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Assessment of Soil Erosion Risk in Komering Watershed, South Sumatera, Using SWAT Model

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Abstract. Changes in land use watershed led to environmental degradation. Estimated loss of soil erosion is often difficult due to some factors such as topography, land use, climate and human activities. This study aims to predict soil erosion hazard and sediment yield using the *Soil and Water Assessment Tools* (SWAT) hydrological model. The SWAT was chosen because it can simulate the model with limited data. The study area is Komering watershed (806,001 Ha) in South Sumatera Province. There are two factors land management intervention: 1) land with agriculture, and 2) land with cultivation. These factors selected in accordance with the regulations of spatial plan area. Application of the SWAT demonstrated that the model can predict surface runoff, soil erosion loss and sediment yield. The erosion risk for each watershed can be classified and predicted its changes based on the scenarios which arranged. In this paper, we also discussed the relationship between the distribution of erosion risk and watershed's characteristics in a spatial perspective.

INTRODUCTION

Land or land resources is one of the resources that play a role in the system of human life. A rapid change of the land use can lead to environmental degradation. Land use change (LuC) is a process by human activities which transform the landscape. There are some modifying land into various ways and intensities. For example, natural forest and grassland are converted into agricultural and grazing areas for crop and livestock production, to urban and industrial land. Wetlands are drained and converted into agricultural, residential, etc.

Changes in land use watershed can result in high level of erosion and sediment level of watershed. Estimation of soil erosion loss is often difficult due to some factors such as topography, land use, climate and human activities. The result of Komering watershed monitoring showed that the watershed have experienced disruption or deterioration of ecosystem and environmental quality. It is because of illegal logging to the area of aquaculture and plantations that are not observing the principles of environmental sustainability and the turbidity of water on estuaries Komering [1].

Quantification of soil loss is one of the greatest challenges in natural resources and environmental planning [2]. Estimating watershed erosion using computer model are quite popular. There are a lot of models to predict soil erosion, such as the Areal Nonpoint Source Watershed Environment Response Simulation [3], the Water Erosion Prediction Project [4], Agricultural Non-Point Source Pollution model [5], and Soil and Water Assessment Tool [6].

The SWAT was chosen because it can simulate the model with limited data. The model is applicable especially to large watershed [7]. SWAT was used for erosion modeling in several catchments and in different climatic conditions. It was tested and used in many regions. SWAT was used for hydrologic and soil predictions for the Keleta watershed in central Ethiopia [8], and SWAT tested in the Bouregreg basin, Morocco [9], the evaluation indicates that SWAT model had a good performance for both calibration and validation periods in Bouregreg Watershed. The model showed a good correlation between the observed and simulated monthly average river discharge. It revealed that if properly calibrated, SWAT model can be used efficiently in semi-arid regions to support water management policies. Predicted runoff and sediment yield in Sarrath river using SWAT and

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successfully prioritization of the critical sub-watersheds after calibrating the model against surface runoff that was obtained from flow separation techniques [10].

The objective of this study is to assess the performance of the hydrological model SWAT in the Komering watershed in predicting soil erosion hazard and sediment yield. The erosion risk for each watershed can be classified and predicted its changes based on the scenarios which arranged. In this paper, we also discussed the relationship between the distribution of erosion risk and watershed's characteristics in a spatial perspective.

METHODOLOGY

Study area

The study area is Komering watershed (8,060 km^2) in South Sumatera Province, it is sub-basin of Musi watershed. Geographically located in 103°34'12''-105°00'36'' BT and 02°58'12''-04°59'24'' LS. This watershed administratively located in three regions, Ogan Komering Ilir (OKI), Ogan Komering Ulu Timur (OKU Timur) and Ogan Komering Ulu Selatan (OKU Selatan).

The headwaters of Komering watershed located in OKU Selatan, downstream in OKI, and middle in OKU Timur. Topography of this watershed dominated by plain area (Fig. 1). The elevation is 10-1025 m above the mean sea level. Average monthly rainfall around the Komering watershed ranged from 124.25 mm/year to 381.58 mm/year with the number of rainy days ranges from 2-2751 days / year.

