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Predicting Land Use and Climate Changes Scenarios Impacts on Runoff and Soil Erosion: A Case Study in Hoa Binh Province, Lower Da River Basin, Northwest Vietnam

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Abstract

Land use and climate changes are the key factor for altering runoff and soil erosion, and understanding its impacts play an important role in developing as sustainable program to preserve watershed. However, there is lack of detailed studies on land use and climate change impact on hydrology and soil erosion for the sustainable water management in Vietnam. Therefore, the study aims to predict future runoff and sediment yield, and soil loss in Hoa Binh province, Lower Da river basin, Northwest Vietnam using Soil and Water Assessment Tool (SWAT) model. Two projected land use changes (LU_1: economic scenarios and LU_2: conservation scenarios) were simulated based on the Vietnam government's restrictions for land use change. Future climate projections were derived from three Regional Climate Models (RCMs). In the study, A_2 and B_2 scenarios were selected for the study because scenario A_2 assumes a very heterogeneous future world, with continuously increasing population and regionally oriented economic development, whereas, scenario B_2 is an intermediate level of economic development. Results indicated that SWAT model was a powerful tool for simulating the impacts of land use and climate change on hydrology and sediment yield. The results show that in future land use and climate change are to be responsible for a 0.35 to 1.07% increase in runoff and 0.86 to 6.96 % increase in sediment yield, respectively. Moreover, it can be seen that the areas of moderate and very high soil erosion intensity mainly occupied in Hoa Binh province ranges from 23 to 52 ton/ha·yr. In conclusion, the results obtained in this study can provide useful information for land use planning and management as well as soil and water conservation in the Hoa Binh province, Lower Da river basin, Northwest Vietnam

Keywords: Climate Change; Land Use Change; Remote Sensing; Runoff; Sediment Yield; SWAT model.

1. Introduction

Impact assessments of land use and land cover changes (LULCC) on soil erosion, sedimentation, water quantity and quality are one of the most central issues for watershed management and ecological restoration (Cochard, 2017). Changes in land use may result in disruption to the hydrological cycle because of alteration of base flow (Huyen *et al.*, 2017, Shrestha *et al.*, 2016) and annual mean stream discharge of the catchment (Costa *et al.*, 2003). Changes in land-use such as a result of deforestation, agricultural expansion, and urbanization have altered surface runoff generation and have then affected the hydrological processes and the transport of pollutants. As a result, climate and land-use are identified as main factors controlling the hydrological and sediment behavior of catchments (Phan *et al.*, 2010). In the northwest of Vietnam, land use and agricultural systems have been rapidly changing since the 1990s alongside economic development of this region (Trinh, 2007). Very large forests and protected areas were deforested by expansion of cultivated land, cutting and burning of forests, leading to decreased land cover and quickly declined soil quality (Trinh, 2007). Moreover, under the pressure impacts of population growth, natural forest and fallow land have been taken the place of permanent upland crops like corn, cassava, orange, upland rice, and sugarcane. These crops were cultivated by farmers without application of any soil conservation and management practices (Trinh, 2007); therefore, most soils in agricultural slopping lands are seriously eroded. This soil erosion, combined with strong overland flow and soil loss due to high variable intensity of rainfall, is the principal reason of soil degradation in the northwest of Vietnam (Trinh, 2007). Soil erosion may also result in several serious off-site effects, which include river and reservoir sedimentation, negatively affecting irrigation efficiencies and hydroelectricity generation (NWRB, 2004). Hence, quantitative estimations of LULCC impacts on runoff and sediment yield are significant issues for soil and water conservation practices (Wasige, 2013).

Climate change also bring alteration in the sediment flux and the river morphology which in turn will affect the river systems. Many countries in Asia have been suffering frequent floods and droughts for last two to three decades as consequences of climate change and extensive human activities (Kranz *et al.*, 2010). According to IPCC (2007), climate change may result change in temperature and precipitation and is considered as global issues influencing regional communities who are depending on climate for their livelihood such as agriculture, forestry, and water resources (Mahmood, Babel and Shaofeng, 2015). Many studies indicated river flow and sediment loads are associated with the change in temperature and precipitation (Dao and Tadashi, 2013). However, very limited researches have been conducted on the potential impacts of land use and climate change in this region.

