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Effect of Land Use Change on Runoff and Sediment Yield in Da River Basin of Hoa Binh province, Northwest Vietnam

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Abstract: The objective of this study was to assess runoff discharge and sediment yield from Da River Basin in the Northwest of Vietnam using Soil and Water Assessment Tools (SWAT) model. The SWAT model was calibrated and validated using the observed monthly stream flows and sediment yield at selected gauging stations. The results indicated that SWAT generally performs well in simulating runoff and sediment yield according to Nash-Sutcliffe efficiency (NSE), Observation's standard deviation ratio (RSR), and percent bias (PBIAS) values. For runoff, the values of NSE, RSR, and PBIAS were 0.98, 0.02, and 3.69 during calibration period and 0.99, 0.01, and 1.56 during validation period, respectively. For sediment yield, the efficiency was lower than the value of NSE, RSR, and PBIAS during calibration period were 0.81, 0.19, and -4.14 and 0.84, 0.16, and -2.56 during validation period, respectively. The results of the study indicated that the vegetation status has a significant impact on runoff and sediment yield. Changes in land use type between 1995 and 2005 from forest to field crop and urban strongly contributed to increasing the average annual runoff from 182.5 to 342.7 mm and sediment yield from 101.3 to 148.1 ton^{-1} ha. Between 2005 and 2010, a decrease of both runoff (from 342.7 to 167.6 mm) and sediment yield (from 148.1 to 74.0 ton^{-1} ha) was due to the expansion of forested area and application of soil conservation practices. The results of this study are important for developing soil and water conservation programs, extending future SWAT modelling studies and disseminating these results to other regions in Vietnam.

Keywords: Land use change; Hydrology; Soil erosion; Soil and Water Assessment Tools (SWAT); Da River Basin

Introduction

Impact assessments of land use and land cover (LULC) changes on soil erosion, water quantity and quality are one of the most important topics for watershed management and ecological restoration. Changes in land use can result in disrupting the hydrological cycle by altering base flow (Wang et al. 2006) and annual mean discharge of the catchment (Costa et al. 2003). In the northwest of Vietnam, land use and agricultural systems have been rapidly changing since the 1990s alongside

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economic development of this region (Trinh 2007). Very large forests and protected areas were deforested by expansion of cultivated land, forest cutting and burning, leading to decreasing land cover and rapidly declining soil quality (Trinh 2007). Moreover, under the influence of population pressure, natural forest and fallow land have been replaced by permanent upland crops such as corn, cassava, upland rice, and sugarcane. Farmers cultivate these crops without applying any soil conservation practices; therefore, most cultivated upland soils are seriously eroded (Lanh 1999). This soil erosion, associated with high runoff and soil loss, is the main cause of soil degradation in the northwest of Vietnam (Phong 1995). Soil erosion may also result in several serious off-site effects, which include river and reservoir sedimentation, affecting irrigation efficiencies and hydroelectricity generation (NWRB 2004). Hence, quantitative estimations of the impacts of land use change on runoff and sediment yield are significant issues for soil and water conservation practices.

Over the past decades, several studies on simulating the hydrological process and soil erosion have been performed at plot and slope scales (Phien et al. 2000). At plot scale, soil erosion and runoff mainly vary among crop systems and conservation practices. Soil loss measurements using plot scale require long term experiments that include a combination of different crops, soil types and slope angles, hence, these experiments are demanding in terms of human and financial resources. However, soil erosion can also be assessed using soil erosion modelling at catchment scale when soil erosion and runoff mainly depend on watershed size in terms of topography, slope, shape, and land use types (Trinh 2007). Use of hydrological models, both spatial and temporal variation in runoff and sediment yield can be simulated, requiring less human and financial resources, and results are useful for soil and water management planning. With the expansion of GIS capabilities and the models available presently, many physically-based distributed models have been developed to simulate runoff and erosion dynamics of larger and complex catchments. The principal advantage of such a model is that it can realistically represent the spatial variability of catchments characteristics (Mishra et al. 2007). Many hydrological models, such as Limburg Soil Erosion Model (LISEM) (De Roo et al. 1996a, b; Jetten and De Roo2001), Areal Non point Source Watershed Environment Response Simulation (ANSWERS) (Beasley et al. 1980), Agricultural Non-Point Source Pollution Model (AGNPS) (Young et al. 1989), MIKE-SHE (Refsgaard and Storm 1995), Morgan-Morgan-Finney (MMF) (Morgan 2001), Water Erosion Prediction Project (WEPP) (Flanagan et al. 2001), and Soil and Water Assessment Tool (SWAT) (Arnold et al. 1990) are currently used to simulating the hydrological processes. Among the most widely used computer simulation modelling techniques for predicting runoff and sediment yield, SWAT model was selected for the present study because it can be applied to a large basin (Arnold et al. 1998) and it has available plug-in interfaces like ArcSWAT (Winchell et al. 2009) and MWSWAT (Luis 2013), and which makes it more accessible and user-friendly in handling input data. MWSWAT is available even in Vietnamese version (Binh 2013) which can facilitate many more SWAT users in Vietnam.

SWAT is a spatially distributed, physical based model in which the hydrological response unit (HRUs) is a fundamental concept (Neitsch et al. 2005). Since 1993, SWAT has proven to be an effective tool for simulating flow, water quality and soil erosion in small to large complex basins around the world. Rossi et al. (2009) have been using SWAT to facilitate the joint planning and management of the Mekong River Basin, Vietnam. Quyang et al. (2010) investigated soil erosion dynamics in the upper watershed of the Yellow River, China. Nie et al. (2011) applied SWAT to simulate how change in land cover influences hydrological components in the upper San Pedro watershed, Mexico. Phan et al. (2011) used SWAT for assessing the impact of climate change and deforestation on stream discharge and sediment yield in the Phu Luong watershed, Vietnam. To our best knowledge, there are few SWAT studies that focus on evaluating and predicting runoff and sediment yield in the tropical climate regions, like Vietnam, Thailand, and Philippines. This may be because of limited temporal and spatial data availability and data reliability in developing countries. Also, as we know, there has been so far no study reported the effect of land use change on runoff and sediment yield in Da River basin. It is considered very important for management of the river basin, where it is developing fast in economy.

