Estimation of erosion using Soil and Water Assessment Tool (SWAT) model in Samin Sub-watershed, Karanganyar and Sukoharjo Districts, Jawa Tengah

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Abstract. Over the past 10 years (2005-2015) there has been an increase in settlement land use in the Samin Sub-watershed, with an average of 26.8 ha/year [1]. Land in the study area is also widely used as plantations and agriculture without regard to soil conditions that are easily eroded and prone to landslides. Inappropriate land use has caused river siltation problems downstream and flooding. The purpose of this study is to determine the erosion rate of the Samin Sub-watershed predicted using the Soil and Water Assessment Tool (SWAT) model, test the suitability of the model in predicting erosion, and create scenarios for the application of Soil and Water Conservation in the form of terraces to reduce erosion level. The results indicated that the average erosion rate in the Samin Sub-watershed is 57.4 tons/ha/year. The highest erosion value is in dry land use. The three criteria for the Erosion Hazard Level (TBE) that predominate are the medium, light, and very light classes. Model suitability testing is carried out in 2 stages, namely calibration and validation. The calibration process obtained the value of R2 0.77 and NSE 0.23. The validation process resulted the value of R2 20.57 and NSE 0.40. The scenario of the application of Soil and Water Conservation technique in the form of a terrace will reduce erosion in the Samin Sub-watershed up to very light erosion hazard grade reaching 53%.

1. Introduction
Erosion is the process of land or parts of land moving from one place to another caused by rainwater or wind. The impact of erosion happens both in site and outside area of the erosion process [2]. The watershed ecosystem, especially the upstream area is an important part because it functions to protect the entire watershed. The activities in the upstream area will greatly affect the condition of the downstream.

The Samin sub-watershed is located in the upstream area of the Bengawan Solo watershed which has an important role in preserving the ecosystem of the Bengawan Solo watershed. Over the past 10 years (2005-2015) there has been an increase in settlement land use in the study area, with an average of 26.8 ha/year [1]. The upstream of the study area is widely used as plantations and agriculture [3]. As a result of these complex pressures, the current condition of the Samin Sub-watershed is critical. There have been recorded major catastrophic floods in the downstream area due to the overflow of the Samin River, in 2007, 2013, 2015 and 2016 [4]. The flooding caused by the overflow of the Samin river in 2016 inundated thousands of houses covering five sub-districts including Sukoharjo, Bendosari, Polokarto, Mojolaban and Grogol [5].
One of the causes of flooding is sedimentation resulting from the transport of soil particles by surface runoff which causes river siltation. Sedimentation is a product of the erosion process, so it is necessary to estimate erosion to determine management direction to improve the current critical condition of the Samin Sub-watershed. There are various ways that can be used to predict erosion, one of which is the modelling of the Soil and Water Assessment Tool (SWAT). The SWAT model was chosen because it is connected to the Geographic Information System so that it makes work more effective and efficient [6]. In addition, the SWAT model can produce more accurate data in simulating problems in the watershed [7].

On this basis, it is necessary to conduct research on the "Estimation of Erosion Using the Soil and Water Assessment Tool (SWAT) Model in Samin Watershed, Central Java". This study aims to calculate the magnitude of erosion in the Samin Sub-watershed predicted using the SWAT model, test the suitability of the model in predicting erosion in the Samin Sub-watershed, and create scenarios for the application of soil and water conservation in the form of terraces to reduce erosion in the Samin Sub-watershed.

2. Methods

2.1. Research Location
The research was carried out in the Samin Sub-watershed, located in the Karanganyar and Sukoharjo Regency, Central Java Province (Fig. 1). The astronomical location of the study area is at latitude south 7° 36’ 34’’ - 7° 41’ 46’’ and east longitude 110° 49’ 48’’ - 111° 11’ 16’’. The research was conducted from March to November 2019.

2.2. Tools and Materials
The material used in this study consisted of two data, primary data and secondary data. Secondary data consists of Digital Elevation Model (DEM), river network maps, land use maps, soil type maps, soil characteristics data, daily rainfall data (2014-2018), climate data (2014-2018) consisting of maximum air temperatures and minimum, wind speed and solar radiation, water level data, and Landsat 8 satellite. The primary data used in this research is the canopy closure data. The tools used in this research consisted of Personal Computer (PC), Office, ArcGIS, Soil and Water Assessment Tool (SWAT), STAT pcp, SWAT-CUP, SWAT Output Viewer, ENVI, roll meter, compass, camera, fisheye, lens, Avenza Map.
2.3. Methods
This research consists of several stages including data collection, input data processing, canopy closure data processing, running the model, testing the model (calibration and validation), and scenarios for applying Soil and Water Conservation.

2.3.1. Data Collection. The data used in this study consists of two types of data, namely secondary data and primary data. Secondary data was collected from several agencies and websites. The data and sources can be seen in Table 1. Primary data of canopy closure were taken directly in the field using a plot measuring 20 x 20 m completed with a fish eye lens.

