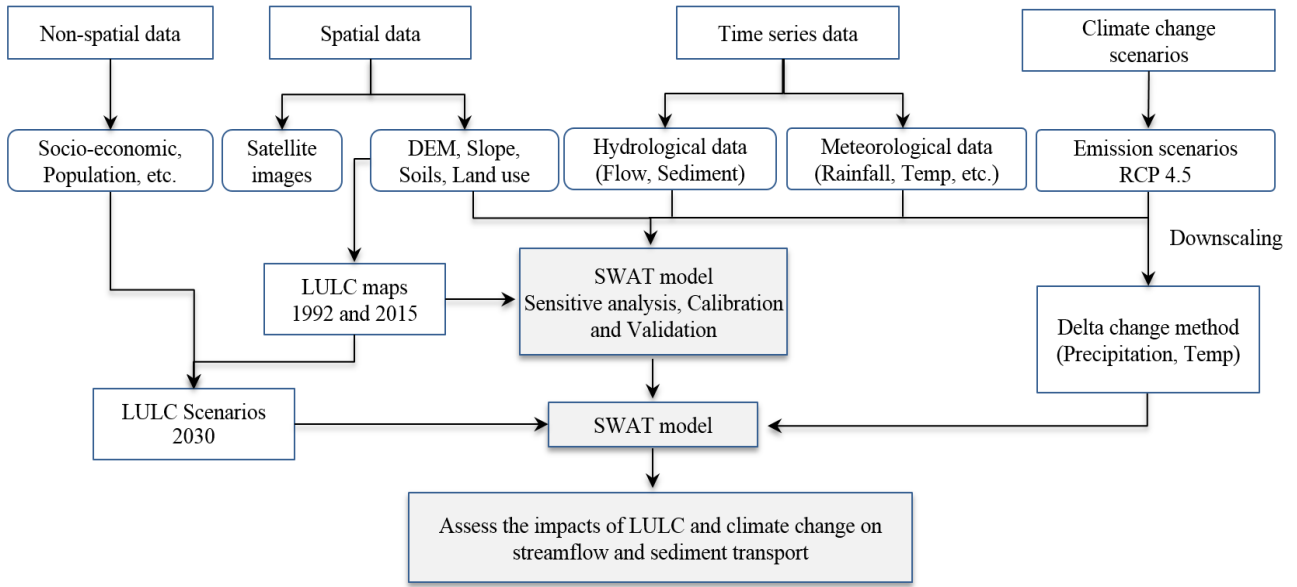


Figure 1. Research methodology applied for this study

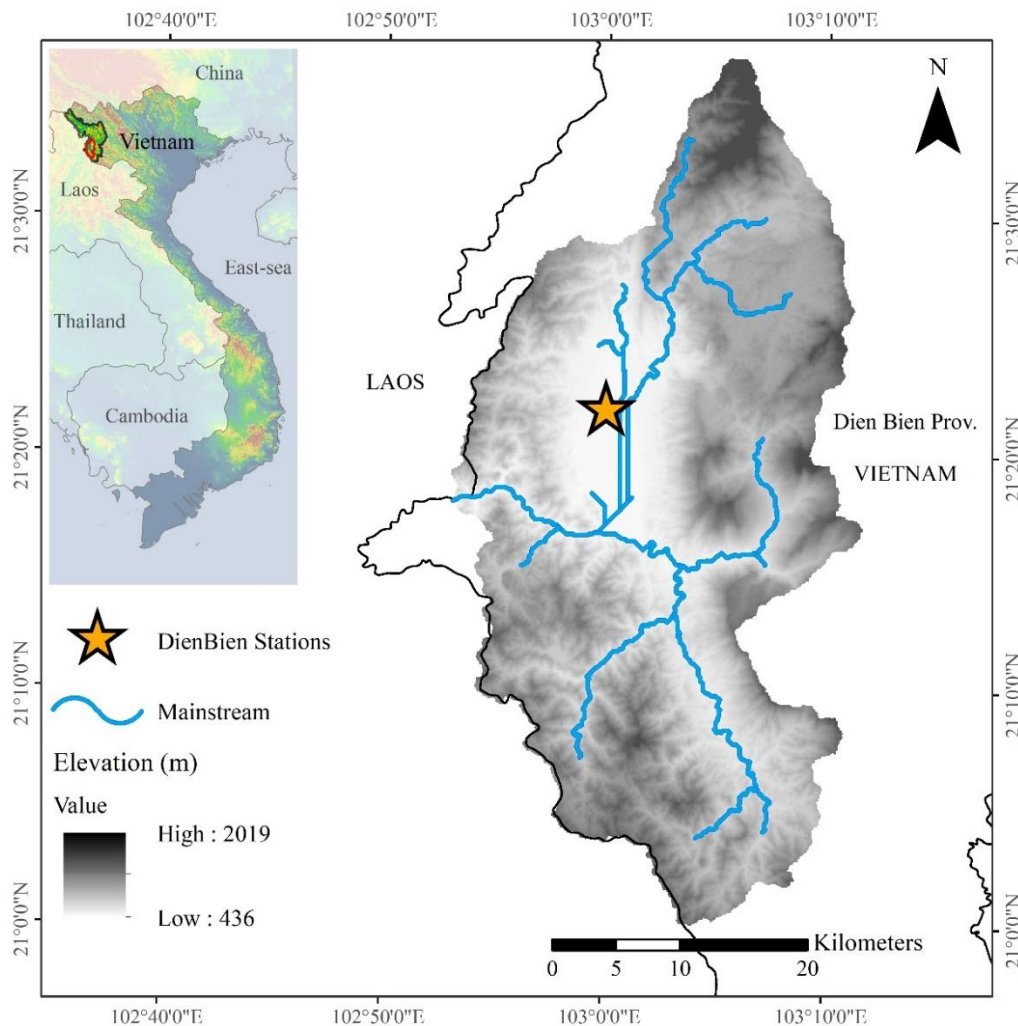


Figure 2. Study area

2.2 Data collection

Time series data including climate data (daily precipitation, temperature, evapotranspiration, and humidity) and hydrological data (flow and sediment yield) were collected from the station nearest to the center of each sub-basin in the Northwestern region.