Over the past decades, with the expansion of remote sensing, GIS, and modelling, various studies on simulating hydrological process have shown important regional water resource vulnerabilities to changes in both temperature and precipitation patterns in Vietnam. In the present study, Soil and Water Assessment Tool was selected because it is widely used in studies on the impact on water quantity and quality and sediment in agricultural catchments around the world (Khoi and Tadashi, 2013). Another reason for this selection is because of its friendly and user-friendliness in handling input data (Arnold *et al.*, 1998). Results of the present study are expected to provide useful information for land use planning and management as well as soil and water conservation to cope with future land use and climate change in Hoa Binh province, Lower Da river basin, Northwest Vietnam

2. Materials and Methods

2.1. Model data inputs

In this study, Digital Elevation Map (DEM), climate data (temperature, precipitation, solar radiation, wind speed, and relative humidity), and hydrology were collected from several sources including the Ministry of Natural Resources and Environment (MONRE), Center for National Climatic Data in Vietnam, Institute of Meteorology Hydrology and Environment (IMHEN), and Center for Environment Monitoring (CEM)in the Northwest region (Table 1).

Table1. Data and Sources

SN	Data	Sources	Spatial/Temporal Resolution	Number/Time Period
Physical Characteristics of the Catchment				
1	DEM	MONRE	90m	
2	Soil	MONRE	1:1.000.000	
3	Land use			2 maps – 1995,2010
4	1995	Landsat 5	30mx30m	
	2010	Landsat 7 ETM+	30mx30m	
Time series observations				
1	Meteorology	IMHEN	Point/daily	21 stations (1961-2010)
2	Hydrology	IMHEN	Point/daily	2 stations (1961-2010)
3	Sediment	IMHEN	Monthly	1961-2010
4	Management Operations	Rotation timing in plants and fertilizer application	Son La people's committee report. DoARD	2010

2.2.SWAT model description

SWAT is "a continuous, long-term, physically based distributed hydrological model which was designed to simulate the influence of land management practices on water quantity and quality, sedimentation, soil erosion, and nutrients in complicated watersheds with heterogeneous soil and land use environments" (Arnold *et al*., 2012). In the SWAT model, the hydrological processes based on water balance formula were calculated and represented as below.

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

where, SW_t is the final soil-water content (mm H_20), SW0 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 percolation and bypass flow exiting the soil profile bottom on day *i*, and Q_{gw} is the amount of return flow on day *i* (mm) (Arnold *et al*., 1998). Soil erosion in SWAT is estimated using a Modified Universal Soil Loss Equation (MUSLE) (William *et al*., 1975) as shown below.

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

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 USLE soil erodibility factor, C_{USLE} is the USLE cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor (Wischmeier and Smith, 1978) and *CFRG* is the coarse fragment factor.

2.3. Model setup

The model set up included preparing the input data, watershed delineation and configuration using digital elevation model (DEM), inputting soil, climate, land use types and agricultural practice data, and a test run of the model. The total modeling area of 18,467 km^2 covers Son La and Hoa Binh provinces. The monitoring of flow and sediment yield data was available only at Ta Bu and Hoa Binh gauging stations (Figure 1).

