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Research Paper

Rain Station Distribution Analysis On Design Flood Debit In Bondoyudo Watershed, Lumajang District

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ABSTRACT: *Several things that need to be considered regarding rain stations, one of which is that the optimum density means a sufficient number and adequate distribution throughout the watershed. Then the density is not too high, because it will result in expensive installation and maintenance costs. And the distribution of rain stations is able to describe the well-observed variability of the watershed space. To be held, an analysis of the distribution of rain stations on the design flood discharge in the Bondoyudo watershed, Lumajang Regency was conducted. Based on the results of the analysis carried out, it was revealed that the distribution conditions of the rain stations in the Bondoyudo watershed are relatively large, where currently there are 16 rain stations in the watershed area of 267.3 km2. According to WMO standards, 2 stations are represented, whereas Bleasdale is recommended 4 stations. Varshney defined the number of 8 stations as the ideal number, then Sugawara suggested 10 or 15 stations. The strongest relationship between topographic aspects of rainfall is the height difference to rainfall (R = 0.918), where the higher the elevation of the rain station (the greater the height difference to AWLR), the rainfall will also be of higher value.*
KEYWORDS: *distribution, rain station, discharge*

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I. INTRODUCTION

Geographically, Lumajang Regency Government is located approximately 154 km to the east of Surabaya City, the capital city of East Java Province which lies at a position between 1120 50'-1130 2" East Longitude and "70 52" - 80 23"" South Latitude. Lumajang Regency consists of 21 (twenty one) districts, namely: Yosowilangun, Kunir, Tempeh, Pasirian, Candipuro, Pronojiwo, Tempursari, Rowokangkung, Tekung, Lumajang, Sumbersuko, Sukodono, Senduro, Pasrujambe, Padang, Gucialit, Jatiroto, Randuagung, Kedungjajang, Klakah and Ranuyoso. The administrative boundaries of Lumajang Regency are as follows:

- In the north, it is bordered by Probolinggo Regency
- In the east, it is bordered by Jember Regency
- To the south is bordered by the Indonesian Ocean
- In the west, it is bordered by Malang Regency

Overall, Lumajang Regency has an area of 1,790.90 km², with the largest area in Senduro and Pasirian Districts, respectively 12.77% and 10.27% of the total area of Lumajang Regency.

Hydrological analysis is part of the initial analysis of water construction planning. Water structures in this case are in the form of weirs, overflow buildings, flood-retaining embankments, culverts and so on. Hydrological analysis requires data consisting of rainfall data, discharge data and climate data. This requires multiple numbers of rain stations and the correct placement of rain locations.

To determine the amount of rain that falls in a watershed (DAS), a number of rain stations are required to be installed in such a way that data representing the amount of rain in the watershed is obtained. The accuracy of the measurement of rain data is influenced by the number of rain stations and the distribution pattern in the watershed. The precise placement of rain stations, the number of rain stations, and the distribution patterns will be able to obtain accurate data regarding the depth, distribution and intensity of the rain. Rain intensity is the height of rainfall that occurs at a time during which the water is concentrated [1]. experimental formulas such as the Tallbot, Mononobe, Sherman and Ishigura formula [2]. Things that need to be considered about rain stations [3], are:

1. The optimum density means sufficient quantity and adequate distribution throughout the watershed

2. The density should not be too high, because it will result in expensive installation, operation and maintenance costs.
3. The distribution of rain stations is able to describe the well-observed variability of the watershed space.

Getting the optimum density and distribution of rain stations in Indonesia is not easy. Moreover, the topographic conditions in Indonesia are different from the topographical conditions where the methods of distribution patterns are formulated. The higher the density of the rain station, the more accurate the data obtained, but it must also be noted that the costs are not small for the construction, operation, maintenance, measurement, processing and publication of data as well as the procurement of equipment.

Analysis of the distribution of rain is needed to determine whether the current number of rain stations can represent the conditions of the research location area so that it can optimize the number of rain stations which aims to be a consideration for decision making for institutions for cost, energy and time efficiency. So it is necessary to rationalize the optimal and efficient rain station network both from an economic and management perspective so that it can be seen which rain stations are dominant and representative in the Bondoyudo watershed.