This study attempts to apply SWAT model for assessing the impact of land use change on runoff and sediment yield in the northwest region of Vietnam. The study area includes the lower part of Da River Basin in Hoa Binh province where mountainous high land use changes and higher rainfall intensity are the cause of high stream flow as well as sediment yield (Hoa Binh People's Committee 2010). In addition, the study will provide the needed experience and techniques that can possibly be replicated and applied to other river basins of Vietnam. As such, this study aims to: (1) set-up, calibrate, and validate the SWAT model in terms of runoff and sediment yield; (2) evaluate the effect of land use changes on runoff and sediment yield, and (3) recommend decision makers for implementation of appropriate land use planning and sustainable watershed management.

1 Methodology

1.1 Study area

Hoa Binh is located in the Northwest of Vietnam between 20°19' to 21°08' N and from 104°48' to 105°52' E covering a total area of 4698 km² with elevation ranging from 200 to 1373 m above mean sea level (Figure 1). The topography ranges from valley to gentle slope, to steep slope. The slope of moutainous areas in the northwest region ranges from 20° to 35°. The climate is subtropical monsoon with mean annual rainfall of 1400 to 1900 mm with 80% of the rainfall falling in May through October. The maximum temperature is about 42°C in the summer and minimum is 3°C in the winter. The area has a hot-wet season that occurs from May to October and a cold dry season from November to April. Most parts of the area are dominated by soils such as Ferralsols, Fluvisols, and Acrisols, which are the remains of ancient soils on slopes after exposure from severe soil erosion (Hoa Binh people's committee 2005).

The population is approximately 794,000 people in total, with a population density of 170 persons per square kilometers. This is relatively low compared to Ha Noi with 1980 people per square kilometers (GSOV 2010). Major land use types in Hoa Binh province are forests (47.9% of the total area) and field crop (10.7%). Paddy rice accounts for 14.2% of the land area while urban areas comprise less than 8.7% of the area. The remaining land use types are barren land (10.4%), rock (4.1%), and water (4%). The major crops cultivated in this area include upland rice, lowland rice, maize, cassava, and sugarcane. The annual report from the Ministry of Natural Resources and Environment (MONRE) and Hoa Binh People's Committee in 2010 showed that the area is characterized by land use changes, soil degradation and nutrient losses associated with massive deforestation in the last 15 years, expansion of agricultural activities, and inappropriate conservation practices.

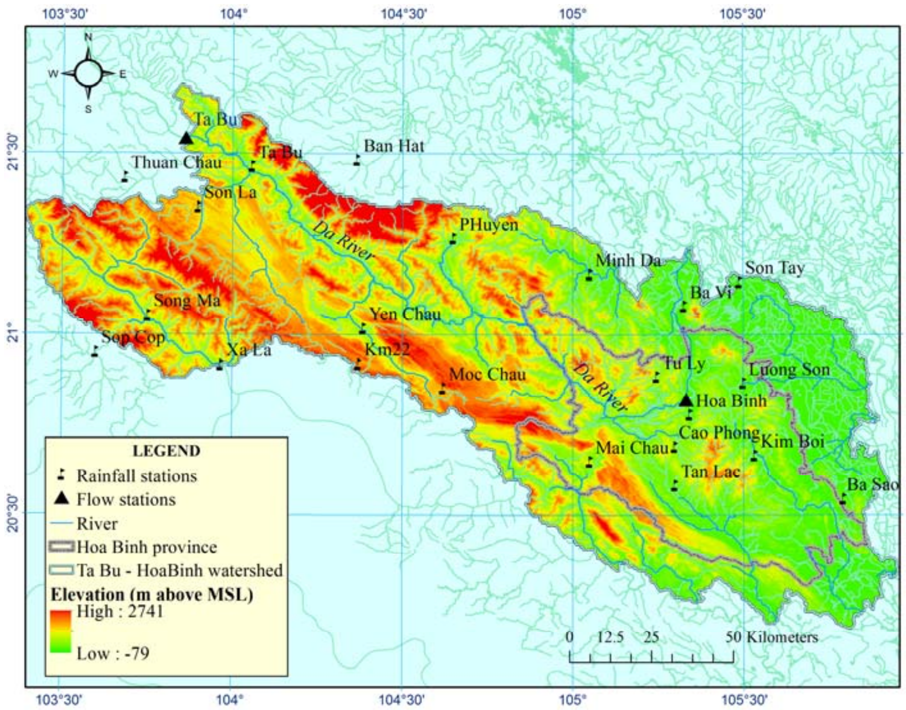

Figure 1 Location map of the Da River Basin, Northwest of Vietnam.

1.2 SWAT model

In this study SWAT (Neitsch et al. 2005) was applied in the Da River Basin to assess the effect of land use changes on runoff and sediment yield. SWAT is a continuous, long-term, physically based distributed hydrological model developed to predict the impact of land management practices on water, sediment loading and agricultural chemical yields in complex watersheds with heterogeneous soil and land use conditions (Arnold et al. 1998). In the SWAT model, the catchment is divided into sub-watershed or sub-basins and these are further divided into a series of HRUs based on unique soil and land use combination. Hydrological components, sediment yield, and nutrient cycles are simulated for each HRU and aggregated for the sub-basins. SWAT2005 provides several options when simulating the hydrological process, which can be chosen by users based on the data availability. In this research, the Pennman-Monteith method was used to calculate potential evapotranspiration (PET) and the Soil Conservation Services (SCS) curve number method was used to estimate surface runoff. The hydrological processes were calculated based on the water balance equation which can be represented as:

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

where SW_t $SW_t$is the final soil-water content (mm), SW_o is the initial soil water content on day i (mm), 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) (Neitsch et al. 2005). Soil erosion in SWAT is estimated using a Modified Universal Soil Loss Equation (MUSLE) (William et al. 1975) as shown below.