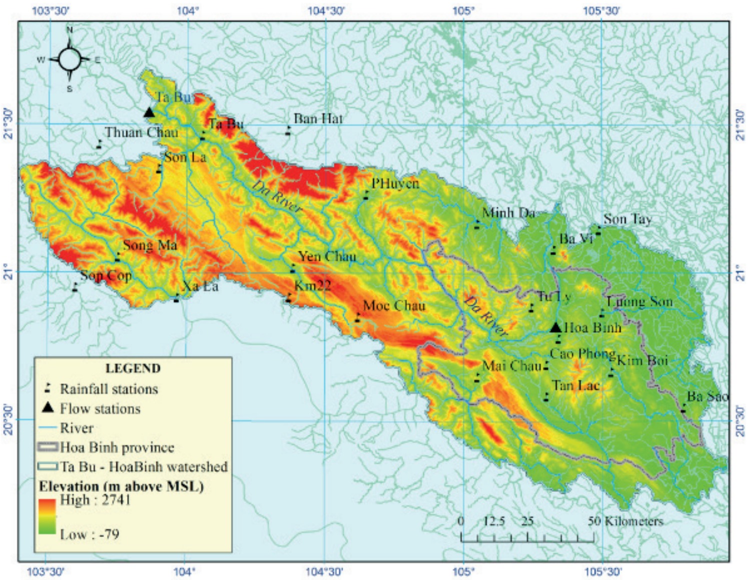

Figure 1. Location map of the Da River Basin, Northwest of Vietnam

2.4. Sensitive analysis, model calibration and validation

In the study, the watershed was first divided in to 103 sub-basins and then further divided into a total of 13,424 HRUs. The most sensitive parameters for model calibration were categorized by using Latin Hypercube and One-factor-At-a-Time (LH-OAT) in SWAT (Van Griensven *et al.*, 2006; Gassman, Reyes, Green and Arnold, 2007). After identifying their parameters (Table 2) the SWAT model was using records across a 10-year period (1971-1981) for calibration and validation. In 1981 a hydropower plant began operation in the Hoa Binh reservoir, which caused a complete change flow and sediment yield downstream of the dam. Therefore, observations of flow and sedimentation at the Hoa Binh outlet station (located downstream of the dam) are no longer representative for naturally hydrological conditions.

Monthly-observed runoff and sediment yield for 1971-1975 and the land-use in 1995 were utilized for calibration, while monthly observed runoff and sediment for 1976-1981 and the land-use 2010 were utilized for validation. Three indicators were used to evaluate model performance: Nash-Sutcliffe efficiency (NSE); Observation's standard deviation ratio (RSR), and percent bias (PBIAS) (Moriasi *et al.*, 2007). The equations for the above mentioned indicators are given below.

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

Table 2. Range and calibrated values of model parameters

Parameter	Description	Range	Value used
ALPHA_BF	Base flow recession constant	0-1	0.48
CN2	Curve number for moisture condition	35-98	60
GW_REVAP	Groundwater re-evaporation coefficient	0.02-0.2	0.05
ESCO	Soil evaporation compensation factor	0.01-1	1
SOIL_K	Saturated hydraulic conductivity	0-100	50%
PRF	Peak rate adjustment	0-2	1.2
SPCON	Coefficient in sediment transport in the channel	0.0002-0.01	0.001
SPEXP	Exponent in sediment transport in the channel	1-1.5	1.1

where, n is the number of time steps, Q^i_{obs}, and Q^i_{sim} are the observation and simulation, on the i^{th} time step, and $\overline{Q}_{obs}$ is the mean of observation (Q^i_{obs}) across the n evaluation time steps.

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\sqrt{\left[\sum_{i=1}^{n}\left(\left(Q^i_{obs} - Q^i_{sim}\right)^2\right)\right]}}{\sqrt{\left[\sum_{i=1}^{n}\left(Q^i_{obs} - \overline{Q}_{obs}\right)^2\right]}} \quad (4)$$

where, n is the number of events, Q^i_{obs}, and Q^i_{sim} are the observation and simulation on the i^{th} time events, is $\overline{Q}_{obs}$ the mean of observation across the n evaluation time steps

$$PBIAS = \sum_{i=1}^{n}\left(Q^i_{obs} - Q^i_{sim}\right) \times 100 / \sum_{i=1}^{n} Q^i_{obs} \quad (5)$$

where, n is the number of time steps, Q^i_{obs}, and Q^i_{sim} are the observation and simulation on the i^{th} time step.

The performance of the model is acceptable when RSR is close to 0, NSE ≥ 0.65 and PBIAS ≤ 10 (Moriasi *et al*., 2007). The optimal value of NSE is equal to 1 indicating the model performs almost perfectly. On the other hand, NSE less than or close to 0 indicates the model predictor is worse as compared to observation data. The PBIAS is 0 indicates that the model performance is the best (Li *et al*., 2009).

2.5.Model applications

Land use change Scenarios

Land use scenarios have been developed based on the population growth and social economic development in the study area. The projected population of Hoa Binh in 2030 is proximately about 930,000 people in total, with population density of 197 people per square kilometers (GSOV, 2010). In Hoa Binh province, the purpose of predication for land use changes is to settle 930,000 people and maintain food security by increasing about 16% in agricultural land; therefore, the projected land use in 2030 of Hoa Binh was created following baseline land use in 2010 under its consideration. In addition, on-going changes in land use types in Hoa Binh are the conversion of barren land to field crop and perennial crops; hence, assumption of this trend is maintained in the future. Table 4 presents land use scenarios of Hoa Binh province in 2030 compared with the baseline scenario in 2010.

