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Water Storage for Controlling Surface Runoff in Upstream Watershed

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Abstract

Flood disasters in Indonesia have shown an increase, both in magnitude and frequency. In fact, the area, depth, and duration of inundation tend to increase. Current flood control focuses on increasing river capacity: widening and/or deepening the cross-section of the river and controlling surface runoff by building storage upstream of the watershed. The storage requirement depends on the surface runoff rate in the upstream watershed. This study aimed to find the formulation of the most optimal watershed storage volume requirement through the correlation of flood discharge and surface runoff in the upstream watershed area. The results of the study found the optimum watershed storage volume capacity and produced 2 (two) representative equations to calculate the upstream watershed storage volume (WSVO) based on 2 (two) river slopes (slope 0.1, slope 0.01). WSVO is intended to facilitate the determination of the storage volume capacity in the upstream area if complete data, both primary and secondary data are not available.

Keywords

Surface Runoff, Increase in Watershed Function, Storage Volume, and Upstream Watershed.

Introduction

Flood disasters in Indonesia tend to increase, both in magnitude and frequency (Umar & Dewata, 2018; Koem et al., 2019; Al Habib et al., 2020). Flood parameters: area, depth, and duration of inundation, are increasing from time to time (Suripin & Kurniani, 2016). In 2019 there were 790 flood events, increasing to 1,138 flood events in 2020. (BNPB, 2021).

Population growth, effort to fulfill the life necessities, and policies taken by decision makers unavoidably encourage the exploitation of natural resources (Directorate of Rivers and Coasts, 2019). As a result of changes in land use from green open spaces to built spaces, environmental degradation increases. Likewise, droughts, floods and landslides are increasing both in quality and quantity (Kodoatie & Sjarief, 2008; Maryono, 2018). Increasing population, deforestation, expansion of agricultural land, increased urbanization, road construction, wetland reclamation, climate change have resulted in reduced available water storage capacity in the watershed (Al Amin, 2016). Peak flood discharge increases with shorter time, then increasing runoff can create significant flood risk (Westra et al., 2013; Soetanto et al., 2017).

Flood management has so far focused on increasing river capacity, while the management of rainwater in the watershed as a water source is still neglected. Flood control (structural) that has been existed/built so far include; system of canals, canals, drains, and canal drains (Gunawan, 2010; Faisal et al., 2017); improvement of rivers and embankments (Djati, 2007; Widyanti et al., 2014); sediment dredging, crib planning, ground sill (Sarwono et al., 2015); plans and policy concepts for flood management with sea wall and deep tunnel infrastructure (Wiyono et al., 2016); cross-sectional improvement and slope reinforcement in watersheds (Choirul et al., 2015; Wahyuningtyas et al., 2017; Maulana et al., 2017). In addition, current (structural) flood control is more about controlling surface runoff/rainwater quantity by increasing/returning the watershed function, namely storing and storing rainwater in the form of building reservoirs upstream of the watershed (Martdianto & Kadri, 2012), building retention ponds that serves to control the magnitude of the peak discharge by suppressing the peak of the flooding that occurs (Harmani & Soemantoro, 2017), applying biopore hole technique to avoid flooding problems (Yohana et al., 2017).

A sustainable flood control approach is the attenuation of peak discharge through a rainwater containment system (Bellu et al., 2016). Flood control with the concept of reservoirs in the upstream area as a flood storage area has been used in many countries for downstream flood protection when a flood comes (Jonoski et al., 2019. UDFDC (2016). Formulating the need for optimal water storage volume capacity at the research site was based on Colorado Urban Hydrograph Procedure (CUHP) United States. The UDFDC research (2016) was conducted in urban areas/downstream watersheds by using the excess urban runoff volume (EURV) equation, determining the volume of flood runoff based on soil group parameters (HSG) with variable depth of runoff in one hour of rainfall Therefore, a model was developed to determine the capacity of the surface runoff storage volume in the upstream watershed area, based on river slope parameters with variable runoff depth, taking into account the time of concentration (tc) peak flood, and nila i curve number (CN). The results of the study are useful for facilitating calculations in determining the capacity of the reservoir volume to control surface runoff.

Methods

The method used includes the following steps: analyzing flood discharge and its correlation with surface runoff, determining the storage volume as a function of surface runoff, determining the most optimal storage volume, and formulating the watershed storage volume capacity. The methods and stages are shown in Figure 1.

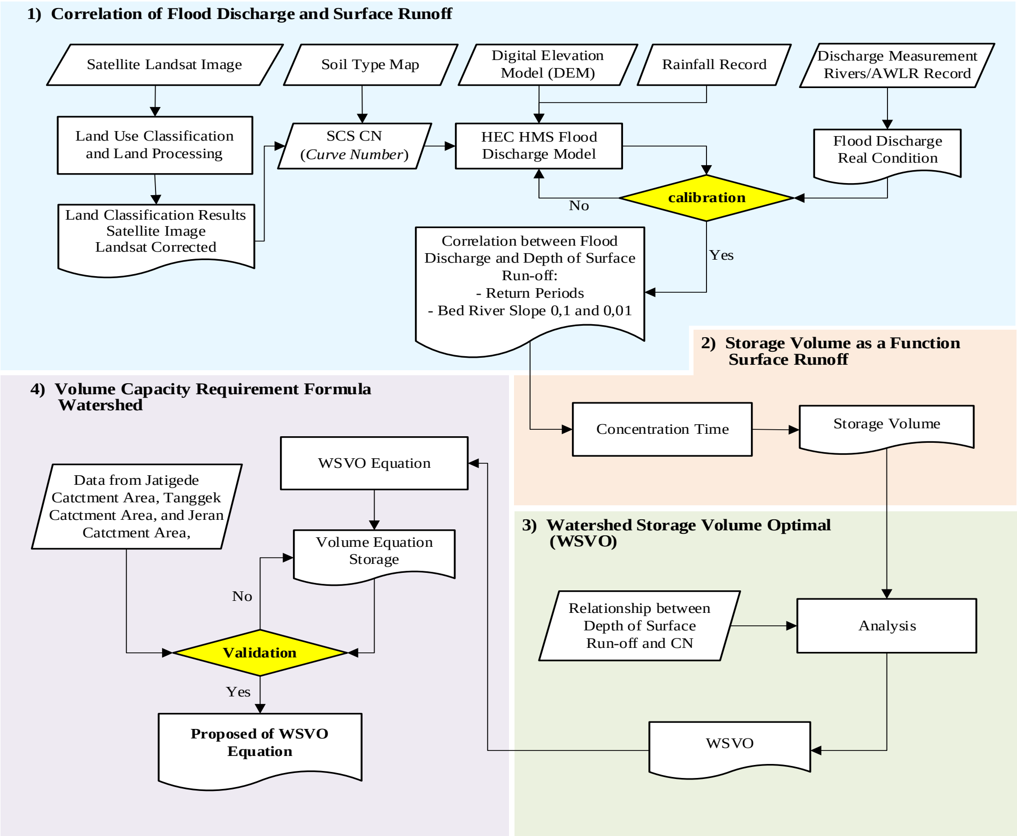

Figure 1 Research stages

The rain data used was data from the last ten years, 2011 to 2020, taken from eight rain stations. The analysis of the area's average rainfall used the Thiessen Polygon method which was based on eight selected rain stations in the Jatigede watershed. Application with the Thiessien Polygon method and testing with the ArcGIS application program for analysis of the distribution of the rain surface can provide a pattern of distribution of location points containing information in the form of map layouts (Ningsih, 2012). By knowing the amount of rainfall in an area, it can also provide information about the amount of rain intensity in the area which can be used to calculate the amount of flood discharge in the area (Harto, 2000).