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

where, Sed is the sediment yield on a given day (metric tons), Q_{surf} is the surface runoff volume (mm ha^{-1}), q_{peak} is the peak runoff rate (m^3 s^{-1}), $area_{hru}$ 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 et al. 1978) and $CFRG$ is the coarse fragment factor.

1.3 Model setup

1.3.1 General

The model set-up was carried out using ArcSWAT interface package which runs under ArcGIS environment. The set up included preparing the input data, watershed delineation and configuration using digital elevation model (DEM) data, inputting soil, climate, land use and agricultural practice data, and a test run of the model.

One of the important issues is determination of the modeling area extension. In this study, the modeling area not only has to cover Hoa Binh province but also the gauging station upstream of the province boundary where the monitoring of flow and sediment transport data is available. Since Ta Bu is the closest station upstream to Hoa Binh, the modeling area starts from Ta Bu gauging station and ends at Hoa Binh gauging station (Figure 1). 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.

The input data in terms of topography, soil, climate, land use and agricultural practice data is described in the following sections.

1.3.2 Model data inputs

DEM

In this study, a DEM map at the scale of 1: 50,000 with resolution 30 m × 30 m was obtained from the Center of Land Planning and Management of the Ministry of Natural Resources and Environment (MONRE).

Climate data

Climate data is one of the most critical datasets for watershed analysis. In this case, developing an adequate spatial and temporal coverage for the study area was a challenge, considering the vast differences in elevation from mountain tops to lowland areas. Daily climate inputs for the period from 1961-2010 including minimum and maximum temperature, precipitation, solar radiation, wind speed, and relative humidity were utilized in this SWAT2005 model application. All of these inputs were collected at the stations nearest to the Northwestern region. These data were obtained from several sources including the National Climatic Data Center of Vietnam, Institute of Meteorology Hydrology and Environment, and Center for Environment Monitoring in the Northwest region. Temperature data from 17 stations and precipitation data from 21 stations within the area were available. Additional climate variables, such as solar radiation, wind speed and relative humidity inputs was measured from weather generators using monthly observed values from the nearest weather stations.

Soil data

Soil data obtained from MONRE's soil investigations in 2005, was used to formulate soil input data (Figure 2). In order to assign more representative Northwestern region specific soil properties and minimize the number of HRUs modeled, the areas of each MONRE soil map unit were tabulated and soil properties were derived by comparison with soil units of the Mekong River Commission (MRC) (Binh et al. 2005). According to the soil survey report published by Hoa Binh province (2005), there are six main groups with 22 types of soil dominant in the study area. Ferrasols being dominant soil occupy 78.93% of the total study area followed by Acrisols (8.29%), Fluvisols (2.92%), Leptosols (1.21%), Luvisols (1.03%), and Gleysols (0.36%).

In addition to soil properties, the most important parameter for soil erosion and sediment yield estimation in SWAT is the soil erodibility (K) factor, USLE_K (Table 1). In this study, data from various soil experiments conducted in the region (e.g., Ziegler et al. 2007), was examined and combined with MRC data (Binh and Trung 2005) to derive appropriate value of USLE_K.

Land use data

MONRE provided the land use data (ESRI shape file), which were derived from supervised classification of thematic mapper in 1995, 2005, and 2010 from satellite images. There are eight types of land use in the study area (Table 2 and Figure 3). The most common land uses are known to be continuous forest in the upper and medium hills, field crop and agricultural land in the low hills and valleys. Natural forest is mostly located on

