The Impact of Land Use on Hydrological Characteristics and Erosion Rate of Cilutung Watershed with SWAT Model

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Abstract. Cimanuk watershed will be affected directly by the dynamics of Cilutung watershed as one of its tributaries. Cimanuk is one of the watershed areas in West Java Province, that is categorized as a critical potential due to erosion and vegetation damage. This study aims to simulate hydrological conditions and erosion rates for each sub-watershed. This research uses several variables: 1) soil type; 2) topography; 3) land use; and 4) climate (temperature, rainfall, solar radiation, wind speed, and relative humidity). Analysis conducted is Hydrology Response Units (HRUs) and statistical analysis. Variable physical characteristics are processed by the overlay method for HRUs analysis. Statistical analysis showed the values of R2 and NSE were 0.48 and 0.32. Based on the calibration and validation results, the values of R2 and NSE are 0.75 and 0.46. This shows a satisfactory and acceptable model. The runoff value tends to show a moderate category between 50-80 in the category of Coefficient of Flow Regime and this is precisely proportional to the rate of erosion. Each sub-watershed shows a high runoff value, tends to produce high erosion rate as well and its reverse. The rate of erosion indicates 175.0 tons/ha / year in the medium category.

Keywords: **Cilutung; Erosion Rate; Hydrology; Runoff; Watershed**

1 Introduction

Changes in land use patterns in a watershed especially reduced forest area, increased agricultural land area and rainfall variability can lead to changes in hydrological equilibrium in a watershed system [1]. Land use change and land management are less precise to decrease infiltration capacity [2]. Soil erosion has been considered a major cause of soil degradation. This stems from the fact that soil erosion produces relatively lower organic and soil materials compared to the underlying soil, which is important for plant growth [3]. In addition, rivers, reservoirs and irrigation/drainage flows in the downstream areas become shallow, so that the usability is reduced [4]. Cilutung watershed is one of the tributaries of Cimanuk, which will directly affect the dynamics of the Cimanuk watershed, it is one of the watersheds in West Java Province, that is categorized as a critical potential due to erosion and vegetation damage. Erosion and sedimentation in the Cimanuk watershed are one of the characteristics that threaten the sustainability of natural resources [5]. One factor contributing to the high rate of erosion is sand mining which ignores soil conservation techniques. Ministry of Environment Indonesia West Java states that there are cases of illegal mining in the Cilutung watershed of Majalengka Regency in 2016. Mining activity affects topographic changes or forms steep slopes. In addition, the activity will be traced to the loss of vegetation and high rates of erosion [6]. An increase in the rate of erosion can affect the extent of critical land of a watershed [7]. These conditions can affect the hydrological characteristics and erosion rate of Cilutung watershed as one of the tributaries of Cimanuk watershed. Changes in hydrological characteristics occurring as a result of human activity and physical conditions may result in flooding, erosion, and sedimentation [8-9].

Literature review shows that there are many hydrology and erosion models such as Agricultural Nonpoint Source Pollution (AGNPS) model, Gridded Surface Subsurface Hydrologic Analysis (GSSHA) model, Water Erosion Prediction Project (WEPP) model [10-11] and Soil and Water Assessment Tool (SWAT) model [12]. SWAT is a model that can be used for land use against waterways, sediments, and other chemicals in watersheds with good results [8,12,13]. The SWAT model is recommended for the calculation of soil erosion in the tropics because the calibration of the model results is close to the actual data [14]. Information on hydrological conditions and erosion rates in a watershed is important because it can be data to determine the conditions of watershed management planning and a good land use plan. Based on this, this study focuses on simulating the hydrological characteristics and erosion rate of each sub-watershed in Cilutung watershed using the SWAT model.

