THE IMPACTS OF LAND USE CHANGE ON SOIL EROSION IN BO RIVER WATERSHED, CENTRAL VIETNAM

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ABSTRACT

Soil erosion has been considered as the primary cause of soil degradation since soil erosion leads to the loss of topsoil and soil organic matters, which are essential for the growing of plants. Land use, which relates to land cover, is one of the influential factors that affect soil erosion. The objective of this study is to assess the effects of land use changes on soil erosion in Bo River watershed, Central Vietnam. This paper presents a comprehensive methodology that integrates Soil and Water Assessment Tools (SWAT) model with a Geographic Information System (GIS) for simulating effects of land use change on soil erosion. The data on precipitation, inflow, outflow, DEM, soil map and Landsat 7+ETM images of the study site were collected and analyzed. The results show that water body and dry agriculture land area increased while mixed Forest and rice land declined continuously over the study period between 2000 and 2010. Different land use types in terms of area size and pattern influenced the soil erosion risk in Bo River watershed. The integrated approach in this study allows for relatively easy, fast, and cost-effective estimation of spatially distributed soil erosion and analyses of the land use changes effects on soil erosion. It thus provides a useful and efficient tool for assessing erosion impacts of conservation support practices.

Key words: *Land use change, soil erosion, SWAT, GIS, Central Vietnam*

1. INTRODUCTION

Land use change, the physical change in land cover caused by human activities, is a common phenomenon associated with population growth, market development, technical and institutional innovation. Changes in land use can have various consequences on economic growth and natural resources, such as soil and water (Wijitkosum, 2012).

Soil erosion is a complex process that physically takes place by the movement of soil particles from a given site. Soil erosion can affect soil quality and induce soil deterioration by the loss of top soil that is enriched with organic matter. Therefore, the soil erosion can cause a reduction of crop productivity. Factors that are considered as the main causes of soil erosion are climate, soil type, topography, vegetation and human activities. In the areas where climate, soil type and topography are similar, differences in soil erosion rates are commonly related to land use or land cover (Del Mar López *et al*. 1998). Since soil erosion generally occurs when the soil is displaced by rain and transported from the specific area, therefore rainfall is considered as the driving factor of soil erosion. However, the factor that significantly affects the soil displacement by rain is land cover or vegetation cover. The reduction of vegetation cover can increase soil erosion. This relationship is a reason why vegetation cover and land use have been widely included in soil erosion studies (Del Mar López *et al.* 1998; Zhou *et al*. 2008*;* Solaimani *et al.* 2009; Su *et al.* 2010). Many studies found that land use can greatly affect the intensity of runoff and soil erosion (Martínez-Casasnovas & Sánchez Bosch 2000*;* Cebecauer & Hofierka 2008*;* Zhou *et al.* 2008; García-Ruiz 2010; Mohammad & Adam 2010*).* The objective of this study was to analyze the impact of land use changes on soil erosion in Bo River watershed of Vietnam from 2000 to 2010 applying SWAT.

2. STUDY AREA

Thua Thien Hue province is located in the Center of Vietnam between $16^0$20’ to $17^0$15’ of the north latitude and $107^0$05’ to $108^0$15’ east longitude, comprising 2 basins of 4 rivers. The largest river basin in Thua Thien Hue province is Huong River with 104 km length and 2.830 km^2 total area that representing 56% of total area of the province. The second one is Bo River has a basin area of 938 km^2, with a length of 94 km, and its confluence is in the Sinh cross-river with a distance of 9 km from the estuary of Huong River. There is 80% area of Bo River watershed is mountainous, and slope over 25^0 accounted for 54%. The range elevation of the watershed is 384 m. Moreover, it is located in the most abundant potential flow region of Central Vietnam, with large amount and high intensity of rainfall leading to soil erosion and river bank erosion risk is very high.

The Bo River plays an important role on water resource status of Thua Thien Hue province due to it is the main subflow lying in the left of Huong River, and a main source of irrigation for agriculture, aquaculture, provides water supply for industry and energy generation, municipal and civil use, for existence of aquatic and water related environment, ecosystems and wild life on the large area. One reservoir, Huong Dien hydropower plant, was built in 2008 with the total volume of 820.67 million m^3.

