Simulation of Surface Water Retention using HEC-GeoHMS Model (Case Study: Upper Ciliwung Watershed, West Java)

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Abstract: ***Surface water retention is the ability of the soil in retaining the water (water storage). One of the ways that use to be as surface water retention is waterworks through the reservoir. The reservoir is expected to accommodate water and increase infiltration. The optimizing of the reservoir is a part of runoff management, which in the process, the rainwater is retained as long as possible in somewhere before entering the sewer so that the amount of the flow can be lowered in order to reduce the flood in a drainage area or a basin river. Flooding can occur due to the inability of a watershed in retaining and absorbing the water that falls to the surface of the earth, which in turn, the overload of water turns to be runoff and then flowing through the river to a downstream or a sea. One of the watersheds that undergo the environmental damage is the Upper Ciliwung watershed. The analytical approach in the study of the hydrological watershed system is a theoretical basis for integrating the components information of a watershed system into a hydrological model. One of hydrological models application is HEC-GeoHMS Model (Hydrologic Engineering Centre-Geospatial Hydrologic Modeling) which is effective in reducing the runoff. The model proved the effectiveness from the data calibration which was seen by the value of R^2 from 0.73-0.87 and value of NSE from 0.52-0.85. Meanwhile, validation data value showed by the R^2 from 0.69-0.97 and value of NSE from 0.80-0.88. Simulations with the implementation of Ciawi and Sukamahi Reservoirs reduced runoff by 70% from the actual condition.***

Keywords: Flooding, HEC-GeoHMS Model, runoff, soil and water conservation

1. Introduction

Watershed conditions in Indonesia are very apprehensive with the increasing frequency of flooding [1]. The problem of flooding occurs due to the inability of a watershed (catchment) to hold and absorb water that falls to the soil surface, where the excess water then becomes runoff and flows through the river downstream or sea. One of the watersheds in West Java Province that suffered damage was Upper Ciliwung Watershed. [2]. Another problem is that the land use changes can have negative effects on the watershed hydrological conditions such as the peak discharge, the inter-seasonal fluctuation, and the increasing of the runoff volume. Increasing of the runoff volume is due to the reduction of infiltration capacity, potentially resulting in flooding during the rainy season and the dry season [3]. These problems can be analyzed by using a hydrological model which is a simple description of an actual hydrological system [4], as well as a computer model that can be used for rapid and precise assessment of component changes that affect the hydrological response of the watershed [5]. One application of the hydrological model is the HEC-GeoHMS (Hydrology Engineering Center-Geospatial Hydrology Modeling System) model that can simulate runoff as rain response, and analyze the reservoir capacity. The HEC-HMS model is effective in simulating the surface runoff around the watershed [6], [7], [8].

This study aimed to analyze the hydrological characteristics of Upper Ciliwung watershed using HEC-GeoHMS Model and simulate the surface water retention and hydrological response of Upper Ciliwung Watershed.

2. Research Method

2.1 Title and authors

The study was conducted from September 2015 to December 2016 in the Upper Ciliwung Watershed with the River Flow Observation Station (SPAS) in Katulampa which located in West Java Province. It astronomically located between $6^0 37'$-$6^0 46$ 'SL and $106^0 49'$-$107^0 00'$EL with 15 097 hectares of area. Also, it administratively located in the area of Bogor Regency West Java Province. Laboratory analysis was conducted at Soil and Water Conservation Laboratory, DITSL (Department of Soil Science and Land Resources) Faculty of Agriculture, IPB.

2.2 Research Tools and Materials

The equipment used in this research were (1) ground sampling equipment (Ring sampler, field knife, plastic, label paper, meter), stationery, digital camera, Global Positioning System (GPS), field observation manual; (2) a set of PC computers with ArcGIS 10.1 software, HEC-GeoHMS 10.1;

HEC-HMS 4.0; ERDAS Imagine, Microsoft Office 2007; and other equipment required for the laboratory analysis.

