Application of the Soil and Water Assessment Tool (SWAT) to predict the impact of best management practices in Jatigede Catchment Area

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Abstract. Cimanuk watershed is one of the national priority watersheds for rehabilitation considering its critical condition. In this area, Jatigede Reservoir operates, which is the second largest reservoir in Indonesia, after Jatiluhur Reservoir. The reservoir performs several functions, including flood control, irrigation for 90.000 ha of rice fields, water supply of 3.500 litres per second, and power generation of 110 MW. In 2004 the Jatigede Reservoir catchment area had a critical land area of 40.875 ha (28% of the catchment area). The sedimentation rate in Cimanuk River at Eretan station shows a high rate (5.32 mm/year), which potentially decreases the function of Jatigede Reservoir. Therefore, a strategy of Best Management Practice's (BMP's) is required to mitigate the problem by using SWAT hydrology modelling. The aim of this study is to examine the impact of BMP's on surface runoff and sediment yield in Jatigede Reservoir Catchment Area. Simulations were conducted using land use in 2011. The results of this study suggest that SWAT model is considered as a reasonable modelling of BMP's simulation concerning Nash-Sutcliffe Coefficients (0.71). The simulation is using terraces, silt pit, and dam trenches as BMP's techniques. The BMP's application can reduce surface runoff from 99.7 mm to 75.8 mm, and decrease sediment yield from 61.9 ton/ha/year to 40.8 ton/ha/year.

1. Introduction

The condition of critical watersheds in Indonesia tends to increase. In 1984 there are 22 critical watersheds, which increased to 39 watersheds 1992, and in 2005 it increased again to 62 watersheds, and up to108 watersheds in 2009 [1]. This increasing number of critical watersheds indicates that watershed management has not been optimal and needs to be improved in terms both of geographic coverage and of strengthening the concept/substance of integrative management. The impact of this critical watershed increase results in increased sedimentation in reservoirs as a result of accelerated soil erosion and changes in river flow patterns. In the wet season the river flow is greater, but when the dry season the discharge decreases.

Cimanuk watershed located in West Java is one of the national priority watersheds for rehabilitation due to its critical condition. The upstream watershed areas have problems, namely: high soil erosion rates and increasingly extreme river fluctuation. These problems are exacerbated again due to the impact of increased extreme climatic events. In the Brantas watersheds there is an increase in rainfall, and river discharge is very extreme. However, the Cimanuk watershed is in contrast to rainfall and river discharge is very large [2]. If this condition if left, it can threaten the preservation of water resources, both in the form of surface water in Cimanuk River or groundwater.

Cimanuk River, one of the major rivers in West Java Province, has an average annual rainfall of 2,800 mm with a potential water of about 7.43 billion m3/year and crosses four districts, namely Garut,

Sumedang, Majalengka and Indramayu. Jatigede Reservoir has been built at a cost of US $ 239.573 million. Construction of this reservoir aims to control floods in Indramayu area, to irrigate rice fields of 90,000 ha, to supply raw water for drinking water at about 3,500 liters per second and to generate 110 megawatt of electricity [3].

The Jatigede Reservoir Catchment Area (CA) in 2004 has a critical land area of 40,875 ha (28% of CA). Critical land is scattered in Garut District of 30,459 ha and Sumedang District of 10,416 ha. The result of measurement of sedimentation rate of Cimanuk River at Eretan Station is in average 5.32 mm/year in 1985 - 2007 [4] and sedimentation rate is high. In addition, the data from 1975 - 2009 shows an increase in the ratio of maximum-minimum discharge on Cimanuk River. Increasing sedimentation and max-min ratio in the long run can threaten reservoir sustainability as the reservoir age will be less than planned (50 years).

Based on these problems, there is an urgency of having an analysis of the critical factors causing and the strategy to overcome these issues. The lack of soil and water conservation efforts and the conversion of forest land into agricultural land or agricultural land transformed into settlements degrade the capacity of infiltration and increase erosion and sedimentation. Upper river basin management that is well integrated to tackle the damage is very important; it is necessary to study the effect of changes in land cover to flow discharge and sediment loading. This study aims to examine the impact of BMP's on surface runoff and sediment yield in Jatigede Reservoir CA.

