Prediction of surface runoff and erosion rate using SWAT (soil water assessment tool) model in Selopamioro catchment as directions of soil and water conservation

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Abstract. Selopamioro catchment part of Oyo Watershed, is located in downstream area of Selopamioro village which consist of steep slope gradient, and has been constantly exposed to intensive farming activities. Thus, this watershed is susceptible to erosion. One of models to predict the impact of land use on hydrological and sedimentary conditions is SWAT (Soil Water Assessment Tool). Therefore, the purpose of this research was to apply the SWAT model in predicting surface runoff and erosion. The result of this study will be used as initial analysis to support the direction of soil and water conservation. Topography, land use, and climate data were collected to simulate erosion and surface runoff. Two adjacent sub-catchments namely DTA 1 and DTA 2 were analyzed. Surface runoff in DTA 1 is 333,660,000 liters/year and in DTA 2 is 316,920,000 liter/year. The erosion rate in DTA 1 is 24.6 mm/year and in DTA 2 is 21 mm/year. The result of SWAT model tends to be overestimate. This shows that SWAT model might not suitable to be used for erosion prediction in tropical agriculture country, such as Indonesia. Updates of SWAT data for physical characteristic in tropical country might need to be carried out for reliable result.

1. Introduction

Headwater catchment, areas from which water originates within a channel network, are characterized by interactions among hydrological, geomorphic, and biological processes [1]. Headwater systems are important sources of sediments, water, nutrients, and organic matter for downstream reaches [2]. Selopamioro catchment is part of Oyo watershed, consist of 60% agricultural land, in which intensive agriculture activities were carried out. This raises various possibilities for damage to land resources due to erosion and may lead to the decrement of soil productivity. Cultivated agricultural land without a break (fallow) and without proper management of crops, soil and water is prone to decreased soil productivity [3].

Surface runoff and erosion are essential processes within catchment system as it is the main factors of transport and deposition of sediment within a hillslope. Erosion is the process of detachment and transport soil particles caused by water or wind movements. Sediment particles then will be deposited or transport on the hillslope [3]. Soil degradation which includes the change of physical, chemical, and biological soil characteristics is an indirect impact of erosion and it might lead to other physical damages within watersheds [4].
One of ways to predict soil erosion within a watershed is by the application of SWAT model. The SWAT model has the ability to predict the impact of land management and sedimentation based on the hydrological characteristics of a watershed with high resolution of 1:25,000. This model can predict long-term impacts of land use change, soil conservation techniques, and climate change [5]. Therefore, the objective of this study is to analyze surface runoff and erosion using SWAT model. The result of this study can be used as initial analysis to support the direction of soil and water conservation measures.

2. Methods
Selopamioro catchment are located at 7°57’45.55” - 7°58’24.62” and 110°21’57.12” - 110°22’8.17”, 25 km from the center of Yogyakarta. In general, Selopamioro catchment has morphometry longitudinal catchment area, two-order river branching, moderate drainage density and rather steep slope. Two adjacent catchments with area of 83 hectares (DTA 1) and 76 hectares (DTA 2) were analyzed. These catchments have different characteristic.

The catchment has the average slope gradient of 22% that are include as mild to very steep slope. DTA 1 is dominated by a rather steep slope, while DTA 2 is dominated by steep slopes. Soil types in the Selopamioro catchment are classified based on FAO 1974 soil map. There are 2 types of soil in the Selopamioro catchment, namely Litosol soil and Regosol Eutrik soil. Regosol Eutrik Soil dominates with 74.14% areas of two catchment areas. Land use in Selopamioro catchment is obtained from worldview image interpretation. Based on this analysis, the Selopamioro catchment area is divided into four types of land use, namely mixed forests, gardens, intensive agriculture land and settlements. DTA 1 was covered with 61 % of agriculture land and DTA 2 has 58 %. Selopamioro catchment has tropical type of climate with rainfall intensity of 1,227 mm/year. Rainfall data from the SWAT database is tested for consistency using the RAPS (Rescaled Adjusted Partial Sums) method. The results showed that the rainfall data were homogeneity and consistent.

![Figure 1](image_url). Map of the location of the Selopamioro catchment area in the Opak-Oyo watershed: a) Map of the Selopamioro catchment area, and b) Map of the Opak-Oyo watershed
Topography, land use, and climate data were used to predict surface runoff and soil erosion rate with SWAT model. High resolution of maps was used to analyze the erosion at 1:25,000 scale of land use maps, 1:25,000 scale of river network, 1:25,000 scale soil maps, and 1:25,000 scale of administration. Surface flow calculation in the SWAT model use the SCS curve number (CN) method and the Green and Ampt infiltration method [4]. Meanwhile, the erosion rate of SWAT model uses the MUSLE method. In contrast to USLE which uses the rain kinetic energy factor for basic calculations, MUSLE uses runoff factors to predict erosion and sediment [5]. Conservation directives are aimed at reducing erosion by reducing the C and P values to a minimum [6]. Furthermore, the direction of soil and water conservation refers to the modification [12].