Spatial data (Figure 3) include: (a) a 50 m-DEM covering Nam Rom Watershed obtained from Ministry of Natural Resources and Environment (MONRE); and (b) slope map was divided into five classes, 0°-3° (Very Gentle), 3°-8° (Gentle), 8°-15° (Moderate), 15°-35° (Moderate to Steep) and >35°

(Very Steep) (MONRE, 2015); (c) Soil characteristics of 18 soil types inputted in the SWAT model collected from MONRE and Mekong River Commission (MRC); and (d) to (f) LULC: satellite images in digital format of the area in 1992 and 2015 produced using Landsat satellite images downloaded from the USGS website (<http://glovis.usgs.gov>) at Path/Row-128/55 and 129/45 in the respective year, the LULC maps have been performed through image classification using the maximum likelihood classification (MLC) algorithm.

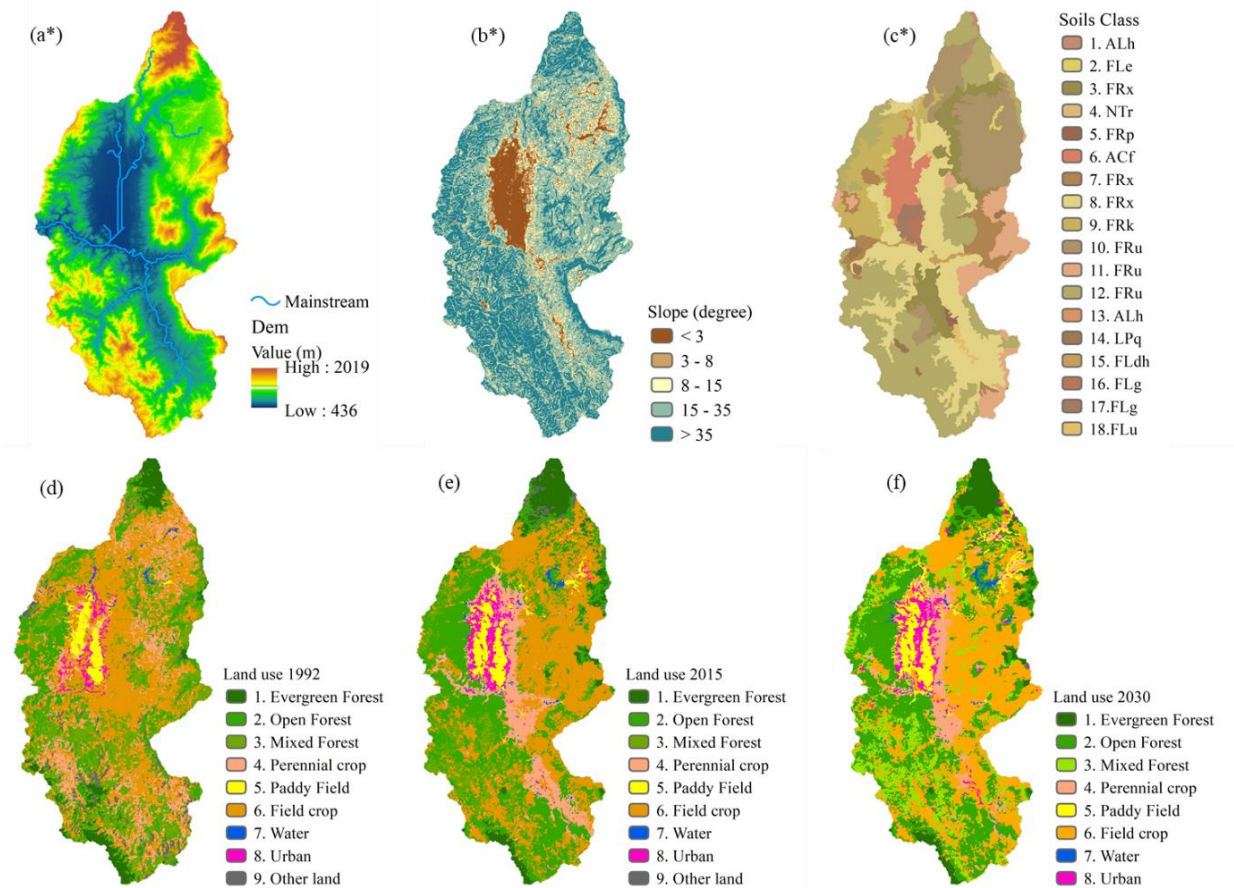


Figure 3. SWAT model inputs and delineated outputs [(a) DEM and meteorological station; (b) Slope; (c) Soil classes; (d) Land use in 1992; (e) Land use in 2015; and (f) Land use in 2030] *Sources: MONRE (2015)

2.3 Application hydrological model (SWAT)

2.3.1 SWAT model description

SWAT, a spatial and physical distributed model, is applied widely in the world for evaluating the environmental change of hydrology in large and complex watersheds over long term periods. In addition, SWAT has been examined in several climate conditions in the world from arid and semi-arid regions to humid and tropical areas (Ngo et al., 2015).