Table 3. Projected land use scenarios in 2030 under two scenarios

Land use name	Baseline	%	LU_1	%	LU_2	%
Barren land	68610.62	14.60	0.00	0.00	0.00	0.00
Disturbance forest	89363.27	19.02	89363.27	19.02	135659.17	28.87
Field crop	25476.36	5.42	71772.26	15.28	25476.36	5.42
Paddy	43983.39	9.36	43983.39	9.36	43983.39	9.36
Rock	19013.31	4.05	19013.31	4.05	19013.31	4.05
Un-disturbance forest	165793.49	35.29	165793.49	35.29	165793.49	35.29
Urban	38930.21	8.29	61244.93	13.03	61244.93	13.03
Water	18680.09	3.98	18680.09	3.98	18680.09	3.98

LU_1: land use scenario 1 in 2030
LU_2: land use scenario 2 in 2030

Table 4. Spatial distribution of soil loss in 2030

Class	Soil loss (ton ha^{-1} yr^{-1})	Intensity	LU_1&A_2	LU_1&B_2	LU_2&A_2	LU_2&B_2
			(%)			
1	0	Nil	6.20	6.71	5.75	4.99
2	0-10	Weak	11.06	16.03	16.90	30.18
3	10-50	Moderate	30.46	28.11	39.27	31.32
4	>50	Very high	52.28	49.15	38.08	33.51

Sources: TCVN 5299-2009
LU_1&A_2: Land use scenario 1 & High emission scenario (A_2)
LU_1&B_2: Land use scenario 1 & Medium emission scenario (B_2)
LU_2&A_2: Land use scenario 2 & High emission scenario (A_2)
LU_2&B_2: Land use scenario 2 & Medium emission scenario (B_2)

Land use scenario 1 (economic Scenario) in 2030 (LU_1): In this scenario, 68610.62 ha BRNL will be converted by 22314.72 ha for urban land and 46295.90 ha for FCRP (Corn) and the land use remains will be kept the same as in the past.

Land use scenario 2 (conservation scenario) in 2030 (LU_2): In this scenario, 68610.62 ha BRNL will be converted by 22314.72ha for urban land and 46295.90ha for DTFR (rubber). This scenarios restricts rapid expansion of cash crop whereas an increase in reforestation. Land use remains will be kept the same as in the past

Climate change Scenarios

In the northwestern provinces, A_2 and B_2 scenarios were selected for the study because of their simulation by GCMs in IPCC-AR4. The delta change method (Diaz-Nieto and Wilby, 2005) was used in order to apply GCMs on a regional scale and create future climate scenarios for local hydrological impact assessment. In the previous studied, this method has been extensively used on climate change (for example Khoi and Tadashi, 2013) by modification of observed historical time series via adding the difference between future and the baseline periods as simulated by GCM. The monthly differences between future and reference periods were calculated for maximum and minimum temperature and precipitation over the region covering at least one grid point based on the resolution of each GCM. Regional differences acquired with more grid points that will give more physically representative results than a value calculated with just one grid point (Khoi and Tadashi, 2013). Therefore, the differences are then added to the observed daily maximum and minimum temperature during the baseline period while the ratio is applied to precipitation.

3. Results and Discussion

3.1. SWAT model calibration and validation

It can be seen that a good correspondence between observed and simulated runoff and sediment yield during both the calibration and validation period (Figure 2). Taking into account the criteria of Moriasi et al. (2007) the SWAT model showed good to very good performance for monthly runoff and sediment yield prediction. For runoff, Nash-Sutcliffe coefficient of efficiency (NSE), observation standard deviation ratio (RSR), and percent bias (PBIAS) were 0.98, 0.02, and 3.67, respectively for the calibration period and 0.99, 0.01, and 1.56 for the validation period. With regard to sediment yield, the exponent parameter for calculating sediment (SPEXP), linear parameter for calculating maximum amount of sediment (SPCON), and peak rate adjustment for main channel were adjusted to the values of 1.1, 0.001, and 1.2, respectively. The values of NSE, RSR, and PBIAS were 0.81, 0.19, and -4.14 for the calibration period and 0.84, 0.16, and -2.56 for the validation period. The above results confirm that the SWAT model can be successfully used for predicting the effects of land use changes in the study area.