Materials used in this study were Digital Elevation Model (DEM), river network and hydrological maps, Land units map of 1992 from Soil and Agroclimate Research Center (Puslittanak), Citra SPOT 6 (land use analysis of 2013), LANDSAT 7 (Land use analysis of 2014) from the National Aeronautics and Space Agency (LAPAN), hourly rainfall data (2013-2014), and discharge data (2013-2014).

2.3 Research Stages

This research was conducted in two stages: the first step was to analyze the hydrological characteristics of Upper Ciliwung Watershed that is topographic data processing (DEM data) constructed from the interpolation of contour lines 12.5 m sourced from the Earth Raw Map 1: 25: 000 scale. The next process was the DAS delineation process performed automatically by the HEC-GeoHMS Model through the project generate process, by adding the point of the watershed outlet (watershed observation point). The result of the delineation of the watershed was the formation of the outer border of the Upper Ciliwung Watershed wherein the model was defined as Subbasin and the formation of river network in which the model was defined as River.

Subbasin formation in the HEC-GeoHMS model is obtained from the Stream Definition process, which provides a threshold limit of flow accumulation. The size of the threshold used will determine the main river network and the other rivers. The established river network will determine the number of sub-watersheds formed within the watershed [9]. The number of sub-watersheds can affect the model output [10]. In this research scale, the threshold used was 25 km^2 / 2500 ha. Based on the delineation process of Upper Ciliwung watershed is presented in Figure 1. This process formed the main river network and 3 Sub basins which were W40, W50, and W60. After that, it processes the characteristics of Sub-basin and the river network, and then processes the components of the HEC-GeoHMS Model.

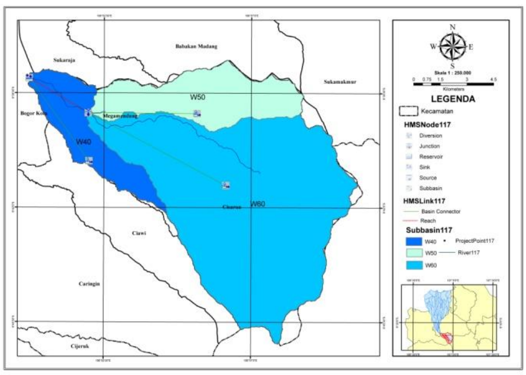

Figure 1: Results of delineation model HEC-GeoHMS

The second stage was to simulate surface water retention and hydrological response of the Upper Ciliwung Watershed using HEC-GeoHMS Model. Simulation is the process required to operate model or model handling to imitate the actual behavior of the system, whereby the smaller the size of the surface water retention the smaller the flow rate reduction contribution. Model simulation was done based on an effective simulation, that is:

Simulation 1: The Implementation of Ciawi Reservoir and Sukamahi Reservoir Development. This simulation was planned to control flood in the Upper Ciliwung Watershed. Reduction of the flood by utilizing a container above a spill like a reservoir is generally not possible because the resulting flood reduction will be very small, so that operation conducted by applying the concept of a single purpose dry reservoir. The single purpose dry dam is a function of the usage that is as flood controller [11]. The concept of a dry dam is when the dam is full, it will directly be drained/flowed. On the other hand, the concept used in the dry dam is (1) during the wet conditions, it will use a spillways technique, the required parameters such as initial elevation, elevation, length, and coefficient, (2) while during the dry conditions, it will use spillways and outlet techniques, required parameters such as initial elevation, elevation, length, coefficient, center elevation, area, coefficient, tunnel diameter. The most important parameters are the information of dam elevation and the total volume of reservoir capacity**.**

Simulation 2: Spatial pattern of regional geospatial planning (RTRW) of Bogor District and Bogor Regency. Simulation 2 is based on the authority given by the government regulation (UU No. 26 year 2007) about the urban use plan of Bogor Regency Year 2005-2025. The regional regulation shall be regulated in all aspects and all needs related to those are in line with the urban planning policy which are also expected to realize the integration among the sustainable environmental elements [12].