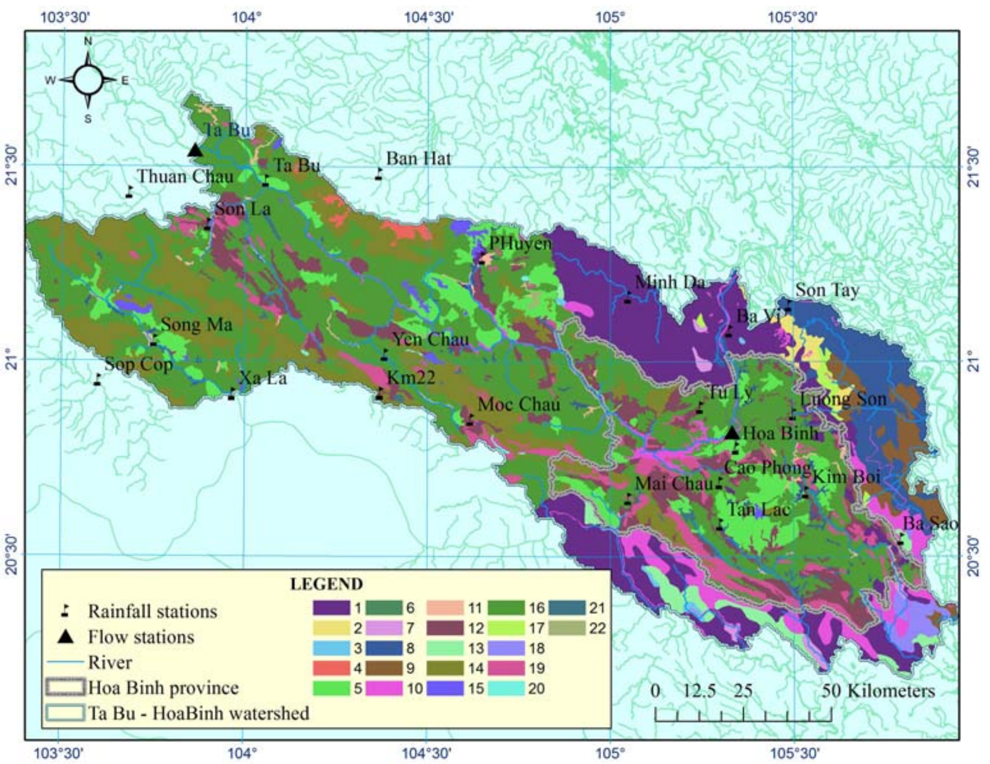

Figure 2 Soil map in the study area (names of soil series are given in Table 1).

Table 1 Soil group classes in the North West region of Vietnam

Code	Soil group name	USLE_K default*	USLE_K calibrated
1	Ferralic acrisols	0.15	0.15
2	Plinthic acrisols	0.27	0.25
3	Gleyic acrisols	0.13	0.19
4	Humic alisols	0.07	0.17
5	Haplic acrisols	0.16	0.18
6	Dystric/cambisols fluvisols	0.15	0.16
7	Dystric fluvisols	0.15	0.15
8	Eutric fluvisols	0.33	0.33
9	Gleyic fluvisols	0.30	0.15
10	Stagnic fluvisols	0.30	0.30
11	Humic fluvisols	0.15	0.15
12	Calcic ferralsols	0.15	0.12
13	Rhodic Ferrasols	0.09	0.10
14	Humic ferralsols	0.15	0.15
15	Calcaric humic ferralsols	0.15	0.20
16	Xanthic ferralsols	0.15	0.20
17	Dystric gleysols	0.15	0.08
18	Umbric gleysols	0.2	0.10
19	Lithic leptosols	0.18	0.00
20	Ferralic luvisols	0.15	0.12
21	Haplic luvisols	0.14	0.13
22	Chromic luvisols	0.15	0.15

*Source: Center of Land Planning and Management, MONRE, 2005 based on FAO classification.

steep slopes and on top of the mountains. In the upper hills, the major land use is artificial forest (mostly bamboo) that was planted in the 1990s after cutting of the forest to supply raw material for bamboo processing factories. After growth of 10 to 20 years, bamboo was harvested on a large scale and regrowth was very slow resulting in poor land cover over this period of time. In the sloping land, fruit trees such as orange, plum, lychee, and longan are grown; on the high terraces upland crops such as cassava, maize, pineapple, and bean are grown. Around the farms, mixed gardens occupy about three fourths of the total residential area. On the middle and low terraces which lie along the watershed drain network, slopes are gentle and soils are more suitable for annual crops such as rice, maize, and beans, with the main land use type being double rice and winter crops (maize, vegetable, and soybean). The cropping pattern of

Table 2 Land use types in the North West region of Vietnam

Land use	Abbre.	USLE_C default*	USLE_C calibrated
Barren land	BRNL	0.400	0.015
Disturbed forest	DTFR	0.250	0.250
Field cop	FCRP	0.350	0.350
Paddy	PDDY	0.030	0.003
Rocks	ROCK	0.001	0.001
Undisturbed forest	UDFR	0.001	0.005
Urban	URBN	0.015	0.015
Water	WATR	0.000	0.000

*Source: Center for Land Planning and Management, MONRE, 2010.

land use in Hoa Binh is spring rice from February to June, summer rice from July to September and winter crops starting from October to the middle of January next year. The transition time between crops is about 10-25 days for land preparation and transplanting/sowing with substantial soil surface disturbance.

Agricultural management practices

Based on experiments conducted by Watanasak (1978), Srikhajon et al. (1984), Srikhanjon (1998), and Kim (2006), values of different vegetative cover types (C factor) were assigned accordingly (Table 2). Moreover, all agricultural management and activity input to the model was derived from information provided by multiple local farm planners and agricultural researchers as described by MONRE (2010).

1.4 Model calibration and validation

In this study, the watershed was divided in to 103 sub-basins and then further divided into a total of 13,424 HRUs. Sensitive analysis was carried out to identify the most sensitive parameters for the model calibration using Latin Hypercube and One-factor-At-a-Time (LH-OAT), an automatic sensitivity analysis tool implemented in SWAT (Van Griensven et al. 2006; Gassman et al. 2007) After identifying the most sensitive parameters (Table 3) the model was calibrated and validated using records across a 10-year period (1971-1981). 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 sediment