In this research, potential evapotranspiration (PET) was calculated by using the Penman-Monteith method, while surface runoff (overland flow) was calculated by Soil Conservation Services (SCS) curve number method. The water balance was likewise used in the SWAT model to calculate the hydrological cycle which represents as follows (Neitsch et al., 2011): which represents as follows (Neitsch et al., 2011):

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

Where; SW_t is the: final soil-water content; SW_0 is the initial soil water content; R_{day} is the precipitation amount; Q_{surf} is the surface runoff amount; E_a is the amount of evapotranspiration; W_{seep} is the percolation; Q_{gw} (mm H_2O) is the return flow; and t is time in days (Neitsch et al., 2011).

Modified Universal Soil Loss Equation (MUSLE) used for the simulation of soil erosion (Wischmeier and Smith, 1978) is computed as below:

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

Where; Sed (metric tons) is the sediment yield; q_{peak} (m^3/s) is the peak runoff rate; $area_{hru}$ (ha) is the hydrologic response unit (HRU); K_{USLE} is the soil erodibility factor; C_{USLE} is the cover and management factor; P_{USLE} is the practice factor; LS_{USLE} is the topographic factor; and CFRG is the coarse fragment factor (Wischmeier and Smith, 1978).

2.3.2 Model calibration and validation

The Sequential Uncertainty Fitting (SUFI-2) algorithm was applied to implement calibration and validation of the hydrological model in this study. According to Moriasi et al. (2007), to evaluate model performance, three (3) indicators Nash-Sutcliffe (NS); percent bias (PBIAS), Observation's standard deviation ratio (RSR) as shown in equations (3)-(5) respectively, must be used:

$$NS = 1 - \left[\frac{\sum_{i=1}^n (Q_{obs}^i - Q_{sim}^i)^2}{\sum_{i=1}^n (Q_{obs}^i - \bar{Q}_{obs}^i)^2} \right] \quad (3)$$

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\sqrt{\sum_{i=1}^n ((Q_{obs}^i - Q_{sim}^i)^2)}}{\sqrt{\sum_{i=1}^n ((Q_{obs}^i - \bar{Q}_{obs}^i)^2)}} \quad (4)$$

$$PBIAS = \frac{\sum_{i=1}^n (Q_{obs}^i - Q_{sim}^i)}{\sum_{i=1}^n Q_{obs}^i} \times 100 \quad (5)$$

Where; n is the number of time steps; Q_{obs}^i , and Q_{sim}^i are the observation and simulation; on the i^{th} time

step; and \bar{Q}_{obs} is the mean of observation (Q_{obs}^i) across the n evaluation time steps.

2.3.3. Model applications

(1) Land use change analysis

Change analysis in LULC was performed by overlaying classified LULC maps of two-time periods (1992 vs 2015, and 2015 vs 2030). There were nine land use classes in the basin with the most common agricultural land use in the basin known to be the evergreen forest, open forest, mixed forest, perennial crop, paddy field, field crop, urban, water body and aquaculture, and other lands (Table 1). LULC in the Nam Rom Watershed was dominated by converting forests (FRST and ORCD) to the paddy field, open forest, and urban area. Five land use classes (open forest (FRSD), mixed forest (FRST), field-crop (FCRP), rice (PDDY), and urban (URBN)) turned out to significant effect LULC change. From 1992 to 2015, FSRD, URBN, and PDDY increased from 15,739.7 ha to 39,876.9 ha (18.1%), 2,175.3 ha to 4,196.9 ha (1.5%), and 3,292.7 ha to 4,939.0 ha (1.2%), respectively. In contrast, there was a significant decrease in the area of FRST, ORCD, and BARR from 34,849.4 to 14,084.8 ha (15.5%), 17,729.5 to 14,127.8 ha (2.7%), and 4,652.4 to 1,323.8 ha (2.5%), respectively.

The projected LULC scenario in 2030 was created following and in consideration of its baseline land use in 2015. The predication was done in order to settle the population growth rate estimated at 1.22 and maintain food security by increasing over 50% in the paddy field and 15% in urban land. Note that the following types of on-going changes in LULC were found in the Nam Rom Watershed: (1) vacant lots especially urban lands are utilized for all other purposes of land use; (2) inefficient upland fields were converted into forest land or orchard; (3) mixed forest or open forest to evergreen forest are converted, if possible; (4) lowland are transformed into paddy fields and expand existing residential neighborhoods are expanded nearby lands. These trends, as seen in Figure 3, are assumed to be maintained in the future.

Table 1. LULC change in the period of 1992-2015 and 2015-2030

No.	Land use classes	SWAT code	Area (ha)			Change (%)	
			1992	2015	2030	1992-2015	2015-2030
1	Evergreen forest	FRSE	6,320.52	7,367.31	7,349.76	16.56	-0.24
2	Open forest	FRSD	15,739.56	39,876.93	40,689.09	153.35	2.04
3	Mixed forest	FRST	34,849.35	14,084.55	14,802.84	-59.58	5.10
4	Perennial crop	ORCD	17,729.46	14,127.84	9,434.70	-20.31	-33.22

Table 1. LULC change in the period of 1992-2015 and 2015-2030 (cont.)