Simulation 3: RTk-RHL of Upper Ciliwung Watershed. This simulation is implemented based on the application of soil and water conservation according to the field plan for BPDAS-HL. In the implementation of Forest and Land Rehabilitation (RHL) is an initial step that must be passed in accordance with the mandate of Government Regulation No.76 Year 2008 on Forest Rehabilitation and Reclamation, the plan consists of Forest Rehabilitation and River Rehabilitation Plans (RTk-RHL DAS). Based on the RHL planning hierarchy, the RTk-RHL DAS document as the basis for preparing the RHL activity directives for the preparation of Rehabilitation Management Plans within the Forest (RPRH) and Land (RPRL) areas. Determination of RTk-RHL DAS plan divided into two methods namely vegetation method and technical civil method [13].

2.4 Analysis Method

Prior to do the simulations above, the model was analyzed using two data levels, that is in the form of calibration and the validation. The calibration process was required to determine the value of each watershed parameter and as a basis of simulating the rain-flow. In order to a good calibration result, the hydrograph graph of model result must be the same or similar to the measurable hydrograph graph with the objective function value that should be small [7]. Calibration was performed using the discharge data per hour in the period time of 2013. The statistical method used was the Nash-Sutcliffe (NSE) coefficient, equation (1) and the coefficient of determination (R^2) equation (2), with the equations as follows:

$$NSE=1-\frac{\sum_{i=1}^{n}(Y_i^{obs}-Y_i^{sim})^2}{\sum_{i=1}^{n}(Y_i^{obs}-Y^{mean})^2} \quad (1)$$

$$R^2=\frac{(O-\bar{O}^2)-(O-P)^2}{(O-\bar{O}^2)} \quad (2)$$

NSE is the *Nash-Sutcliffe* coefficient. Y_i^{obs} is the data of the observation / measurement of *i*. Y_i^{sim} is the simulation data of *i*. Y^{mean} is the average observation / measurement data and *n* is the number of observations. O is the observed data, while Ō is the average discharge of observation data, and P is the simulated discharge data. This NSE statistical model was used to show the performance of a model as it can provide more accurate information about the given value, and statistical methods that can indicate how close the measurement discharge to the model discharge. The NSE range is between -∞ and 1.0. Where the value of NSE of 1.0 indicates the optimal value. The model capability in describing the watershed characteristics was evaluated using the discharge data and accepted if the value of NSE > 0.5 [8].

Validation model is a process in testing the consistency of the results of a process according to the determined specifications. Validation was done by running the model using predetermined parameters during the calibration process, and comparing the predictive data with the observation data which were not used in the calibration process. Statistical methods which used in the validation performance were the coefficient of determination model (R^2) and NSE model with the same criteria as in calibration process. The data period of the validation was the discharge data per hour in the period time of 2014.

3. Result

3.1 Calibration and Validation of HEC-GeoHMS Model

The calibration method used in the HEC-HMS Model of this study was the objective functions method. The value of the calibration parameter used the *peak weighted* Root Mean Square Errors (RMSE) criterion aimed to present the mean of deviation squares (difference) between the model output value of the measurement or the target values. The RMSE value is required to close to 0 (zero). The calibration results are presented in Table 1.

Table 1: Hasil calibration (Year 2013) using HEC-GeoHMS Model

Calibration (Year 2013)			
Year	NSE	R^2	RMS Error (m^3 sec $^{-1}$)
16 January	0.83	0.87	7.5
17-18 January	0.78	0.85	7.9
12-13 February	0.56	0.73	3.0
19-20 May	0.52	0.83	9.8
2-3 August	0.85	0.85	13.8

Validation is an evaluation process of a model in order to get an idea of the degree of uncertainty of the model in predicting the hydrological process [7]. Validation step aimed to prove that a method can provide consistency results according to the determined specifications. Validation results used the HEC-GeoHMS Model are presented in Table 2.

