Soil erosion prediction using GeoWEPP model in Cimanuk Hulu sub-watershed

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Abstract. Runoff, soil erosion, and sedimentation can be used to assess the watershed condition. GeoWEPP is one of the erosions predictions models that can be used to predict those parameters and also can be used as a tool to arrange watershed management. Cimanuk Hulu sub-watershed is one of the important watersheds in West Java Province, Indonesia, as its function for water resources for Jatigede reservoir. The condition of this sub-watershed is in poor condition because of the high rate of sedimentation in water body. Therefore, we use the GeoWEPP model to assess runoff, erosion, and sedimentation in the Cimanuk Hulu sub-watershed. The model is also used to arrange the watershed management scenario. The input data are climate data, soil characteristics, land cover management, channel characteristics, digital elevation model, soil and land cover map. Land cover types were classified using Google Earth Engine (GEE) with SmileCART algorithm. Soil samples, land cover management, and channel characteristics were collected from the field survey. The result showed that runoff value in the existing condition is classified as a high class that affected higher soil erosion and sediment yield compared to tolerable soil loss in the Cimanuk Hulu sub-watershed. Simulation of watershed management showed that scenario 3 is the best in reducing the runoff, erosion, and sedimentation in the Cimanuk Hulu sub-watershed.

1. Introduction

Soil erosion was resulted from the combination of rainfall erosivity index, soil characteristics, topography factor, crop management, and conservation factor [1-4]. It is a common cause of land degradation in over the world, includes Indonesia [5-8]. Erosion can affect the decrease of soil fertility and sedimentation. Sedimentation is one problem that happens in the Cimanuk Hulu sub-watershed [6,8]. It indicates that there was an erosion process of the watershed. The understanding of this process could be very useful for the sustainable management of land resources.

Cimanuk Hulu sub-watershed is one of the important watersheds in West Java Province because it functions as a catchment area for the Jatigede reservoir [7,10]. Based on the watershed classification map, the Cimanuk Hulu sub-watershed is classified as a watershed with recovered carrying capacity [11]. The classification is determine based on land condition; water quality, quantity, and continuity;
social economy, and water building investment, as well as the utilization of regional space, does not work properly. Technically, the indicator has high and very high values [12].

Based on monitoring data from river gauge in Cimanuk Hulu sub-watershed with a coverage area of the catchment is 256.16 ha [13], sediment discharge was as large as 12,630.381 tonnes/day in year 2018. Besides that, the Cimanuk Hulu sub-watershed also has problems with the water distribution in the rainy and dry seasons, which is showed by the flow regime coefficient of 73.04 (classified as very high). The problems that happen in the watershed could be an obstacle to the sustainability of the Jatigede reservoir function.

Refers to the problems, it is needed to arrange the watershed management for the Cimanuk Hulu sub-watershed to ensure its sustainability. One model that can be used to simulate the management of watersheds is GeoWEPP. GeoWEPP model is a geospatial interface for WEPP (Water Erosion Prediction Project) which was developed to simulate a complex watershed [14]. This model can be used for soil conservation planning and design [15]. The use of the WEPP model showed that simulation of conservation techniques able to reduce erosion and sedimentation [16]. Therefore, the existing condition of the watershed needs to be known so can be used as basis to simulate the watershed management scenario.

2. Methodology

2.1. Watershed Description

Cimanuk Hulu sub-watershed is located in Garut Regency, West Java Province and geographically at 107°44′0″ - 108°12′0″E dan 6°50′0″- 7°26′0″LS. The study area of the Cimanuk Hulu sub-watershed in this research is limited to the outlet before Jatigede Reservoir that has an area of 121,745.63 ha (Figure 1).

Figure 1. Research area.

Soil types in the sub-watershed consist of ordo Inceptisols, Ultisol, Alfisol, and Entisol. Land use types consist of forest, plantation, settlement, agriculture, rice field, bare land, and water body. The drainage pattern in the sub-watershed is dendritic.

2.2. Model Description

GeoWEPP Model is a geospatial interface for WEPP (Water Erosion Prediction Project) which was developed to simulate a complex watershed [14]. The WEPP model is a process-based and continuous
model to predict erosion and sediment deposition from runoff, rill erosion, and sediment deposition in the pond [17,18]. The model considers the distribution of erosion and sediment both spatial and temporal and predicts where and when the erosion is occurring in a watershed or slope length so that the conservation techniques can be applied effectively to control erosion and sediment. Climate data, infiltration component, and plant growth component are needed to calculate the water balance using this equation:

\[
\theta = \theta_{in} + (P - I) \pm S - Q - ET - D - Q_d
\]  

(1)

where: \( \theta \) is soil water content in the root zone (meter), \( \theta_{in} \) is the initial soil water content in the root zone (meter), \( P \) is cumulative rainfall (meter), \( I \) is interception by vegetation (meter), \( S \) is snow water content (meter), \( Q \) is cumulative surface runoff (meter), \( ET \) is cumulative evapotranspiration (meter), \( D \) is cumulative percolation that missing under root zone (meter), and \( Q_d \) is subsurface flow (interflow).

