Estimation of erosion rate in Cileungsi upper watershed
Bogor Regency

P A Widyasa, E Kusratmoko and K Marko
Department of Geography, Faculty of Mathematics and Natural Sciences (FMIPA), Universitas Indonesia, Depok 16424, Indonesia
Corresponding author’s email: eko.kusratmoko@sci.ui.ac.id

Abstract. Land use of upper watersheds Cileungsi located in Bogor, West Java has always progressed from year to year due to increased human activities that have an impact on land degradation such as erosion. Soil erosion in Java estimated the loss of US $400 million per year. This study aims to estimate of erosion rate by using the Modify Universal Soil Loss Equation (MUSLE) is already integrated into the modeling Soil and Water Assessment Tool (SWAT). SWAT can provide simulation results based on the physical characteristics of the Hydrological Response Unit (HRU) that is considering climate parameters such as rainfall, temperature, solar radiation, humidity, and wind speed. The results showed that the highest rate of erosion on the upstream sub-basin 15 (Ci Janggel) to contribute to the erosion of 184 tons/ha/year classified as heavy erosion. The high rate of erosion occurs on the characteristics of the area with 25–45 % of slope, clay loam soils, land use, and agricultural drylands.

Keywords: Erosion rate, upper watershed, Cielungsi, MUSLE, SWAT

1. Introduction
Soil erosion on Java’s island is an estimated loss of US $400 million per year [1]. That number may increase each year. Damage that occurs comes from the change in land use [2] and other physical conditions due to physical factors, social and infrastructure. The impacts of erosion resulted in the decline in soil organic matter, the reduction to the inner land, and decreasing the capacity of drainage in the watershed. In terms of agriculture, erosion will also drop its productivity, loss of soil fertility resulting in high production cost by farmers.

Predicting an erosion can be done directly or indirectly through erosion model prediction. Prediction in direct erosion has many obstacles, which is a long workmanship time, with limited tools and the coverage area is not vast. Required erosion and sedimentation that can be used for the modeling is Soil and Water Assessment Tool (SWAT). SWAT is a model that can be harnessed to predict the impact of current use on air, sediments, and other chemicals that enter the streams in the watershed. This will predict the erosion rate, sedimentation, and runoff by reviewing the response of hydrological units in the watershed as conducted by Ref. [3-6]. It can be used as a tool to develop a scenario to decide the best watershed management planning and also the best land-use. In this study, we used a quantitative approach and descriptive analysis to determine the spatial pattern of erosion rate in the upper watershed of Cileungsi. These studies focus on predicting the rate of erosion in the upper watershed Cileungsi area by observing the variation of hydrological characteristic from the
Hydrological Response Unit (HRU). HRU is based on slope, land use, and also soil type which is directly related to erosion and sedimentation in each sub-watershed using SWAT model.

2. Materials and method
This study used a quantitative research method with spatial analysis and calibration analysis on the hydrological model. The research was conducted at Upper Watershed Cileungsi, Bogor Regency, West Java. The flowchart of this research can be seen in figure 1.

The main variables in the research are physical characteristics of watershed represented by HRU (i.e. slope, soil type, and land use). Then climate data (e.g. temperature, rainfall, solar radiation, humidity, and wind velocity) will determine the model generated by SWAT. During the analysis of this model, it will produce in the estimation of erosion rate in the research area. HRU needs to use three types of data processing: slope data from the Digital Elevation Model (DEM), land use, and soil type. Land use data were obtained from Landsat OLI 8 2016 image which then is classified based on the National Land Agency classification reference (BPN). A field survey is conducted to verify the land use map before processing on SWAT. The soil type data (vector data) were classified by the classification of soil texture, according to FAO in 2014. All three data are overlaid into HRU using a multiple type to get more variation of HRU produced [7, 8]. The threshold values of each variable is 5% based on the default value on SWAT.

Spatial pattern analysis is used to analyze the distribution of erosion rate based on physical characteristics of sub-basin on simulation result obtained from the SWAT model. To predict erosion by rain and surface runoff, the SWAT model uses the Modified Universal Soil Loss Equation (MUSLE), the improvement from the Universal Soil Loss Equation (USLE). In contrast to USLE which uses rain kinetic energy for erosion-based calculations, MUSLE uses flow factors to predict sediment yields, so Sediment Delivery Ratio (SDR) is no longer needed because flow factors have provided the used energy for breaking and transporting sediment [7].

