A study of Watershed characteristics of tiga dihaji dam

By Anis Saggaff

A Study Of Watershed Characteristics Of Tiga Dihaji Dam

Teguh Prastowo, Anis Saggaff, Febrian Hadinata

Abstract : Tiga Dihaji Dam is a vital water resource infrastructure building because it has a very important function for the community living downstream of the dam as a provider of raw water with a capacity of 1 m^3/second, serving 38,500 Ha of irrigation, generating 35.74 MW of electricity and also playing a role in reducing floods by 7.04%. With this role, a study of the characteristics of watersheds (DAS) is needed so that the services provided by the Tiga Dihaji Dam will always be optimal and also this study will provide a basis for the management agencies in preparing the Watershed Management Plan. The analysis of the morphometric characteristics of the Watersheds of Tiga Dihaji Dam reveals that the watershed area of 1,158.2 km^2 can be identified, with an elongated watershed and a river length of 61.3 km. The density of the watershed is classified as Very Rough as indicated by a Dd value of 0.26. It can also be illustrated through the river branching variable through the Br value of 5.42 which means that the Tiga Dihaji Dam Watershed has the characteristics of a rapid increase in flooding, as well as its decline. Based on its meteorological characteristics, this watershed has a high average annual rainfall of 2,535 mm / year, while the climate condition of the watershed is known to have an average temperature of 26.5 - 28.0 °C, irradiation time ranges from 35.8 - 67.4%, humidity ranges from 78.7 - 87.6% and wind speeds range from 1.2 to 1.8 m/second. Geologically, the Tiga Dihaji Watershed is composed of clay rock, sandstone, silt and napal rock at 43.3%, while the soil type is dominated by Sandy Clay Loam, which means that the watershed has the potential to produce a fairly large river discharge. While the distribution of heights ranges from 0-2,500 masl with a slope of 0.965%. In terms of land use, the Tiga Dihaji Dam watershed is dominated by 47.1% of dry land farming mixed with bushes. The land use map and the land map results in composite curve number for the Tiga Dihaji Dam watershed of 79 which means that this watershed is large enough to pass rainwater to become runoff discharge.

Keywords : Dam, Morphometry of Watershed, Morphology of Watershed, Meteorology of Watershed, Curve Number.

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1. INTRODUCTION

Adam is one of the infrastructure buildings built in certain places along the river. Many benefits are expected from the construction of the dam, among others are in the form of water supply for irrigation, power generation, flood control, fisheries and recreational facilities. In regard to this matter, the Ministry of Public Works and Public Housing through the Office of River Region of Sumatra VIII carried out the construction of the Tiga Dihaji Dam located in Sukabumi Village, Tiga Dihaji Subdistrict, South OKU Regency, South Sumatra Province. According to the Dam Design General Criteria Guidelines, Tiga Dihaji Dam is classified as a type of dam with multipurpose function [1], because the Tiga Dihaji Dam can serve irrigation with an area of 38,500 ha, generate electricity by 35.74 MW, reduce flooding by 7.04% and provide raw water of 1 m^3/s. Considering the vital functions of the Tiga Dihaji Dam, the existence of the Dam must be maintained so that the function of the Dam can be optimized. One way that needs to be done in order to prepare for the handling of the maintenance of the function of the dam is to study the characteristics of the Tiga Dihaji Dam Watershed. It is also mandated in the Government Regulation (PP) No. 37 of 2012 concerning Watershed Management Article 22 Paragraph (a) regarding the making of an Inventory of Watershed Characteristics as a basis for the preparation of Watershed Management Plans as mandated in Article 21. In addition , by identifying the Tiga Dihaji Dam Watershed will assist the managers in estimating conditions and potentials in order to support the development of natural resources and human resources as well as institutions optimally. The scope of the characteristics of the watershed that will be studied for the Tiga Dihaji Dam Watershed is meteorological characteristics, morphological characteristics of the watershed and watershed morphometric characteristics.

2 METHODOLOGY

The characteristics of watershed is a specific description of watershed characterized by parameters relating to morphometric, topographic, soil, geological, land use, and hydrological conditions. The watershed characteristics analyzed in this study are meteorological characteristics, morphological characteristics and watershed morphometric characteristics.