3. Results and discussion

3.1 SWAT model application for erosion and surface flow prediction

3.1.1 SWAT hydrological cycle. The difference in hydrological parameters of the Selopamioro catchment area into DTA 1 and DTA 2 (Table 1) refers to different catchment areas and inputs. From the result, it shows that the hydrological response in DTA 1 and DTA 2 has no significant different values. Such findings might be related to similar morphometric conditions and inputs such as climatic conditions, soil types, land use and slopes in DTA 1 and DTA 2 do not have significant differences in values.

Previously study Noges [7] and Kairun et al.[8] showed that the morphometry of the watershed affects the results of the hydrological response in the watershed.

Table 1. Hydrological parameter in DTA 1 and DTA 2

| Hydrological Parameters | DTA 1 (mm) | DTA 2 (mm) |
|------------------------|------------|------------|
| Precipitation          | 1,227      | 1,227      |
| Surface runoff         | 402        | 417        |
| Lateral flow           | 75         | 71         |
| Return flow            | 255        | 245        |
| Percolation            | 305        | 294        |
| Recharge aquifer       | 15         | 15         |
| Evapotranspiration     | 443        | 443        |

3.1.2 Surface flow. DTA 1 has a surface runoff value of 402 mm/year or 333,660 m³/year, while DTA 2 has a value of 316,920 m³/year or 417 mm/year (Figure 1). Different in runoff water can be related to the different physical conditions between the two catchments. Differences characteristics in slope, soil type, and land use give different runoff values. The slope level in DTA 2 is dominated by a steep level which gives a high effect on surface runoff, then DTA 1 which is dominated by a rather steep slope.

The size of the surface runoff can be expressed in terms of the surface runoff coefficient or the ratio between rainfall and surface runoff. The surface flow coefficient of Selopamioro DTA fluctuates from the highest value of 0.39 to the lowest value of 0.07. The surface runoff coefficient of Selopamioro catchment in months and the surface flow distribution in the Selopamioro catchment area are presented in Figure 2.
3.1.3 Erosion. Based on the modeling results in DTA 1, the erosion was 522.8 ton/ha/year or 24.6 mm/year and in DTA 2 is 445.4 ton/ha/year or 21 mm/year. The difference in the value of erosion that occurs in DTA 1 and DTA 2 is influenced by the HRU (slope, soil type, and land use) formed in each catchment and then contributes to the erosion results. This result was classified into the five levels of erosion hazard based on *Peraturan Dirjen Balai Pengelolaan DAS dan Perhutanan Sosial Number P.3/V-SET/2013*. The erosion hazard level classification and erosion distribution map in the Selopamioro catchment are presented in Figure 3 and Figure 4.
Figure 4. Comparison of erosion hazard levels in DTA 1 and DTA 2

Figure 5. Map of the erosion distribution of Selopamioro watershed

3.2 The usage of SWAT for Erosion prediction in tropical country

The SWAT modeling results for erosion in the Selopamioro catchment are classified as very high (overestimate). The maximum erosion rates in tropical region that can be tolerated are between 2.5–12.5 ton/ha/year [1, 9]. The erosion results of the SWAT modeling in the Selopamioro catchment are almost the same as the results of the SWAT modeling in tropical region by Rahmad et al. in the Deli watershed, North Sumatera with an average erosion of 410.72 ton/ha/year and with the validation test using a deterministic coefficient ($R^2$) of 0.75. However, this value is very different from the SWAT modeling for erosion carried out by Hammer et al. [10] in the Watugede sub-watershed, upstream of the Oyo watershed, with the highest value of 25 ton/ha/year.
There are several factors that might influence a high result of erosion analysis. This analysis used SWAT database that mostly taken from the condition in sub-tropical country. Therefore, it might not be suitable for the usage of erosion prediction in tropical country. In addition, the use of DEM data to determine the degree of slope gradient might also affect erosion values. Previous report Hammer et al. [10] and Salawati and Saidi [11] stated that a high-resolution DEM can represent the surface of the earth's terrain realistically, where as a large DEM resolution is not suitable at representing the earth's surface terrain. Therefore, the usage of large-scale DEM might fail to give detail insight of geomorphic condition of the slope such as slope terraces as part of agricultural management practice.