No.	Land use classes	SWAT Code	Area (ha)			Change (%)	
			1992	2015	2030	1992-2015	2015-2030
5	Paddy field	PDDY	3,292.74	4,939.02	7,456.32	50.00	50.97
6	Field crop	AGRR	48,290.31	47,110.32	48,090.33	-2.44	2.08
7	Water	WATR	659.52	682.47	1,014.48	3.48	48.65
8	Urban area	URBN	2,175.30	4,196.88	4,871.61	92.93	16.08
9	Other lands	BARR	4,652.37	1,323.81	0.00	-71.55	-100.00
Total area (ha)			133,709.13	133,709.13	133,709.13		

(2) Climate change scenarios

In the northwestern provinces, AR5 scenarios were selected for the study site because it was downscaled by AOGCM, GCMs, RCM, Global Ocean model, and statistic downscaling techniques (Thuc et al., 2016). The PRECIS (Hadley Centre-UK) method was utilized for downscaled future climate change scenarios in the Northwest of Vietnam. Also, based on the climate change set for the Northwest regions in the future, RPC 4.5 (2016-2035) scenarios were used for evaluating LULC and CC effects on streamflow and soil erosion in the present study.

(3) SWAT applications

In this research, one factor such as land use or climate change was changed while others were kept constant. The influences of LULC and climate change

were computed by comparing five scenarios: S1: 1992 LULC and 1992-2003 climate ; S2: 2015 LULC and 1992-2003 climate; S3: 1992 LULC and 2004-2015 climate; S4: 2015 LULC and 2004-2015 climate; S5: 2030 LULC and 2016-2030 climate (projected LULC and climate scenarios).

3. RESULTS AND DISCUSSION

3.1 Model calibration and validation

Results of the SWAT model in Figure 4 and Table 2 indicated flow simulation in the following values at calibrated and validated periods for NS: 0.76 and 0.65; RSR: 0.49 and 0.60; and PBIAS: 6.76 and 8.37, respectively. In terms of sediment yield, respective values at calibrated and validated periods appeared at 0.82 and 0.81 for NS; 0.47 and 0.55 for RSR; and -16.06 and -18.95 for PBIAS (Table 3).

Table 2. Indicators for model performance

SWAT model performance	NS	PBIAS	RSR
Very good	$0.75 < NS \leq 1.00$	$PBIAS \leq \pm 10$	$0.00 \leq RSR \leq 0.50$
Good	$0.65 < NS \leq 0.75$	$\pm 10 \leq NS \leq \pm 15$	$0.50 < NS \leq 0.60$
Satisfactory	$0.50 < NS \leq 0.65$	$\pm 15 \leq NS \leq \pm 25$	$0.60 < NS \leq 0.70$
Unsatisfactory	$NS \leq 0.5$	$PBIAS \geq \pm 15$	$RSR > 0.70$

Sources: Yang et al. (2014)

Table 3. Model performances for the monthly simulated flow and sediment

Indicators	Flow		Sediment yield	
	Calibration (1992-2003)	Validation (2004-2015)	Calibration (1995-2003)	Validation (2004-2010)
RSR	0.49	0.60	0.47	0.55
NS	0.76	0.65	0.82	0.81
PBIAS (%)	6.76	8.37	-16.06	-18.95

In comparison with the guidelines set in Moriasi et al. (2007) the SWAT performance is from good to very good, meaning that the model can be applied to

simulate LULC and climate change on streamflow and sediment transport in Nam Rom Watershed.