The boundary line between watersheds was the back of the earth's surface that can separate and divide rainwater into each watershed. The boundary line was determined based on changes in the contours of the topographic map and the area of the watershed using AutoCAD Land Desktop software. The outer boundary line of the Jatigede Reservoir watershed was obtained from the Jatigede Reservoir watershed map in shapefile format (.shp) with sources from Garut Regency Regulation No. 29 of 2011 and the Regional Regulation of Sumedang Regency No. 2 of 2012 which was later edited (delineated) by using ArcGIS. The analysis of land use change in the Jatigede Reservoir watershed was carried out by using the HEC-HMS software which was one of the hydrological models that fall into the category of mathematical models developed by the Hydrologic Engineering Center (HEC) of the US Army Corps of Engineers (Schaffenberg et al., 2018).; Feldman, 2000).

a. Correlation of Flood Discharge and Surface Runoff

HEC-HMS software was used to calculate the runoff discharge in various return periods which were: 2 years, 5 years, 10 years, 25 years, 50 years, and 100 years. The data used were land cover from Landsat satellite imagery, soil types from soil type maps, digital elevation model (DEM), and rainfall. Rainfall data used were the maximum daily rainfall for the last 10 years. The discharge from the HEC-HMS simulation for various return times was calibrated with the flood discharge in real conditions from the AWLR measurement data).

The runoff discharge was converted into surface run-off so that the surface runoff height was obtained for various return periods.

b. Storage Volume as a Surface Runoff Function

Based on the results of the flood discharge, the reservoir volume of all tributaries of the Jatigede watershed was analyzed. The time of concentration (tc) was used in the analysis.

The result showed the storage volume of the Jatigede watershed tributary (Sub-watersheds of Jatigede) for discharge of various return periods. The definition of a tributary of the

Jatigede watershed or Jatigede sub-watershed was more specific because the analysis carried out was located in the upstream watershed with a relatively small watershed area. Similarly, the analysis was carried out with a relatively large river slope.

c. The Most Optimal Watershed Storage Volume

The most optimal storage volume was obtained by analyzing the correlation between surface runoff depth and CN. The correlation analysis was conducted by including the slope of the river. The CN parameter is a function of soil type and land cover.

The analysis of the correlation was carried out with various discharges at different times. The most optimal relationship was the one that is close to linear.

d. Formulation of Watershed Storage Volume Capacity Requirement and Validasi

Regarding the need of storage volume capacity for 2 (two) representative river slopes, an equation was obtained for each slope where the storage volume was the cumulative of the river slope found at the research location. The most consistent curve of the correlation between runoff depth and CN produceed an equation to calculate a representative reservoir volume in the upstream watershed at the study site.

As for the validation of the formulation, other data outside the Jatigede watershed were used. If the results were consistent, then the formula for the volume capacity requirement of the watershed could be used.

Result and Discussions

a. Correlation of Flood Discharge and Surface Runoff

The Jatigede watershed (1,468.22 km2) was divided into Upstream Jatigede, Middle Jatigede and Downstream Jatigede sub-watersheds in this study. There were 73 tributaries of the Cimanuk River and 19 tributaries directly entering the Jatigede Reservoir. The delineation of the sub-watershed boundaries followed the ridges on the left and right of the river flow based on a contour map with the help of arcGIS software and autoCAD land desktop software. The division of sub-watersheds in the Jatigede watershed is shown in Figure 2. The location of the Jatigede watershed is on a river with a slope > 0.01 as shown in Figure 3.