3. MATERIALS AND METHODS

3.1. Analyzing land use change

Changes in land cover were measured using time series of satellite data. Landsat images for the research area were visually interpreted for the years 2000 and 2010. Two images were taken in the spring season between March 4th and April 7 th. Hence, they stem from the same cropping season and from comparable climatic conditions. This enhances the interpretation as the spectral reflection of land cover/use is easier to compare. The Landsat satellite was selected because of its high temporal frequency, thus providing more choices for the most cloud-free images. Moreover, the data is available at no charge. The images were geo-rectified and geo-referenced into the Universal Transverse Mercator (UTM) coordinate system, WGS 84, 48N.

The images were classified using a supervised classification technique. The land use signatures were selected based on the spectral reflectance of the images, with the guidance of the topographic map scale at 1:25,000 published in 2007 and land use map in 2000 (hard copy, obtained from Department of Natural Resources and Environment (DONRE) of Thua Thien Hue province), 150 tract points and our familiar of the study area. To achieve a highly distinctive classification, we developed highly separable land signatures. One hundred and twenty-nine final signatures were used in the maximum likelihood algorithm to produce land use maps. The signatures represented six major land use classes as documented in Table 1.

An accuracy assessment of the classified images was performed by developing a set of sample areas using land use map of the year 2000 in hard copy version produced by the government offices, DONRE. Because no ground-truthing was possible for the year of 2000, this map was the best available information. Although assuming that these official maps were true, as they have been widely used by planers and stakeholders, we performed an additional verification of the selected sample areas during the second filed visit on April 2010. We checked the agreement between the land use of the selected sample areas and the field reality through observation and through collecting information from local inhabitants and from the author’s own familiar and judgment as a local inhabitant. Overall accuracies of 90.39% (Kappa coefficient 0.88), and 93.49 (Kappa coefficient 0.91) were obtained for the 2000 and 2010 images, respectively.

3.2. SWAT model setup

3.2.1. SWAT model input

The ArcSWAT 2009 (Soil and Water Assessment Tool) model was used for the study to assess soil erosion. SWAT is a basin scale, continuous time hydrology model that can produce simulation results on a daily, monthly, or annual basis (Arnold and Fohrer, 2005*)*. The model can simulate stream flow as well as sediment yield. This study focuses on the effects of land use change on soil erosion based on sediment yield and surface runoff parameters in Bo River watershed in 2000 and 2010.

The SWAT model inputs are Digital Elevation Model (DEM) from DONRE belong to Thua Thien Hue province, soil map from Department of Science and Technology, land use maps in 2000 and 2010, weather and hydrology data from HydroMeteorological Center in Hue city and Institute of Geography, Vietnam.

3.2.2. Watershed configuration

SWAT divides a watershed into sub-watersheds and the sub-watersheds can be further sub-divided into Hydrologic Response Units (HRUs). Within each sub-watershed, HRUs in are formed as unique soil and land use combinations that are not necessarily contiguous land parcels. In this study, the ArcGIS interface *(*Winchell *et al., 2010)* of the SWAT 2009 version was used to describe a watershed and extract the SWAT model input files. The DEM was used to delineate the watershed and provide topographic parameters for each sub-watershed. The watershed was delineated and described into 31 sub-watersheds and 1419 HRUs. The HRUs was defined at 10% land use, 10% soil class and 5% slope class.

3.2.3. Model Calibration and Validation

The SWAT calibration method was used for the study, which included calibration of model manually by adjusting hydrologic and sediment parameters in SWAT. The calibration process was basically trial-and-error to yield the highest Nash-Sutcliffe coefficient. Validation is taken to mean 'model testing' and validated model not necessarily be a perfect predictor. Rather, good validation results are simply stronger evidence that the calibrated model is a good simulator of the measured data and does not over measure data in the calibration period. In this study, the model was calibrated and validated only for flow due to lack of data on annual sediment load in outlet station. The flow monitoring data in 2000 and 2010 were used for calibration and validation.

The coefficient of determination (R^2) and Nash-Suttcliffe coefficient *(*Nash and Suttcliffe, 1970*)* were used to quantitatively assess the ability of the model to replicate temporal trends in measured data. The percent bias is defined as the relative percentage difference between time steps.