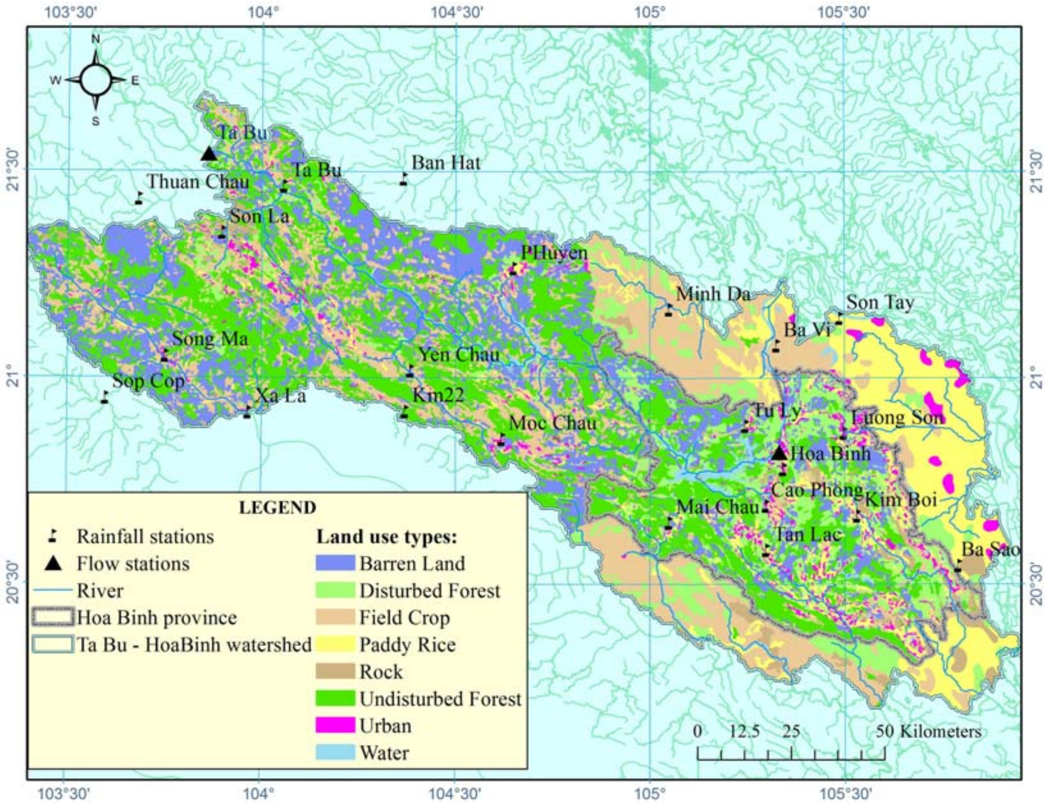

Figure 3 Land use type in the study area.

Table 3 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

yield at the Hoa Binh gauging station (located downstream of the dam) are no longer representative for naturally hydrological conditions.

Initially, identification of the sensitive parameters to improve the calibration efficiency was necessary. Only the most sensitive parameters were adjusted in order to minimize calibration variances in the study area. Several simulations using Latin Hypecube and One-factor-At-a-time (LH-OAT) were performed with different values of parameters to get a good calibrated model (Van Liew et al. 2005). For runoff calibration, the most sensitive parameters included CN2 (SCS runoff curve number for moisture condition), ALPHA_BF (base flow recession constant), ESCO (soil evaporation compensation factor), SOL_AWC (available water capacity of the soil layer), GW_REVAP (re-evaporation coefficient), and GWQMN (threshold water level in shallow aquifer for base flow). For sediment components, the most sensitive parameters included USLE_C (land cover and management), USLE_K (soil erodibility factor), USLE_P (soil conservation practices) PRF (peak rate adjustment for sediment routing in the channel), SPCON (coefficient in sediment transport in the channel), and SPEXP (exponent in sediment transport in the channel). Monthly observed runoff and sediment yield for 1971-1975 and the 1995 land-use map were used for calibration, while monthly observed runoff and sediment for 1976-1981 and the 2010 land-use map were used for validation. Three indicators were used to evaluate model performance: Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance. NSE indicates how well the plot of observed data variance; Observation's standard deviation ratio (RSR) is a development of root mean square error (RMSE), which is one of the most frequently used error index statistics. RSR standardizes RMSE using the observations standard deviation and is calculated as the ratio of the root mean square error and the standard deviation of the observed data; and percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than observed counterparts (Moriasi et al. 2007). RSR may be a misleading criterion for model evaluation according to Licciardello et al. 2007; Zema et al. 2012. The equations for the above mentioned indicators are given below.

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

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

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

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

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

where, n is the number of time steps, Q^i_{obs}, and Q^i_{sim} are the observed and simulated data, respectively, 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 is a worse predictor of the measured data. The optimal value of PBIAS is 0; positive values indicate model underestimation; and negative values indicate model overestimation (Li et al. 2009).

1.5 Model applications

To assess the effect of land use changes on runoff and sediment yield, the validated models were applied for three land-use change scenarios: 1995, 2005 and 2010.

2 Results and Discussion

2.1 Model Calibration and validation

The comparison of observed and simulated runoff showed a good correspondence between observed and simulated runoff and sediment yield during both the calibration and validation period (Figures 4 and 5). 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 (Table 4). 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

Table 4 **Model performance for the monthly simulation of runoff and sediment yield**

Indicator	Runoff		Sediment Yield	
	C#	V#	C#	V#
NSE	0.98	0.99	0.81	0.84
RSR	0.02	0.01	0.19	0.16
PBIAS (%)	3.67	1.56	-4.14	-2.56

Notes: NSE = Nash-Sutcliffe coefficient of efficiency; RSR = observation standard deviation ratio; PBIAS = percent bias; C# = Calibration in 1971-1975; V# = Validation in 1976-1981

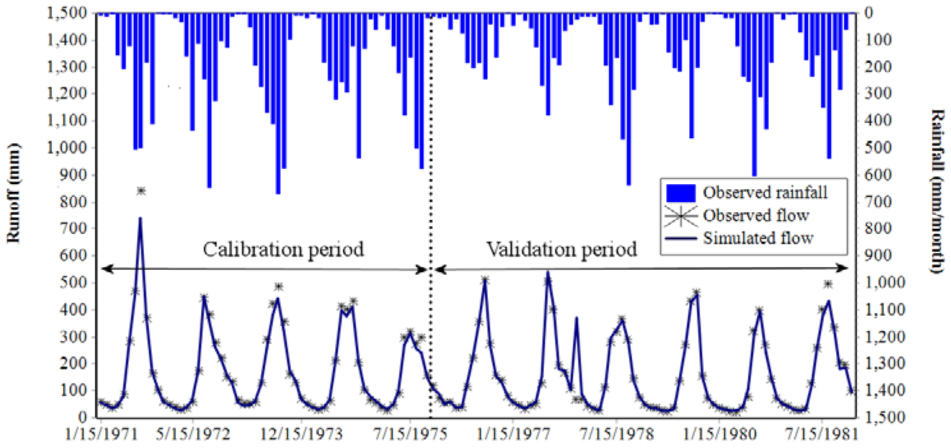

Figure 4 Observed and simulated monthly runoff during calibration (1971-1975) and validation (1976-1981) period at the outlet of the study area.

