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Prediction of Surface Runoff and Erosion by Hydrological SWAT Model in Sumpur Watershed, West Sumatra

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Abstract. Sumpur Watershed is 15,478 hectares in West Sumatra Province is one of Watershed priority. Located of the slope of Mount. Merapi is a complex area with various type of landuse and flows to Techtronic Lake Singkarak. The purpose of the study are predict of surface runoff and erosion by hydrology model SWAT to find impact of land use change on hydrology response. Land use change in watershed in dominated by decreasing of paddy field area area in 10 years the forest is reduced by about 2672 Ha, while the agricultural field cover for 10 years increased by 2334 Ha. The decreasing of forest area is about 128 hectares. Impact of land use change the impact of this land change increases surface flow by 18.2 mm/year while the base flow becomes reduced by 17.6 mm/year. The land use change also increased loading sediment about 6.2 Ton/ha/years. Whereas the mudflow watershed flows to the lake Singkarak whose water is used for electricity generation

1. Introduction

Watershed degradation in West Sumatra Province based on the number of priority I watersheds, there are 10 sub-catchment in 3 watersheds whose area has reached 1,302,514 ha. According to [1], there is a 220,260 ha of critical land spread over the upper reaches of the West Sumatra watershed. Among them, the sub-catchments that began to be damaged were the Sumpur 10 sub-catchment which is one of the sources of water from the Ombilin watershed and Singkarak Lake [2]. Sumpur Singkarak watershed is 15,478 hectares Padang Panjang West Sumatra. This area is flowed by a river called the Aie Batanang River where the source of the water comes from Mount Marapi and empties into Lake Singkarak. Its Upper Area is a forest area, agricultural and settlement. While between the Upper and Lower Lakes estuaries are settlements in Batipuh and Padang Panjang.

Sumpur Watershed located on the slopes of Mount Marapi is a complex area with various types of land use, is a fertile area and is very suitable to be planted with horticultural and plantation crops. Coupled with the rapid development of settlements in the vicinity of Padang Panjang, the Sumpur



watershed conditions began to worry. The community has not used many conservation methods in managing their land. If this is not done conservation efforts then land use changes will accelerate degradation, erosion, landslides, and pollution of water sources for people in the downstream areas. This will cause greater environmental damage.

Land use change is a complex dynamic process, which is interconnected between the natural environment and humans which has a direct impact on land, water, atmosphere and other global environmental issues [3]. According to Pawitan [4], Development of use Land in a number of river basins in Indonesia in the last three decades has had the effect of increasing the frequency, discharge and volume of floods that have inundated residential areas and public infrastructure that have caused material and non-material damage and losses.

Watershed management is a human effort in regulating the reciprocal relationship between natural resources and humans in the watershed and all its activities, in order to realize the sustainability and harmony of ecosystems and the increasing utilization of natural resources for humans in a sustainable manner. To manage the land, the land must be seen as a hydrological unit, because the plants or plants on the land depend on the availability and management of water in the land. Optimizing DAS land use must be carried out thoroughly by looking at the physical, economic and social aspects. Analysis of the physical aspects of the environment, including those that need to be considered are land degradation due to surface flow, erosion and sedimentation. Many methods can be done to examine surface flow, erosion and sedimentation. Some are done directly in the field using erosion plots, there are also methods for predicting erosion using models. Among them the model that has been widely used is the Soil Water Assessment Tool (SWAT). The purpose of this study is analysis of Estimation of Surface Flow, Erosion and Sedimentation using the SWAT hydrological model and the impact of land use changes in the Sumpur River Basin which flows to Lake Singkarak.

2. Materials and Methods

2.1. Studi Area

The study area is Sumpur Watershed, located in Tanah Datar Regency and a small part of Padang Panjang City, the middle part of West Sumatra, Indonesia (Figure 1). The catchment has an area of 15.478 ha and lies between latitude $-0^{\circ} 34.19'$ to $-0^{\circ} 23.319'$ and longitude $100^{\circ} 23.19'$ to $100^{\circ} 29.745'$. The average annual precipitation was 2.524 mm, and the average of maximum and minimum temperature were 27°C and 25°C , respectively. The topography of the Sumpur watershed in general includes a wavy surface in the south and mountainous in the northern and central regions, the height ranges from 145 - 2,886 m asl. The river of Sumpur flowed to Lake Singkarak.