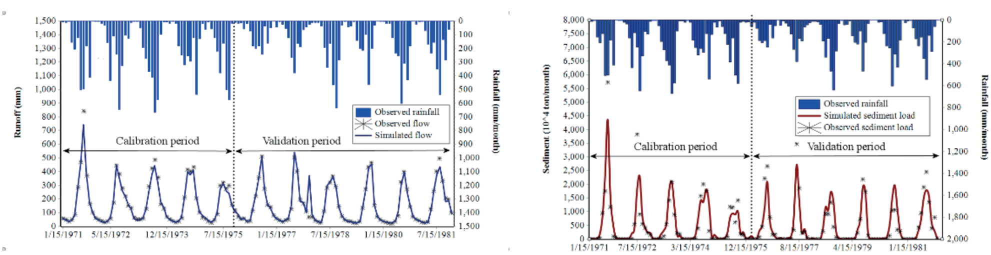

Figure 2. Observed and simulated monthly runoff (left) and sediment yield (right) during calibration (1971-1975) and validation (1976-1981) period at the outlet of the study area

3.2. Combined effect of future land use and climate change on runoff

Land use and climate change impacts on runoff were estimated by importing both land use and climate scenarios into SWAT model. The simulation results present in Figure 3 a, b. In comparison with the baseline, the simulation outputs presented that combination effects of projected land use and climate change are expected to increase slightly in annual mean runoff with 1.07% under $LU_1\&A_2$ and 0.79% under $LU_1\&B_2$ (Figure 3a). Considering the seasonal point of view, the seasonal runoff is expected to increase by 3.88% ($LU_1\&A_2$) and 2.72% ($LU_1\&B_2$) in the wet season and decreased by 1.74% ($LU_1\&A_2$) and 1.15% ($LU_1\&B_2$) in dry season. The increase in annual and seasonal runoff can be explained by the replacement of barren land by field crop and urban land and also the increase in precipitation accounts for 80% of total precipitation per year in the wet season in the study area. Other studies in Asian basins (Kim *et al.*, 2013; Park *et al.*, 2011; Trang *et al.*, 2017) also report big impacts from land use and climate change on streamflow because of future changes in precipitation land use patterns.

In contrast LU_1, LU_2 is predicted to decrease slightly in annual runoff ranges from 0.35% under B_2 climate scenario to 0.40% under A_2 climate scenario (Figure 3b). Regarding seasonal mean runoff changes, the predicted runoff is expected to decrease by 1.40% ($LU_2\&A_2$) and 1.13% ($LU_2\&B_2$) in the dry season but increased slightly by 0.60% ($LU_2\&A_2$) and 0.43% ($LU_2\&B_2$) in the wet season, respectively. The decrease in runoff can be attributed to increase in rubber plantation as a result of increase in infiltration rate and help soil restore organic matter and nutrients resulted in runoff reduction. The results are similar to previous researches conducted in Northwest of Vietnam such as Trinh (2007) and Lam (2009). The increase of forest cover led to a reduction of raindrop energy and increase of infiltration rate and organic matter.

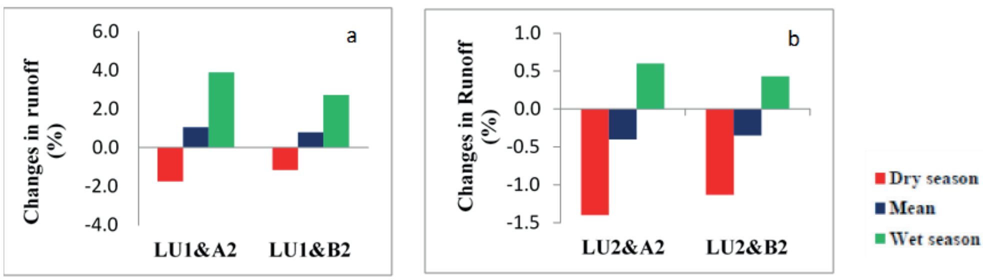

Figure 3. Changes in Average annual, wet and dry season runoff uder land use scenarios I (a) and land use scenario 2 (b)

