Conservation of Jatigede Reservoir catchment area based on sediment and water yield control

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Abstract. Jatigede Reservoir serves to control floods in Indramayu area. The reservoir irrigate rice fields by 90,000 ha, supply raw water for clean water by approximately 3,500 l/sec, and produce electricity by 110 MW. Yet, the condition of the Cimanuk watershed is reported in a critical situation. It was characterized by high soil erosion and high fluctuations in river discharge. This study aims to evaluate the sedimentation and river flows that entering the Jatigede Reservoir. The rainfall-runoff simulation determined by SWAT (Soil and Water Assessment Tools) on Jatigede Reservoir is based on existing land use. According to SWAT, it showed the possibility of current land use on annual crop and garden land which is carried out some conservative measurements, such as terrace, grass strip, and ditch and also building area that constructed an infiltration well would reduce the sediment yield from around 9.05 to 5.96 million tons per year. Not only that, but also runoff will decline from 99.7 to 75.8 mm per year. If the measurements are based on land use according to the 2011-2030 Spatial Plans of Garut Regency and Sumedang Regency, the sediment yield can be reduced to 4.97 million tons per year and runoff which become 97.6 mm per year. However, if the environmental degradation of the Cimanuk watershed is allowed to continuously increase that is marked by changes in uncontrolled land use, it will raise the sediment yield and runoff by about twice as the current conditions, so that it can threaten the sustainability of the function of Jatigede Reservoir.

Keywords: conservation, land use, runoff, sedimentation, Jatigede Reservoir

1. Introduction
Watershed can be seen as part of the hydrological cycle. Water that comes out of a watershed outlet comes from rain water after experiencing a process in the watershed. The process occurred in the watershed may change the variety of inputs in the form of rain into output in the form of water yield. If the process that occurs in the watershed is still running well, the surface flow fluctuation at the watershed outlet has a relatively small difference and the sediment content is also small. The process in the watershed is influenced by the physical characteristics of both the watershed and anthropogenic. Thus, the main of nature conservation is about how to maintain the condition of the watershed environment to continue the function optimally, capture rainwater and hold it in the soil (as ground water or as soil moisture), so that there is no flooding in the rainy season. Also, erosion is small and there is no drought during the dry season.
Cimanuk Watershed-West Java is one of the national priority watersheds utilized for rehabilitation because its condition is critically classified. This watershed can represent the environmental conditions of watersheds, especially in Java. The Cimanuk watershed has some problems, such as a high level of soil erosion, extreme fluctuations in river discharge and river water pollution.

The upstream part of the Cimanuk watershed is in the Jatigede catchment area, covering an area of 1,462 km². In 2004, the land was identified as critical which about 28% of the catchment area, scattered in Garut Regency covering 30,459 ha and Sumedang Regency covering 10,416 ha. The measurement results of the Cimanuk River sedimentation rate at the Eretan Station are relatively high with average range 5.32 mm per year between 1985-2007 [1]. Based on land use, the erosion is generally and largely occurs on annual crop plantations and gardens, due to intensive land management factors without regard to conservation techniques [2].

Another problem is the fluctuation in river discharge which are getting higher. If the rain in the rivers are extremely high, otherwise the river discharge in the dry season is quite low or the base flow is small. It is predictable that a long dry season might be impacted to a greatly reducing of water supply at the reservoir, though the water demand from the reservoir is relatively similar, so that it will disrupt the productivity of its reservoir.

The problem is compounded due to the impact of an increase in extreme climate phase. Also, there has been a marked decrease in rainfall season at the southern part of Java Island during a hundred years ago, which with a rate of rain reduction of 10 mm per year [3]. Long-term decrease in annual rainfall will disrupt water quantity, quality, and continuity in reservoirs. Another impact of global climate change is an increase of extreme rainfall, though it could raise sedimentation and fluctuations in the river discharge. Mostly in urban areas, land cover existed by waterproof buildings or settlements is very intensive, particularity it will be difficult to infiltrate into the soil during the rain, so that it will decrease in the long run the groundwater reserves. If this condition left uncontrolled, it would threaten the sustainability of water resources, especially in the Cimanuk Watershed.

On the other side of the Cimanuk River, Jatigede Reservoir built has a function to control floods in Indramayu, irrigate rice fields by 90,000 ha, supply raw water for drinking utilization by 3,500 L per second and generate 110 MW of electricity [4].

The upstream watershed has an important role in the overall conservation of the watershed area. If the upstream area is carried out water conservation then received a positive impact from another area, the downstream will receive the benefits [5]. Therefore, the upstream part of the Cimanuk watershed is very important for conservation to be carried out in order to reduce sediment concentration and fluctuations in river discharge, so that the preservation of the function of the Jatigede Reservoir can still be optimized. This study aims to analyze the current land cover causing both sedimentation and fluctuation in river discharge and compile the simulations of soil and water conservation measurement to maintain the function of the Jatigede reservoir.