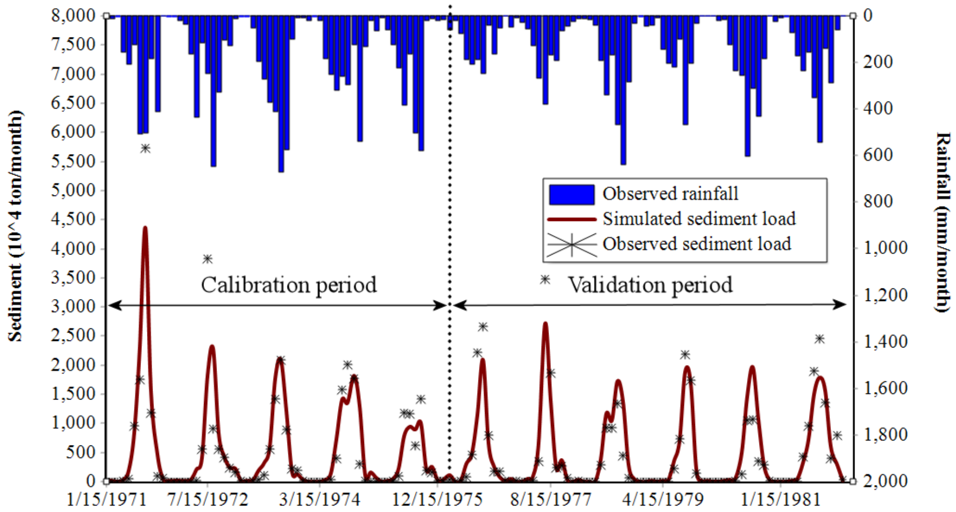

Figure 5 Observed and simulated monthly sediment load during calibration (1971-1975) and validation (1976-1981) period at the outlet of the study area.

(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, 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 an acceptable tool for predicting the effects of land use changes in the study area and also for further modeling analysis in other basins in Vietnam.

2.2 Land use changes

In recent decades in Hoa Binh, rapid land use change has occured and is known for its traditional farming system called “composite swidden farming”. Table 5 shows that the major land use types with the most significant change occurring in five land use classes: barren land (BRNL), disturbed forest (DTFR), field crop (FCRP), paddy (PDDY), undisturbed forest (UDFR), and urban (URBN). From 1995 to 2005, the proportional extent of FCRP, PDDY, and URBN, was from 5.36% to 11.89%, 10.91% to 15.66%, and 5.98% to 8.48%, respectively. On the other hand, the proportion of DTFR and UDFR dramatically decreased from 22.92% to 14.32% and 30.61% to 24.43%, respectively. The reason for these changes was the expansion of cash crops grown in monoculture being replaced by the swidden and multi crop

Table 5 Land use changes, average annual values of water yield, surface runoff, base flow, and sediment yield in the period from 1995 to 2010

Period	BRNL (%)	DTFR (%)	FCRP (%)	PDDY (%)	ROCK (%)	UDFR (%)
1995	16.97	30.61	5.36	10.91	3.53	22.92
2005	17.18	24.43	11.89	15.66	4.04	14.32
2010	10.35	31.90	10.74	14.24	4.05	16.04
2005/1995	0.21	-6.18	6.53	4.75	0.52	-8.60

Period	URBN (%)	WATR (%)	Water yield (mm)	Surface runoff (mm)	Base flow (mm)	Sediment yield (ton/ha)
1995	5.98	3.73	660.2	182.5	407.7	101.3
2005	8.48	4.01	1037.1	342.7	597.1	148.1
2010	8.71	3.98	732.2	167.6	471.6	74.0
2005/1995	2.50	0.27	376.9	160.2	189.4	46.8

Note: See Table 2 for the abbreviations of BRNL, DTFR, FCRP, PDDY, ROCK, UDFR, URBN, WATR.

systems as reported by many researchers (Nguyen et al. 2004; Thanh 2009). According to annual reports and interview data, many parts of the forest were converted to agricultural land, timber was exploited and there was a lack of regulation to protect and sustainably use forest resources which led to a reduction of natural forest cover. The expansion of field crops and paddy were due to population pressure, food demand and transition from a subsistence and planned economy towards market orientation. After 2005, the proportion of land use was changed due to the decrease in BRNL, FCRP, and PDDY and the increase in DTFR, and UDFR land uses. The reasons for such change can be attributed to peoples' awareness about the soil fertility decline, and soil erosion and degradation. Aside from this, a decreased productivity could be the cause of increasing FCRP and decreasing DTFR and URBN. In addition, government policies to protect forests were implemented such as handing over forest protection to local people and applying mulching or crop residue for upland fields.

2.3 Runoff and sediment yield variation in Hoa Binh provinces

It can be seen that surface runoff was strongly changing in the period of time from 1995 to 2010 accounting for 182.5 mm (1995), 342.7 mm (2005), and 167.6 mm (2010). Similarly, water yield was also increasing 660.2 mm (1995) to 1037.1 mm (2005) and 732.2 mm (2010). Table 5 shows the results of sediment yield was a similar trend to runoff. The variation in sediment yield increased from 101.3 ton ha^{-1} (1995) to 148.1 ton ha^{-1} (2005) and tends to decrease from 148.1 ton ha^{-1} (2005) to 74.0 ton ha^{-1} (2010). The possible explanations could be the complexity, fragmentation and the spatial distribution of different land use types which influence the runoff and sediment yield. In conclusion, land use types as well as spatial distribution of the land use, determine the impact of land use changes on runoff and contribute to changes in sediment yield.