2.2. Data collection

The data used in this study consisted of primary data collected from field sampling and secondary data in spatial and tabular forms derived from various sources (Table 1). The collected data are used for two main stages of the study which are land use analysis and hydrological modeling using SWAT.

Table 1. Summary of data requirements

No	Data	Data format	Source
1	Digital elevation model	Grid (cell size 30 x 30 m)	USGS
2	Soil types scale 1:250.000	Vector (shapefile)	Land and agro-climate research center, Ministry of agriculture
3	Meteorological data (daily) from two weather stations	Table (.dbf and text)	Meteorology and climatology agencies
4	Landsat image 2004		USGS
5	Landsat image 2016		USGS
6	Soil properties for SWAT database	Numeric	Soil data global (FAO)
7	Daily discharge	Table (.dbf and text)	Ministry of public works

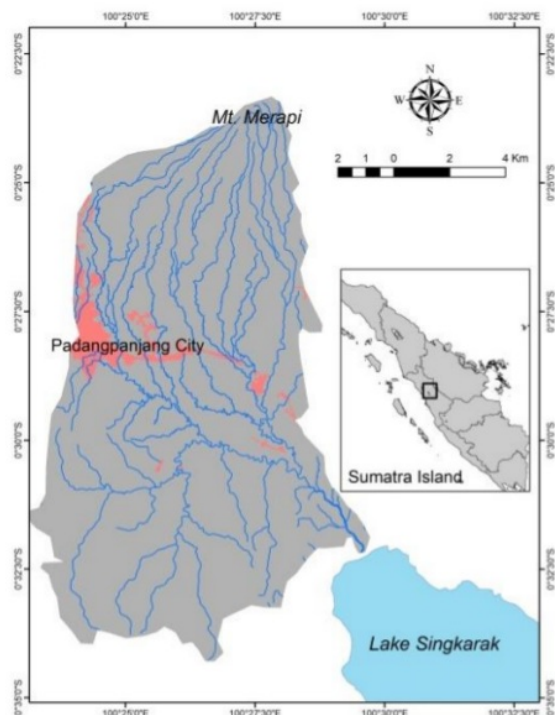


Figure 1. Study Area

2.3. Model description

SWAT model was utilized to examine the prediction of surface runoff and erosion in Sumpur Watershed. SWAT is a physically based, distributed hydrological model regarded as a versatile model that used to integrate environmental processes to support more effective of watershed management [5]. A more explanation of SWAT is available in form several publications of Neitsch et al. [6, 7].

Analysing of SWAT was using ArcSWAT2018.10.19 tools application in ArcGIS 10.2. In the process of input data and simulation, this model required a series of stages. The first step is to delineate watershed and Sub-catchment using Automathic Watershed Desalination (AWD) by Digital Elevation Model (DEM) data, The DEM data derived from SRTM 30 x 30 m. After that we define the Hydrology Response Unit's (HRU's) and input the weather file, this model simulation used two rain gauge there are: malelo in Southern area and Padangpanjang rain gauge in the middle of the watershed. And then the model can be executed and continued at the calibration and validation stage. Data used as input data for SWAT model which are landuse, soil type map, soil characteristics, climatology data, and Digital Elevation Model (DEM). Meanwhile discharge data of several observation stations in the study area was used in the calibration and model validation process.

The performance of SWAT model was evaluated using Nash-Sutcliffe efficiency [8] and the coefficient of determination [9]. The NSE statistical model is most widely used to show the performance of a model because it can provide more accurate information about the value given [10] dividing the statistical value criteria for NSE are: $0.75 < NSE < 1.00$ (very good), $0.65 < NSE < 0.75$ (good), $0.5 < NSE < 0.65$ (satisfying) and $NSE \leq 0.50$ (unsatisfactory).

After calibration and validation, SWAT was further applied in this study to predict the daily discharge and erosion potential for two land uses condition. Therefore, the results can reflect the impact of land use on hydrological response.