2. Methodology
2.1. Research location

The Research was carried out in the upstream Cimanuk watershed, which is a Jatigede Reservoir. The reservoir covers an area of 1,462 km², spreads over 30 sub-districts in Garut Regency and 7 sub-districts in Sumedang Regency-West Java (figure 1).
2.2. Data collection
The data used in this study are derived from primary and secondary data source. Primary data is the result of either direct observation or measurement in the field, among others, such as soil characteristics and condition of agricultural land in the upstream area. Field observations are also needed to be done particular in dryland farming, which is focused on upstream areas or on steep slopes. This is done to evaluate agricultural techniques that trigger a soil erosion. Imagery interpretation was also carried out to determine the condition of land cover in the Jatigede Reservoir. Beside that, secondary data are needed as well, that consist of climatology and hydrology, soil, land use, and regional spatial plan of Garut Regency and Sumedang Regency.

2.3. Data processing and analysis
Cimanuk River discharge analysis is based on data from a discharge measurement station over a long period of time. This discharge pattern reflects the environmental condition of the watershed. Watershed environmental conditions are still good if the fluctuation of river flow is not too extreme. Soil characteristics are emphasized to reveal soil properties in relation to soil sensitivity to erosion, related to the large content of the river water sediment.

Hydrology modeling is intended to quantify the input, process and output parameters in the Jatigede Reservoir, so that the model can be evaluated for conservation scenarios with sediment yield and direct runoff parameters. The watershed hydrology model used in this analysis is the SWAT (Soil and Water Assessment Tool). This model was developed from an earlier model by Arnold of the United States Department of Agriculture (USDA) in the early 1990s [6], then expanded to predict the impact of agricultural land management on water quality and quantity on a watershed scale [7].

In SWAT, runoff calculation uses the SCS runoff equation [8], which uses parameters of soil characteristics, land use, and rainfall [9]. Whereas, erosion is predicted by using Modified Universal
Soil Loss Equation (MUSLE), a development of Universal Soil Loss Equation (USLE) [10]. This method uses surface runoff as energy for the release and transport of sediments.

In this study the use of SWAT Model calibration and validation for the Jatigede catchment area has been done previously [11], so that this model is directly used to simulate various scenarios of Jatigede catchment area conservation with output sediment yield and direct runoff parameters.

3. Results and Discussion

3.1. Discharge conditions and sediment yield of the Cimanuk River

The ratio between maximum and minimum discharges during the period 1975-2012 shows a steady increase at WadoCimanuk River Station (figure 2). According to the graph, in the period 1975-1980 and 1981-1990, there was a slight raising in the value of the ratio of both maximum and minimum debit, only from 25.05 to 26.95. However, it then raised considerably to 31.80 in the 1991-2000 period. The changes in the value of the ratio of the maximum and minimum discharge are triggered by the conversion of land from either forests or plantations in agricultural areas in the upstream area, which also causes an increase in surface runoff and a decrease in rainwater catchment function. The increase in the value of the ratio in the period 2000-2012 by 33.42 that become a problem in the upstream region is also caused by extreme low flow and the influence of El Nino in 2004, 2006 and 2010.

![Figure 2. Ratio of Q\text{max} and Q\text{min} of Cimanuk River in the period 1975 – 2012.](image)

Analysis of data from the West Java Forest Service [4] demonstrates that soil erosion occurred in the upper Cimanuk watershed is divided into 11 sub-watersheds, the smallest erosion in the Cicajur sub-watershed by 1.48 mm per year, while the largest erosion in the sub-watershed Upstream Cimanuk by 12.12 mm per year (table 1). The large erosion classification shows that only 2 sub-watersheds (Cicajur and Cipedes) are classified as good condition (smaller erosion 2 mm per year) which covers 12.6% of the total Cimanuk watershed and those that are moderate (erosion 2-5 mm/year) 3 sub-watersheds (Ciherang, Cibodas and Citameng) which cover an area of 24.1%. While those classified as poor (erosion greater than 5 mm per year) covers 7 sub-catchment with very broad coverage relatively (63.3%). The upstream erosion of the Cimanuk watershed is also reflected by the sediment content carried by the Cimanuk River downstream [1].
Table 1. Erosion Rate and Classification of Cimanuk Watershed.