3.3 Possible Soil and Water Conservation Measures
Specifically, soil and water conservation were carried out by changing the land cover factor (C) and conservation measures (P) to reduce the amount of erosion produced [6]. Based on the multivariate analysis of the erosion factor variables, namely soil type, land use, and slope, it shows that the value of multiple R is 0.77, this value shows the relationship between the variable factors of soil type, land use, and slope to the value of erosion. Meanwhile, the R square is 0.60 which means that the relationship between the independent variable and the dependent variable has a strong correlation.

| Parameter   | t-stat | p-value       |
|-------------|--------|---------------|
| Type of soil| -3.48  | 0.00087432    |
| Land use    | -6.27  | 2.8765E-08    |
| Slope       | 7.04   | 1.1782E-09    |

Based on t-stat and p-value analysis in Table 4, it shows that slope and land use factors have most influence on the erosion value. This shows that the slope level and land use in the Selopamioro catchment are important part of the process of erosion. Earlier study Kumajas [12] provides reference for soil and water conservation based on the level of erosion hazard that occurs in an area by taking into account the slope of land against land use types and soil and water conservation practices.

In general, the Selopamioro catchment area is used for intensive agriculture by farmers. According to the reference for soil and water conservation in areas with heavy erosion levels with 30-45% slope of land, bench terraces can be made. The bench terraces in DTA Selopamioro have a “talud” (Embankment) that is protected by several types of reinforcement such as using grass and rock structure or even without wall bracing. The “talud” is part of the bench terrace which is critical to erosion [3]. In Selopamioro DTA there are still many bench terraces that do not use wall braces. Whereas the use of bench terraces with reinforcement of stone arrangement is very helpful to reduce soil and water loss and to hold soil sliding from the top so that gradually bench terraces can be formed [13].

In addition, the use of both natural and artificial mulch in Selopamioro DTA is very rare. Whereas with the presence of both organic and inorganic mulch, evaporation from the soil will be reduced and will maintain the stability of groundwater so that it does not quickly disappear due to evaporation [3]. By using mulch, at least it can reduce the need for irrigation for plants.

4. Conclusion
Surface runoff and erosion prediction were carried out with SWAT model in study. The surface flow in the Selopamioro catchment based on SWAT modeling results are 333,600,000 liters/year or 402 mm/year in DTA 1 and 316,920,000 liters/year or 417 mm/year in DTA 2, while the amount of eroded soil are 522.8 ton/ha or 24.6 mm/year in DTA 1 and 445.4 ton/year or 21 mm/year in DTA 2. The results of surface runoff and erosion are classified as very high. Thus, it might be related to the incompatibility of SWAT model database with the conditions in Selopamioro DTA and the absence of model calibration. Conservation measures can be carried out to prevent high erosion rate by constructing bench terraces with rock structure and applying of both organic and inorganic mulch.
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Reference
[1] Gomi T, Sidle R C and Richardson J S 2020 BioScience 52 905–916
[2] Hack J T and Goodlett J C 1960 Geomorphology and Forest Ecology of a Mountain Region in the Central Appalachians (Washington (DC): US Geological Survey)
[3] Suripin 2002 Pelestarian Sumber Daya Tanah Dan Air (Yogyakarta: Penerbit Andi)
[4] Arsyad S 2010 Konservasi Tanah (Bogor: IPB Press)
[5] Neitsch S L, Arnold J G, Kiniry J R and Williams J R 2005 Soil and Water Assessment Tool User’s Manual Version 2005 (Temple, Texas: Blackland Research Center, Texas Agricultural Experiment Station)
[6] Asdak C 2007 Hidrologi dan Pengelolaan Daerah Aliran Sungai (Yogyakarta: Gajah Mada University Press)
[7] Noges T 2009 Hydrobiologia 633 33–43
[8] Khairun, La-Baco S and Hasani U H 2017 Jurnal E cogreen 3 105–115
[9] Hudson N W 1971 Soil Conservation (Ithaca. New York: Cornell University Press)
[10] Hammer R D, Young F J, Wallenhaupt N C, Barney T L and Haithcoate T W 1995 Soil Science Society of American Journal 59 509–519
[11] Salawati and Saidi B B 2008 Klasifikasi Bentuk Wilayah yang Diturunkan dari Digital Elevation Model: Kasus DAS Citarum, Sub DAS Cilalawi, Jawa Barat (Jambi: BPTP Jambi)
[12] Kumajas M 1992 Kajian Morfokonservasi Daerah Tangkapan Hujan Danau Tondano (Yogyakarta: Thesis of Magister Program, Universitas Gadjah Mada)
[13] Priyono 2002 Konservasi Tanah dan Mekanisasi Pertanian in: Makalah Teras: Bebas banjir, 2003 (Indonesia)