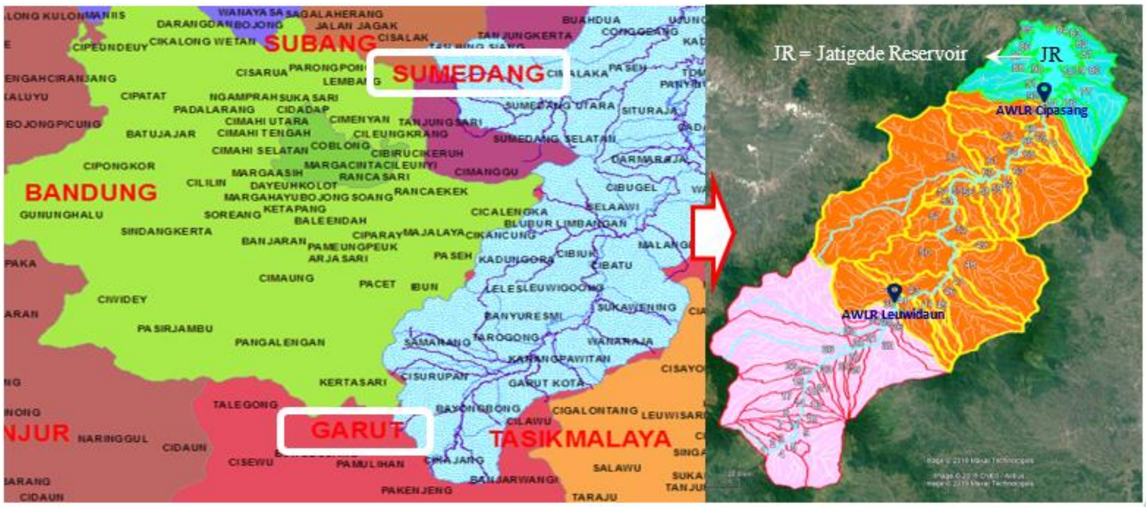

Figure 2 Jatigede watershed

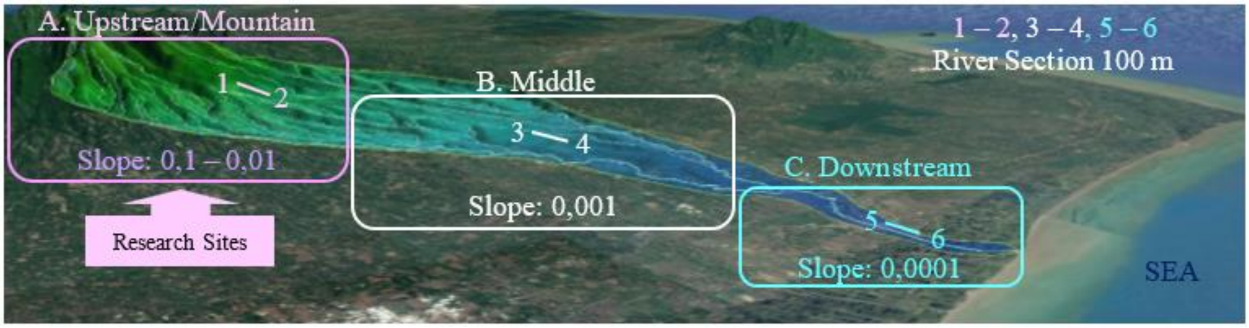

Figure 3 Illustration of research location based on river slope

Maximum Rainfall

The rain stations used in the Jatigede watershed are shown in Table 1 and the locations of the eight rain stations used are shown in Figure 4.

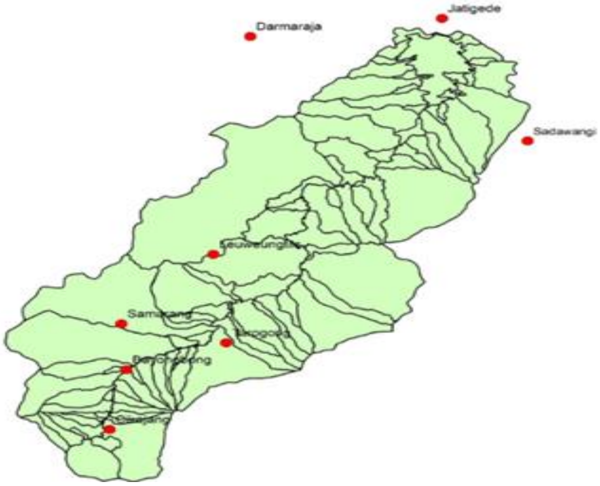

Figure 4 The location of the rain stations in the Jatigede watershed

Table 1 Jatigede watershed rain stations

No.	Rain Stations	No. Sta.	Coordinate	
			X	Y
1	Cikajang	9	107.802	-7.346
2	Bayongbong	8	107.817	-7.272
3	Leuweungtiis	0	107.895	-7.130
4	Darmaraja	5	107.927	-6.861
5	Jatigede	12	108.100	-6.837
6	Tarogong	7	107.895	-7.189
7	Sadawangi	12	108.179	-6.988
8	Samarang	10	107.812	-7.216

The rainfall occurrence used in the analysis to verify the hydrological model was the annual maximum daily rainfall in each sub-watershed in the Jatigede watershed. The amount of rain was then used as an input rain in the simulation of flood occurrences by using the HEC-HMS software. The data used in this analysis were the daily rainfall data which then the distribution of the hourly rainfall occurrences used was the hourly rain distribution of the nearest rain station which was considered the same.

The average daily maximum rainfall for the Jatigede watershed calculated using the Thiessen Polygon method is shown in Table 2. The results of the statistical logarithm of the data from the analysis using AProb 7.1 showed that (1) the number of data is ten; (2) the minimum is 1.672098; (3) maximum is 1.913814; (4) the average is 1.765151; (5) standard deviation (Sd) is 0.077418; (6) kurtosis (Ck) is 2.952931; (7) excess kurtosis (Cv) is -0.047069 and (8) skewness (Cs) is 0.801917. Rain intensity is the depth of rain that falls on the earth's surface per unit time, and is usually in units of mm/hour, mm/day, mm/week, mm/month, mm/year and so on (Triatmodjo, 2008).

Table 2 The average daily maximum rainfall in the Jatigede watershed

Year	Average of maximum rain daily (mm)
2011	73
2012	61
2013	62
2014	50
2015	59
2016	56
2017	47
2018	82
2019	51
2020	50

Soil Conservation Service (SCS) Curve Number (CN) Methods

The volume of surface runoff was calculated from rain data, a method with a curve number (CN) issued by the soil conservation service (SCS) was used. In this method, surface runoff was expressed as a function of rainfall and CN value. The steps in this method were as follows: (1) determining the type of soil per sub-watershed from the soil type map, after the watershed map was overlaid onto the soil type map, data on the type of soil per watershed was obtained, (2) determining the land cover of each sub-watershed from land use map, after the watershed map was overlaid onto the land use map, the area of land use in each sub-watershed in 2020 was obtained, (3) determining the CN and CN coefficients for each sub-watershed, obtained from the CN coefficient table according to hydrologic soil group (HSG).

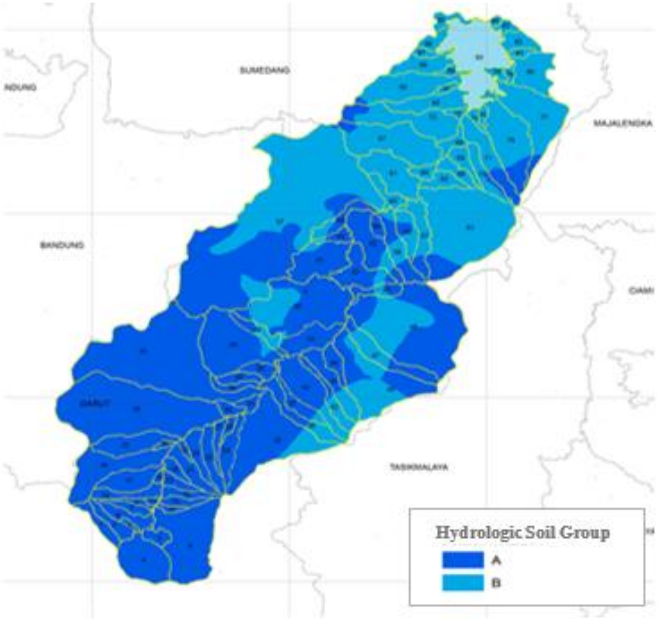

Figure 5 The results of soil type classification based on HSG

Hydrologic soil group A was soil with low surface runoff potential and high infiltration capacity which has great potential to seep into the soil. Hydrologic soil group B had the characteristics of a rather low surface runoff potential and a rather high infiltration capacity. The results of the classification of soil types in the Jatigede watershed were: soil hydrological group A (HSG A) in an area of 711.68 km2 (48.47%) and HSG B in an area of 756.54 km2 (51.53%).

Besides soil types, land use was also reclassified based on the SCS method. Then a map overlay with details of the results of each sub-watershed was conducted. CNs with various land cover are shown in Table 3.