2.1 Meteorological Characteristics of Watersheds

The meteorological characteristics of the watershed can be disclosed by looking at the results of the recording of the value of rain posts around the watershed. To reveal the amount of annual rainfall received by the watershed, it can be determined by using the Thiessen polygon method. This method is carried out by inputting the regional influence factor represented by the rain measuring station which is called the weighting factor or also called the Thiessen Coefficient. The magnitude of the weighting factor depends on the area of influence represented by the station bounded by polygons that intersect perpendicularly in the middle of the connecting line of two stations. Thus each station will be located in a closed polygon.

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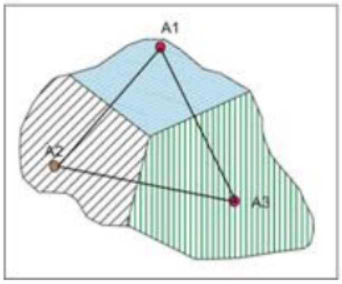

Figure 1. *Sample Information of the Thiessen Polygon*

With the existing digital maps, the area of influence of each station (An) and the area of flow area (A) can be calculated. Average rainfall in the flow area can be calculated using the following formula:

$$Rt = \frac{A_1 R_1 + A_2 R_2 + \ldots + A_n R_n.}{A_1 + A_2 + \ldots + A_n R_n.}$$

In which:

Rt = Regional rainfall

$A_{1,2,n}$ = Area of polygons from station 1.2 up to n

$R_{1,2,n}$ = Station rainfall for each station.

If the amount of annual rainfall in the watershed is known, the classification of rainfall can be determined based on the following table [2].

Table 1. *Categories of rainfall quantities*

No.	Rainfall (mm / year)	Category of Value
1.	< 1500	Very Low
2.	1500 – 1999	Low
3.	2000 – 2499	Medium
4.	2500 – 2999	High
5.	≥ 3000	Very High

Source: Director General of Watershed and Social Forestry Management (2013)

To disclose the characteristics of climatology, it is necessary to collect climate data around the watershed location, to know the average value of climate parameters. Climate parameters to be revealed are air humidity (%), average temperature (^{o}C), exposure time (%) and average wind speed (m /s).

2.2 Morphological Characteristics of Watersheds

The data on the morphological characteristics of the watershed were obtained from the interpretation, analysis and reading of geological, topographic and soil maps. Geological variables are very important variables in the formation of watershed characteristics because they are very closely related to surface water and groundwater. If in a watershed area there are types of rocks that are impermeable (lava, andesite, granite), the resulting water discharge will be more and more because the rain water that falls to the surface of the earth will be absorbed less and the rainwater that becomes runoff will be much more. Unlike the case when rain water that falls on the type of rock which is not water resistant such as limestone and sandstone, it will produce smaller runoff discharge because a lot of rain water is absorbed into the ground. The rock information can be obtained from the 1996 Ministry of Energy and Mineral Resources Geological Map. The topographic variables analyzed are the height and the slope of the watershed. The height variation in a watershed needs to be known because it affects the rain patterns and climatic conditions of a watershed. This watershed elevation variation can be analyzed using ASTER DEM (Data Elevation Model) map with a resolution of 30 x 30 m. The mean slope variable of watershed is produced from the process of DEM data processing with a map processing device to reveal the difference in elevation in the upstream and downstream of the watershed and the distance between the two points. This slope is very influential on the speed of the process of rain becoming into runoff, water travel time or time travel and erosive power of ground level runoff. The following is the formula used to calculate the average slope of a watershed.

$$\text{Watershed slope } (\%) = \frac{c}{d} x100\%$$

In which:

c : elevation difference between the highest and the lowest point in the watershed (m)

d : horizontal distance between the elevation of the highest point and the lowest point (m)

The calculation results are then classified as presented in Table 2.

Table 2. *Categories of watershed slopes*

No.	Slanting of Slope	Description
1.	0 < 7.99	Flat
2.	8 – 14.99	Slightly Titled
3.	15 – 24.99	Titled
4.	25 – 44.99	Steep
5.	≥ 45	Precipitous

Source: Directorate General of Watershed and Social Forestry Management (2013)