Soil types dominated by inceptisols (727 Ha) or 90.25 % of Komering Watershed. Others entisols (8.63 %), ultisols (0.6 %), and mollisols (0.5 %). Inceptisols are categorized as a soils of relatively new origin and are characterized by having only the weakest appearance of horizons, or layers, produced by soil-farming factors. The inceptisol profile is characterized by the presence of clay mineral indications, metal oxides, or the accumulation of plated humus. They commonly are found either with underlying weathering-resistant parent material or in topographic settings conducive to soil erosion or waterlogging. The land use class of Komering watershed is dominated by land cultivation (313 Ha) or 39 % of Komering Watershed and agriculture (30 %) or 236 Ha especially on flat areas, whereas on the steep area is covered by forest (25 %) or 208 Ha.

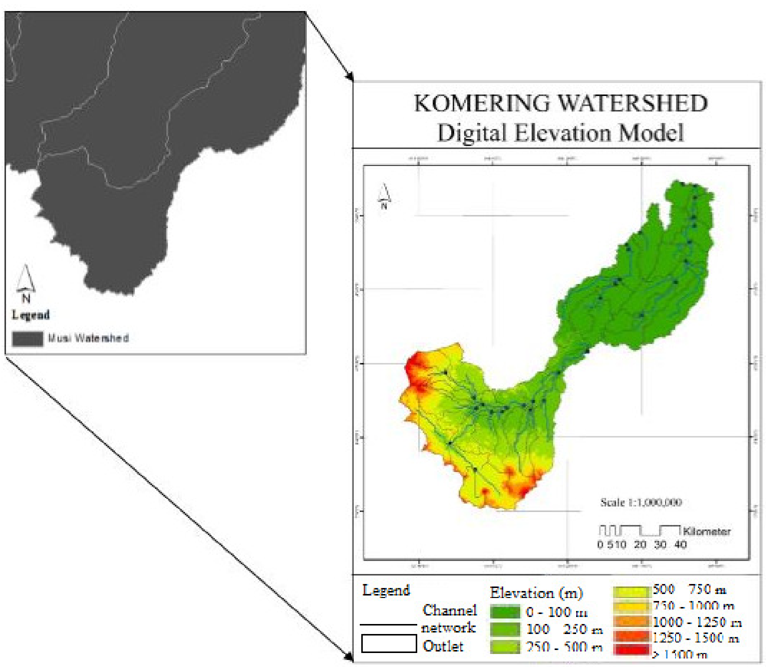

FIGURE 1. Location of the Komering watershed

MATERIALS AND METHODS

SWAT Model

SWAT is one of the hydrological models which can predict soil erosion hazard and sediment yield. The SWAT was chosen because it can simulate the model with limited data. SWAT includes many useful constituent and functions for simulating the water balance, sediment loss, climate change, crop growth, and land management practices. In brief, only the relevant sediment components of the SWAT model is discussed in this paper.

SWAT subdivides a basin into sub-basins closely joined by stream network and hereinafter delineates hydrological response units using a unique combination of land cover, soils, and slope in each sub-basin. SWAT simulates surface runoff volumes and peak runoff rates for each HRU using daily or sub-daily rainfall amounts using a modification of the soil conservation. SWAT can describe the relationship of land use on watershed hydrology.

SWAT involves various kinds input data for simulation of the watershed. The materials required are Digital Elevation Model (DEM), Land use/Land cover, soil cover, and precipitation. All these data were collected and processed to convert into the SWAT input format. Then the software is run by giving these data as inputs. The various steps involved in the software are watershed delineation, HRU (Hydrological response Unit) analysis, and write input tables, edit input data and SWAT simulation. Once it is over software will begin the execution and will print the output file. This output file will be used to plot the graphs and maps. These graphs and maps will show the characteristics of watershed.

To get a map of Komering watershed using ArcSWAT is obtained by overlay process between Musi watershed and SRTM DEM data. The watershed delineation with phases of activity: data input DEM (add DEM grid), the determination of the network river, determination outlet, outlet selection and determination of the watershed, and calculations parameter sub-basins. The end result of this process is the formation of the watersheds, sub-basins and watersheds. HRU analysis is form HRU by defining the input data using land use map, soil type map, and slope map that are overlaid to form the HRU. The third stage is the process of climate data generalization (GWD). This step is performed climate data input from each of the existing climate variables.

Soil layer was from World Soil Map by USDA-NRCS, land use layer was interpreted from Landsat Thematic Mapper 8 by U.S Geological Survey taken in 2016 with a resolution of 30 m. Land use is one of the dynamic parameters caused by human activities. The DEM is used to delineate watershed which is the very first step of the simulation. The DEM was extracted from the ASTER Global Digital Elevation Model (ASTER GDEM) which has a spatial resolution of 30 m. Based on the elevation, the flow accumulation, stream network and the stream links will be created. The topographic parameters such as terrain slope, channel slope or reach length were also derived from the DEM.