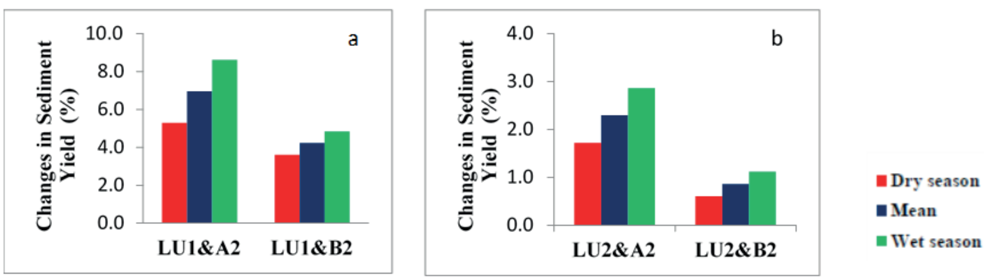

Figure 4. Changes in Average annual, wet and dry season sediment yield uder land use scenarios I (a) and land use scenario 2 (b)

3.3. Combined effect of land use and climate change on sediment yield

Figure 4a, b shows mean annual sediment yield increases in both combined impacts of projected land use and climate change by 4.22% under LU_1&B_2 and 6.96% under LU_1&A_2. Considering seasonal sediment changes, sediment is predicted to increase by 4.83% under LU_1&B_2 and 8.62% under LU_1&B_2 in the wet season. Similar to wet season, the sediment yield is also expected to increase by 3.61 under LU_1&B_2 and 5.30 under LU_1&B_2 in the dry season.

Similar to LU_1, the trend of mean annual sediment yield is expected to slightly increases in both combined impacts of projected land use and climate change (Figure 4b) by 0.86% under B_2 and 2.29% under A_2. Considering seasonal sediment changes, the sediment is predicted to increase by 1.12% under LU_2&B_2 and 2.86% under LU_1&B_2 in the wet season. Similarly, the sediment yield is also expected to increase by 0.60% under LU_2&B_2 to 1.72% under LU_1&B_2 in the dry season corresponds to the decrease in precipitation in these months. These results are similar to previous researches conducted in Vietnam by Phan *et al.* (2010), Ranzi *et al.* (2012), and Dao *et al.* (2013). The conversion of 11.07% forest land to agricultural land caused an increase of 8.94% in sediment load in Cau River Catchment (Binh *et al.* 2010). Ranzi *et al.* (2012) showed that a 35% decrease in forest area resulted in a 28% increase in sediment load at Lo River and Dao *et al.* (2013) also reported that 14.07% decrease in forest and increase 14.89% crop land led to an increase of 25.4% sediment load. It is shown that field crops such as corn, cassava, etc have aggravated soil erosion problems across the whole province. Along with these changes, the spatial distribution, combination of different land use types, and the fragmentation of land cover are also important factors affecting sediment yield (Nie *et al.*, 2011). Sediment yield is influenced by land use changes and the variation of land use changes are the main factors that caused sediment yield to increase or decrease.

In general, it is indicated that runoff and sediment yield have a positive relationship to forest cover and soil conservation practices such as strip grass barrier, contour hedgerow system, and crop residue could be used to explain both decrease in runoff and sediment yield. The increase of forest cover led to a reduction of raindrop energy and increase of infiltration rate and organic matter. Aside from this, implemented its soil conservation practices enabled soil to retain more moisture, reduce soil crusting and allowed organic materials such as leaves and plant parts to accumulate over time, helping to restore nutrients to the soil resulted in reduced runoff and sediment yield.

3.4. Predication of the future potential soil erosion in Hoa Binh province under land use and climate change

According to the simulated results obtained from the SWAT model, the areas with severe soil erosion can be identified. The standard indexes used in this study were classified into four erosion classes: nil, weak, moderate and very high based on classification proposed by the Ministry of Science and Technology (Table 4) The spatial distribution of intensity of soil erosion in Hoa Binh was given in Figure 5 a, b, c, and d. It can be seen that the areas of moderate and very high soil erosion intensity mainly occupied in Hoa Binh province ranges from 38 ton/ha.yr- under LU_1 & B_2 to 52 ton/ ha.yr under LU_1 & A_2, and from 23 ton/ha.yr under LU2 & B2 to 32 ton/ha.yr under LU_2 & A_2, respectively. In general, the future soil erosion in Hoa Binh was from moderate to very high. It can be seen that the soil erosion in 2030 under LU_2 & A_2 and LU_2 & B_2 is a little serious than soil erosion under LU_1 & A_2 and LU_1 & B_2 because in this scenario, the barren land is mainly replaced by rubber plantation. However, the combination of land use and climate change effects which led to the increase in intensity of soil erosion for whole area. In addition, the complexity, fragmentation and scatters of different land use types combined with increasing precipitation in both quantity and intensity contribute to increase in soil erosion. In the Table 4, we can see that serious soil erosion