Soil variables are very influential on underground flow. This is closely related to the process of rain becoming into runoff. The type of soil with sand texture will have a higher infiltration rate than that of the clay type textured soil. Thus the type of soil with a texture of sand (coarse) will have smaller surface runoff than the type of soil with a clay texture (smooth). For this condition, the watershed with predominantly fine-textured soil type is more prone to erosion than the watershed with predominantly coarse-textured soil type. To obtain this information a land map issued by FAO in 2009 is needed. The CN value is a conceptual parameter with a value of 0 to 100. This parameter describes the characteristics of rainwater catchment and is related to the amount of surface runoff that occurs. This parameter is very dependent on land use and soil [3]. The greater the CN value in the watershed, the greater the rainwater which will become surface runoff. To find out the average CN value of the studied watershed, a CN composite calculation with the following formula is needed:

$$CN = \frac{CN_i A_i + CN_{i+1} A_{i+1} + CN_{i+n} A_{i+n}}{\sum_{i=1}^{n} A_i}$$

In which:
CN_i is a curve number value of sub-watershed i
A_i is the area of a sub-watershed affected by CN

2.3 Morphometric Characteristics of Watersheds

The data on the morphometric characteristics of watershed were obtained from the results of interpretation and measurement after watershed boundary delineation was done which includes: watershed area, watershed shape, flow density, river branchig and length of main rivers. Here is an explanation on how to get this variable:

a. Watershed Area

A watershed is a land area that is an integral part of a river and its tributary, which functions to accommodate, store, and flow water that comes from rainfall to lakes or to the sea naturally, of which the boundary on land is a topographic separator and the boundary at sea is up to waters that are still affected by land activities [4]. The watershed is generally limited by ridges or mountains and ends at a point or an outlet. The watershed illustrates the extent of an area in capturing rainwater, so that the broader the watershed, the greater the potential of water owned. The watershed can be revealed by processing contour maps or DEM (Data Elevation Model) [5] that are processed with geographic information systems. The watershed area can be classified as follows.

Table 3. *Categories of watershed types based on watershed area*

No.	Watershed Area (km^2)	Description
1.	≥ 15.000	Very Large Watershed
2.	5.000 – 14.999	Large Watershed
3.	1.000 – 4.999	Medium Watershed
4.	100 – 999	Small Watershed
5.	< 100	Very Small Watershed

Source : Directorate General of Watershed and Social Forestry Management (2013)

b. The Shape of Watershed

The shape of the watershed greatly influences the duration and magnitude of the occuring flood. In the elongated shape of the watershed, it usually results in a smaller flood discharge than a watershed that has an almost oval shape which usually results in a larger flood discharge because all tributaries will collect at a point. In general, the form of this watershed is difficult to state, but it can be approached using a circularity ratio [6], using the following formula.

$$R_c = \frac{4\pi A}{p^2}$$

In which:
R_c : circularity ratio
A : watershed area (km^2)
P : perimeter / circumference of watershed (km)

The classification of the value of R_c, if the value of $R_c < 0.5$ then the shape of the watershed is elongated and if the value of $R_c > 0.5$ then the shape of the watershed is circular / round [7].

c. River flow density

Flow density or Dd is the length of river flow per square kilometer in area in a watershed [8]. The greater the value of flow density, the better the drainage system in the area, the greater the amount of total runoff water (the smaller the infiltration) and the smaller groundwater stored in the area. River flow density can be disclosed by comparison between river length and watershed area [9].

$$D_d = \frac{\sum L_n}{A}$$

In which:
Dd : flow density (km / km^2)
L_n : river length (km)
A : watershed area (km^2)

The Dd value can be classified into 5 based on its magnitude [10], namely

Table 4. *Categories of Dd Value*

No.	Value of Dd	Description
1.	< 2	Very Rough
2.	2 – 4	Rough
3.	4 – 6	Medium
4.	6 – 8	Smooth
5.	> 8	Very Smooth

[11] If the flow density value is smaller than 0.62, then the watershed will tend to experience flooding, whereas if the watershed density value is greater than 3.1 then the watershed will tend to experience drought.

d. River branching

[12] and [13] state that the Strahler method can be used to determine the river order, in which the most upstream river channel that has no branches is called the first order (order 1), the confluence of the first order is called second order (order 2), and so on. By knowing the order of the river, the branching level index can be calculated that illustrates the speed of the increase in flood water level. The formula used to calculate this branching index is as follows.

$$B_r = \frac{N_u}{N_{u+1}}$$

In which:
B_r : river branching level index

N_u : number of river flows for the u-order
N_{u+1} : number of river flows for order of (u + 1)

The index value can be interpreted as for example the value of $B_r < 3$, it is identified that the river channel has a rapid rise in flood levels, while the decline is slow. B_r between 3 – 5 indicates that the river channel has an increase and decrease in the flood water level not too fast or not too slow. If the value of $B_r > 5$ then the river channel has a rapid increase in flooding so has with its decrease [14].

e. The length of the main river
The length of the watershed is the flat distance from the river mouth upstream along the main river. [15] Basin length is the longest river flow measured from the outlet to the farthest river point. This calculation can be obtained from the results of analysis of the watershed and river using geographic information systems.