Baker and Miller (2013) explain that increased surface runoff will lead to increase surface erosion and

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topsoil loss [12]. USGS (2018) defines runoff as part of rainfall or irrigation water getting into the river surface, river, drainage or sewer [15]. The amount of erosion that occurs depends on the amount of surface flow, the higher the surface flow the higher the rate of erosion [16]

Based on Asdak (2010) it is stated that the rate of erosion is related to runoff, if the runoff is large then the erosion rate will be directly proportional to produce a large erosion rate [17]. In addition, the rate of erosion resulting from sedimentation occurs due to a plot of land or agricultural cultivation areas that ignores soil and water conservation techniques [18]. The productivity of land by the United Nations Environmental Program in Rahim (2000) of 20 million ha annually decreases to zero or becomes uneconomic due to erosion or degradation caused by erosion [19]. Decreased land productivity due to soil erosion, is an on-site effect, while off-site effects may include river sedimentation, reservoirs, irrigation networks and other damages.

Characteristic of the hydrology of the watershed in this study include maximum discharge (Q max), minimum discharge (Q min), average discharge (Qav), and flow regime coefficient (KRA) [20]. The Regulation of the Minister of Forestry of the Republic of Indonesia (2014) states that the coefficient of the flow regime compares the maximum discharge and minimum discharge of the watershed . Table 1 indicates the class of flow regime coefficients based on regulation of the Minister of Forestry of the Republic of Indonesia (2014). The value of the flow regime coefficient in this study indicates runoff. High coefficient of flow regime value indicates that the average value in the rainy season (water flood) that occurs large, whereas in the dry season the flow of water that occurs small or shows drought. [21-22].

Table 1. Flow Regime Coefficient (KRA)

Nilai KRA	Kelas
KRA $\leq$ 20	Very Low
20 < KRA $\leq$ 50	Low
50 < KRA $\leq$ 80	Moderate
80 < KRA $\leq$ 110	High
KRA > 110	Very High

Soil erosion (soil erosion) is an ongoing natural phenomenon and the process of grinding washing during surface runoff. The process of erosion based on the appearance of the land is related entirely to the causes that affect the rate of erosion. There are five factors, namely: (a) climatic factors. (b) soil factors, (c) topographic shape factors, (d) crop cover (vegetation) factors, and (e) human activity factors. According to Utomo (1989) in Soil Conservation in Indonesia, the rate of erosion is also dependent on l) the resistance of the soil to external damaging forces, both by rainfall and runoff; 2) the ability of soil to absorb rainwater ; 3) determining the volume of surface runoff that erodes and transports soil destruction [23].

Table 2. Erosion Hazard Level

Soil Loss (ton/ha/year)	Level
< 15	Very Light
16-60	Light
60-180	Medium
180-480	Heavy
> 480	Very Heavy

In the wet tropics, like Indonesia, erosion is caused by water. The rate of erosion occurring in a region can be done by calculating the amount of soil loss in the Erosion Hazard Level based on the forestry department (Table 2) [24].

2 Overview of SWAT Model

The Soil and Water Assessment Tool (SWAT) model is a physical process-based hydrology model to be simulated in a watershed developed by the USDA Agricultural Research Service. The SWAT model is usually used to predict surface flows, subsurface flow, underground flow, water yield, sediment yield, BOD (biological oxygen demand), nutrients (especially Nitrogen and Phosphorus) and water-soluble pesticides [25]. The parameters in the SWAT Model are designed to calculate long-term runoff and nutrient exports from rural watersheds, especially those dominated by agriculture [26]. Hydrologic cycle is simulated with SWAT model based on the following water balance equation [25]:

$$SW_t = SW_0 + \sum (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})_i \qquad (1)$$

where SW_t = final soil water content (millimeters); SW_0 = initial soil water content (millimeters); t = simulation period (days); R_{day} = amount of precipitation on the ith day (millimeters); Q_{surf} = amount of surface runoff on the ith day (millimeters); E_a = amount of evapotranspiration on the ith day (millimeters); W_{seep} = amount of water entering the vadose zone from the soil profile on the ith day (millimeters); and Q_{gw} = amount of base flow on the ith day (millimeters).

$$Sed = 11.8 \times (Q_{surf} \times q_{peak} \times Area_{hru})^{0.56} \times K_{USLE} \times C_{USLE} \times P_{USLE} \times LS_{USLE} \times CFRG \qquad (2)$$

where Sed = sediment yield on a given day (metric tons); Q_{surf} = surface runoff volume (millimeters per hectare); q_{peak} = peak runoff rate (cubic meters per second); $Area_{hru}$ = area of the hydrological response unit (HRU; hectare); K_{USLE}= universal soil loss equation (USLE) soil erodibility factor; C_{USLE} = USLE cover and management factor; P_{USLE} = USLE support practice factor; LS_{USLE} = USLE topographic factor; and CFRG = coarse fragment factor.