3. Results and Discussions

3.1. Land use changes in Sumpur Watershed

The rate of landuse change in the Sumpur watershed is shown in more detail in Table 2, where the forest is reduced by about 128 hectares. A large change was found in rice fields, where for 10 years the rice field area was reduced by 2672 Ha, while the agricultural field cover for 10 years increased by 2334 Ha. The results of field observations of this agricultural field are in the form of; vegetables, corn, and some cassava. Furthermore, the results of the analysis of land use change are simulated using the SWAT hydrological model to see the impact on surface runoff and erosion in the Sumpur watershed.

Table 2. Landuse change in Sumpur Watershed

Landcover	Landuse 2004		Landuse 2014		Landuse 2004 - 2014
	Area (ha)	%	Area (ha)	%	
Forest	7836.2	50.63	7708.0	49.80	-128.20
Plantation	2025.0	13.08	2351.2	15.19	326.20
Open area	135.1	0.87	135.1	0.87	0.00
Settlement	552.1	3.57	695.4	4.49	143.30
Paddy Field	4929.9	31.85	2254.5	14.57	-2675.40
Dry Agriculture			2334.0	15.08	2334.00
Total	15478.3	100	15478.2	100	

3.2. SWAT Hydrology Model Setup

The baseline models formed sub-catchments on threshold area of 100 ha and produced 25 sub-catchments. The number of sub-catchment considered the conservation techniques applied on farmland in each sub-catchment. The formation of the HRU's used the 2014 land use from Landsat 8 satellite data, and global soil map. Slope was divided into five classes. Figure 2 show the map as data input in HRU's formation and Table 3 show the extent of each parameter.

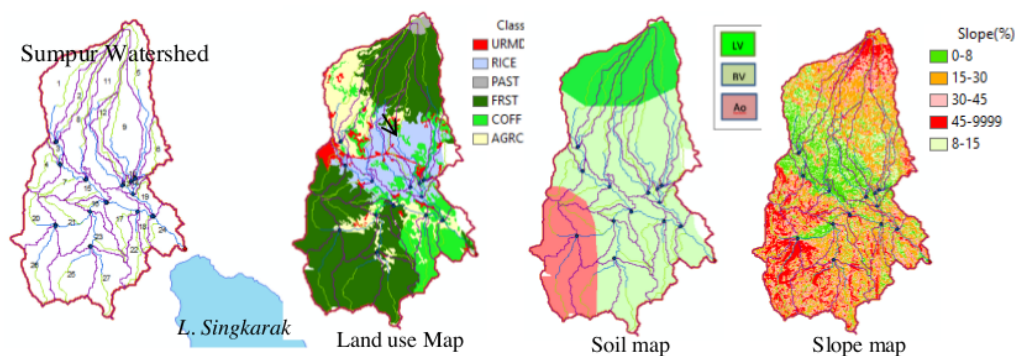


Figure 2. The map as data input in HRU's formation

After input file have been generated, SWAT is ready to do simulation. The simulation period is from 1 January 2010 to 31 December 2013. The options are to get comparison between river discharge simulation and observed data. The rest of options available in the SWAT Running dialog box is presented in the last chapter. Several options must be considered; time step for rainfall and routing (daily), method for calculating runoff-Curve Number Method, rainfall distribution-skewed normal and method for evapotranspiration-Penman-Monteith.

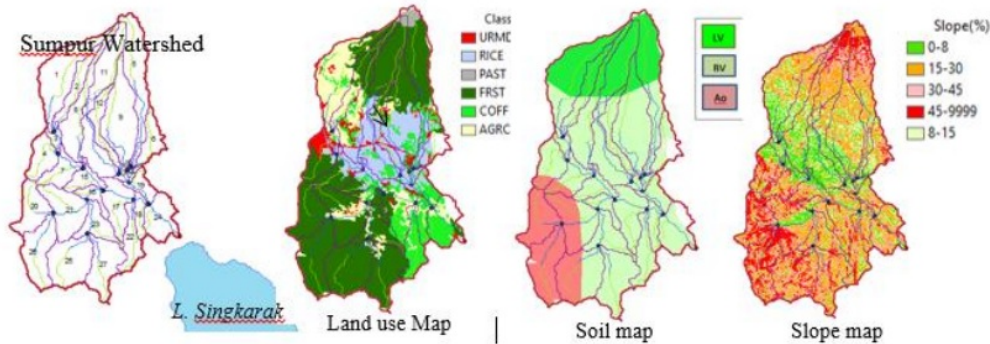


Figure 3. Automatic Watershed Delineation Proses HRU's Analysis in Sumpur Watershed

Table 3. Characteristic of Land use, Soil Types and Slope in Sumpur Watershed.