3.3. Soil erosion assessment using SWAT

Erosion and sediment yield in SWAT are estimated of each HRU with the Modified Universal Soil Loss Equation (MUSLE) developed by *Wischmeier* and *Smith* (1965; 1978). While the USLE uses rainfall as an indicator of erosive energy, MUSLE uses the amount of runoff to simulate erosion and sediment yield. The hydrology mode supplies estimates of runoff volume and peak runoff rate, which, with the sub-basin area, are used to calculate the run off erosive energy. The crop management factor is recalculated every day that runoff occurs. It is a function of aboveground biomass, residue on the soil surface, and the minimum C factor for the plant. The modified universal soil loss equation is given by:

$$sed = 11.8\left(Q_{surf}\,.\,q_{peak}.area_{hru}\right)^{0.56}.K_{USLE}.C_{USLE}.P_{USLE}.LS_{USLE}.CFRG \quad (1)$$

Where *sed* is the sediment yield on a given day (metric tons); Q_{surf} is the surface runoff volume (mm H_2O/ha); q_{peak} is the peak runoff rate (m^3/s); $area_{hru}$ is the area of the HRU (ha);

K_{USLE} is the USLE soil erodibility factor (0.013 metric ton m^2 hr/(m^3-metric ton cm)); C_{USLE} is the USLE cover and management factor; P_{USLE} is the USLE support practice factor; L_{SUSLE} is the USLE topographic factor and *CFRG* is the coarse fragment factor.

4. RESULT AND DISCUSSION

4.1. The impacts of land use change on soil erosion

There are many previous studies on the impact of land use change on soil erosion by using different techniques. In this study, an assessment of the spatial variability of soil erosion at different land uses has been done.

According to the land use change study of two periods, it was found out that in 2010 the mixed forest, bare land and wet agriculture land slightly decreased by 3.65%, 16,30% and 36.66%, respectively compared to the year of 2000, while water body area significantly increased by 57.16% and dry agriculture area increased by 19.90% (Table 1). The residential land sharply increased by 91.35% over 10 years period since 2000.

Table 1. Changes in land use from 2000 to 2010

SWAT code	Land use type	Area (ha)		
		2000	2010	Change (+/-)
WATR	Water bodies	3791.93	5959.66	2167.73
FRST	Forest Mixed	68615.47	66107.62	-2507.85
WARL	Wet Agricultural Land	9523.06	6032.21	-3490.85
DAGL	Dry agricultural Land	5987.93	7179.41	1191.48
URBN	Residential land	3342.63	6396.07	3053.44
BRNL	Bare land	2539.06	2125.11	-413.95
	Total	**93800.08**	**93800.08**	

The reasons how land cover/use affects soil erosion can be explained in various ways. According to *Neitsch et al. (2009)*, the canopy affects erosion by reducing the effective rainfall energy of intercepted raindrops. Water drops falling from the canopy may regain appreciable velocity but it will be less than the terminal velocity of free-falling raindrops. The average fall height of drops from the canopy and the density of the canopy will determine the reduction in rainfall energy expended at the soil surface. The relative changes in soil loss areas due to changes in land use types from 2000 to 2010 are shown in *Table 2*.

Table 2. The estimate of soil loss at different land uses in 2000 and 2010

Land use type	Soil loss (tons/yr)	
	2000	2010
Forest mixed	9784.557	73640.224
Residential land	1074.843	0.175
Bare land	2710.027	6070.378
Wet agriculture land	35168.213	52330.188
Dry agriculture land	49343.941	30605.700
Total	**98081.581**	**162646.67**

The *Table 2* revealed that the plants with small canopy particularly in dry agricultural land could be strongly affected by erosion risk. For instance, dry agricultural land was only the third largest in the study area but the amount of soil loss was highest from this among all land use categories in 2000. Wet agricultural land, mainly is paddy rice land, is a second highest soil loss in 2010. It is also to note that the soil erosion risk of forest mixed area get highest value in 2010, although it was changed to other land use types with a small area (3.65%) during ten years. The cause of this is due to a large area of natural forest converted to plantation forest with mainly acacia, rubber and pine tree that are small canopy plant. Meanwhile, residential land was occupied by buildings, therefore this land use type was considered as low soil erosion risk. The changes in the area of water bodies were neglected because the area of water bodies was not considered in soil erosion risk assessment.