2. Data and Methods

2.1. Study area

The Cimanuk Watershed is located in the northern part of West Java, between 6° and 8° South Latitude, and 107° 30' and 108° 30' East Longitude. The river starts at an elevation of approximately 2500 m at Mount Papandayan and flows north into the Java Sea near the town of Indramayu. The upstream area of the river from Garut to downstream until Wado is occupied by a relatively high Quaternary mountain plateau with several peaks rising to 2000 m. In this area, the river flows in a steep valley that intersects the plateau.
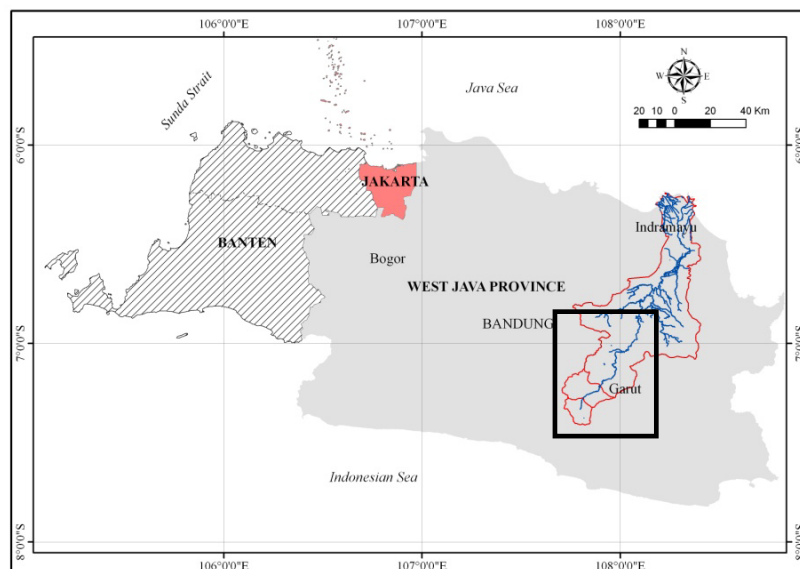

Figure 1. Study area.

Jatigede Reservoir CA has an area of 1,462 km^2, which is mostly situated in Garut and Sumedang regencies, covering 37 districts. While the area of Sumedang Regency which belongs to Jatigede Reservoir CA covers 7 districs. Figure 1 shows the location of Jatigede CA in the Cimanuk Watershed.

2.2. Model description

In recent years, the SWAT Hydrology Model has been widely used in watershed management as a hydrological model [5,6]. The SWAT model is currently regarded as a versatile model that can be used to integrate environmental processes that support more effective watershed management [7]; however, in tropical watersheds, especially in Indonesia, this model has not been widely used.

Analysing of SWAT using ArcSWAT tools applicatication in ArcGIS 10.1 in the process of preparing input data and running the SWAT model requires a series of stages. The first step is to delineate watershed and Sub-watershed using Digital Elevation Model (DEM) data. After that we define the Hydrology Response Unit's (HRU's) and input the weather file, then the model can be executed and continued at the calibration and validation stage of the model. Figure 2 depicts the schematic framework of the SWAT model.
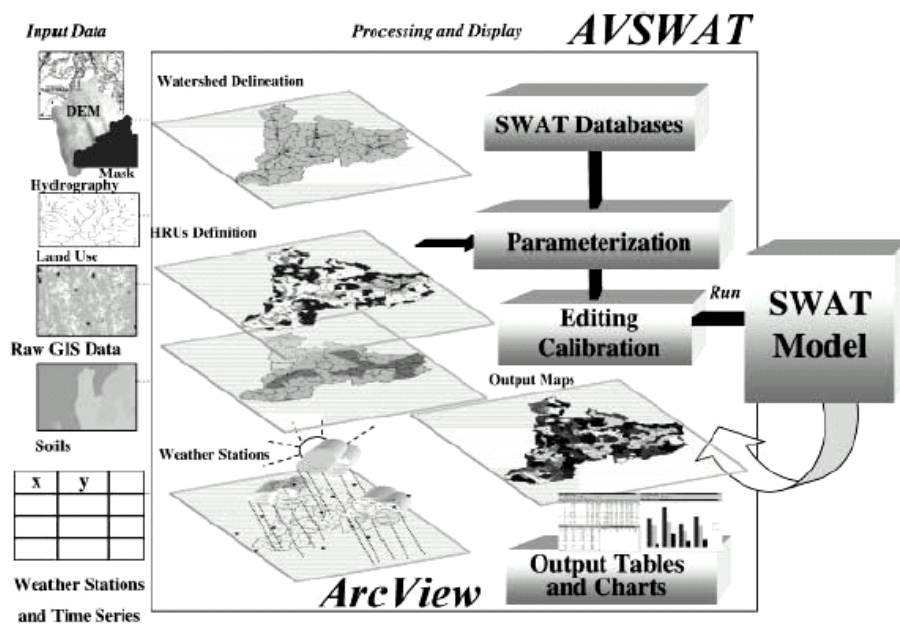

Figure 2. Schematic SWAT Hydrology Model.