Land use Class	SWAT ID	Area (ha)	%
Agricultural Land cross grown	AGRC	2254,1	14,95
Residential Medium Density	URMD	204,2	1,35
Paddy Field	RICE	2315,1	15,36
Forest Mixed	FRST	8203,8	54,4
Plantation	COFF	2097,6	13,9
Soil	SWAT Code	Area (ha)	%
Aeric tropaquept	Ao	3022,4	20,05
Aeric tropic fluvaquent	Bv	9278,3	61,55
Association Typic Dystropepts-Typic Paleudults	Lv	2774,0	18,40
Slope		Area (ha)	%
<8%		2032,5	13,48
8% – 15%		2595,0	17,21
15% - 30%		4952,7	32,85
30% - 45%		3429,8	22,75
>45%		2064,7	13,70
		15074,7	100

General result of SWAT model simulation can be found in general input output section (file.cio) or in result.txt file in txtInOut folder. The result of simulation based on landuse 2011 is shown in Figure 4.

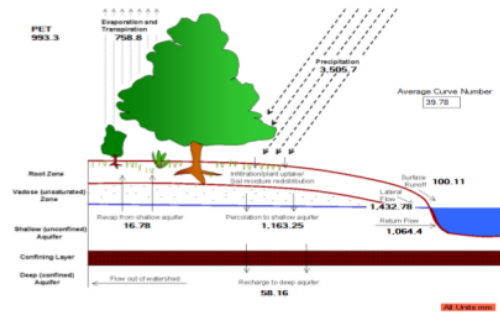


Figure 4. Hydrology balance in Sumpur Watershed base on Landuse 2014 Simulation

The result of daily simulation is presented in Figure 4, which also shows the observed data. The result showed that simulation has lower base flow and higher peak flow in early year mainly on January 14th 2011. Statistic comparison between observed data and un-calibrated simulation is shown in Figure 6, and the linier correlation is not good enough (R^2 0.4129; $Q_{Obs} = 0.8647 \cdot Q_{Sim} + 1.9017$), where the value approaching 0.5 is much better. The Nash Sutchliffe efficiency (NSE) value is 0.39, which is far from the expected value.

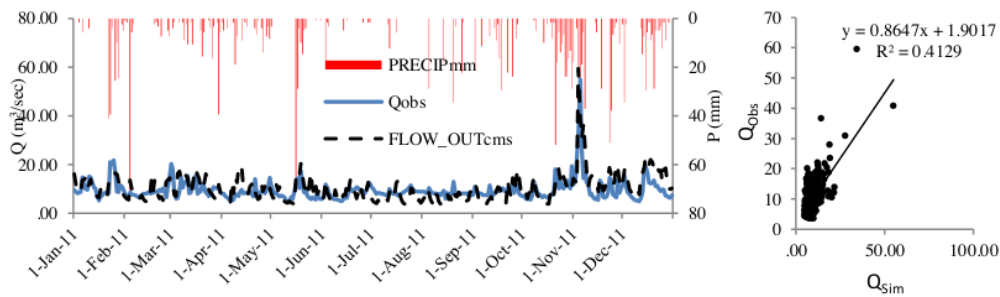


Figure 5. Comparison Between Observed and Simulated Daily Stream Flow at Malelo River Gauge Before Calibration

3.3. Calibration and Validation

Hydrology was calibrated by comparison of observed data from an in stream Public Works Department flow gauging station to model and to adjust the key of hydrologic parameter. Based on the fact of hydrograph comparison the calibration focused on several solutions which are adjusted to infiltration, interflow and base flow recession parameter. Details of adjustment for calibration are shown in Table 4, while the result of discharge calibration in Malelo river gauge is shown in Figure 5.

Manual calibration of several parameters resulted in correlation error (R^2) of 0.53 where $Q_{Sim} = 0.9598 \cdot Q_{Obs} + 0.6337$, and NSE is 0.5, the value of R^2 and NSE value is not good enough and the error is caused by un-detailed soil parameter, where in this model soil map used global soil map. The correlation error and Nash is shown in figure 5. The results of this validation are lower than the results of modelling at Ciliwung upstream which reached a value of NSE 0.7 [11] but this simulation comparison is only carried out at six months. This validation value is also almost the same as the SWAT modelling results in Cisadane with NSE values reaching 0.56 and in Upper Cimanuk with NSE 0.71 [12, 13].