Table 3 CN based on land cover of each sub-watershed

Sub-Watershed	Land Cover	Area (km2)	Coefficient	CN
1	Shrub	0.24	30	7.20
	Secondary Forest	1.25	36	45.21
	Settlement	0.14	77	11.23
	Plantation	0.74	64	47.54
	Dryland farming	0.92	61	56.14
	Dry Land Agriculture with Shrub	1.02	72	73.72
	Ricefield	1.48	61	90.56
	Total	5.81		57.04
2	Secondary Forest	0.95	36	34.34
	Settlement	0.09	77	6.97
	Plantation	0.45	64	29.03
	Dryland farming	2.50	61	152.82
	Dry Land Agriculture with Shrub	0.44	72	32.18
	Ricefield	1.74	61	106.63
	Total	6.19		58.39
3	Plantation	0.42	77	32.45
	Dryland farming	0.13	61	8.10
	Ricefield	0.45	61	27.96
	Total	1.01		67.65

HEC-HMS Model

Hydrological modeling in the Jatigede watershed was made using the HEC-HMS software. In the basin model, the background map was obtained by importing from autoCAD software and arcGIS software. Runoff simulation (sub basin, reach, and junction) is shown in Figure 6.

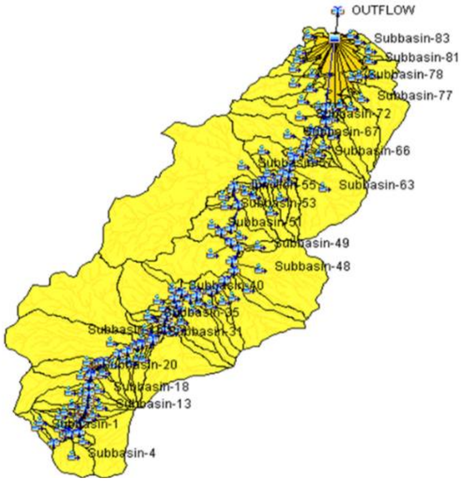

Figure 6 Basin model of Jatigede watershed

Result of Design Rain Simulation (Flood Discharge for various Return Periods (m3/s) and CN)

The design rain from the frequency analysis which then was distributed into hourly rain using the rain distribution pattern in the Jatigede watershed was used as rain input in the design rain simulation using the HEC-HMS software. The results of the planned discharge with a return period of 2 years, 5 years, 10 years, 25 years, 50 years, 100 years in 2020, are shown in Figure 7.

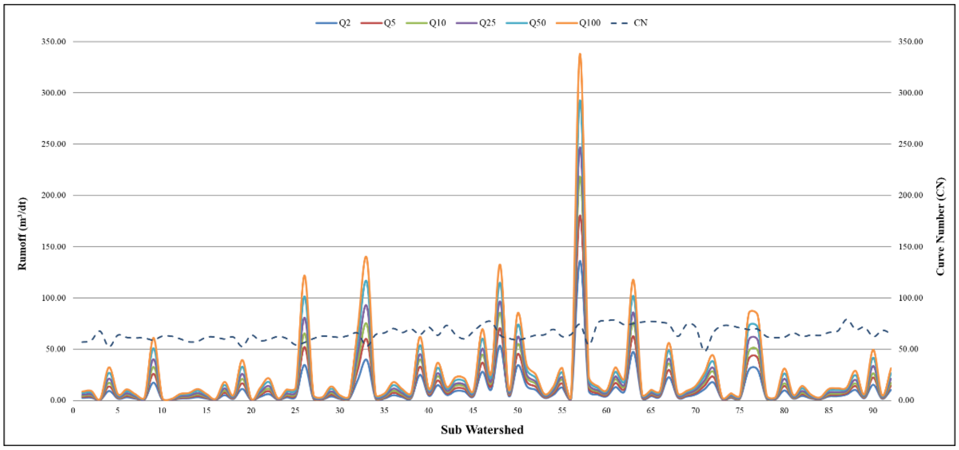

Figure 7 The output results of running flood discharge plans for HEC-HMS and the value of CN

Model Calibration

The process of calibrating flood discharge in the Jatigede watershed was done by comparing the discharge from running HEC-HMS: average discharge with the average measured discharge from 2011 to 2020. The results are shown in Figure 8 and Figure 9.

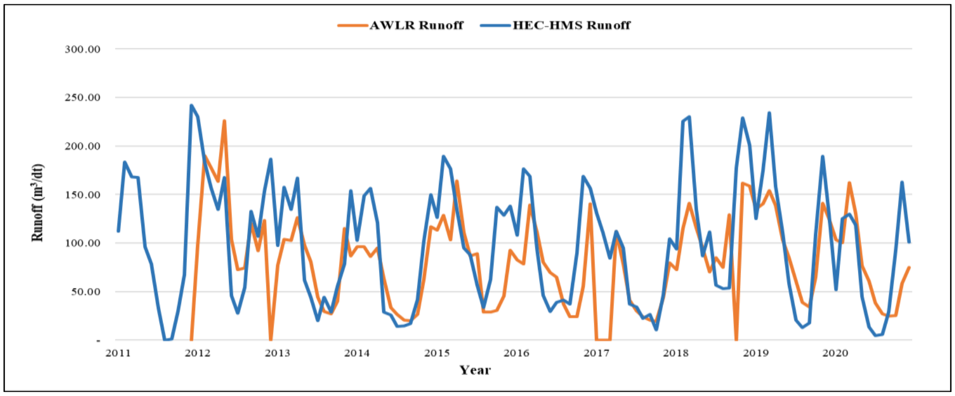

Figure 9 Graph of HEC-HMS discharge and AWLR discharge in 2011 - 2020, Upstream Jatigede sub-watershed

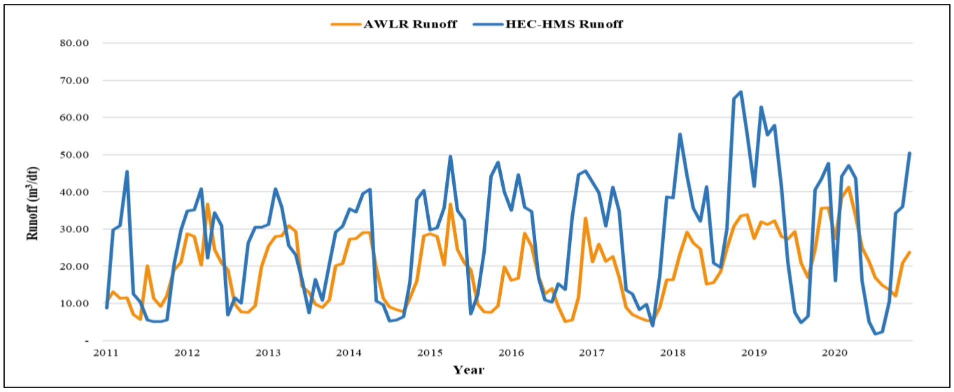

Figure 9 Graph of HEC-HMS discharge and AWLR discharge in 2011 - 2020, Middle Jatigede sub-watershed

HEC-HMS model parameter calibration was done by estimating initial parameters based on watershed characteristics. Optimization was done by comparing the simulation results with the observed discharge. The calibration results in Figure 8 and Figure 9 show that the simulation discharge was similar to the observed discharge in the sense that the function value was relatively small or close to zero, so the calibration process was considered complete. This means that the model has shown good performance.