2.4 Effect of land use changes on runoff and sediment yield

Average annual water yield, surface runoff, base flow simulated by SWAT at Hoa Binh province under different land use varied strongly in the period of time from 1995 to 2010 (Table 5). Water yield was 376.9 mm in 2005 and 72.0 mm in 2010 higher than in 1995. Similar to water yield, base flow increased 189.4 mm and 63.9 mm in 2005 and 2010, respectively. The increase in water yield and base flow from 1995 to 2010 could be due to a decrease in forest area, urban expansion and expansion of field crops. Other authors (Li et al 2009, Phan et al. 2010, and Nie et al 2011) reported that the conversion of forest land to agriculture has caused increases in both water yield and base flow. In contrast to water yield and base flow, surface runoff increased by 160.2 mm in 2005 and then decreased by 14.9 mm in 2010 (Table 4). The increase in surface runoff from 1995 to 2005 is associated with the conversion of forests (DTFR and UDFR) to agricultural and urban land, while the surface runoff decrease after 2005 is related to the increase of forest cover, decrease of agricultural land area and implementing appropriate techniques, such as strip grass barrier, the contour hedgerow system, and crop residue. It is known that these techniques reduce surface runoff (Schlesinger et al., 1990 and Dao et al. 2013). Concerning sediment yield, simulation results also showed that sediment dramatically increased with an increase of agricultural land (FCRP and PDDY), urban expansion and the removal of forest land (DTFR and DTFR). For example, while the runoff increased from 182.5 mm in 1995 to 342.7 mm in 2005, increase of agricultural land, urban expansion and the removal of forest land led to a predicted sediment yield ranging from 101.3 ton ha^{-1} to 148.1 ton ha^{-1} in the whole catchment. 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. The decrease in surface runoff after 2005 led to sediment yield decrease from 148.1 ton ha^{-1} (2005) to 74.0 ton ha^{-1} (2010). It is shown that surface runoff and sediment yield have a positive relationship to land cover and soil conservation practices. As mentioned above, the increase of forest cover from 38.75% (2005) to 47.95% (2010) and implementation of soil conservation practices such as strip grass barrier, contour hedgerow system, and crop residue could be used to explain both decrease of surface 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, implemeted 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 surface runoff and sediment yield.

Table 6 shows the erosion rate and soil loss in 1995, 2005, and 2010 from the different land use types. It can be seen that the largest changes in erosion rate and soil loss came from FCRP, DTFR, UDFR, PDDY, and URBN. The highest soil erosion rate came from field crop (mainly cultivated corn and cassava) varying from 2.95 ton ha^{-1} (1995) to 6.04 ton ha^{-1} (2005), and 4.23 ton ha^{-1} (2010). The erosion rate of barren land is not as high as field crop because it is controlled by the rainfall amount and intensity, while, field crop is larger due to tillage and seed sowing. Disturbed forest and undisturbed forest have a moderate soil erosion rate (Table 6) varying from 0.16 to 1.04 ton ha^{-1} but the total sediment yield is still large (Table 6) because the forest area is the largest (Figure 3). It is shown that conversion of primary forest to annual crops through slash and burn and the replacement of upland forests with annual crops have aggravated soil erosion problems across the whole province. Along with land use changes, the spatial distribution, combination of diferent 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.

Table 6 **Major land use types, erosion rate, and soil loss from 1995 to 2010**

Land use	Erosion rate (ton ha^{-1} year^{-1})			Soil loss (ton)		
	1995	2005	2010	1995	2005	2010
BRNL	0.79	1.22	0.70	15445	17807	7024
DTFR	0.56	1.04	0.50	60629	101199	45019
FCRP	2.95	6.04	4.23	74333	156048	107738
PDDY	0.62	1.32	0.79	31558	57388	34542
ROCK	0.41	0.32	0.41	6730	6048	7876
UDFR	0.23	0.38	0.16	33357	54968	26463
URBN	1.20	1.72	1.57	33722	68521	60992
WATR	0.00	0.00	0.00	0	0	0

Note: See Table 2 for the abbreviations of BRNL, DTFR, FCRP, PDDY, ROCK, UDFR, URBN, WATR

In brief, the increase of runoff and soil erosion rate is associated with decline in soil fertility and crop yield. Rapid expansion of intensive agriculture, with application of ever increasing fertilizer doses, increases the risk of negative environmental impacts. According to surveyed data and the annual report of Hoa Binh (2010), upland rice yield rapidly declined from 2115 kg ha^{-1} in the first year to 1250 kg ha^{-1} in the second year, 580 kg ha^{-1} in the third year and less than 120 kg ha^{-1} or even no production in the following years. Similarly, the decline in soil fertility rapidly reduced the productivity of maize after forest clearing from 5300 kg ha^{-1} in the first year to 1200 kg ha^{-1} in the second year. To maintain crop yield, farmers increased fertilizer application by 20% every year leading to inefficient nutrient utilization and causes environmental pollution by runoff (Trinh 2007). Efforts should therefore be exerted to address forest land conversion to agricultural land and urban land. Policies should be developed both at local and national level. Likewise, information and education campaigns on the consequences of forest conversion and ways of rehabilitating the whole watershed should be conducted. The results of this study showed that application of appropriate techniques, such as reforestation, forest protection, mulching, use of crop residues, and strip grass barriers since 2005, contributed to reduced runoff and sediment yield in the study area.