SWAT was developed and updated from previous models by Arnold of the United States Department of Agriculture (USDA) in the early 1990s [8], then expanded to predict the impact of land management practices on water, sediment, agricultural and chemical yields on a watershed scale with various spatial and temporal aspects. The calculation of the hydrological cycle is based on the water balance equation as follows [9]:

$$SW_i = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{Surf} - E_a - W_{Seep} - Q_{gw})$$

i.e. SW_t is the final groundwater content, SW_0 represents the initial groundwater content on day i, t is time (day), R_{day} is the amount of rainfall on day i, Q_{surf} is the amount of surface flow on day i, Ea describes the amount of evapotranspiration on day i, W_{seep} represents the amount of water entering the unsaturated zone of the soil profile on day i, and Q_{gw} is the total flow of groundwater on day i. SCS Curve Number Procedure is used to get the runoff. The Soil Conservation Service run-off equation is an empirical model that began to be used in general in the 1950s. The model was developed to provide a consistent basis for estimating runoff on various land uses and soil types.

Automatic and manual calibration does the calibration process. The automatic calibration was using SWAT-CUP software (Soil and Water Assessment Tool-Calibration and Uncertainty Programs) with SUFI-2 (Sequential Uncertainty Fitting version 2) approach. Model calibration was done by comparing daily discharge at Wado river gauge with daily discharge of simulation result from 2005-2007, while validation used daily discharge data of year 2006. Nash-Sutcliffe's efficiency coefficient (NSE) [10] and correlation coefficients (R^2) conducted as a method for evaluating and analyzing daily data simulations between predicted and observed values.

2.3. Best management practice's simulation
The conservation of mechanical soil is all mechanical, physical treatment given to the soil, and the manufacture of buildings is aimed at reducing surface flow and erosion as well as improving soil ability classes. This soil conservation technique is also known as civil technical method. Best management practice in agricultural areas is the treatment of the land using terrace sharing and planting contour parallel. According to [11], the utilization of natural resources in a watershed, that does not pay attention to the ability and environmental sustainability, will result in damage to ecosystems and water use. Therefore, in planning watershed management, appropriate technology should be made based on ground and water conservation principles.

Conservation activities undertaken in Jatigede CA are divided in several actions based on the slope class. On the slope > 45%, the action is reforested on non-forest lands; this activity will change the model parameter values on CN and USLE_C. Ot the slope of 30% - 45%, the application of terracing and planting of contours on the use of agricultural land is applied. The terracing technique used is a bench porch that can be used on slope up to 30% or higher [12]. The application of this technique to the model will change the CN, USLE_P (soil processing factor) and the slope length and (SLSUBBSN) factor. While on the application of parallel contour, planting also follows the parallel processing of the contour with the aim of forming a surface flow inhibitor that increases water absorption and reduces sediment transport. The application of this technique will change the CN and USLE_P values in the model parameters [13]. On the slope of 15% - 30%, the technique of conservation silt pit and planting contour parallel has been applied. Silt pit is designed to capture eroded soil and soil flows. Based on a research conducted by [14] in Carita, Banten shows that silt pit conservation techniques can reduce runoff by 25% and erosion by up to 15%. The shape of silt pit is a pit with a depth of 0.6 m, a width of 0.5 m and a length between 1 - 5 m. On a slope of 15% -30%, the distance between silt pit is 3-5 m. The application of the silt pit technique to the model will reduce the CN value to 75%.

The planting of the grass is applied to the slope of <15% where in the model will change VFSCON (total runoff fraction), VFSRATIO (ratio between land area and plant path) and VFSCH (river flow fraction). The trench drain is applied to a river channel with a slope of <15%, this technique is used to inhibit the flow velocity and sediment deposited. The selected implementation technique on SWAT model can be done by adding parameter pond on sub-catchment of AWD result designed by slope.

BMP's methods are not widely applied to agricultural areas in Jatigede CA. This not only leads to high surface runoff but also raises the potential for erosion that carries nutrients necessary for crops. Therefore, one of the efforts to increase the age of Jatigede reservoir is by applying the BMP's of sharing terrace and planting contour parallel to all agricultural areas of dry land in Jatigede CA. Besides, the model simulation adds check dam development to ten sub-catchments at Jatigede CA.