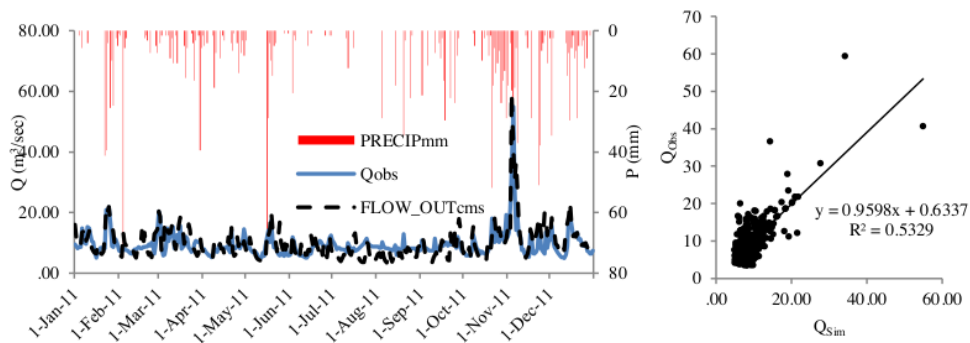


Figure 6. Comparison between observed and simulated daily stream flow at malelo river gauge after calibration

Hydrology model of Sumpur Catchment Area was calibrated by comparison of observed data from a River gauging station to model and to adjust the key of hydrologic parameter. Based on the fact of hydrograph comparison the calibration focused on several solutions which are adjusted to infiltration, interflow and base flow recession parameter. The calibration is done on groundwater parameter (.gw), Routing parameter (.rte) and management parameter (.mgt). Manual calibration is conducted by SWAT Editor Application, details of adjustment for calibration are shown in Table 4.

Table 4 Initial and final value of SWAT Calibration parameters for stream flow

SWAT variable name	Parameter	Range	Final value
SURLAG	Surface runoff coefficient	1 - 40	4
Alpha BF	Base flow alpha factor (days)	0 - 1	0.48
GW_Revap	Groundwater "revap" coefficient	0.02 - 0.2	0.2
REVAP_MN	Percolation to the deep aquifer to occur (mmH ₂ O)	0 - 500	0
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mmH ₂ O)	0 - 5000	10
GW-Delay	Groundwater delay (days)	0 - 500	10
SHALLST	Initial deep of water in shallow aquifer (mmH ₂ O)	0 - 1000	10
CH_N1	Manning's value for tributary stream	0 - 0.5	0.5
CH_N2	Manning's value for main stream	0 - 0.3	0.25
CH_K1	Effective hydraulic conductivity in tributary stream	0-300	0.5
CH_K2	Effective hydraulic conductivity in main stream		0.5
CN2	Curve Number	0 - 100	X 1.2

The simulation results of SWAT model display a notable effects of land use on hydrology response. Table 5 provides the respective results of SWAT model simulation and comparative impact from different land use condition on Sumpur Watershed. The results of the analysis of land use changes in the Sumpur watershed during 2004 to 2014 show a reduction in forest cover and an increase in built

area resulting in an increase in surface runoff and finally increase in sediment loading at the watershed then to Singkarak Lake.

Table 5. Impact of Landuse Change on Hydrology and Sediment

Hydrology Par.	LU2006	LU2014	LU 2006 - 2011
Surface run off (mm/year)	81.89	100.11	18.22
Base flow (mm/year)	1082	1064.4	-17.6
Inter flow (mm/year)	1422.4	1432.8	10.4
Sediment load (T/ha)	9.6	15.8	6.2
CN Average	38.29	39.9	1.61

4. Conclusions

Calibration and validation results show this model can be used as a tool in watershed management planning, but a more detailed input data for smaller areas such as catchment is needed. Observations of rain, discharges, and sediment are also need to be improved for better result. The Hydrology model simulation shows Changes in land use in the Sumpur watershed mainly residential land improvement, reduction in agricultural land and forests will lead to lower hydrology conditions such as the increase in surface runoff and base flow discretion and increasing loading sediment to Singkarak Lake.

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