| Sub-catchment          | Percentage Area (%) | Erosion Rate (mm per year) | Classification |
|------------------------|---------------------|-----------------------------|----------------|
| Cimanuk Hulu            | 11.0                | 12.12                       | Poor           |
| Cicajur/Cipujeuh       | 4.7                 | 1.48                        | Good           |
| Ciherang/Cisangkan      | 9.1                 | 2.99                        | Moderate       |
| Cibodas                | 6.6                 | 4.36                        | Moderate       |
| Cikamiri/Ciroyom       | 6.9                 | 5.76                        | Poor           |
| Citameng               | 8.4                 | 2.11                        | Moderate       |
| Cibeureum              | 8.0                 | 7.02                        | Poor           |
| Cipedes                | 8.0                 | 1.50                        | Good           |
| Cianten                | 17.4                | 7.48                        | Poor           |
| Cialing                | 10.1                | 9.54                        | Poor           |
| Cikujang               | 10.0                | 5.02                        | Poor           |

3.2. Analysis of landuse and slope

The results of the interpretation of the IKONOS satellite imagery carried out by the 2014 ground check in the land cover of the Jatigede watershed are dominated by rice fields at 33.5%. Following this, forests are recorded by 20.34%, gardens by 19.34%, seasonal plants by 11.56%, settlements by 10.94%, tea gardens by 2.17%, bare land by 0.84%, shrubs by 0.68%, water bodies by 0.32% and non-residential buildings by 0.25%.

Rice fields are the largest land use in the Jatigede watershed, which are mostly on flat slopes to ramps and on alluvial plains around rivers. Rice fields have a very small risk of erosion or even close to zero, yet rice fields need a fairly large amount of water [12]. It is thus necessary to make efforts for the use of water efficiently for rice farming with water-saving technology or cultivation innovations, such as the SRI (System of Rice Intensification) method that could save water demand by 28% [13]. Furthermore, the management of rice fields can result in a thin, relatively impermeable layer of rice field, thereby reducing water infiltration into the soil.

Cultivation of plantation and fields causes the increasing erosion, especially in the beginning of the planting and weeding, while it is planted with annual crops in the fields and generally carried out in the upstream areas with steep slopes. In cultivation area that needs more attention, especially on horticultural, agricultural land, food crops and community forests. Utilization of land for agricultural cultivation is currently causing a huge erosion. The conversion of land from non-agricultural land to agricultural land and deforestation is required to be controlled to reduce the rapid changes in critical land.

Based on the Regional Spatial Plan of Garut Regency in 2011-2031 [14], it states that the Regency Spatial Planning aims to realize conservation districts that are supported by agribusiness, tourism and maritime affairs. This is reflected by the establishment of a Protected Area covering an area of 84.99% of the district area. The establishment of this vast protecting area is in line with the conservation of water resources in the Jatigede Reservoir catchment area. In terms of catchment area, it is known that the majority of the catchment area is in the region of Garut Regency which around 79% and Sumedang Regency 19%, and Tasikmalaya Regency and Bandung Regency [15].

Based on the interpretation of the Topographic Map of the Jatigede Reservoir, the slope that greater than 30% is 49,602 Ha or about 47% of the reservoir area, the slope with 15-30% range is 26,295 Ha (18%), the slope with 5-15% range is 50,918 Ha (20%), and slope with <5% is 16,349 Ha (14%).

Slope is an important factor to be considered in the conservation of water resources, the greater the slope of the land is directly proportional to soil erosion and inversely proportional to the opportunity of water that can be absorbed into the soil surface. Land with a slope above 2% has a significant influence on the infiltration rate [16]. Land with a slope that greater than 35% should be planted with
annual crops which less cultivate. Slope of 15-35% using slides in land management to reduce the steepness and length of the slope, so that erosion will decrease.

3.3. Conservation of Jatigede Reservoir

3.3.1. Identification of soil and water conservation techniques

The Cimanuk watershed conservation is aimed at high erosion land, namely agricultural cultivation of annual crops and plantation. This erosion is also managed to increase the capacity of agricultural land infiltration and groundwater preservation in the future.

Focused on urban area, water resources conservation is intended to compensate the reduction in rainwater infiltration due to construction of the building or settlement by making infiltration wells. This infiltration well is useful to increase groundwater reserves and also reduce the potential for flooding or fluctuation in river discharge.

These soil and water conservation actions are carried out on agricultural land and developed areas, which include:

- Land of seasonal crops: on slopes above 45% is planted annual crops, slope of 20-45% the land covered with mounds with vertical mulch and reinforced with annual plants, slope of 15-20% make a ditch and reinforced with annual crops, slope with smaller than 15% is cultivation with grass strips.
- Plantation area: ditch and grass strips.
- Building area: infiltration wells.