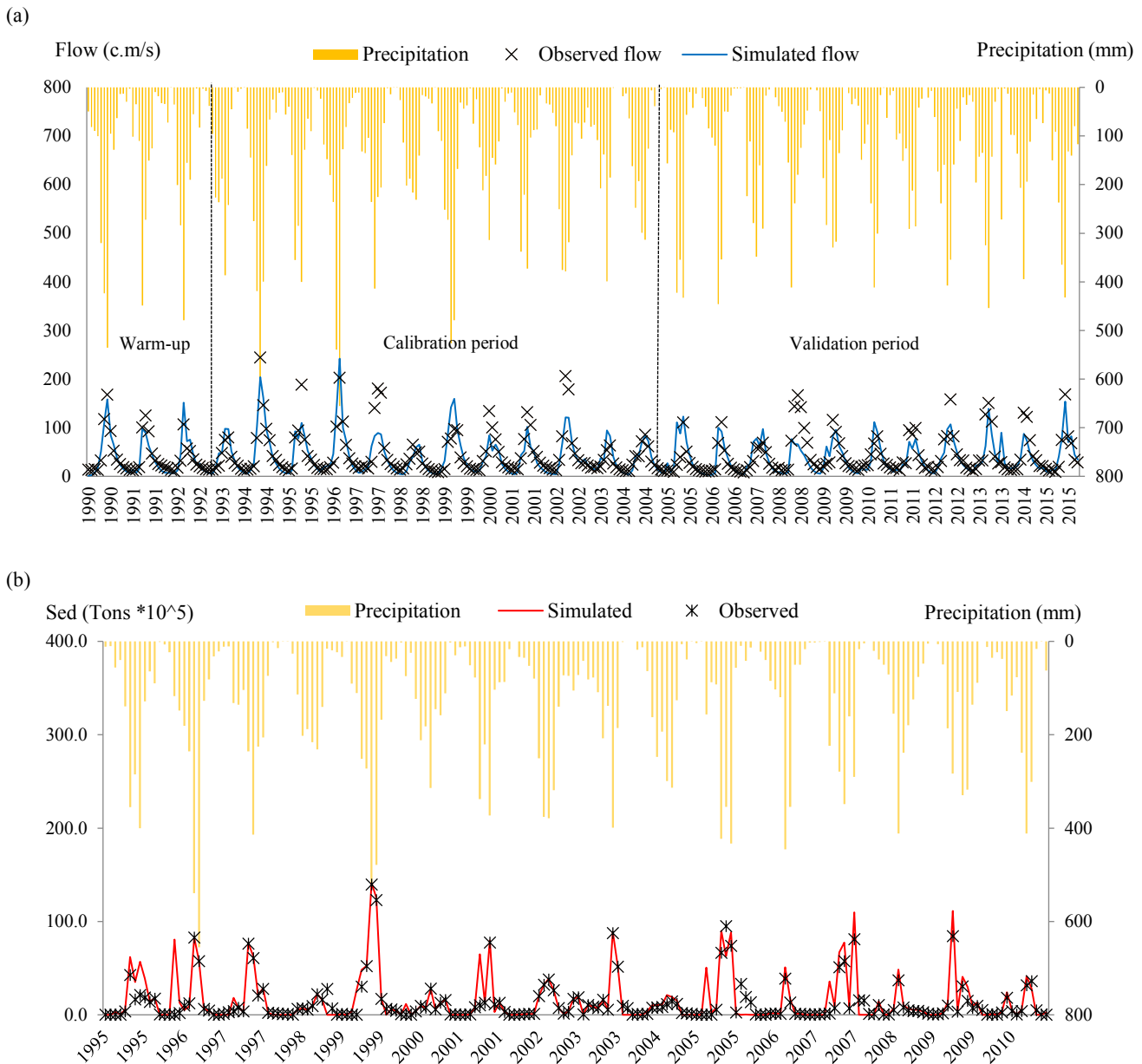


Figure 4. Calibrated and validated flow (a) and sediment (b)

3.2 Impacts of the past LULC and climate change on streamflow, sediment yield, and soil erosion in the basin scale

Under the impact of LULC change, sediment yield and soil loss decreased by 4.3%, 13.7%, and 26.3%, respectively. The above results indicated that the change was influenced by increased forest cover (open and mixed forest) in combination with the decrease of precipitation from 1992-2015. These changes also led for productive use of area by adopting suitable treatment measures, like change in cropping pattern and in soil and water conservation practices. In addition, the results are the same with the findings of Phan et al. (2011) and Khoi and Suetsugi (2014) who found that the conversion of forest land (11.07%) to

agricultural land leads to an increase in streamflow by 3.93% because of the fragmentation of soil structure, and scatters of different farming practices which all contribute to an increase in streamflow. Khoi and Suetsugi (2014) also reported that the increase in average annual streamflow (1.2%) was due to rapid deforestation and the expansion of agricultural land. Forest cover stored more water than any other types of land use and the infiltrated rate of forestland is the largest in comparison with other types of land use. However, forest in NW has been cut and burned for expansion of agricultural land (corn and cassava, pineapple, and vegetable), therefore causing an increase in average annual streamflow.

Under climate change, sediment yield and soil erosion increased by 12.2% and 52%, respectively. The increase in sediment load and soil erosion could be explained by increasing quantity and intensity of precipitation in the dry season (from December to January) that had a large effect on sediment load. In addition, the traditional farming systems or LULC change in this area are mostly based on the last month of the dry season. Therefore, when precipitation occurs, especially peak precipitation occurs, farmers also start plowing and preparing to sow seed or cultivate plants on their farms. This causes complexity, fragmentation, and scatters of different farming practices which all contribute and encourage soil erosion (Ngo et al., 2015; Li et al., 2011; Phan et al., 2011).

As to the assessment of the combined impacts of LULC and climate change on sediment load and soil loss in the basin scale, Figure 5 presents the compared simulated results of S4 (LULC 2015 and climate change 2004-2015 period) and S1 (LULC 1992 and climate change 1992-2003). Based on the data, compared with S1, S4 showed that the combined impact of LULC and climate change led to a slight decrease in sediment load by -4.9% although soil loss increased by

20%. The increased soil erosion could be caused by increased and altered precipitation patterns such as timing, quantity, and intensity. The rainfall erosivity (R) is mostly related to overland flow which is recognized as a principal factor for soil erosion in the sloping land at Nam Rom Watershed.

For the future assessment of the changing streamflow, sediment yield, and soil loss in the basin-scale under the LULC and climate change scenario, the projected LULC 2030 and climate from 2016 to 2030 were compared to the corresponding current conditions (S4 scenario). Figure 5 (right) indicated that sediment yield and soil loss are projected to decrease by 12 % and 34%, respectively in the future. The decrease is brought about by the increase of forest cover and paddy field (FRST, FSRD, and PDDY) in combination with implementing contour line hedgerow, grass and plastic cover, cropping systems (food production, fruit production, and forest trees) and sustainable agroforestry land technology (SALT) which results in reducing raindrop speed and energy and increasing the rate of infiltration, improving organic matter, reducing soil crusting, and restoring nutrients.