Table 2: Hasil validation (Year 2014) using HEC-GeoHMS Model

Validation (Year 2014)			
Year	NSE	R^2	RMS Error (m^3 det $^{-1}$)
16 January	0.87	0.97	9.7
22 February	0.88	0.95	9.0
5-6 April	0.80	0.78	5.5
6-7 April	0.80	0.69	10.2
26-27 December	0.83	0.84	9.0

The output calibration of HEC-GeoHMS Model showed by R^2 and NSE values that are 0.73-0.87 and 0.52-0.85, respectively. It indicated that the HEC-GeoHMS model is excellent for simulating the runoff in the Upper Ciliwung Watershed. The NSE value is the accuracy of the model, where the NSE value <0.5 indicates a low accuracy; 0.5 <NSE <0.7 indicates a high accuracy and NSE> 0.7 indicates a very high accuracy [8]. If the model has a very high accuracy, it can be used to evaluate the changes of hydrological response due to modification of the land use. Model output validation showed that the most dominant R^2 and NSE values are 0.69-0.97 and 0.80-0.88, respectively. It indicated that the evaluation stage of the model to assess the accuracy and consistency level of the model in conducting a simulation of hydrological process predictions are a very good category.

3.2 Characteristics of Hydrology Using HEC-GeoHMS Model

The hydrograph is a graphical representation of one of the flow elements and the time. The hydrograph shows a watershed response to a particular input. This model aimed to analyze hydrological characteristics based on the hydrograph of the Upper Ciliwung Watershed river basin using HEC-GeoHMS Model. The model output parameters are shown by the results of the hydrograph ratio of the runoff between the hydrographs results of the model and the hydrographs result of the measurement in 2013 and 2014, which are presented in Table 3.

Table 3: Surface hydrograph comparison results between model results and measurement results in 2013 and 2014

Year 2013 (Date)	Model		Observed	
	Qp (m^3 det $^{-1}$)	Volume (10^3 m^3)	Qp (m^3 det $^{-1}$)	Volume (10^3 m^3)
16 January	96.2	**2 825.2**	103.7	**2 616.6**
17-18 January	81.8	1 881.5	76.8	1 860.4
12-13 February	25.8	879.4	24.0	838.7
19-20 May	63.1	2 249.3	68.5	1 716.2
2-3 August	**123.2**	1 833.1	**146.2**	1 475.0
Year 2014 (Date)	Model		Observed	
	Qp (m^3 det $^{-1}$)	Volume (10^3 m^3)	Qp (m^3 det $^{-1}$)	Volume (10^3 m^3)
16 January	120.9	2 712.6	144.4	2 580.5
22 February	88.4	2 710.0	108.2	2 411.6
5-6 April	35.7	951.6	52.5	1035.3
6-7 April	75.4	1 537.9	81.8	1 335.9
26-27 December	81.2	2 714.7	85.6	2 530.7

This HEC-GeoHMS model application prepared the data of watershed characteristic according to the HEC-HMS hydrological model required by the peak discharge, the rainfall volume, the lost volume, the excess volume, the peak discharge time, the DRO volume, the baseflow volume, and the discharge volume. The best correlation between rainfall and discharge was on 2-3 August 2013 (actual condition) which is presented in Table 4 and Figure 2.

Table 4: Hydrological characteristics based on HEC-GeoHMS Model analysis results from 17-18 January 2013

Subbasin	2-3 Agustus 2013			
	Peak Discharge (m^3/s)	Precipitation Volume (10^3m^3)	Loss Volume (10^3m^3)	Excess Volume (10^3m^3)
W60	**69.8**	**6 959.7**	**6 327.7**	**632.0**
W50	31.1	1 756.1	1 458.8	297.3
W40	24.5	1 188.1	867.4	320.7
Subbasin	2-3 Agustus 2013			
	Time of Peak Discharge	Direct Runoff Volume (10^3m^3)	Baseflow Volume (10^3m^3)	Discharge Volume (10^3m^3)
W60	21:50	**631.9**	**352.5**	**984.4**
W50	22:20	296.4	138.1	434.5
W40	23:20	302.0	178.7	480.7