The Bondoyudo Watershed is one of the major watersheds in Lumajang Regency. Information on hydrological conditions is needed to support the management of water resources in a watershed. Hydrology also studies the behavior of rain, especially covering the return period of rainfall because it is related to flood calculations and plans for water structures. This is inseparable from the importance of the ideal number of rain stations and the placement of stations that can represent the characteristics of a watershed.

Based on the above background, it is necessary to conduct research with the topic of analyzing the distribution of rain stations to the design flood discharge in Das Bondoyudo, Lumajang Regency.

II. METHODOLOGY

The Research Location

Most of the main rivers in Lumajang Regency flow into the Indonesian Ocean. Lumajang Regency has 46 rivers, 369 dams, 254 water pumps and 6 waterfalls, besides that there are also potential lakes / ranu such as Ranu Pakis, Ranu Klakah etc. Hydrographic potential has provided considerable opportunities for development both for drinking water, irrigation, industry and tourism. There are several rivers that flow in Lumajang Regency, namely in Glidik, Kali Rawan, Kali Gede, Kali Regoyo, Kali Rejali, Besuk Sat, Kali Mujur and Bondoyudo. River management in Lumajang Regency is carried out by two agencies, namely the Bondoyudo - Mayang Regional Water Resources Management Office, which is the UPT of the Office of PU Pengairan, East Java Province in Lumajang, which manages primary and secondary irrigation networks in irrigation areas with an area of 1000 - 3000 Ha or irrigation areas <1000. Ha which is cross regency / municipality, meanwhile for primary and secondary irrigation networks in irrigation areas within districts with an area of <1000 ha, it is managed by the Lumajang District Public Works Office. The following are the names and discharge of rivers in Lumajang Regency.