Surface Runoff as a Function of Flood Discharge for various Return Periods

Surface runoff was a function of the discharge, thus the discharge for various returns was converted into the depth of surface runoff. For discharges with a return of 2 years, 5 years, 10 years, 25 years, 50 years, 100 years in 2020, the runoff height is shown in Table 4.

Table 4 Conversion of discharge to surface runoff

No.	Sub-Watershed	Slope	Depth of Surface Runoff (mm)					
			Q2	Q5	Q10	Q25	Q50	Q100
1	Ciroyom	0.18	0.90	1.40	1.57	2.24	2.81	3.31
2	Cikandang	0.17	0.99	1.54	2.02	2.40	3.04	3.68
3	Simpang	0.13	0.72	1.09	1.36	1.72	2.08	2.53
4	Cihideung	0.06	0.96	1.61	1.94	2.83	3.69	4.60
5	Girijaya	0.05	1.26	1.64	2.06	2.57	3.29	3.92
6	Cipanyingkiran	0.09	1.48	2.28	2.97	3.31	4.25	6.37
7	Cibeureum	0.10	1.26	2.01	2.30	2.81	3.73	2.67
8	Mekarsari	0.10	0.87	1.64	1.64	2.03	2.80	3.57
9	Cikuray	0.10	1.13	1.74	2.16	2.81	3.58	4.35
10	Barusada	0.07	0.93	1.60	2.45	1.27	1.77	2.28
11	Cigedug1	0.09	0.28	0.51	0.51	1.08	0.19	0.09
12	Cigedug2	0.14	0.85	1.43	1.88	2.55	3.17	3.04
13	Cikalongkrang	0.18	0.83	1.11	1.29	1.98	2.69	3.41
14	Cipanglalangon	0.14	1.15	1.59	2.10	2.75	3.56	4.38
15	Sindangsari	0.13	0.82	1.09	1.27	1.91	2.55	3.18
16	Sukahurip	0.10	0.21	0.24	0.09	0.24	0.49	0.73
17	Ciparugpug	0.12	1.88	2.84	3.47	4.05	5.10	6.15
18	Cintanegara	0.11	0.61	1.09	1.45	1.01	1.45	1.88

19	Cibeureum Gede & Leutik	0.11	0.86	1.34	1.65	2.10	2.64	3.17
20	Cidadap	0.05	0.92	0.92	2.07	2.75	0.57	0.23
21	Cicadas Gantung	0.17	0.99	1.41	1.68	2.34	3.06	3.33
22	Cibeunying	0.10	1.22	1.68	2.20	2.56	3.23	3.89
23	Cihanjuang	0.08	0.69	0.69	0.69	1.55	2.33	3.10
24	Cinisti	0.14	1.19	1.82	2.48	2.31	2.97	3.63
25	Cisaat	0.16	0.95	1.63	2.32	1.97	2.66	3.34
26	Cisoru & Cibodas	0.08	2.72	4.05	4.88	6.27	7.85	9.43
27	Sirnagalih	0.11	0.84	1.67	2.27	1.97	2.81	3.64
28	Mangkurakyat	0.05	0.49	1.22	2.04	1.55	1.63	1.71
29	Cipamuluhan	0.16	0.97	1.47	1.91	2.33	2.24	2.15
30	Cisumong	0.03	0.68	1.09	1.61	2.13	2.60	3.07
31	Ciburuy	0.04	0.69	1.25	1.94	2.35	3.26	4.16
32	Cipeujeuh	0.09	1.99	2.70	3.31	3.78	4.52	5.25
33	Cikamiri Cintakaya & Cintarakyat	0.05	2.66	4.27	5.35	6.90	8.80	10.69
34	Cipari	0.03	0.24	0.52	0.79	1.06	1.52	1.98
35	Cilutung	0.03	0.22	0.37	0.51	0.71	0.96	1.20
36	Cikendi	0.05	1.01	1.39	1.78	2.04	2.51	2.98
37	Lengkongjaya	0.03	0.89	1.38	1.92	2.27	2.92	3.57
38	Sukasenang	0.02	0.23	0.36	0.48	0.63	0.86	1.08
39	Ciojar & Cilingga	0.06	2.14	2.93	3.25	4.19	5.07	5.93
40	Majunus	0.07	0.29	0.39	0.49	0.63	0.83	1.03
41	Cidoronglang	0.06	1.70	2.34	1.36	3.43	4.21	4.87
42	Cimurah	0.07	1.15	1.40	1.68	1.99	2.47	3.03
43	Cipicung	0.01	1.18	1.53	1.70	2.19	2.69	3.22
44	Situsari	0.05	1.01	1.34	1.81	2.02	2.58	3.05
45	Cinunuk	0.04	0.73	0.69	0.69	0.94	1.25	1.59
46	Cisangkan	0.06	2.60	3.26	3.94	4.25	4.94	5.70
47	Sukamulya	0.06	2.81	3.34	3.77	4.19	4.82	5.25
48	Citomeng	0.08	2.05	2.75	3.44	3.82	4.55	5.29
49	Sukahaji	0.14	0.40	0.30	0.30	0.23	0.28	0.28
50	Siturancakuku	0.02	1.85	2.56	3.30	3.64	4.41	5.23
51	Cangkuang	0.01	2.94	3.92	4.51	5.34	6.35	6.35
52	Cibunar	0.09	1.54	1.98	2.54	2.59	3.00	4.11
53	Sindangsuka	0.05	0.97	0.97	0.97	0.97	0.97	0.97
54	Cipicung	0.06	1.67	2.04	2.36	2.43	2.73	2.73
55	Cipacing	0.09	1.53	2.04	2.53	2.74	3.21	4.03
56	Sukamerang	0.10	0.10	0.17	0.25	0.33	0.60	0.81
57	Cipancar	0.05	4.76	6.21	7.42	8.38	9.82	11.22
58	Cipicung Nanjungjaya	0.13	1.23	1.97	2.70	2.19	3.12	4.35
59	Cikamasan	0.07	3.18	4.42	5.66	5.87	5.00	4.18
60	Cibarunang	0.02	3.20	4.69	6.41	6.81	8.18	9.32
61	Cikuya	0.04	1.98	2.65	3.21	3.59	4.18	4.74
62	Cianjur	0.11	2.54	3.65	4.75	5.33	6.44	7.54
63	Citarik	0.07	5.02	6.56	8.15	8.78	10.24	11.75
64	Cigadung	0.07	0.31	0.47	0.86	1.37	2.04	2.43
65	Cibitung	0.08	0.21	1.03	1.62	1.94	2.53	3.12
66	Ciojar	0.08	0.21	0.90	1.56	2.10	3.04	3.87
67	Cipicung Cisaruhan	0.08	1.97	2.69	3.40	3.75	4.47	5.24
68	Cipasang	0.20	0.15	0.27	0.36	0.46	0.59	0.73
69	Cilampuyang	0.10	0.63	1.27	1.35	1.48	1.45	2.50
70	Sukajadi	0.13	2.30	0.67	0.73	1.09	1.04	0.08
71	Cikareo	0.10	1.48	1.13	1.75	1.29	1.48	1.62
72	Cigunung	0.08	1.12	2.49	2.98	3.30	3.95	4.54
73	Cisurat	0.07	0.58	1.24	2.69	3.86	5.82	8.00