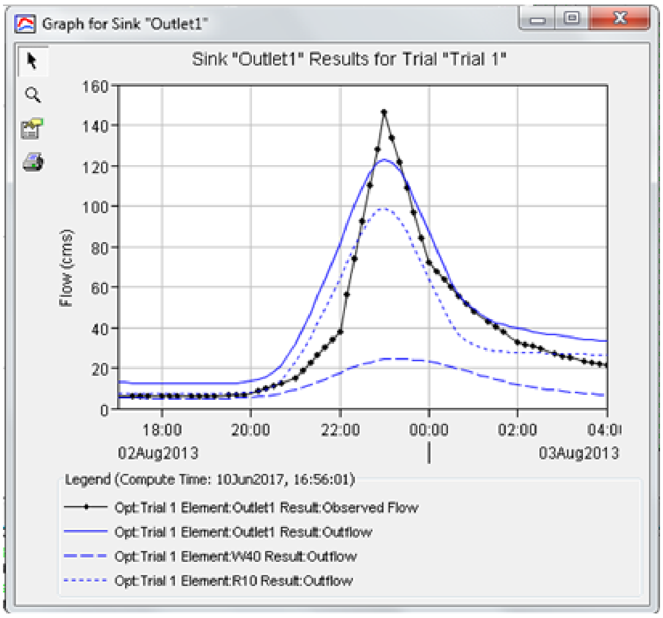

Figure 2: Hydrograph Results from 2-3 Agustus 2013

The results of the model analysis showed that the peak discharge, the rain volume, the lost volume, the excess volume, the DRO volume and the predominant discharge volume in sub-basin (W60). It showed that the upper watersheds had the largest runoff.

The drastic changes from the surface that was originally covered by the vegetation into a hard-coated surface would increase the runoff. The coefficient of the runoff of a watershed was influenced by the natural factors such as relief, the soil infiltration, the soil moisture, the rain distribution patterns, the system of a watershed, the occurence of absorption and condition of land cover in the watershed [14].

3.3 Surface Water Retention Simulations

One model simulation was conducted to determine the effect of surface water retention on hydrological response of Upper Ciliwung watershed, as follows:

Simulation 1: Implementation of Ciawi Reservoir and Sukamahi Reservoir. This simulation applied the concept of dry dam, which at the beginning of the wet season, the water level of the reservoir was in the low elevation, so that at the beginning of the flood, the flood discharge flowed freely through the tunnel. The changes that occurred under the actual conditions with simulation results from Simulation 1 (Ciawi reservoir and Sukamahi Reservoir) during the wet conditions, they used spillways technique and used spillways during dry conditions and the tunnel techniques which indicated the decreasion of the peak discharge from 125.2 (m3s-1) to 27.4 (m3s-1) and the decrease of runoff from 1758.3 (103m3) to 527 (103m3), so that the changes occured was 231.3 (m3s-1) or -70. The simulated results with the presence of the watershed based on the design simulation prepared in respond to the runoff discharge and in the situ is only effective in reducing the local flood discharge for the Subbasin area [7].

Simulation 2: Land pattern of Urban planning of Bogor regency and Bogor district. This simulation based on regional development is an effort to encourage fundamental development of the region in order to improve the quality of communities life and sustainable environment of communities [12]. Changes occurring under actual conditions with simulation results from Simulation 2 (land Pattern) show that peak discharge decreases from 125.2 (m^3s^{-1}) to 75.3 (m^3s^{-1}) to and decreases the runoff volume from 1 758.3 (m^3s^{-1}) to 1 741.7 (10^3m^3) resulting in a change of -16.6 (m^3s^{-1}) or (-0.9%). Simulation 2 is dominated by protected forest 4 918.75 ha or (32.567%) which is a forest categorized as heavy forest class. Based on Government regulation No. 41 year 1999 the definition of protected forests is forest areas that have a basic function as protection of life support system to regulate water system, prevent flood, control erosion, prevent sea water intrusion and maintain soil fertility [12].