Watershed Delineation

Watershed delineation begins with running ArcGIS 10.1 ArcSWAT 2012 extension, with executing automatic delineation menu at ArcSWAT 2012 toolbar to do grid-formatted DEM spatial analysis from DEM data analysis. UTM 1984 map projection was used at zone 48, and WGS 1984 was the reference datum. Creating mask grid to focus on watershed delineation process. The data structure used for modeling the surface characteristics in this study is a data structure in the form of raster data structure/grid with the cell size 25 m x 25 m.

Determining stream digitation process and minimal bandwith gained watershed area. Processing DEM to eliminate sink. Synthetic river channel and each its outlet in vector format are earned through the process. Defining watershed main outlet from stream channel outlets. The model was processing watershed and watershed area delineation. From the process, watershed and watershed area border map in vector formatted are gained. The finally, calculating watershed area parameter to gain topography data consisting of statistical data about spread and elevation distribution for every watershed and watershed area. The result of Komering watershed delineation in Fig. 2.

Hydrology Unit Response

Hydrologic Response Unit (HRU) concept was based on system approach integration which is requirements to dynamically analyze and modelize hydrology from heterogenic basins drainage and its interaction with soil, geology and land cover [11]. As a matter of fact, the soil, geology and land cover influnce evapotranspiration, infiltration, surface flow, interflow and groundwater in all river basins. HRU analysis was able to produce fact and spacial phenomenon existed in the scope and inter-watershed area. Furthermore, soil type, slope, geology and land cover were dynamic variable causing HRU changes from time to time. These HRU changes were occasionally results of area development which require more land for resident or other land covers. SWAT analysis was able to inform HRU value in watershed.

The procedure of HRU was through overlaying the grid topography map, grid-generated land use and soil type map. The result of overlaying process describes land use (Fig. 3a), soil type distribution (Fig. 3b) and slope in each watershed area (Fig. 3c). Executing HRU distribution menu in the ARCSWAT 2012 toolbar to process Hydrologic Response Unit distribution from each watershed area until the table database is earned. The database includes information regarding land use and soil type distribution in Komering watershed and watershed area.

RESULTS AND DISCUSSION

In the calculation of these predictions are to be obtained is the value of output in the form of runoff, erosion, and sediment at any outlet. Estimated results of sediment in the Komering watershed using SWAT obtained from the erosion that occurs in each unit of HRU then be carried by surface runoff to the main tributaries as the erosion of each sub-watershed. The sediments then undergo a process of sediment transport through the creeks (tributary channel) before finally reaching the main river (main channel).

The estimated average soil loss of the entire Komering Watershed is presented in Fig. 4. The highest soil loss (685.86 tha^{-1}) is found in 2007 when rainfall was 320 mm. The lowest value (78.68 tha^{-1}) occurred in 2015 when rainfall was 150 mm. It is found that there is a close correlation between the rainfall characteristics and soil loss. An increase in rainfall amount is generally accompanied by an increase in soil loss. The value of runoff, erosion, and sediment in each year is different because of the value of the factors that influence in every year is different.

Komering watershed dominated by agriculture and cultivation in upstream with slope area more than 40 %. This resulted in high erosion than in other areas. An area with steep slope mostly in the upstream. The slope is the most important factor triggering erosion.