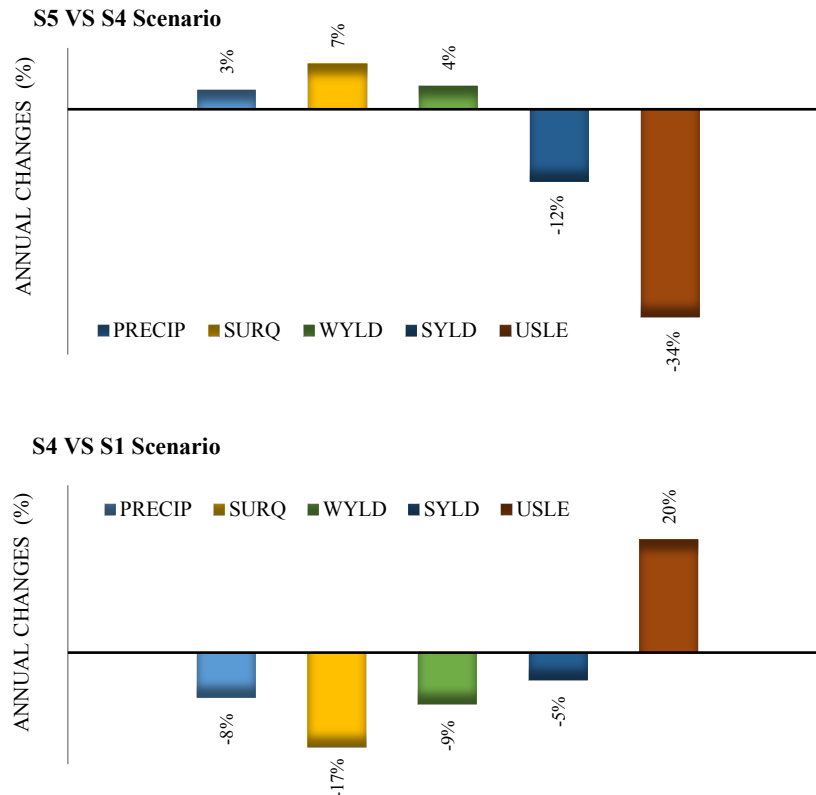


Figure 5. Annual changes of streamflow and sediment yield under different scenarios (Note: PRECIP: precipitation; SURQ: surface flow; WYLD: water yield; SYLD: sediment yield; USLE: soil erosion)

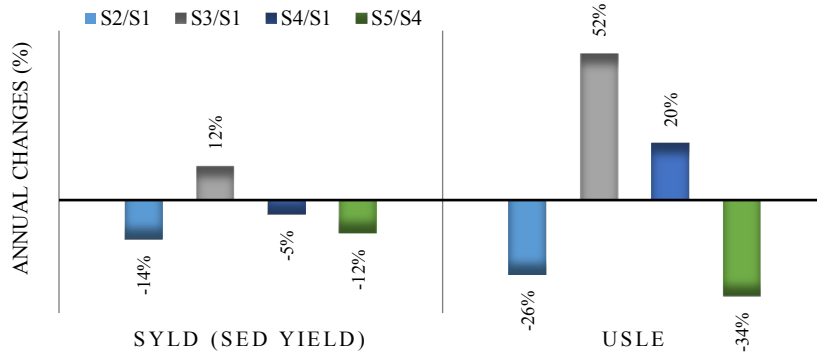


Figure 5. Annual changes of streamflow and sediment yield under different scenarios (cont.)

(Note: PRECIP: precipitation; SURQ: surface flow; WYLD: water yield; SYLD: sediment yield; USLE: soil erosion)

3.3. Contribution of changes for combined LULCs and climate change on runoff and sediment from 1992 to 2015 and 2016 to 2030 in the sub-basin scale

The spatial distribution of changes for the six main LULC classes (open forest, mixed forest, perennial crop, paddy, field crop, and urban area), particularly, the simulated surface runoff and sediment

yield between 1992 and 2015 are shown in [Figure 6](#). The decrease in surface runoff and sediment yield in sub-basin 5 and 14 correspond to where the majority of field crop (corn, cassava, sugar cane, potato, etc) was replaced by forest cover and implementation of soil and water conservation ([Chen et al., 2019](#); [Duan et al., 2020](#)).