2.3.2. Input Data Processing. The Soil and Water Assessment Tool (SWAT) requires input data that is compatible with the input system so that the existing data needs to be processed first. There are two main processes in the analysis of canopy selection, namely the analysis of data retrieval in the field and analysis of satellite data.

2.3.3. Running and testing the Model. The watershed delineation, in the SWAT program can be done automatically based on DEM (Digital Elevation Model) data by entering the coordinates of the outlet of the watershed. Model testing is carried out through two stages, namely the calibration and validation process. This test is aimed at the results of the model closely fit to the actual output of the watershed. The statistical criteria used are R2 and NSE. Both statistical criteria are the methods most often used in the calibration and validation process [8].

3. Results and Discussion

3.1. Canopy Cover in Samin Sub-watershed
The canopy cover in the Samin Sub-watershed are dominated by medium and bad canopy cover classes, namely 40.60% and 40.18% of the area of vegetation land use. For the good and very bad canopy classes each has a percentage of 16.53% and 2.69%. Furthermore, in the Sub-watershed there is no very good canopy cover class. The distribution of canopy cover is served in Figure 2.

| Data                              | Source                  | Year   | Scale/Resolution      |
|-----------------------------------|-------------------------|--------|-----------------------|
| DEM (Digital Elevation Model)     | DEMNAS                  | 2019   | 5 Meter Resolution    |
| River Network Map of Samin Sub-watershed | BPDAS                  | 2019   | 1:500,000             |
| Land Use Map of Samin Sub-watershed | RBI                    | 2019   | 1:500,000             |
| Soil Type Map of Samin Sub-watershed | FAO                   | 1976   | 1:500,000             |
| Soil Characteristics              | FAO                     | 1976   | -                     |
| Rainfall                          | CHRIPS and BBWS Solo    | 2014-2018 | -                 |
| Climate Data                      | Center of PSDA Bengawan Solo | 2014-2018 | -             |
| Water Level                       | Tirta Public Corporation I Malang | 2014-2018 | -             |
| Landsat 8 Satellite              | USGS                    | 2018   | 30 Meter Resolution   |
3.2. Running the Model

The delineation process resulted in 13 sub-watersheds with a total area of 22,931 Ha. These broad results are different from the extensive data from BPDASHL Solo due to differences in the choice of outlet points. The outlet point of the watershed after processing is known to be in Sub-watershed 5. Of the 13 sub-watersheds formed are further divided into 440 HRU as an analysis unit in the Soil and Water Assessment Tool (SWAT) model. HRU are formed based on data overlays of soil types, land uses, and slope classes. The discharge of the SWAT simulation results before calibration seen from the statistical criteria R² and NSE are 0.73 and 0.08.

3.3. Testing the Model

Testing the model is carried out through two stages, namely the calibration and validation process. The calibration process is the process of selecting a combination of parameters to increase the coherence between the hydrological respond as measured by the simulation results. Model calibration is carried out to obtain adaptive conditions in the field [9]. The number of simulations to get good results in the SWFI-CUP SUFI2 program is from 500 to 1,000 simulations [10]. The calibration process with the SWFI-CUP SUFI2 program in this study was carried out as many as 500 times with a simulation period of time used in the calibration process that is for 2 years (2016-2017).

The parameters selected in the calibration process are sensitive parameters that have an influence on the hydrological response/discharge simulation model. The calibration process in this study was carried out more than once in an experiment to obtain sensitive and significant parameters to be applied in the Samin Sub-watershed. The sensitivity and significance of a parameter can be known through the t-Stat and P-Value values. The closer it is to the value of t, the greater the sensitivity value. For the P-Value if the value is close to 1, the more significant it affects the output [11].

The best simulation result is the 4th simulation out of 500 simulations. The validity value after calibration on the statistical criteria of the coefficient of determination (R²) and the Nash-Sutcliffe coefficient of Efficiency (NSE) has increased. The calibration results for each criterion were R² 0.77 and NSE 0.23. R² value of 0.77 indicates that there is a strong relationship between simulation data and observational data while the value of the results of the NSE of 0.23 has increased but the results of the calibration of the NSE values fall into the unsatisfactory criteria (NSE <0.36). Linear regression graph of simulation discharge and observation discharge after calibration can be seen in Figure 3. For fluctuations in observation discharge and discharge of simulation results can be seen in Figure 4.
Validation is the process of evaluating the model to get a picture of the level of uncertainty that is owned by one model in predicting a hydrological process [12]. The validation time period in this research was conducted from 1 January 2018 to 31 December 2018. The coefficient of determination ($R^2$) of the validation results was 0.57 and the Nash-Sutcliffe coefficient of Efficiency (NSE) was 0.40. The simulation results are seen from the NSE criteria that are included in the satisfactory criteria and $R^2$ whose values are more than 0.5 can be accepted so that the data generated from the SWAT model can be used to predict erosion in the Samin Sub-watershed with satisfactory criteria. Fluctuations in the observation discharge and the discharge of the simulation results can be seen in Figure 5. From the figure it can be seen that the discharge of the simulation results has a smaller value compared to the observation discharge. This difference causes a decrease in the value of the NSE which indicates how well the intersection between the observation discharge and the simulation discharge at line 1:1 [13].