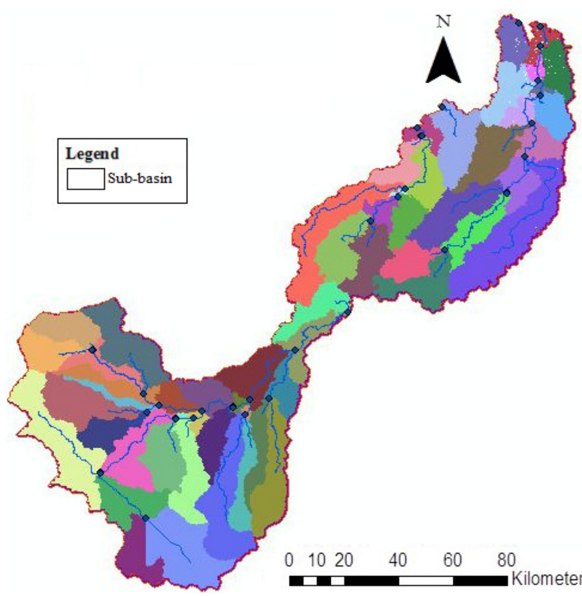

FIGURE 2. Spatial Delineation of the watershed

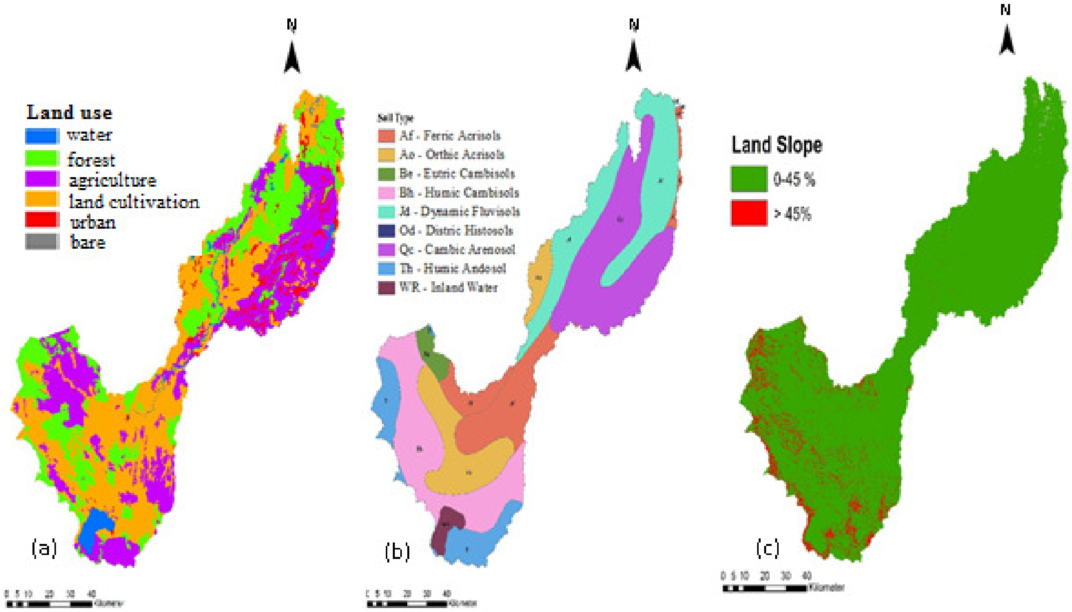

FIGURE 3. Distribution of area: (a) HRU of land use, (b) HRU of soil type, (c) HRU of slope