b. Storage Volume as a Function of Surface Runoff

The analysis was carried out on the Upstream Jatigede and the Middle Jatigede sub-watershed to obtain the storage volume from surface runoff, by distributing the runoff discharge and the time of concentration (tc) of the peak flood into the storage volume. The conversion steps were the volume of surface runoff calculated by using the following equation:

$$\text{Runoff volume} = \text{Q x } t_c$$

with,

$$t_c = \left(\frac{0.87 \times \text{L}^2}{1{,}000 \times S}\right)^{0.385}$$

Notes:

Q= Surface runoff discharge (m3/s)

t_c = Concentration time (hour)

L = Maximum track length (km)

S = Average slope

For example, the volume of runoff discharge Q2 in sub-watershed 1 can be calculated in the following way:

$$t_c = \left(\frac{0.87 \times 6.45^2}{1{,}000 \times 0.18}\right)^{0{,}385} = 0.54 \text{ hour}$$

Runoff volume = 2.70 × 1,941.33 = 5,241 m3

The results of the calculation of the surface runoff volume are shown in the graph in Figure 10.

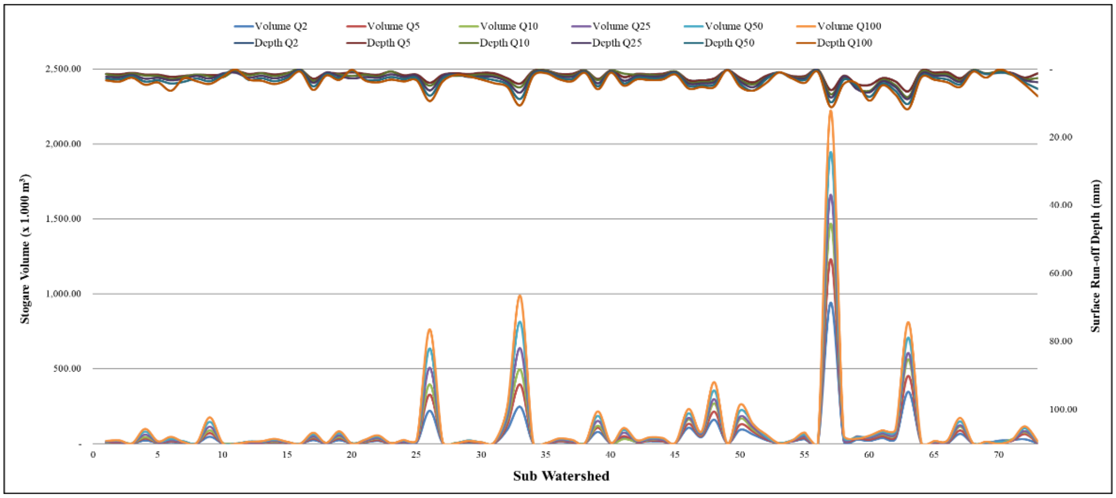

Figure 10 Graph of storage volume and surface runoff depth in Sub-watershed

The Most Optimal Watershed Storage Volume

The analysis was carried out on the Upstream Jatigede and the Middle Jatigede sub-watershed, and the slope of the river in the study site. The reservoir volume equation was obtained by graphing the correlation between surface runoff depth and CN according to the data for each return period for each sub-watershed. In the research site, there were only HSG A and HSG B, and the slope of the river was 0.1 and 0.01.

The surface runoff depth was calculated using the following equation:

$$\text{Runoff depth} = \frac{\text{Runoff volume}}{\text{Area of research location}}$$

For example, the depth of runoff discharge Q2 in sub-watershed 1 can be calculated in the following way:

$$\text{Runoff depth} = \frac{5{,}241 \times 10^{9}}{5.81 \times 10^{12}} = 0.90 \text{ mm}$$

The surface runoff depth data (Figure 10) and CN were plotted into a scatter graph to see the correlation between the two. A simple regression mathematical model with the data used can be shown by knowing the value of R2 or also called the coefficient of determination, the coefficient of determination shows how far the error in estimating the amount of y can be reduced by using the information possessed by the variable x. The regression equation model is considered perfect if the value of R2 = 1 or is an indication of the validity of a data where if 0.8 < R2 < 1 (Neno et al, 2016; Asdak, 2010).

Correlation based on River Slope 0.1

Correlation analysis of runoff depth for various return periods and CN of each sub-watershed with river slope was carried out. There were 27 sub-watersheds with river slopes 0.1 in the Upstream Jatigede sub-watershed and the Middle Jatigede sub-watershed, The correlation of runoff depth for various return periods and the CN of each Sub-watershed as a result of data processing with a river slope 0.1 was 12 sub-watersheds, and the results of plotting the remaining sub-watersheds into scatter form produce an R2 value of 0.5618 to 0.8827 and the results are shown in Figure 11.