3.4. Erosion Analysis

Erosion is an event of loss of soil or part of the land from a place that is transported from one place to another, both caused by the movement of water, wind and ice [14]. Estimation of erosion in SWAT is calculated based on the MUSLE equation [15]. In the MUSLE equation the rainfall factor is replaced by runoff so the results are more accurate when compared to the USLE equation [16]. Simulations for estimating erosion in SWAT are performed at each HRU. HRU is a land formed as a result of a combination of several characteristics.

The erosion rate obtained from the SWAT simulation results from the smallest 0.007 tons/ha/yr to the largest of 844.29 tons/ha/yr with an average erosion value of 57.4 tons/ha/yr. In Figure 6 it can be seen that the type of upland land use has the highest erosion value. The lowest average erosion is in the forest land use. Forest land use has an index C value of 0.001 which means that actual erosion that will
occur is 0.1% of its potential erosion [2]. Canopy cover factor is one of the factors that influence erosion. This can be seen from the results of the 3 highest erosion values, namely in the types of upland, paddy and rocky land use which have a minimum canopy cover value. These results can be seen in Figure 6.

Figure 6. Average Erosion on Each Type of Land Use in Samin Sub-watershed

Soil type is a factor that also influences the amount of erosion. Each type of soil has a different sensitivity to erosion. Soil sensitivity is whether or not a type of soil is eroded. The more coarse the soil grains the more easily broken down by rain drops but more resistant to the carrying capacity of runoff. Land with fine grains will be more difficult to be broken down by rain drops, but more easily transported by runoff [17].

Figure 8 shows that Mollic Andosols and Ochric Andosols soils have the highest average erosion value compared to other soil types. Andosol soil is land that has parent material derived from volcanic eruptions from volcanoes in the form of loose material such as lava, volcanic ash and tuff. The results of these parent materials have developed so that they develop into Molecular Andosol and Andosol Ocri soils. Based on soil characteristics data from FAO, Andosol Molic soil has a texture of clay soil and Okrik Andosol has a dusty clay texture. According to [18] the soil content of Mollic Andosol is dominated by 60% volcanic ash or pyroclastic material with a very fine texture of sandy clay while Okrik Andosol has a dusty clay texture. Both types of soil have fine soil grains that are easily transported by runoff [2].
Erosion simulation results can be grouped according to erosion danger level (TBE) criteria. TBE can be determined by comparing the erosion level of a land (land unit) and the effective soil depth in a land unit. The results of the TBE classification can be seen in Table 2.

| Criteria      | Erosion (tons/ha/yr) | Ha | %  |
|---------------|----------------------|----|----|
| Very Heavy    | 367.70               | 2  |    |
| Heavy         | 2906.96              | 13 |    |
| Moderate      | 5715.58              | 25 |    |
| Light         | 6276.10              | 27 |    |
| Very Light    | 7664.67              | 33 |    |
| Total         | 22931                | 100|    |

3.5. Application Scenario Soil and Water Conservation

The scenario of applying soil and water conservation in this study is the use of terrace buildings. According to [19] terrace buildings are the most effective Soil and Water Conservation techniques in handling surface flow up to 79.21%. The SWAT program is able to carry out scenarios for applying soil and water conservation by entering USLE_P values.

Terrace structure are applied in intensely cultivated land use and in open land without plants. The terrace building scenarios used in this study are bench terraces and mounds terraces. Bench terrace scenarios are applied in farmland, dry fields, rice fields, and rocky soils with slopes of 15-25% and 25-40% in accordance with the scheme. Guludan terraces are applied in farmland, dry fields, rice fields, and rocky soils with a slope of 8-15%.

The application of terrace structure can reduce the average value of erosion which is quite large. The TBE scenario results for heavy criteria have decreased from 13% to 6%. The criteria for moderate have also decreased significantly from 25% to 7% of the Samin Sub-watershed land area. Changes in TBE area before and after the application of soil and water conservation scenarios can be seen in Figure 9.

![Figure 9. The erosion rates before and after the scenario](chart.png)
4. Conclusions

1. The average erosion value in the Samin Sub-watershed is 57.4 tons/ha/yr. The highest average erosion value is in dry land use. The 3 criteria for the Erosion Danger Level (TBE) that dominate in this study are the moderate, light and very light TBE classes.

2. Model testing is carried out through 2 stages, namely calibration and validation. The calibration process was carried out for two years (2016-2017), from this process the value of R2 was 0.77 and NSE was 0.23. In the validation process carried out for one year (2018), the results of the validation process obtained R2 0.57 and NSE 0.40. The value of R2 has decreased and the value of NSE has increased. The value of NSE has increased to > 0.36 so that the results of the SWAT model can be used to predict erosion in the Samin Sub-watershed with satisfactory criteria.

3. The scenario of the application of soil and water conservation in the form of terrace structure can reduce erosion that occurs in the Samin Sub-watershed up to very light TBE class reaching 53%. Very heavy TBE classes still exist which is equal to 2% of the Samin Sub Watershed area.

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