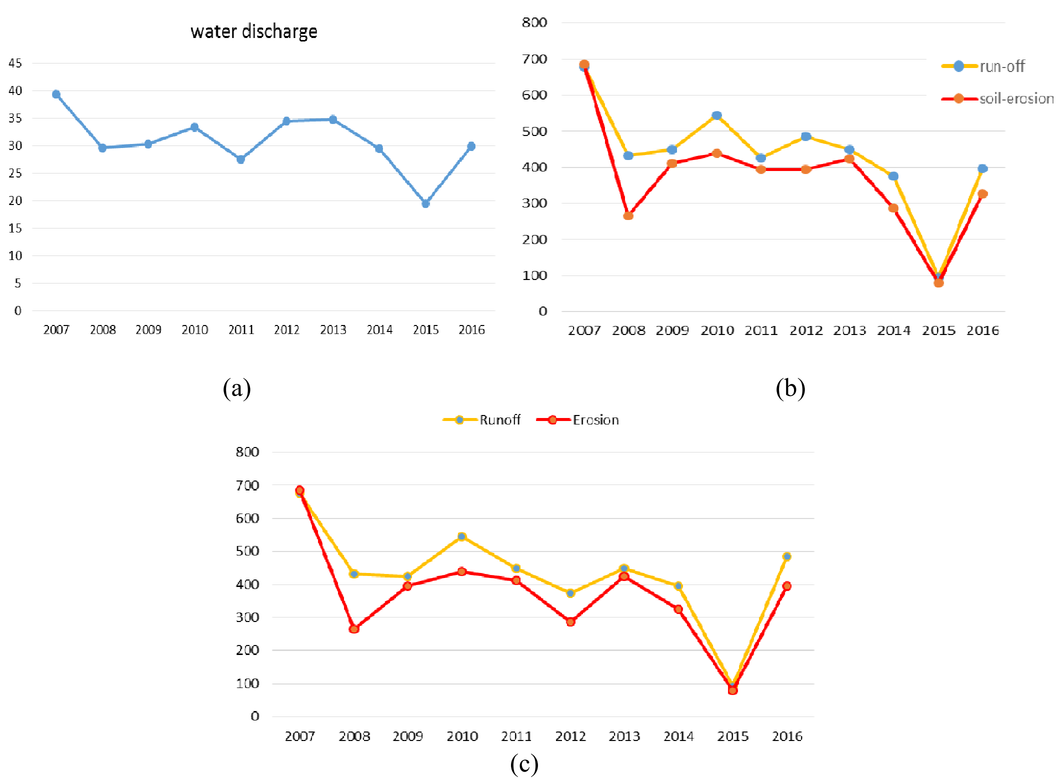

FIGURE 4. Comparison between (a) water discharge, (b) runoff and soil erosion, and (c) sediment yield in Komering 2007-2016

TABLE 1. Classification of soil erosion based on soil loss rate

No	Index	Soil loss severity classes
1	≤1	Low
2	1.01 – 4.0	Tolerable
3	4.01 – 10.00	High
4	≥ 10.01	Very high

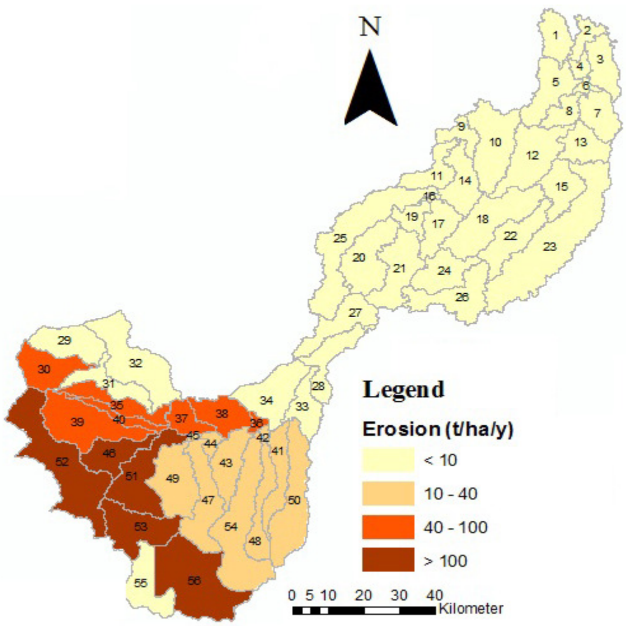

FIGURE 5. Variability in spatial pattern of annual losses in Komering watershed

In regards to erosions, it was first interpreted as soil loss balanced by soil formation through weathering of rocks. This can vary 1 to 12 $tha^{-1}year^{-1}$, according to climate, type of rocks, and soil depth. Erosion hazard index analysis was conducted to determine the class of erosion of the land with takes into account the rate of erosion. Based on soil loss categories (Table 1) [12] that corresponded with the annual sediment yield, the Komering watershed was classified into four erosion severity classes (Fig. 5).

The result of study related to erosion simulation indicated that the parts of watershed that produce high and very high sediment yields are dominated by cultivated land and steep slopes. Land use and slope gradient emerged to be the major clout on the amount of soil loss in the Komering watershed. The estimated soil loss rate wass generally lower in areas covered with forest regardless of slope gradients. An imagery of the land cover with the spatial distribution of sediment yield across the watershed indicates that cultivated lands are more at risk than forest areas. Providing that they have the same slope, management, and erodibility factors. At the same time, less severe erosion was also observed in gentle to flat landscape.

CONCLUSIONS

The results showed that the SWAT model can work together with satellite remote sensing and geographical information system. This provide useful tools to estimate surface runoff and soil erosion. The runoff and sediment are positively related to the land cover in the watershed. More forest cover produce generally less runoff and soil loss. Land with cultivation has more erosion than land with agriculture. This indicates that the model is effective for identifying and prioritizing vurnerable sub-basin. In the end, the study demonstrates that the SWAT model provides a useful tool to predict surface runoff generation patterns and soil erosion hazard and can be used for prioritization of the critical sub-basin in order to develop multi-year management plan to reduce runoff and sediment loss.

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