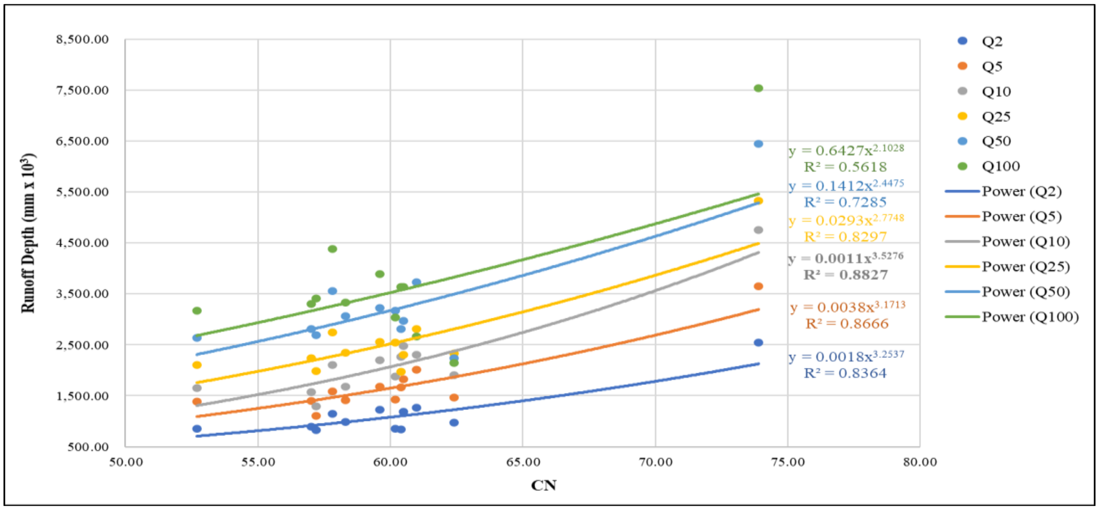

Figure 11 Graph of the relationship between runoff depth and CN with a slope of 0.1

Based on Figure 11, it can be seen that the runoff depth with a return period of 10 years has a strong correlation with CN with a value of R2 = 0.8827.

Correlation based on River Slope 0.01

There were 46 sub-watersheds with a river slope 0.01 in the Upstream Jatigede sub-watershed and the Middle Jatigede sub-watershed. The results of data processing sub-watersheds with a river slope 0.01 were 10 sub-watersheds, and the results of plotting the remaining sub-watersheds into scatter form produce an R2 value of 0.3550 to 0.9388 and the results are shown in Figure 12.

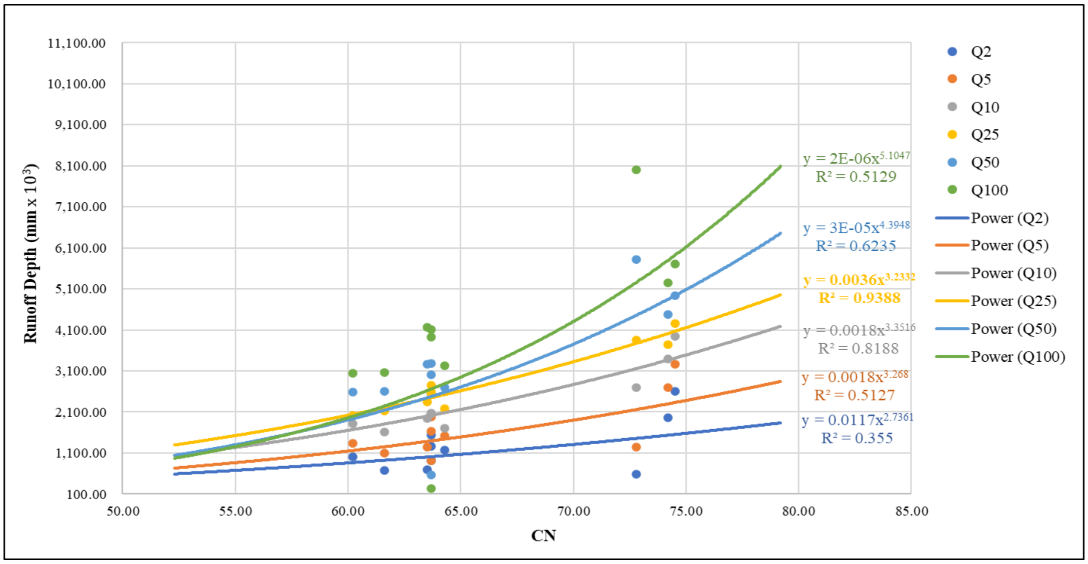

Figure 12 Graph of the relationship between runoff depth and CN with a slope of 0.01

Based on Figure 12, it can be seen that the runoff depth with a return period of 25 years has a strong correlation with CN with a value of R2 = 0.9388.

The most optimal storage volume

The power curve corresponds to the correlation between runoff depth and CN for each return period yielding an equation for the river slope. The most optimal storage volume was the most consistent between return periods based on the slope of the river. From Figure 11, the Q10 return period was the most optimal at the research site. In Figure 12, Q25 return period was the most optimal at the research location.

The most optimal storage volume analysis produces 2 (two) equations as follows:

The correlation based on river slope 0.1 produced the most optimal reservoir volume equation $y_{10} = 0.0011\, x^{3.5276}$

The correlation based on river slope 0.01 produced the most optimal reservoir volume equation $y_{25} = 0.0036\, x^{3.2332}$

d. Formulation of Watershed Storage Volume Capacity Requirements

The upstream watershed storage volume (watershed storage volume optimal/WSVO) is the volume of surface runoff in the upstream watershed (m3), and CN is the imperviousness of the watershed. To calculate WSVO in units of m3, the resulting equation for the correlation between runoff depth and CN for several representative return periods is:

River slope 0.1:
$WSVO = A\, 0.0011\, (CN^{3.5276})$

River slope 0.01:
$WSVO = A\, 0.0036\, (CN^{3.2332})$

Notes:

$WSVO$ = Watershed storage volume optimal (m3)
A = Area of watershed/sub-watershed (km2)
CN = Curve number

e. Validation of the Reservoir Volume Formula

The results of the WSVO formulation were validated as to whether they have similarities with the reservoir volume converted from the HEC-HMS/sub-watershed surface runoff conversion. WSVO validation was carried out on the sub-watersheds of Downstream Jatigede (Java Island), Tanggek watersheds (Lombok Island), and Jeran (Sumbawa Island) watersheds.

The validation steps are as follows:

WSVO sub-watershed Downstream Jatigede/slope 0,1, sub-watershed 88, Cibayawak:

$$WSVO = A\,0.0011\,(CN^{3.5276}) = 10.10 \times 0.0011 \times (69.3^{3.5276}) = 34{,}601 \text{ m}^3$$

WSVO sub-watershed Downstream Jatigede/slope 0.01, sub-watershed 74, Cimanjah:

$$WSVO = A\,0.0036\,(CN^{3.2332}) = 2.10 \times 0.0036 \times (72.90^{3.2332}) = 7{,}963 \text{ m}^3$$

The validation results are shown in Table 5 and Table 6 as follows:

Based on river slope 0.1 and slope 0.01

Table 5 The comparison VWatershed and WSVO river slope 0.1

Sub Watershed	Slope	Area (km2)	VWatershed (m3)	WSVO (m3)	RSME	Accuracy (%)	Accuracy < 25 km2 (%)
Downstream Jatigede Watershed							
88	0.11	10.10	50,141	34,601	15,540	69.01	69.01
91	0.10	1.76	3,450	5,787	2,338	59.61	59.61
Tanggek Watershed							
1	0.11	26.23	89,317	53,409	35,908	59.80	-
Jeran Watershed							
1	0.11	22.62	74,763	40,212	34,551	53.79	53.79
2	0.18	8.79	12,229	14,022	1,793	87.21	87.21
3	0.10	34.02	165,407	68,468	96,939	41.39	-
5	0.16	16.42	34,041	46,416	12,374	73.34	73.34
7	0.16	15.92	45,630	38,015	7,616	83.31	83.31
9	0.11	4.32	5,622	9,458	3,837	59.44	59.44
10	0.17	3.16	5,334	6,485	1,150	82.26	82.26
			Average			66.92	71.00