3 Materials and Methods

3.1. Study Area

The study area, the Cilutung watershed, is located between 6°51'30" to 7°2'30" S. latitude and 108°6'30"-108°23'0" E. longitude. Cilutung River as one of its sub watershed of Cimanuk watershed in West Java, Indonesia. Cilutung watershed is located at the border of Sumedang and Majalengka Regency (Fig.1). It encompasses a geographical area of 62102 Ha. For this study, the Kamun gauging station located at 6°46′47″ S. latitude and 108°10′6″ E. longitude was taken as the outlet of the Cilutung watershed. Average annual rainfall in the study area is 3179 mm/year. The average mean monthly maximum temperature varies is 32.7°C, and a mean monthly minimum temperature varies is 23.9 °C. The mean monthly wind velocity varies is 1.8 m/s.

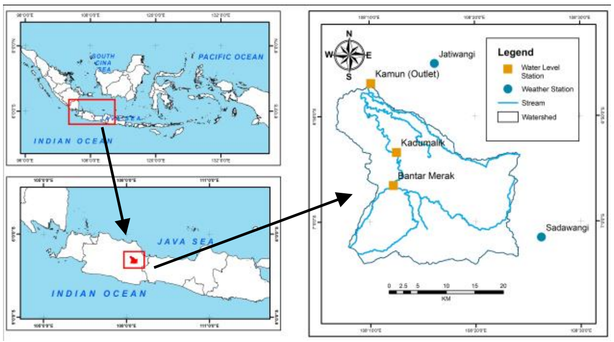


Fig 1. Map of Cilutung Watershed

3.2 Data Acquisition

The data used in this study were as follows:
(1) Daily rainfall data from two rain gauge stations (Jatiwangi and Sadawangi) of the Dinas PU dan PPSDA Majalengka and the daily data on temperature, relative humidity, and wind velocity of the Jatiwangi station from the (BMKG) Meteorological Centre, Majalengka, West Java for an 11-year period (2007-2017);
(2) Daily discharge data from 11 years (2007–2017) of the Cilutung watershed measured at the Kamun gauging station from BBWS Cimanuk Cisanggarung
(3) Soil maps of Cilutung at a scale of 1:250.000 from the Soil and Agroclimate Research Center of 1995
(4) Watershed priority delineation maps of the Cilutung watershed use Digital Elevation Model SRTM 1 Arc-Second (30m) from https://earthexplor er.usgs.gov/.and
(5) Landuse data from Badan Informasi Geospasial and Basemap Imagery ESRI

3.3 Calibration and Validation

The performance of the ArcSWAT model for runoff and erosion rate simulation at daily time steps during calibration and validation periods was evaluated using statistical and graphical indicators.. In this study, the model was calibrated and validated on annual water discharge in outlet station. NSE, R^2 and PBIAS were used to quantitatively assess the ability of the model to compare temporal trends in observation data.