3 Results and Discussion

Geographically, the watershed of Tiga Dihaji Dam is located at the position of 103° 51' 59.035" East Longitude - 4° 45' 46.814" South Latitude. To find out the meteorological and climatological characteristics of the watershed of Tiga Dihaji Dam, rainfall and climate data are needed in and around the watershed. The following is the distribution of the rain, the discharge and the climate posts in the watershed of Tiga Dihaji Dam.

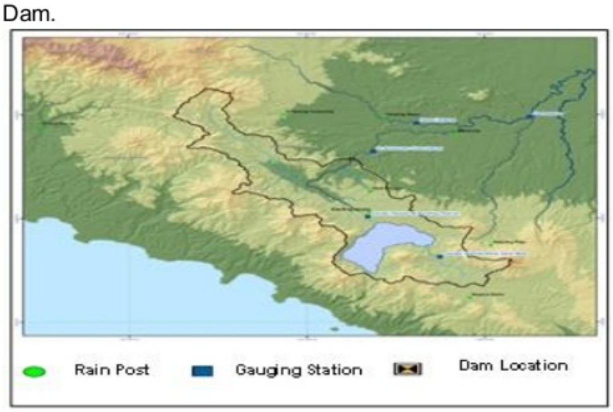

***Figure 2**. Map of the distribution of the rain, the discharge and the climate posts in the watershed of Tiga Dihaji Dam*

Based on the data on the map above, in general the rain posts are dominated by the Geophysical Climatology Meteorological Agency and only one rain post which is under the authority of the Ministry of Public Works and Public Housing, namely the Banding Agung rain post, however the data on the rain post are very few, namely for 7 years. Even though this post is very good to be used in supporting this study because the position of the rain post is right in the middle of the watershed, while the other rain posts are outside the watershed. So that the rain distribution is evenly distributed and represents the whole watershed, the rain posts around the watershed are also included. Identified gauging stations are gauging stations of S. Selabung-Banding Agung, S. Selabung-Kota Agung and S. Warkuk-Ds Kota Batu, however the availability of data in these three gauging stations is very short with dubious data quality that they cannot be used in analysis.

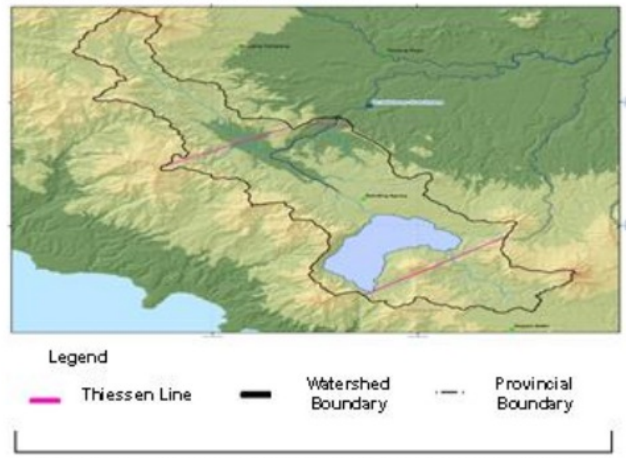

***Figure 3**. Thiessen Polygon Map of the Tiga Dihaji Dam Watershed*

To find out the average annual rainfall in this watershed, weighting of the rain post area is carried out based on the Thiessen polygon method above. Based on the results of the Thiessen polygon analysis, it is known that the most influential rain post on the watershed is the Banding Agung rain post. The weight for Banding Agung rain post is 0.58, the weight for Negara Batin rain post is 0.17, the weight for Tanjung Raya rain post is 0.01, and the weight for Simpang Campang rain post is 0.25. The results of the analysis of the average rainfall in the watershed showed that the amount of rainfall in the region for the Tiga Dihaji Dam Watershed is 2,535 mm / year. Based on the criteria for grouping annual rainfall data, the annual rainfall in the Tiga Dihaji Dam Watershed is classified as High. With the high annual rainfall, it can be concluded that the potential for discharge will also be even greater. When viewed in monthly duration, the peak rainfall in the Tiga Dihaji Dam Watershed occurs in December and the lowest monthly rainfall occurs in June. The following is a graph of average monthly rainfall in the Tiga Dihaji Dam Watershed.