The selection of soil and water conservation measurement takes into account the effectiveness, economy and ease of being accepted by either the community or farmer. The people of West Java are already accustomed to make terraces so that this method was chosen for conservation farming techniques with some modifications to get the optimum results. The terrace functions to reduce the length and steepness of the slope and hold water, thereby reducing the speed and amount of surface runoff, as well as increasing the absorption of water by the soil [17]. And, combining the addition of vertical mulch can reduce runoff and make erosion become quite large. Ditch is built in dimension of 0.5 m x 0.5 m x 4 m with a density of 200 pieces per hectare will reduce runoff to close to 100%, if rainfall is 20 mm.

3.3.2. Application of the SWAT model for the simulation of Jatigede Reservoir catchment conservation

To give an idea of how much influence or effectiveness of the efforts are made to conserve the Jatigede Reservoir watershed, some actions, including the simulation of several scenarios for conservation are needed. The basis of conservation scenario refers to current land use and when compared to the following conditions: 1) greater environmental degradation of watersheds, 2) conservation actions are carried out on current land use, and 3) conservation is carried out based on the Regional Spatial Planning 2011-2030.

The increasing environmental degradation of the Cimanuk watershed is intended to illustrate if the construction of settlement or built area is not well controlled and shifts of agricultural land towards the forest. The main factor is population growth, which requires houses or land to be built and also employment. It is assumed that the development of the built area of the city is 200 meters in all directions, so that the building area has highly increased. In addition, there was also a shift in the allocation of agricultural land, plantation, and annual crops to develop towards the forest as far as 200 meters.

By this time, the annual crops and plantation is a vast land reaching around 37.5% of the Jatigede catchment area, though both types of land use cause high soil erosion. If the land is carried out conservation, it will contribute greatly to the preservation of the function of the Jatigede Reservoir. In addition, construction of infiltration wells in the built area will reduce the percentage of rainwater that becomes surface runoff.

Regional Spatial Planning of Garut Regency and Sumedang Regency are binding on all land use sectors. Therefore, the pattern of land use planning can be used as a basis for conservation actions.
This spatial pattern divides space in Protected Areas and Cultured Areas. If in the Cultivation Area, especially in the planned agricultural land, soil and water conservation measurement will be taken, and the developed land will also be carried out by infiltration well construction.

Based on that conservation scenario, a SWAT model is simulated by using the same rainfall input and producing a model output in the form of direct runoff and sediment yield at the outlet of Jatigede Reservoir catchment area (table 2).

| Table 2. Simulation Results of Conservation in the Jatigede Reservoir. |
|---------------------------------|-----------------|--------------|--------------|--------------|
| **Output Parameters**           | **Landuse and Conservation** |
|                                 | Existing | Scenario 1 | Scenario 2  | Scenario 3  |
| **Sediment yield** (million ton per year) | 9.05    | 15.50      | 5.96        | 4.97        |
| **Direct runoff** (mm)          | 99.7    | 262.5      | 75.8        | 97.6        |

Based on tabel 2, it indicates that if the current conditions are allowed to cause environmental degradation in the Cimanuk watershed, the sediment yield increases from 9.05 million tons per year to 15.50 million tons per year and runoff also increases from 99.7 to 262.5 mm. This means the sedimentation rate in the Jatigede Reservoir would increase about twice, so that this condition can threaten the age of the reservoir and reduce the fertility of agricultural land in the upstream area particularly.

If the current land use, especially on annual crops and plantation, is carried out with conservation measures on the ridge terrace using vertical mulch (plant residues), ditch, and alley plants with grass, and agroforestry, then the sediment yield will decrease by around 30% or become 5.96 million tons per ha per year and runoff also fell to 75.8 mm.

The soil and water conservation actions will be more effective provided that carried out by referring to the Regional Spatial Planning of Garut Regency and Sumedang Regency, especially in the Dryland Agricultural Cultivation Area in controlling the sedimentation that will enter the Jatigede Reservoir, which is marked by a decrease in sediment yield when this is close to half, from 9.05 million tons per year to 4.97 million tons per year.

4. Conclusions

The environmental degradation of the Jatigede Reservoir has been already in critical level, which is characterized by high erosion and tend to increase the Cimanuk River maximum-minimum discharge ratio, threaten a condition to decrease the function of the Jatigede Reservoir as a flood control, irrigation, raw water source and power plant. Cultivation of annual crops in the upper Cimanuk watershed, which reaches an area of 11.6%, mostly does not implement appropriately conservation measurement, cause large erosion and surface runoff. In addition, the type of plantation (19.3%) has a significant role in increasing the sedimentation, so that soil and water conservation measures that have a large effect in reducing sedimentation of the Jatigede Reservoir are carried out on both types of land use.

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