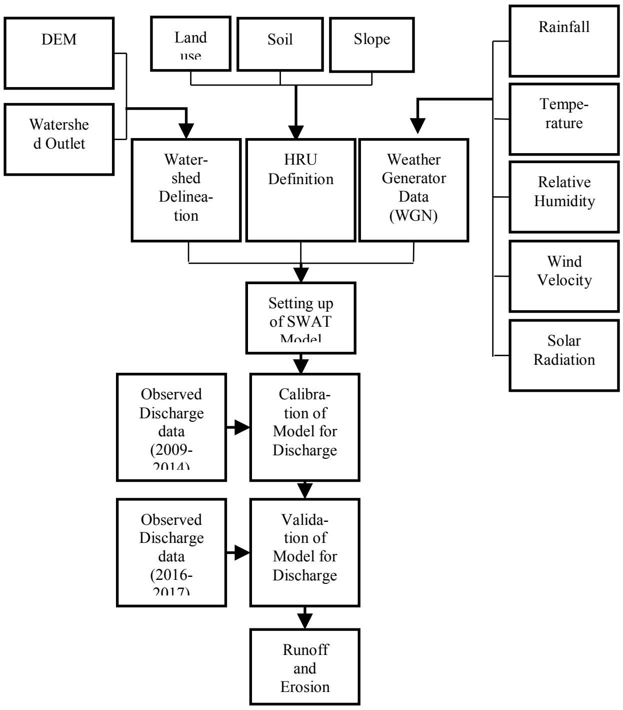


Fig. 2. Flowchart of the methodologies adopted in the study

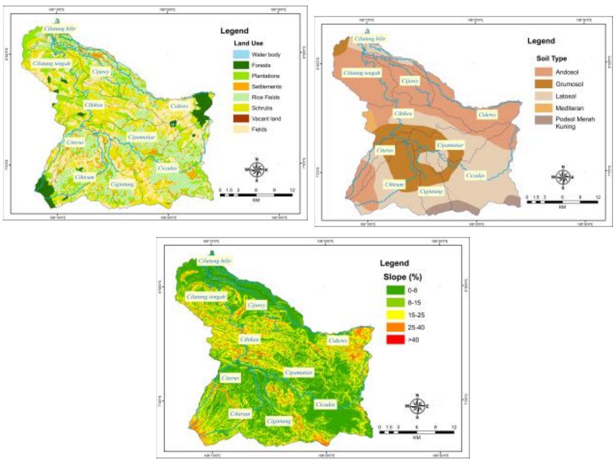


Fig. 3. Land Use, Soil Type and Slope Map of Cilutung

The statistical indicators include Nash-Sutcliffe efficiency (NSE) recommended by Ahl et al (2008), coefficient of determination (R^2) recommended by Moriasi et al. (2007). and percent bias (PBIAS) recommended by Verma & Jha (2015) [27-29]. The values of NSE, R^2, and PBIAS were calculated using the following equations:

$$NSE = 1 - \frac{\sum_{i=1}^{n} \left(y_i^{obs} - y_i^{sim}\right)^2}{\sum_{i=1}^{n} \left(y_i^{obs} - y_i^{mean}\right)^2} \quad (3)$$

$$R^2 = \left(\frac{\left[\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{mean}\right)\left(Y_i^{sim} - Y_i^{mean}\right) \right]^2}{\sum_{i=1}^{n} \left(y_i^{obs} - y_i^{mean}\right)^2 \sum_{i=1}^{n} \left(y_i^{sim} - y_i^{mean}\right)^2} \right) \quad (4)$$

$$PBIAS = \frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim}\right) * 100}{\sum_{i=1}^{n} \left(y_i^{obs}\right)} \quad (5)$$

Where y_i^{obs} is observation data, y_i^{sim} is the simulation data, y^{mean} is the average of the observed data, and n is the amount of data. The value of R^2 ranges from 0 to 1, if the value of R^2 is more than 0.5 then the model is acceptable [28]. The value of R^2 is used to refer to the degree of conformity between the observed discharge and the simulated discharge. The NSE values range from $-\infty$ to 1 (perfect fit), where the negative NSE value means that the model of performance is worse than that derived by means of the observations as a predictor [27].

Table 3. Criteria Value of Nash-Sutcliffe (NSE)

No	Criteria	NSE
1	Good	NSE > 0.75
2	Satisfactory	0 75 < NSE < 0.36
3	Unsatisfactory	NSE < 0.36

Source: (Ahl *et al.*, 2008)

PBIAS measures the average tendency of the simulated data to be larger or smaller than the observed data. The ideal value of PBIAS is 0.0, with the lower PBIAS values suggesting better simulation results. Positive values of PBIAS indicate underestimation by the model and negative values indicate overestimation by the model [29].