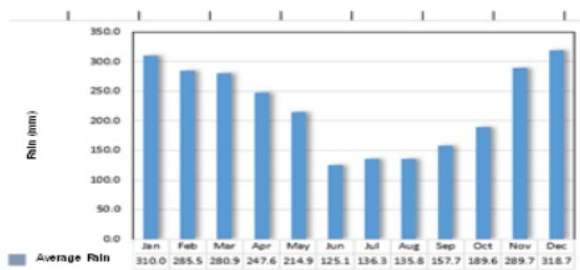

***Figure 4.** Average monthly rainfall of the Tiga Dihaji Dam Watershed*

The climate post used to determine the climate conditions in this watershed is the Simpang Campang climate post. The data that had been collected from BMKG were of the period of 2009-2013. Based on the data, it can be disclosed that the average temperature of this watershed ranges from 26.5 - 28.0 °C, irradiation time ranges from 35.8 - 67.4%, humidity ranges from 78.7 - 87.6% and wind speed ranges around 1.2 - 1.8 m / s.

***Table 5**. Monthly averages of climate post parameters of Simpang Campang*

Parameter	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	De
Temperature (°C)	26.5	26.7	27.2	27.6	28.0	27.8	27.2	27.6	27.9	27.6	27.3	2
Length if Irradiation (%)	40.5	44.7	52.0	57.6	59.8	63.7	58.5	67.4	59.6	55.1	47.9	3
Humidity (%)	86.9	87.6	86.4	85.5	84.5	83.1	83.0	80.0	78.7	81.9	84.9	8
Wind Speed (m/s)	1.67	1.46	1.37	1.26	1.33	1.47	1.58	1.80	1.73	1.35	1.18	1.

Based on the results of the analysis of the characteristics of the watershed in terms of its morphology, the Tiga Dihaji Dam is at the highest elevation of 2,500 meters above sea level to the lowest elevation of 0, with a slope of 0.965% which categorizes this watershed into the sloping watershed criteria. The following is the topographic map display of the Tiga Dihaji Dam Watershed.

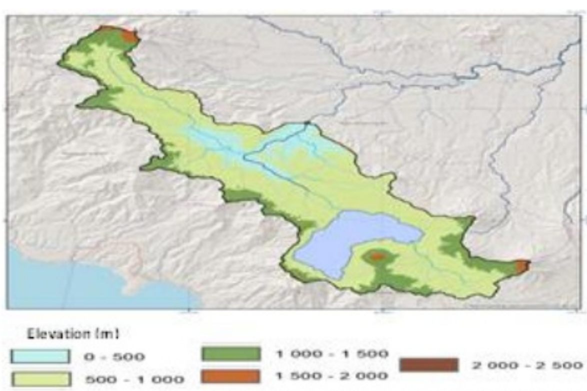

***Figure 5.** Topographical map of Tiga Dihaji Dam*

The Tiga Dihaji Dam watershed is composed by geological rock formations, especially sandstone, claystone, shale, siltstone, and marl of 501.3 km^2 or 43.3%. Because it is dominated by clay rock, it can be seen that there is a lot of rain water that cannot be absorbed properly until it becomes runoff and finally it is very susceptible to fairly high erosion. The following is a display of the rock formation of the Tiga Dihaji Dam watershed spatially.