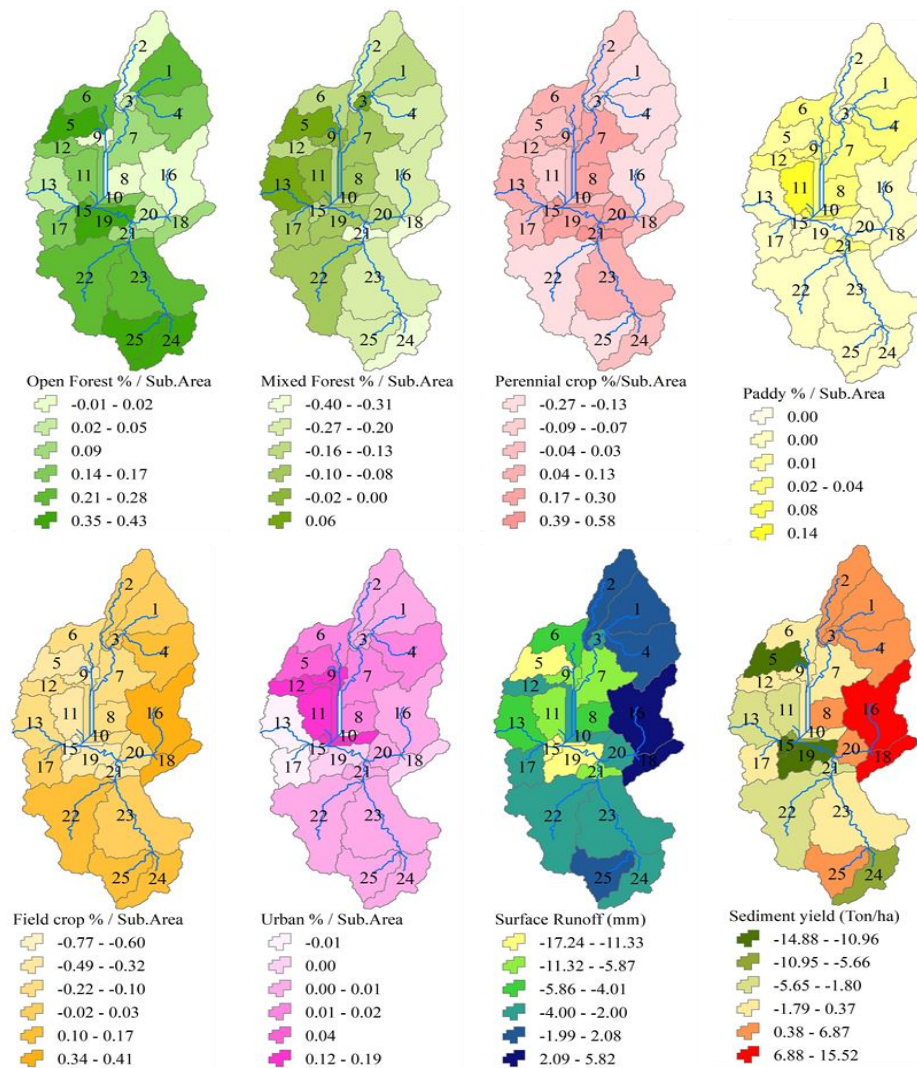


Figure 6. Spatial distribution of LULCs, runoff, and sediment from 1992 to 2015

Similar to the past, the expansion of LULC (open forest, mixed forest, and paddy field) mainly occurred in the northeast of Dien Bien. Due to the increase in forest cover combined with implementing soil conservation practices, the maximum surface runoff and sediment yield decreased compared to land use between 2015 and 2030. This finding largely matches the spatial distribution pattern expansion of FRSE,

FRSD, and PDDY and is confirmed by the negative high correlation between its expansion and decrease in surface runoff and sediment yield (Figure 7). The decrease of surface runoff and sediment yield in sub-basin 14 and 20 correspond to where the majority of field crop (corn, cassava, sugar cane, potato, pineapple) was replaced by forest (teak, rubber, bambbo, eucalyptus, and cinnamon).

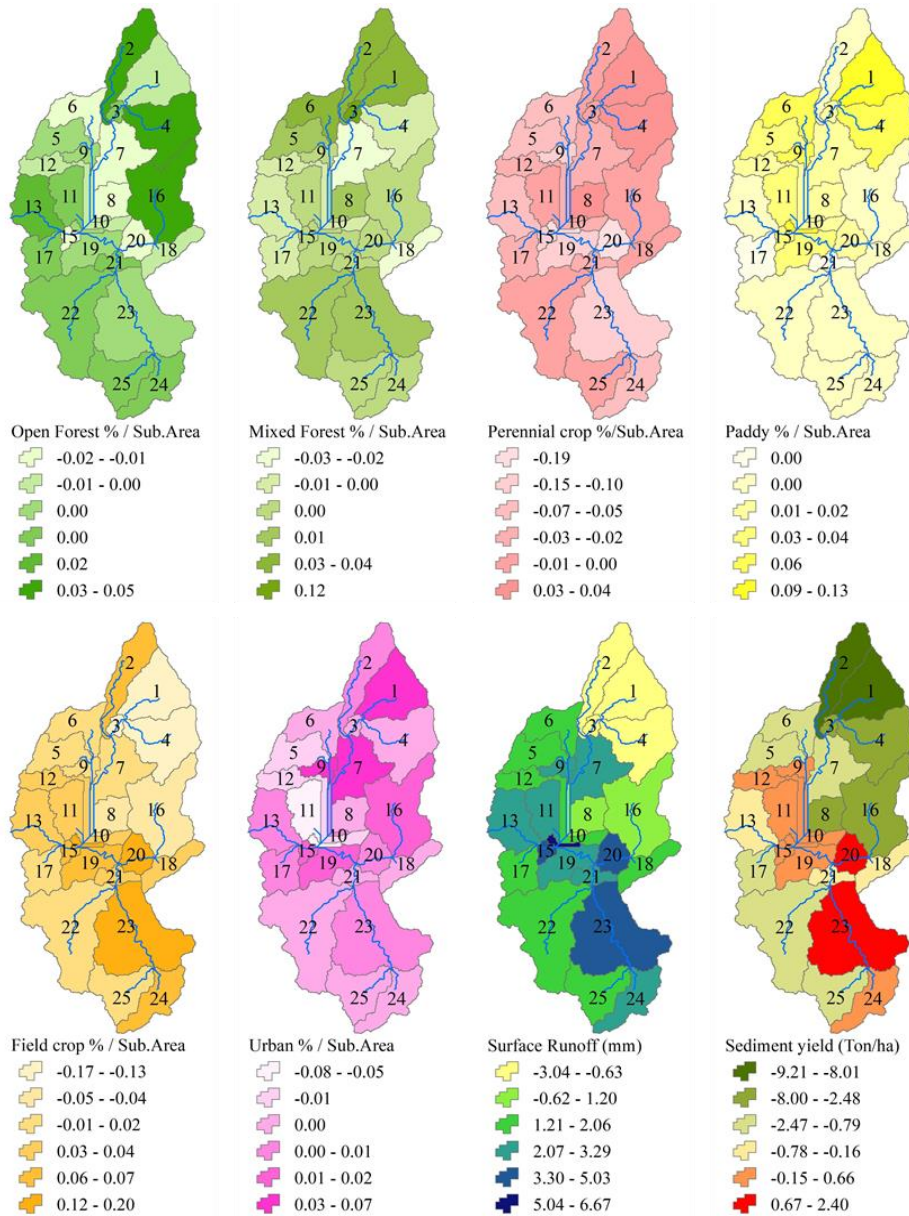


Figure 7. Spatial distribution of LULCs, runoff, and sediment from 2015 to 2030

3.4. Potential soil erosion risk maps under different LULC and climate change scenarios.

The standard soil erosion guidelines recommended by the Ministry of Science and Technology (MOST) in 2009 applied in the present area were categorized into five (5) levels: very low

(Soil loss ≤ 1 ton/ha/year), low ($1 \div 5$ ton/ha/year), moderate ($5 \div 10$ ton/ha/year), high ($10 \div 50$ ton/ha/year), and very high (≥ 50 ton/ha/year). Areas of soil erosion intensity were significantly changing from nil to weak to high erosion rate. This escalation highlights changes in LULC management practices and climate

change in the period of 1992-2015 as the main reason for the increased erosion. Naturally, the increase or decrease in soil erosion is affected by changes in types of land use as well as the spatial alteration and fragmentation of land use. Aside from this, climate change, in terms of quantity and intensity.