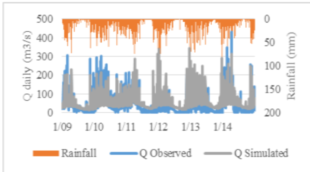
4 Results and Discussion

4.1 Calibration and Validation Results for SWAT Model

This research use hyrological data to calibrate the model because data on sediment measuring in the study site cannot be collected. The matching value generated by the SWAT-CUP software is entered into every parameter present in the model so as to minimize the difference of the model discharge results with the observed discharge [30]. Process of analyzing sensitivity of discharge is done automatically by SWAT model in "Sensitivity Analysis" function of SWAT-CUP. The results of this process show parameters having influence on changing value of hydrology volume in rivers of the watershed. The values of statistical indicators are R^2, NSE, and PBIAS of observed and simulated discharge at daily time steps for calibration periods are 0.48, 0.32, and -42.4 (Fig 4). This validation process uses data that has been calibrated compared to observation data from 2016-2017, corresponding R^2 and NSE values during the validation period are 0.72 and 0.46, respectively. The observed peak discharge has a greater value than the peak discharge simulation (Fig.5). The value of R^2 shows a value of 0.72 where the value of $R^2 > 0.5$ model is acceptable [28]. NSE value shows a value of 0.46 and goes into satisfactory NSE value criteria [27]. The value of PBIAS indicates a value of 35.8 with a negative value and indicates continued deviation.

Table 4. Calibrated Parameters of the Model

No	Parameters	Fitted Value	Min. Value	Max Value
1	V__ALPHA_BF.gw	0.45	0	1
2	V__GW_DELAY.gw	177	30	450
3	R__SOL_BD.sol	-0.1	-0.2	0.2
4	R__SOL_AW.sol	0.1	-0.2	0.2
5	V__SURLAG.bsn	3.6	0.05	24
6	V__GWQMN.gw	0.9	0	2



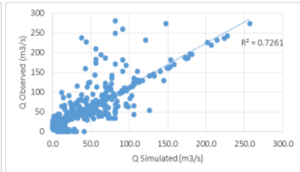


Fig 4. Comparison of observed and simulated daily discharge hydrographs for calibration years (2009-2014) **Fig 5**. Comparison of observed and simulated daily discharge scatter plot and hydrographs for validation years (2016-2017).

However, the difference in PBIAS value from the previous value has increased the value so that it shows the reduced rate of deviation. The result of statistical test relies on observation data due to lack of data on water discharge observation data for several years. Therefore, the calibration and validation results of this study can be accepted. This shows that the simulated discharge are in satisfactory with the observed discharge during validation periods (Fig 6).

4.2 Performance of SWAT Model in Hydrology and Erosion Rate Simulation

The largest sub-watershed is Cicadas of 12380 hectares. The smallest sub-watershed is Cilutung Hilir of 316 hectares. The characteristics of each sub-watershedt if large areas appear to have a higher number of URHs, while small sub-watersheds have relatively few URHs. The average URH distribution does not have a special pattern because each sub-watershed has URH variations. Build on the results of data processing, the greater the number of URH, the more diverse physical characteristics. SWAT processing results based on slope, soil type, and land use show that there are 371 URHs produced for 10 sub-watersheds.

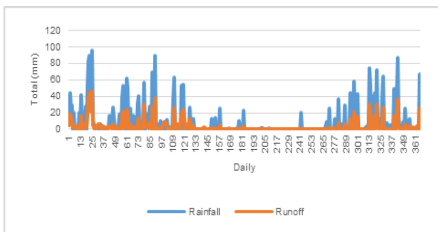


Fig 6. Comparison of daily rainfall and runoff (2017)

Comparison of daily rainfall and runoff data also shows the same with monthly data where the tendency of runoff results follows rainfall conditions. Figure 6 shows rainfall as the input value (precipitation) and runoff (Q Surf) as the output value in the SWAT model. The value

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of this large runoff shows that when the rainy season occurs large runoff, whereas if the dry season the flow of water can be small.

The rate of erosion is obtained from sediment yields of soil deposits in each sub-watershed based on model simulation results. Fig 8 and Table 7 shows the results of erosion rate model treatment in each sub-watershed in Cilutung watershed. The simulation of the erosion rate of each Cilutung sub-watershed has variation. This is due to the different physical characteristics of each sub-watershed. The region with the largest erosion rate of > 480 tons/ha /year can be found in Cihikeu that has dominant physical characteristics of the type of dryland farming land use, andosol soil type, and slope of 25-40. Type of soil andosol according to Ministry of Agriculture Decree no. 837 / Kpts / IV1980 is stated as a type of soil that is sensitive to erosion [31]. Types of land use that dominates and results in the rate of erosion that high in Cilutung watershed tend dryland farming [7]. Dryland farming is contained in human activities that will accelerate erosion.