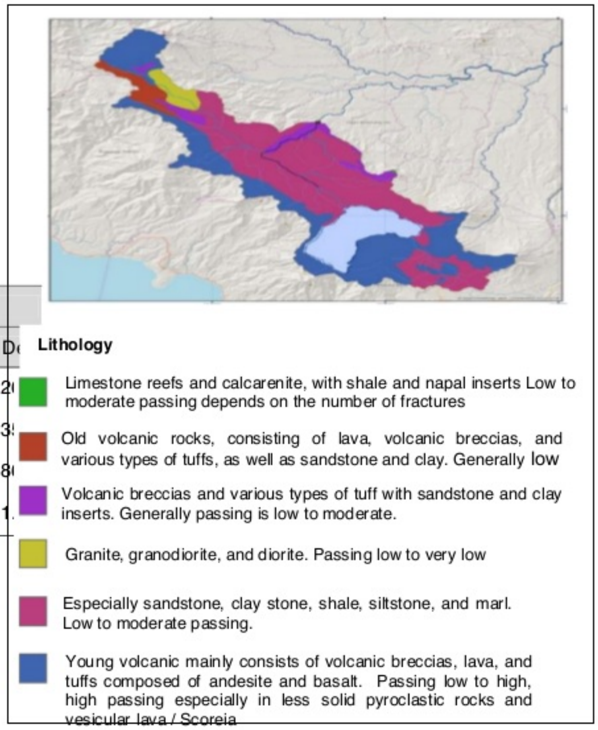

***Figure 6.** Geological Map of the Tiga Dihaji Dam Watershed*

In addition to rock conditions, it is also known that the type of soil of the Tiga Dihaji Dam which is located in Sukabumi Village, Subdistrict of Tiga Dihaji, Ogan Komering Ulu Selatan Regency, is dominated by Sandy Clay Loam soil type. This is consistent with the rock formations above which indicate that rainwater will quickly run off. The following is a spatial display of the land map of the Tiga Dihaji Dam Watershed.

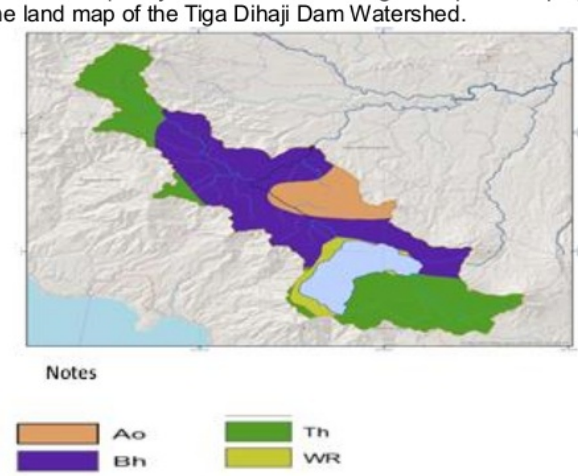

***Figure 7.** Land Map of the Tiga Dihaji Dam*

Based on the 2012 land use map, the land use condition in the Tiga Dihaji Dam watershed is dominated by mixed dryland agriculture and bushes of 545.8 km^2 or 47.1%. The second place is dominated by secondary land forest of 269.9 km^2 or 23.3%. The following is the land use conditions of the Tiga Dihaji Dam Watershed.

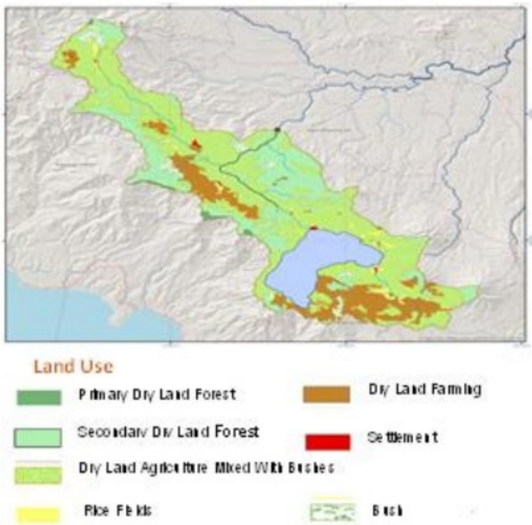

Figure 8. *Map of land use of the Tiga Dihaji Dam Watershed*

By analyzing the geographic system, the CN value can also be disclosed by combining land use map and map of soil types. The curve number map illustrates the ability of the watershed in escaping rainwater to become runoff. The CN composite value generated for this watershed is 79, which means that this watershed has the potential to escape more water to become runoff. The following is a map of the distribution of CN values of the Tiga Dihaji Dam Watershed.