Simulation 3: Application of Soil and Water Conservation according to the Field Plan for BPDAS-HL. This scenario was based on the determination of RTk-RHL DAS plan that were vegetative method and technical civil method. RHL directives were done by combining the model information of the field survey results of the identification results performed both theoretically as mentioned in the PP/76-2008 and regulation of the ministry of forestry P.09/Menhut-II/2013, Directorate General regulation for Management of Watershed and Social Forest Number P1/V-SET/2013 on the technical guidance of the forest and land rehabilitation activities [13].

The changes occurred under the actual conditions with the simulation results of this scenario showed the peak discharge decreation for the vegetative method from 125.2 (m^3s^{-1}) to 35.4 (m^3s^{-1}) and the changes occurred was by -899 (m^3s^{-1}) or -51.1% . Meanwhile, by using the technical civil method the results decreased from 125.2 (m^3s^{-1}) to 43 (m^3s^{-1}) and the changes that occured was by -752.4 (m^3s^{-1}) or -42.8%. It indicated that the utilization of natural resources in the form of forest, land and water have to be planned and managed properly through the watershed management system. The main efforts in the watershed management are the regulation of the land use and the forest rehabilitation efforts and soil conservation. The rehabilitation of forests and critical land are intended to restore the soil fertility, protect the water system, and environmental sustainability [12].

3.4 Best Surface Water Retention Simulations

The results of the surface water retention simulation is presented in figure 3. The best simulation of surface retention was obtained by the applied simulation that has been analyzed, and then compared to the actual conditions (2-3 August 2013).

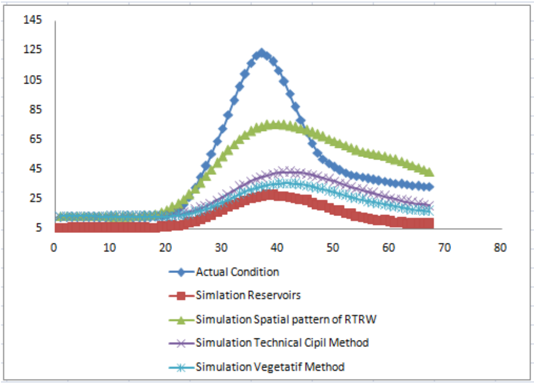

Figure 3: Simulation of surface water retention

Simulation 1 (Implementation of Ciawi Reservoir and Sukamahi Reservoir) was the best Simulation in reducing runoff, judging by the decreasing volume of runoff and the occurence of the peak discharge. Runoff volume decreased by 70% from actual condition. Based on the simulation, it can be proved that simulation by using a reservoir could reduce the flow of the surface, and could be as one of the solutions in the controlling the flood. The Reservoir is a flood control that serves to hold all or part of the flood water in its container and flows according to the capacity of the river. The larger reservoirs are able to accommodate all volumes of flood that can be stored for their usefulness in the future in a controlled manner, however the smaller reservoirs can only accommodate a portion of the flood volume but it could overcome the peak of the inflow resulting in a reduction of the outflow through the spillway [15] .

4. Conclusion

Simulation 1 (Implementation of Ciawi reservoir and Sukamahi reservoir) is the best scenario in reducing runoff, its indicated by the decreasing volume of runoff and the presence of peak discharge. The volume of runoff decreased by 70% from the actual condition. Based on these simulations, it can be proved that by simulation using a dam, it can reduce runoff, and is one of the solutions for flood control. Dam is a flood control that serves to hold all or part of the floodwater in the reservoir and flows according to the capacity of the river. The larger dams are able to accommodate all volumes of the flood that can be stored for their use in the future that will come in a controlled manner, and small dams can only accommodate a portion of the flood volume, however it could overcome the peak of the inflow resulting in a reduction of outflow of the spillway [15].

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