Table 6 The comparison V Watershed and WSVO river slope 0.01

Sub Watershed	Slope	Area (km2)	V Watershed (m3)	VTHD (m3)	RSME	Accuracy (%)	Accuracy < 25 km2 (%)
Downstream Jatigede Watershed							
74	0.04	2.10	7,986	7,963	23	99.71	99.71
75	0.04	1.69	7,754	5,831	1,924	75.19	75.19
76	0.09	30.40	336,129	97,867	238,263	29.12	-
77	0.05	31.00	282,391	100,732	181,658	35.67	-
78	0.05	2.44	5,397	5,567	170	96.94	96.94
79	0.06	1.57	1,682	3,417	1,736	49.21	49.21
80	0.03	15.00	105,010	33,519	71,491	31.92	31.92
81	0.06	2.16	7,619	5,910	1,709	77.57	77.57
82	0.06	6.46	29,818	14,816	15,002	49.69	49.69
83	0.07	2.42	7,232	5,993	1,239	82.87	82.87
84	0.06	1.27	3,005	3,082	77	97.51	97.51
85	0.06	4.21	7,848	11,804	3,956	66.49	66.49
86	0.09	4.37	7,262	13,170	5,908	55.14	55.14
87	0.08	2.62	13,907	12,989	918	93.40	93.40
89	0.02	2.00	12,349	7,123	5,226	57.68	57.68
90	0.08	23.40	121,164	53,113	68,051	43.84	43.84
92	0.09	13.00	53,082	34,022	19,060	64.09	64.09
Tanggek Watershed							
2	0.08	11.46	57,255	36,850	20,404	64.36	64.36
3	0.06	4.69	16,973	21,022	4,049	80.74	80.74
4	0.05	0.78	1,060	3,414	2,354	31.05	31.05
5	0.04	5.13	25,933	28,322	2,389	91.57	91.57
6	0.05	2.78	15,449	18,311	2,862	84.37	84.37
7	0.03	0.59	2,371	3,472	1,101	68.30	68.30
8	0.03	7.27	41,260	40,277	983	97.62	97.62
9	0.04	1.94	8,569	11,349	2,780	75.51	75.51
10	0.05	5.38	33,957	28,844	5,113	84.94	84.94
11	0.02	2.25	9,783	12,974	3,191	75.41	75.41
12	0.02	0.38	2,371	2,124	247	89.60	89.60
13	0.02	1.00	2,115	5,163	3,048	40.97	40.97
14	0.01	0.92	2,360	2,265	95	95.98	95.98
15	0.02	0.22	453	495	42	91.43	91.43
16	0.04	13.74	116,277	72,011	44,266	61.93	61.93
17	0.02	5.04	19,511	13,299	6,212	68.16	68.16
18	0.01	6.69	36,761	16,300	20,462	44.34	44.34
Jeran Watershed							
4	0.08	32.59	168,214	78,007	90,208	46.37	-
6	0.08	24.19	88,095	41,403	46,692	47.00	47.00
8	0.08	36.74	152,761	57,621	95,140	37.72	-
			Average			67.12	70.74

The RSME value shows the sensitivity of the model to the comparison of the calculation of the storage volume capacity. In the sub-watershed area of less than 25 km2, the difference in the storage volume value slightly affects the model results, but the model experiences a significant difference in results above the watershed area.

In a sub-watershed area of less than 25 km2, the average accuracy of the WSVO model with a river slope of 0.1 is 71.00% and a river slope of 0.01 is 70.74%.

The Comparison of VWatershed and WSVO

The results of the VWatershed distribution and the WSVO model are plotted into a scatter graph to see the correlation, shown in Figure 13.

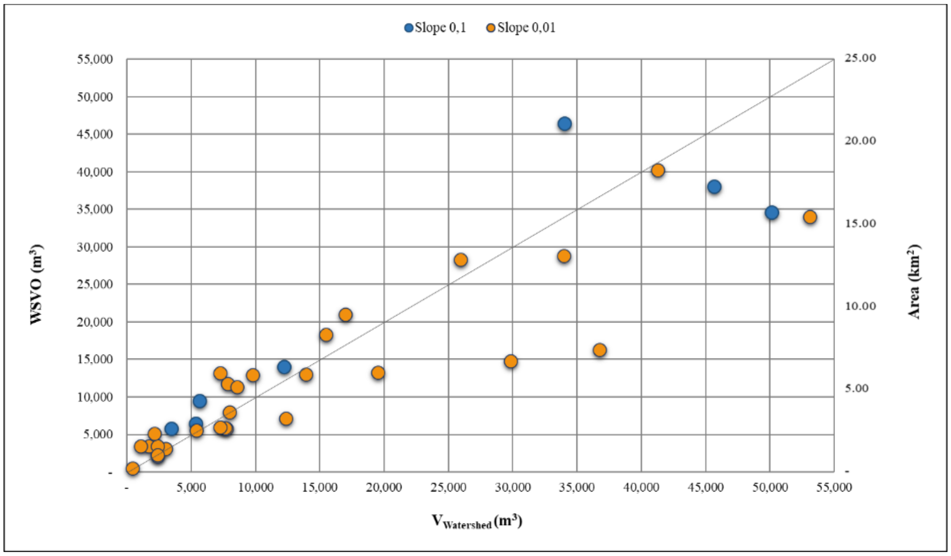

Figure 13 The comparison of VWatershed and WSVO, watershed area < 25 km2

The results of the distribution of VWatershed and the WSVO model in a sub-watershed area of less than 25 km2 show a similar pattern of reservoir volume between VWatershed and WSVO, this means that the validation results have shown good performance resulting in a valid reservoir volume equation.

Conclusion

The results of the research on watershed storage volume requirements resulted in 2 (two) representative equations for calculating the upstream watershed storage volume (WSVO) based on the slope of the river. The slope of the river (slope 0.1) with the equation $WSVO = A\,.\,0{,}0011(CN^{3{,}5276})$, and the slope of the river (slope 0.01) with the equation $WSVO = A\,.\,0{,}0036\,(CN^{3{,}2332})$.

WSVO simplifies the determination of the capacity of the water storage volume in the upstream watershed if complete data, both primary and secondary data, are not available. WSVO is more effectively built/applied in upstream areas with a watershed area of less than 25 km2.

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