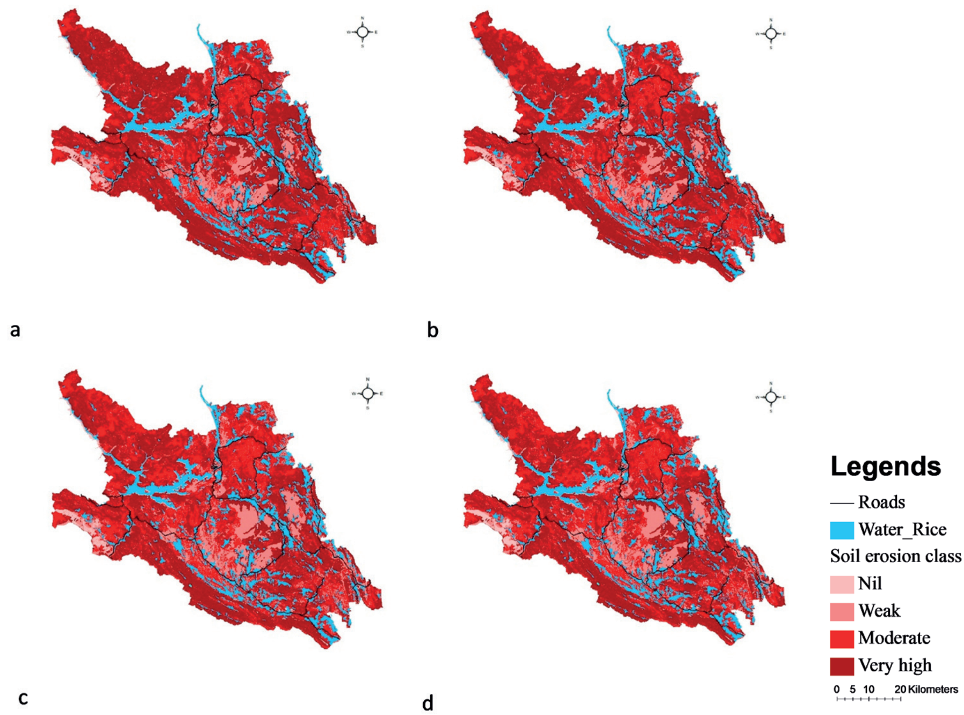

Figure 5. Map of soil erosion under land use scenario 1 and climate scenario A_2 (a), land use scenario 1 and climate scenario B_2 (b), land use scenario 2 and climate scenario A_2 (c), land use scenario 2 and climate scenario B_2 (d)

mainly occupied in Hoa Binh province ranges from 64.83% to 82.74% which suggest that the measures to control soil erosion should be taken at Hoa Binh province in the near future. We therefore recommend that LU_2 should be recommended to decision makers in implementing future land use planning and government policies to protect forests are implemented such as handing over forest protection to local people and applying mulching or crop residue for upland fields.

4. Conclusion

The present study quantifies the combined effects of land use and climate changes on runoff and soil erosion in Hoa Binh province, lower Da River Basin, Northwest Vietnam. There are two projected land use scenarios "Economic" and "Conservation" were developed for future periods. Under the economic scenario, barren land was converted by urban land and field crop. Under conservation scenario, the barren land was converted by urban land and rubber transplantation.

The evaluation results indicated that the SWAT model accurately simulated monthly runoff and sediment yield, soil erosion in the study area, and can successfully be used for assessing the impacts of environmental change including land use change and climate change in Da river basin.

The results show that in future land use and climate change are to be responsible for a 0.35 to 1.07% increase in runoff and 0.86 to 6.96 % increase in sediment yield, respectively. Moreover, it can be seen that the areas of moderate and very high soil erosion intensity mainly occupied in Hoa Binh province ranges from 23 to 52 ton/ha·yr .The results obtained in the present study could be useful to development planners, decision makers, and other stakeholders for planning and managing land use and water resources in this region by enhancing the understanding of the impacts of various land use change and climate scenarios on hydrological responses, sediment yield, and soil erosion.

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