3.2. Model evaluation

In this study, the flow data was applied during calibration process due to lack of sediment data. According to the general guidelines for calibration tolerances or targets from Hydrological Simulation Program Fortran training workshops over the past 10 years (*Donigian, 2000*) and *Moriasi et al.* in 2006, model simulation judged as satisfactory if NSE > 0.5, RSR ≤0.70, and PBIAS = ± 25% for flow (Table 3). Therefore, the calibration and validation results of this study can be accepted. The results of daily flow calibration processes showed good fit between simulated and observed data, however, it was found somewhat poor fits with the observed values of few periods due to limitation of continuous data on stream flow.

Table 3. Model evaluation values for simulated and observed stream flow

Periods	Mean flow (m^3/s)		NSE (R^2)	RSR	PBIAS (%)
	Observed	Simulated			
Calibration	25.37	27.42	0.70	0.23	1.75
Validation	24.43	28.61	0.95	0.48	-2.37

3.3. Soil erosion risk mapping

According to a previous study *by Vu Anh Tuan (2007)*, the soil erosion level was classified into four classes (tons/ha/year): Low (<50), Moderate (50-150), Severe (150-200), Extreme (>200). The assessment of soil erosion risk in the study area by applying SWAT revealed that the soil erosion extent from negligible erosion to 2559 (tons/ha/year), and the low soil erosion risk category occupied in 2000 with approximately 80.99% of total area. However, the area of moderate, severe and especially extreme soil erosion risk categories strongly increased in 2010 as documented in *Figure 1 and Table 4*.

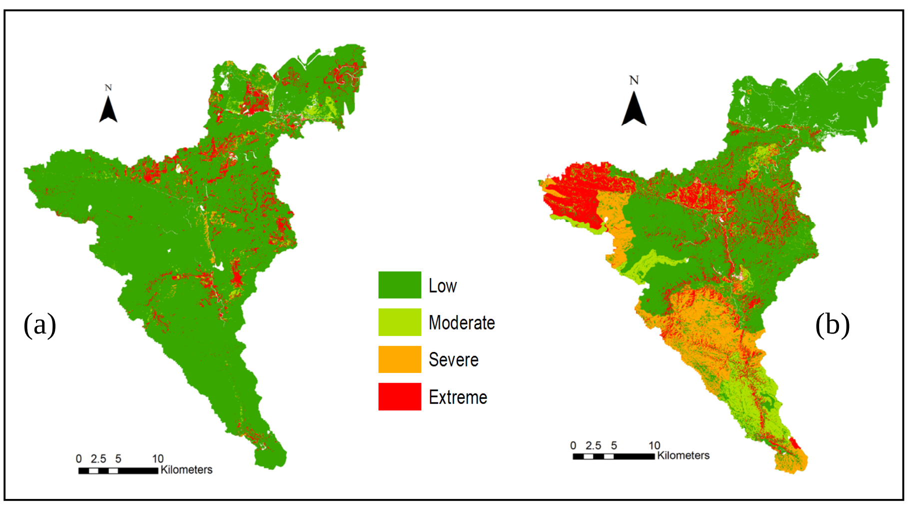

Figure 1. Soil erosion risk (a) in 2000, (b) in 2010

Table 4. The area of soil erosion risk in Bo River watershed

Year	Area of soil erosion risk (ha)							
	Low	*(%)*	Moderate	*(%)*	Severe	*(%)*	Extreme	*(%)*
2000	75862.94	*80.88*	4959.45	*5.29*	3825.37	*4.08*	9152.32	*9.76*
2010	51474.90	*54.88*	11027.74	*11.67*	15127.06	*16.13*	16170.38	*17.24*

5. CONCLUSIONS

In the areas where climate, soil type and topography are similar, differences in soil erosion rates are commonly related to land use. Different land use types in terms of area size and pattern influenced the soil erosion risk in Bo River watershed in the 2000 and 2010. The results of calibration process showed good fit between simulated and observed data, therefore SWAT can be used to evaluate impacts on soil erosion over time in the study site and it can be a useful tool for modeling the impact of land use changes in small mountainous watershed of Central Vietnam. However, application of SWAT required considerable amount of detailed data, which is not readily available and also it rather difficult to evaluate data accuracy/reliability of a certain amount of data.

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