2.5 Identification of the soil erosion risk in Hoa Binh province

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, high and very high based on classification proposed by the Ministry of Science and Technology (Table 7). The spatial distribution of soil erosion risk in Hoa Binh is given in Figure 6. The areas of high soil erosion intensity account for 33.44%, 46.87%, and 34.07 % in 1995, 2005, and 2010, respectively, which highlights that deforestation and agriultural expansion in the 1995-2010 period were the major causes of high soil erosion. The soil erosion risk in Hoa Binh however was from weak to moderate intensity in

Table 7 Characteristics and area of soil loss classes (Unit for Soil loss: ton ha^{-1} yr^{-1})

Class	Soil Loss	Grade	Percentage		
			1995	2005	2010
1	0	Nil	3.82	4.06	3.98
2	0-10	Weak	23.53	14.18	24.67
3	10-50	Moderate	39.21	34.90	37.29
4	>50	Very high	33.44	46.87	34.07

Source: TCVN 5299-2009

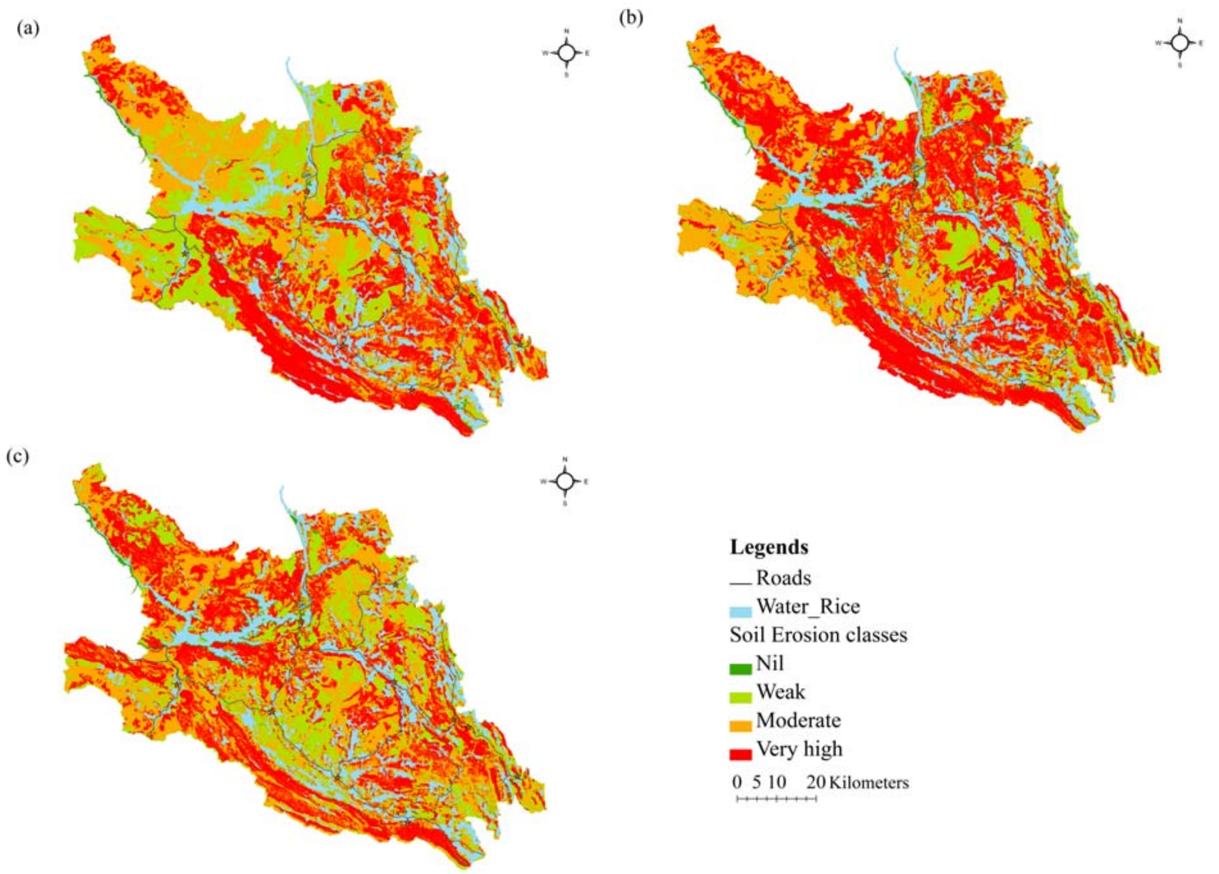

Figure 6 Map of soil erosion risk in Hoa Binh province in the period of time (a) 1995, (b) 2005, and (c) 2010.

61.74%, 49.08%, and 61.96% of total area in 1995, 2005, and 2010, which suggest that the measures to control soil erosion should be taken at Hoa Binh province in the near future. We therefore recommend that policies addressing soil erosion problems should be formulated at both local and national level.

3 Conclusions

The SWAT model was calibrated and validated in Da River Basin of Hoa Binh Province, Northwest Vietnam using observed data from 1971-1981 at Hoa Binh monitoring station. The evaluation results indicated that the SWAT model accurately simulated monthly runoff and sediment yield in the study area, and can successfully be used for investigating the effects of land use changes on runoff and sediment yield and for identifying critical soil erosion areas.

The increase of agricultural land, expansion of urban area and the removal of forest land dramatically increased runoff and sediment, while the increase of forest cover and implementation of soil conservation practices explained the decrease of both runoff and sediment yield.

Although financial and social consequences of land use changes were not taken into consideration in this study, the results obtained from this study could be of value to people living in this area, stakeholders and decision makers to make better choices for land use planning and management.

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