Figure 1. Research flowchart
Sedimentation results on the SWAT model were calculated using equation 1 as mentioned by [5, 6],

$$Sed = 11.8 \left( Q_{surf} \cdot Q_{peak} \cdot A_{HRU} \right)^{0.56} \cdot K_{usle} \cdot C_{usle} \cdot LS_{usle} \cdot CRFG$$  \hspace{1cm} (1)

Sed is the result of daily sediment (ton), and erosion is (ton/ha), \(Q_{surf}\) is the surface flow volume (mm/ha), \(Q_{peak}\) is peak surface flow discharge (m\(^3\)/s), \(A_{HRU}\) is the area of HRU Ha, \(K_{usle}\) is a USLE soil erodibility factor, \(C_{usle}\) is a USLE land use factor, \(P_{usle}\) is a USLE management factor, \(LS_{usle}\) is a USLE topography factor, and \(CRFG\) is a roughness factor of fragments.

Then the result of erosion and other output are calibrated using the runoff data. Software used for calibration and validation analysis is SWAT-CUP (Calibration Uncertainty Program) which is a public domain program. The statistical model used to test the model is by using the Nash-Sutcliffe (NSE) efficiency equation and the coefficient of determination [5, 6]. Where \(Q_{obs}\) is the actual data variable, \(Q_{cal}\) is the simulation variable, and \(\bar{Q}_{obs}\) is the average variable of the actual data. If the NSE value > 0.50, the model can be applied to estimate the erosion rate as shown on table 1.

$$NSE = 1 - \frac{\sum_{i=1}^{n} (Q_{obs} - Q_{cal})^2}{\sum_{i=1}^{n} (Q_{obs} - \bar{Q}_{cal})^2}$$  \hspace{1cm} (2)

3. Results and discussion

The SWAT model calibration results use observational runoff data from the Cileungsi hydrological station due to the absence of observed erosion rate. In this test, revealed that the efficiency value of the Nash-Sutcliffe (NSE) model is 0.74 as good criteria. Thus, the modelling can be used to estimate the rate of erosion. The result of this simulation is displayed in figure 2.

The erosion rate in upper watershed Cileungsi is caused by factors of land use, slope, humans, soil types, and climatic factors. The soil erosion may occur because of gravity-pulled rainfall that falls on the surface of the soil has a higher power to erode the soil than transporting the soil as a surface stream. This explains that sub-basin characteristics have a significant influence on the rate of erosion. When high slope sub-basin has proper conservation techniques in the upstream, this will lead to reduced downstream sediment production showed by smaller HRU value in the upstream region than in the middle and downstream. In the middle of the Cileungsi upper watershed, with slope of 8–15 % and 15–25 % harnessed as plantation and rice fields, this area increases the production of sediment numbers and erosion downstream. The middle section that obtains continued runoff and upstream sediments with the use of plantation and forest land with a 25–45 % slope downstream river will degrade and cause soil transport and increase sedimentation downstream of Cileungsi upper watershed.

Table 2 and figure 3 show that very low erosion rate occupies 4 % of the total area, light erosion occupies an area of 38.2 %, medium erosion rate fills 48.6 % of the area, and high erosion rate fills up 8.8 % of the area.

| No. | Criteria      | NSE                  |
|-----|---------------|----------------------|
| 1   | Very good     | 0.75 < NSE ≤ 1       |
| 2   | Good          | 0.65 < NSE ≤ 0.75    |
| 3   | Satisfactory  | 0.50 < NSE ≤ 0.65    |
| 4   | Unsatisfactory| NSE ≤ 0.50           |
Figure 2. Simulation runoff calibration and observation runoff.

Table 2. The rate of erosion

| Erosion rate (ton/ha/year) | Details  | Area (km²) | %  |
|---------------------------|----------|------------|----|
| < 15                      | Very low | 11.1       | 4.4|
| 15–60                     | Low      | 95.4       | 38.2|
| 60–180                    | Medium   | 121.3      | 48.6|
| 180–480                   | Heavy    | 22         | 8.8 |
| > 480                     | Very heavy| 0          | 0  |

Figure 3. Erosion rate in Cileungsi, Bogor
4. Conclusion
Based on the SWAT model analysis, the physical characteristics of each sub-basin can be seen based on HRU value. The spatial pattern of physical characteristics in the upstream sub-watershed is dominated by physical characteristics (i.e. land use of clay loam soil type plantation), and slope of 25–45 %. The middle area of the sub-basin is dominated by rice fields, clay loam, and slope of 15–25 %. Moreover, the downstream area has characteristics of plantation land use, clay soil type and slope of 0–8 %. Based on the spatial pattern of fissile characteristic, the upstream watershed has the highest erosion production compared to the central and downstream areas due to the characteristic of physical dominance of the high slope percentage and the dryland farmland. In the upstream areas that have the highest erosion rate, sub-watershed 15 produces 184 ton/ha/year erosion rate with the dominant physical characteristics of dryland farming, clay loam, and slope 25–45 %. The lowest erosion rate in sub-watershed 9 producing an erosion rate of 3.2 ton/ha/ year and physical characteristics of wetland, clay loam, and slope 0–8 %.

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