In Figure 8, the soil erosion risk in the Nam Rom watershed mainly shifted from very low and low in 2003 (65.18%) to high and very high in 2015 (58.56%), which suggest that implementation of proper land use planning should be used to avoid conversion of forest land to agriculture land and the built-up area in near future and contributed to reducing soil erosion. From this data, it could be seen that the potential soil erosion in 2030, considering its projected

land use and climate scenarios, is a little more serious than soil erosion under current conditions especially when the leaders in the district are planning to increase the evergreen forest as well as expand plantations for the perennial crop like acacia, coffee, and rubber plantation. It must be noted that the potential soil erosion of the Nam Rom watershed may slightly decrease in the future as compared to 2015 since precipitation intensity has been slightly decreasing. However, it must be still be strongly stressed that the complexity, fragmentation, and scattering of different LULC types combined with the increasing precipitation intensity still puts soil erosion in the area at a very high level.

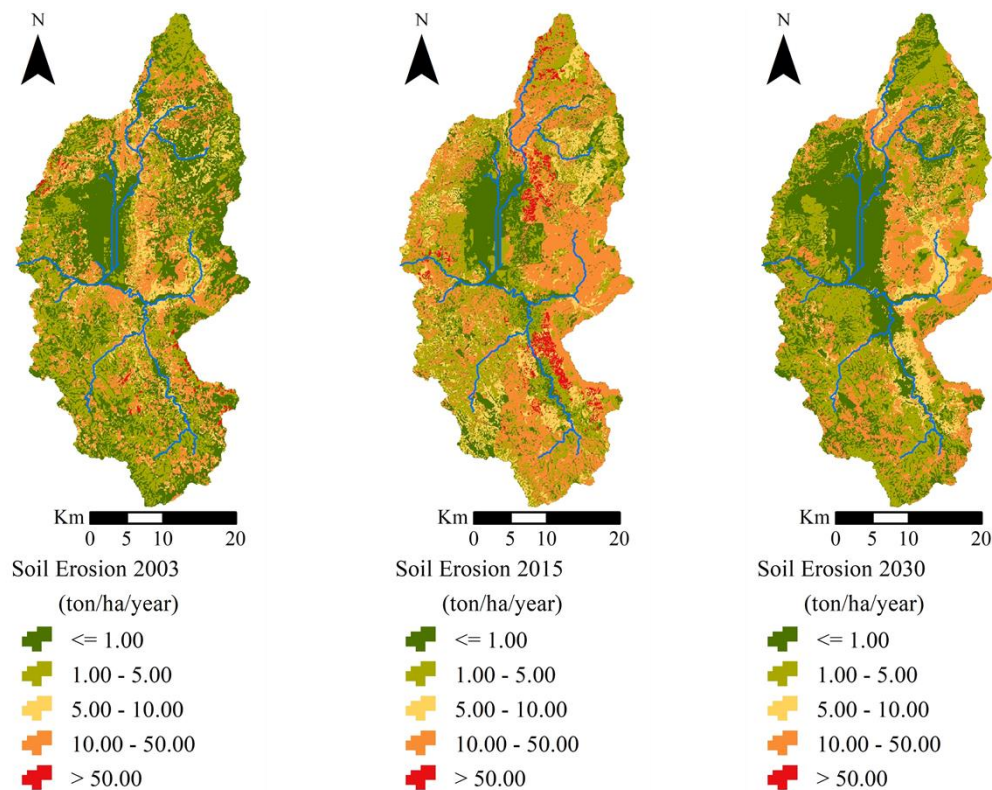


Figure 8. Potential soil erosion in 2003 (left), 2015 (middle), and 2030 (right)

4. CONCLUSION

The present study quantifies the response of streamflow and soil erosion in Nam Rom River Basin of Vietnam. LULC in the Nam Rom River Basin in the past was dominated by converting forests to agricultural land (paddy, maize, cassava) and urban area because of pressure of socio-economic development. In contrast, LULC in the future will shift towards conservation programs by increasing vegetation cover (reclamation, rehabilitation and

restoration) and converting ineffective agricultural sloping lands to forest land.

The SWAT model was applied in Nam Rom River Basin of Vietnam in order to simulate the individual and combined effects of land use and climate change on streamflow, sediment yield, and soil erosion. Evaluation results indicated that SWAT performance is from good to very good during calibrated and validated periods. Therefore, SWAT can successfully be used for assessing the impacts of

environmental change including land use change and climate change in Nam Rom River Basin. .

LULC decreased surface flow (4.3%) and sediment yield (13.7%). Climate change increased sediment load by 12% because precipitation from 2004-2015 was significantly higher than 1992-2003. A combination of LULC and climate change impacts leads to a slight decrease in sediment load (4.9%). Overall, climate change strongly affected streamflow and sediment yield than LULC in the study area from 1992 to 2015. Projected LULC and climate change scenarios indicated that sediment yield and soil loss are predicted to decrease by 12% and 34% in the future. It is noted that the combined climate and land use change analysis revealed that sustainable land use planning and management could be adopted to mitigate streamflow and soil loss in the future, in conjunction with the projected direct impact of climate change.

Finally, the results of the present study will contribute useful knowledge, methods, and techniques that could be applied to other regions in Vietnam and the world in terms of land and water conservation.

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