Simulation of WEPP model consists of hillslope, channel, and watershed component [19]. Simulation of WEPP using GeoWEPP application requires some steps. The first step is to delineate the watershed, sub-watershed, and overland flow elements (OFEs) using Digital Elevation Model (DEM) data (Figure 2). OFEs as the smallest analysis unit generated using soil, land cover, and slope data. Land cover was classified using Google Earth Engine (GEE) with SmileCART algorithm, outside the WEPP model. After that, we define the climate for the research location, then the model can be executed. The schematic framework of the GeoWEPP model is presented in Figure 3.
The application of the GeoWEPP model in the Cimanuk Hulu sub-watershed is not flowed by calibration and validation process. It was because of the limitation of collecting data in the pandemic covid-19 era. But, theoretically and technically, the model was calibrated in watershed-scale [17,21] including in Indonesia and showed satisfactory results [22,23]. Besides that, the application of the GeoWEPP model in this research was done using input from the field. Thus, the model can represent the field conditions.

2.3. Existing and Conservation Practice’s Simulation

Simulation of the condition existing and watershed management scenario was done using DEM SRTM, soil data, land cover 2020, land management, and climate data for the period 2011-2020. SRTM data has pixel size 90 x 90 m. This DEM data was used because the soil map has scale 1:100.000. Soil samples and land management were collected form field survey in 2020. The simulation only running based on the watershed method. The mapping of sediment yield was classified using tolerable soil loss (T).

Soil and water conservation (SWC) techniques were simulated to reduce runoff, erosion, and sediment yield. There are two scenarios i.e.; applying contour, mulch in surface area, tillage consist of a cultivator, row, ridge tillage in dryland agriculture and mix agriculture and implementation of agricultural practices in bare land area (scenario 1); combination of applying contour, mulch in surface area, tillage consist of a cultivator, row, ridge tillage in dryland agriculture with eliminating the burning process of crop waste in a rice field and increasing C-organic value in some hillslope that applied SWC (scenario 2).

3. Result and Discussion

3.1. Existing and Conservation Techniques Simulation

The dominant land cover in Cimanuk Hulu sub-watershed is for rice field (26.95%), followed by forest (24.87%), dryland agriculture (23.98%), settlement (11.51%), bare land (7.69%), mixed agriculture (4.04%), and water body (0.97%). Distributions of land cover type in the Cimanuk Hulu sub-watershed affect surface runoff and soil erosion, with the main sources are agricultural land, and bare land. Condition in agriculture area both dryland agriculture and mixed agriculture in Cimanuk Hulu sub-watershed is not quite good enough in some area. This is reflected in the management practices that are applied by farmers, they still cultivate their land using conventional tillage. Similar to agricultural land, bare land area is susceptible to raindrop energy. It potentially leads to soil erosion and also generates surface runoff.

The results of conservation practices simulation in the Cimanuk Hulu sub-watershed are presented in Table 1. Simulation of scenario 1 (S1) can reduce soil erosion, sedimentation, and runoff compare to the existing condition, respectively as large as 25.50%, 23.12%, and 0.06%. Scenario 2 also reduces soil erosion, sedimentation, and runoff, respectively of 94.63%, 80.11%, and 5.97%. The highest decrease from this scenario is affected by increasing the c-organic value and eliminating the burning of crop residue. Improvement of C-organic value can improve the soil physics characteristics [24,25], while removal burning crop activities can inhibit nutritional loss and prevent the degradation of soil physical health [26]. Research by [16] also showed that soil conservation simulation in watershed-scale can reduce erosion by 75%. Other research also showed that mulch application can reduce erosion [27,28].

| Scenarios          | Runoff (mm) | Soil Erosion (tonnes/ha/year) | Sediment yield (tonnes/ha/year) |
|-------------------|-------------|-------------------------------|---------------------------------|
| Existing condition| 1,011.14    | 1,670.02                      | 95.49                           |
| Scenario 1        | 1,010.52    | 1,244.25                      | 73.41                           |
| Scenario 2        | 950.82      | 89.74                         | 18.99                           |
3.2 Distribution of Sediment Yield
Tolerable soil loss value (T) in sub-watershed can be used to mapping the sediment yield distribution. Thus, the information of specific location that needs to be improved can be known, so the management efforts can be done effectively and efficiently.

T value in Cimanuk Hulu sub-watershed of 21.97 tonnes/ha/year. The location with sediment yields greater than the T value means that the location is in poor condition to support the land productivity. In existing conditions, the Cimanuk Hulu sub-watershed is dominated by sediment yield more than 4T (38.88% of sub-watershed) (Figure 4). Based on this information, the conservation techniques were applied. The simulation of soil and water conservation techniques in the Cimanuk Hulu sub-watershed affected the distribution changes of sediment yield class (Figure 4). Compare to the existing scenario, scenario 2 can reduce the area with sediment yield class largest than 4T as large as 32.51%. The change of sediment yield class distribution is affected by the application of soil and water conservation techniques in a unique hillslope.

Figure 4. Spatial pattern of sediment yield in Cimanuk Hulu sub-watershed: (a) existing condition, (b) scenario 1, (c) scenario 2
4. Conclusion
Application of conservation techniques in a sub-watershed can reduce erosion, sediment, and runoff. The best scenario in reducing those parameters in the Cimanuk Hulu sub-watershed is scenario 2: the combination of contouring, mulch, tillage (cultivator, row, ridge tillage), increasing c-organic value in hillslope that applied soil and water conservation, and elimination of burning crop waste in the rice field.

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