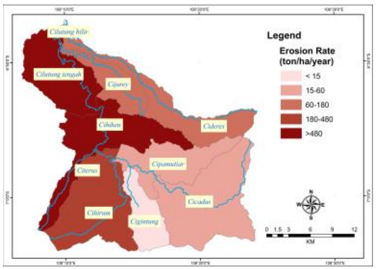

Fig 7. Map of Erosion Rate Cilutung Watershed

This research shows the result of the tendency of high erosion rate results in sub-watershed areas with high slope inclination and low erosion rate in sub-watershed areas with low slope inclination. The slope is one of the most influential topographic elements of surface flow and erosion. Surface flow velocity that has a steep slope will be faster. Larger eroding and carrying power cause considerable erosion [32]. The result of erosion rate model based on the classification of erosion level according to the Ministry of Forestry (1998) according to the Minister of Forestry Regulation Number p.3 / V-SET / 2013 on the characteristics of the Watershed is shown in Table 7.

However, it can be seen also in Figure 9 that each erosion rate class shows significant differences, especially very low-grade levels in light, high-margin classes. Figure 7 and Table 5 show that the rate of erosion rate in Cilutung watershed is based on average erosion in each sub-catchment classified in the medium category of 175.02 ton/ha/year.

Table 5. Classification of Erosion Rate in Cilutung

Erosion Rate (ton/ha/year)	Classification	Wide (Ha)	Percentage (%)
< 15	Very Light	316	0.5
15-60	Light	22729	36.6
60-180	Medium	11131	17.9
180-480	Heavy	10554	17.0
> 480	Very Heavy	17372	28.0
Total Amount		62102	100.0
Average Erosion		175.02	

Erosion and sedimentation in the SWAT model were estimated using the Modified Universal Soil Loss Equation (MUSLE) model. Universal Soil Loss Equation (USLE) that uses rainfall as erosion energy, MUSLE uses runoff to simulate the erosion process.

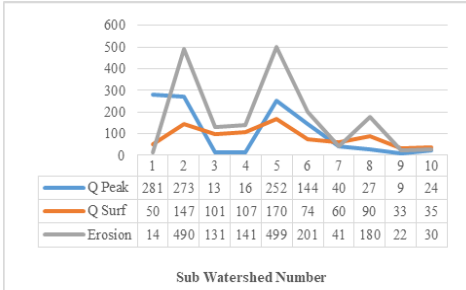

Fig 8. Comparison of Q Peak, Q Surf, and Erosion each sub-watershed in 2017

Figure 8 displays the comparison of Q Peak, Q Surf and Erosion value of each sub-watershed. It can be observed that the tendency of comparison of these three values is directly proportional to each other. Q Peak is the maximum discharge value (peak) and Q Surf is the accumulation of surface runoff.

Conclusion

The performance of the SWAT model was evaluated in this study for the simulation of hydrology and erosion rate in the Cilutung watershed of West Java, Indonesia using statistical and graphical indicators. Based on the findings of the present study, the following conclusions can be drawn:

- The results of statistical analysis on Cilutung watershed shows the value of R2 and NSE 0.48 and 0.32 before calibration and based on the results of calibration and validation of Cilutung watershed the value of R2 and NSE increased to 0.72 and 0.46. This shows a satisfactory and acceptable model.
- The hydrological characteristics of Cilutung watershed are based on average discharge, maximum discharge, minimum discharge, and runoff show a high diversity.
- Any sub-watershed that exhibits a high runoff value, has a tendency to produce high erosion rates and vice versa. The results of the erosion rate of Cilutung watershed show the erosion rate including the moderate level of 175.0 tons/ha/year. Sub-watershed whose runoff value and high erosion rate

indicate the dominant physical characteristics of the type of agricultural land use of dryland, soil type andosol, and steep-steep slopes.

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