3. Result and discussion
3.1. Setup model
SWAT Hydrology model had to setup base on land use in 2011. Calibration process was done by automatic and manual calibration in 2005 to 2007 and validated in 2006. Calibration and validation were done and resulted. The calibration of the above parameters leads to an improvement in the correlation coefficients (R^2) to be 0.7, i.e. $Q_{Obs} = 1.5312.Q_{Sim} + 0.2685$. And the result of model validation done in year 2006 was R^2 value equal to 0.6 i.e. $Q_{obs} = 1.244x + 5.193$ [15].

3.2. Best Management Practice's simulation result

The largest current land use in Jatigede reservoir CA is for rice fields (28.7%), followed by forest (20%), plantation (19.7%), agriculture (17.8%), settlement (10.9%) and bush (2.9%). The main sources of land erosion are dry agriculture and plantation; these two land uses are very wide - reaching 37.5% of the catchment area of Jatigede Reservoir. Therefore, conservation measures in these areas should be immediately undertaken to preserve the function of Jatigede Reservoir. In addition, the built area is also large enough to build a recharge well that will reduce the percentage of rain water into surface runoff. Soil and water conservation measures based on current land use, particularly of seasonal crops, gardens and urban-built areas are spatially classified as presented in Figure 3.
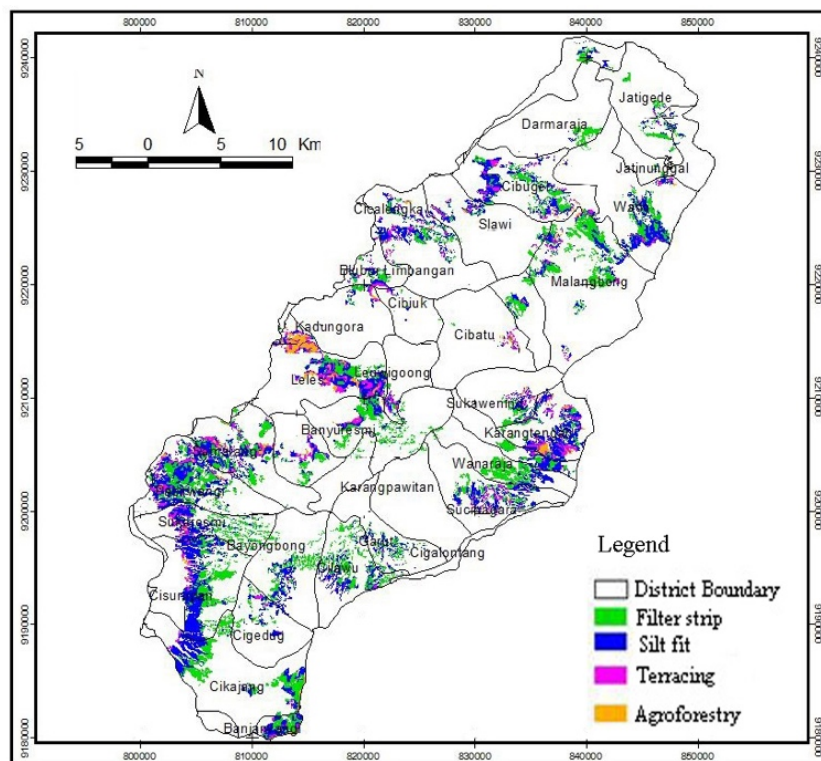

Figure 3. Best management practice based on existing landuse.

SWAT model was simulated based on the above conservation scenarios, using an average rainfall input of several years and producing a model output in the form of river water discharge and sediment yield at the Jatigede CA Reservoir outlet. The simulation results are summarized in Table 1.

Table 1. BMP's simulation result.

Parameter output	SWAT Simulation	
	Existing land use	Existing land use + BMP's)
Sediment yield (ton/Ha/year)	61,9	40,8
Run off (mm)	99,7	75,8

Table 3 shows that if current conditions applying conservation techniques will result in improved Jatigede CA environment, sediment yield decreases from 61.9 to 40.8 tons/ha/year and runoff also decreases from 99.7 to 75.8 mm. Improvement of hydrological characteristics has been done in many watersheds in Indonesia. The application of a combination of techniques such as silt pit combined with mulch can reduce erosion by 94% [16], while [17, 18] calculated that the application of 200 silt pit/ha with the volume of 1 m3 can inhibit the surface flow of 200 m^3/ha.

4. Conclusions

The impact of BMP's on existing land use in Jatigede CA with terraces, vertical mulch, silt pit and filter strip, and agroforestry can reduce the sediment yield by about 30% or into 40.8 tons/ha/year and runoff also decreased to 75.8 mm from 99.7 mm.

Acknowledgments

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