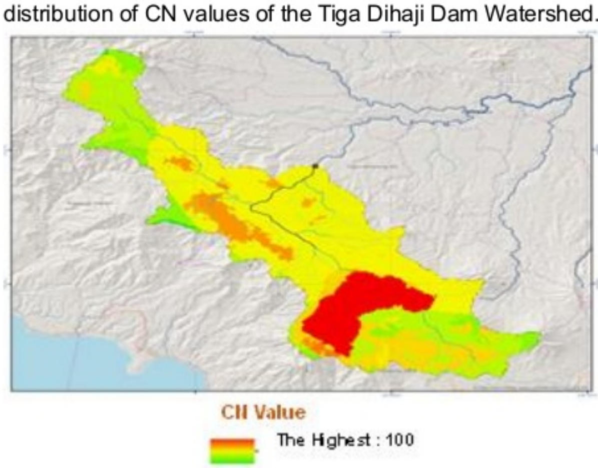

Figure 9. *Map of CN values of the Tiga Dihaji Dam Watershed*

The results of the analysis of the characteristics of the Tiga Dihaji Dam Watershed in terms of morphometry result in a watershed area of 1,158.2 km^2. Based on this value, the Tiga Dihaji Dam Watershed is categorized as Medium Watershed. This means that the watershed has the potential to collect rainwater that is neither too large nor too small. For the watershed shape variable, which is assumed from the circularity ratio value of 0.2049, the watershed has an Elongated Watershed shape [16]. For this shape of watershed, it usually results in flood discharges that are not too large in a relatively long flood duration due to the process of rain becoming runoff discharge that is not too long so that flooding will continue continuously [17]. Flow density or Dd is the length of river flow per km^2 of watershed area. From the calculation of the value of Dd of the Tiga Dihaji Dam Watershed of 0.26. Based on this result, the density of this watershed is classified as Very Rough, meaning that the watershed tends to be flooded during the rainy season and drought in the dry season. The watershed with a Dd value of less than 0.62 is likely to experience flooding. Other variables used to determine the morphometric characteristics of the watershed are the length of the main river and river branching. The length of the main river in this watershed is 61.3 km. For river branching, it is calculated from the number of channels in each order. The following is a resume of B_r value for each order.

Table. 6 *B_r calculations for each order*

Order	Number of Channels (N_i)	B_r
1	29	4,83
2	6	6
3	1	-
	Average B_r	5,42

Based on the results of the analysis, 29 channels are identified for order 1 with a value of B_r 4.83 and 6 channels for order 2 with a value of B_r of 6. On the average, the value of B_r for the Tiga Dihaji Dam Watershed is 5.42. The average value of B_r means that the Tiga Dihaji Dam watershed has the characteristics of a rapid increase as well as decrease in flooding.

4. CONCLUSIONS

Based on the results of the study, it can be concluded that:

1. Based on the results of the morphometric characteristic analysis of the Tiga Dihaji Dam Watershed it is revealed that the watershed area is 1,158.2 km^2 with an elongated watershed shape and a river length of 61.3 km. The density of the watershed is classified as Very Rough as indicated by a Dd value of 0.26. It can also be illustrated through the river branching variable through the B_r value of 5.42 which means that the Tiga Dihaji Dam Watershed has the characteristics of a rapid increase as well decrease in flooding.
2. Based on meteorological characteristics, this watershed has a high average annual rainfall of 2,535 mm / year, while the watershed climate conditions is revealed as follows: the watershed's temperature ranges from 26.5 - 28.0 °C, irradiation time ranges from 35 , 8 - 67.4%, humidity ranges from 78.7 - 87.6% and wind speed ranges from 1.2 - 1.8 m / s.
3. Geologically, the Tiga Dihaji Dam Watershed is composed of clay rock, sandstone, silt and napal stones at 43.3%, while for soil types it is dominated by Sandy Clay Loam which means that the watershed has the potential to produce a fairly large river discharge.

4. This watershed has a height distribution ranging from 0-2,500 masl with a slope of 0.965%. In terms of land use, the Tiga Dihaji Dam watershed is dominated by mixed dryland agriculture and bushes by 47.1%. The value of the composite curve number of the Tiga Dihaji Dam watershed is 79 which means that this watershed is large enough to pass rainwater to become runoff discharge.
5. Based on the results of the analysis of meteorological, morphological, and morphometric characteristics, in general the variables of each watershed characteristic explains that the Tiga Dihaji Dam Watershed has the potential to cause flooding in the rainy season which can cause flooding in several areas. In addition, with the elongated shape of the watershed and very coarse density, it indicates that groundwater storage is very low so that it can cause drought during the dry season.

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