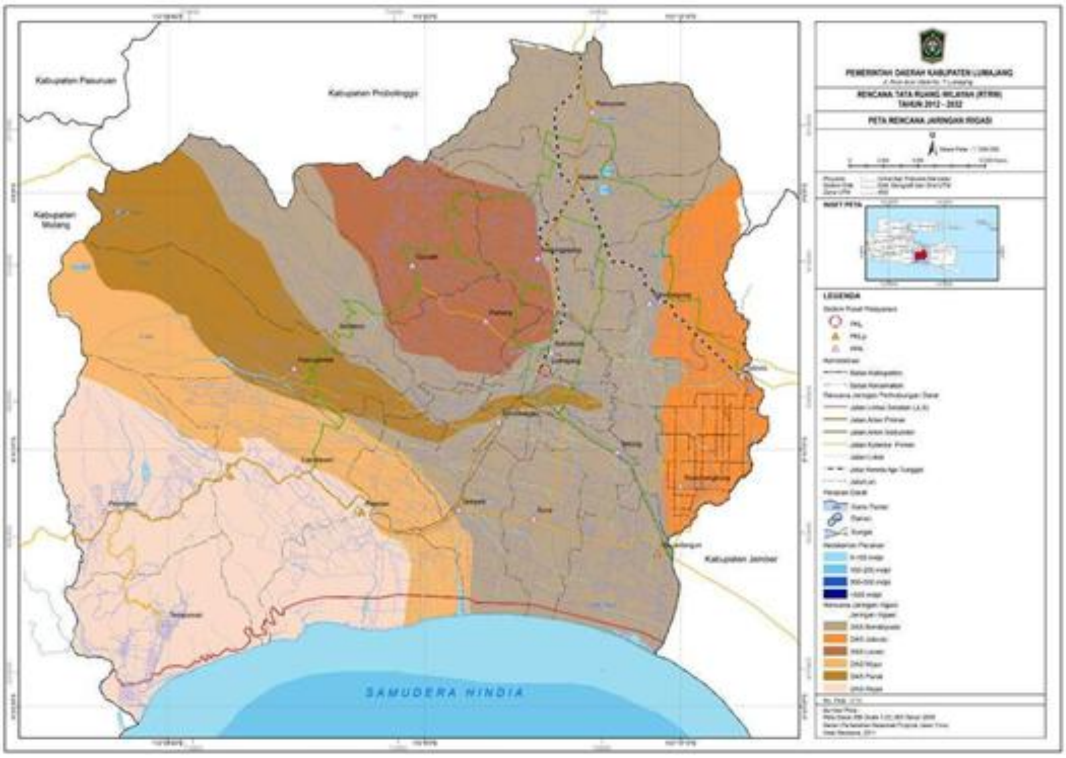
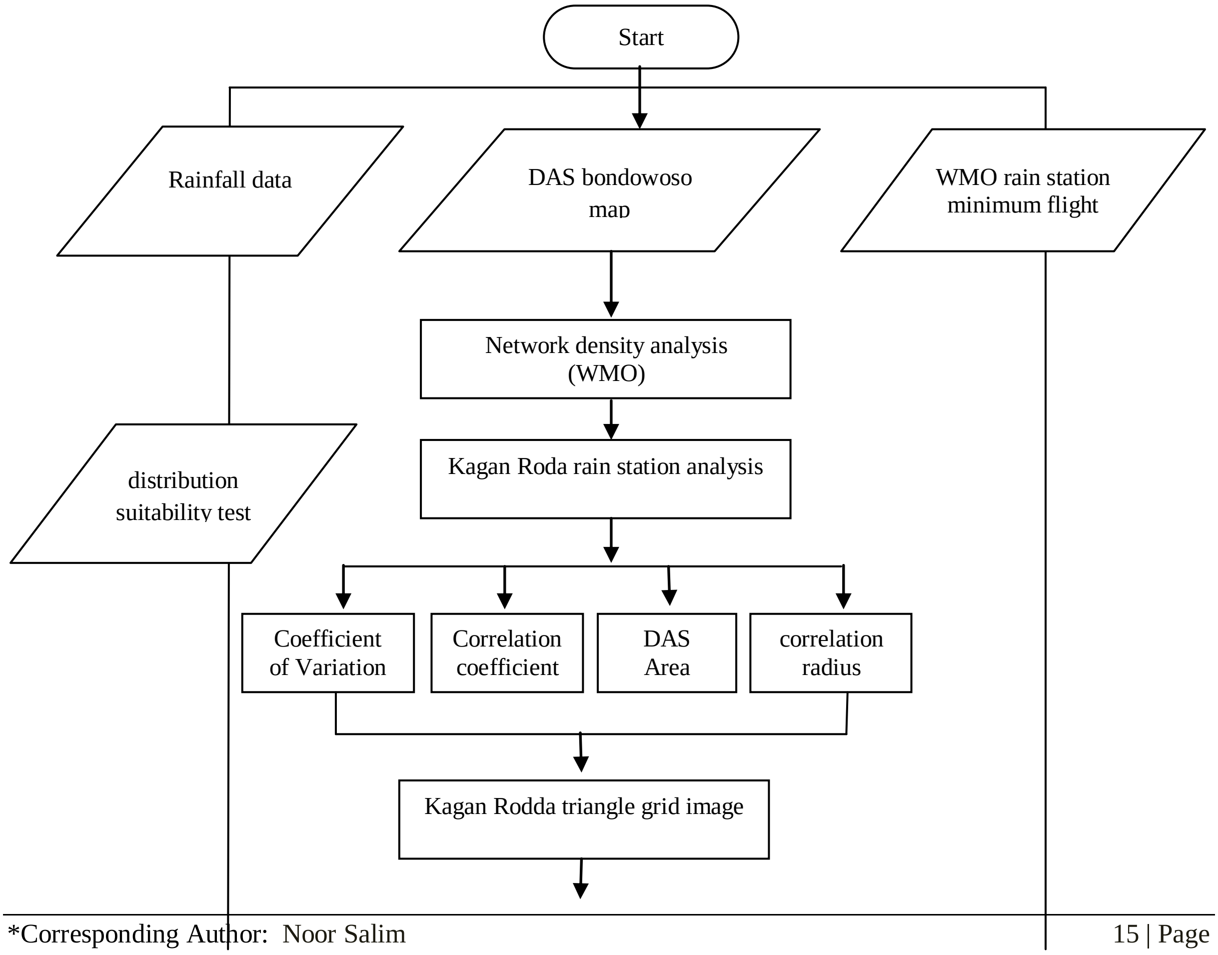


Figure 1 : Lumajang Regency Hydrology Map

Research Flowchart

The flow of research carried out to analyze the distribution of rain stations to the design flood discharge in Das Bondoyudo, Lumajang Regency is presented in the following chart.



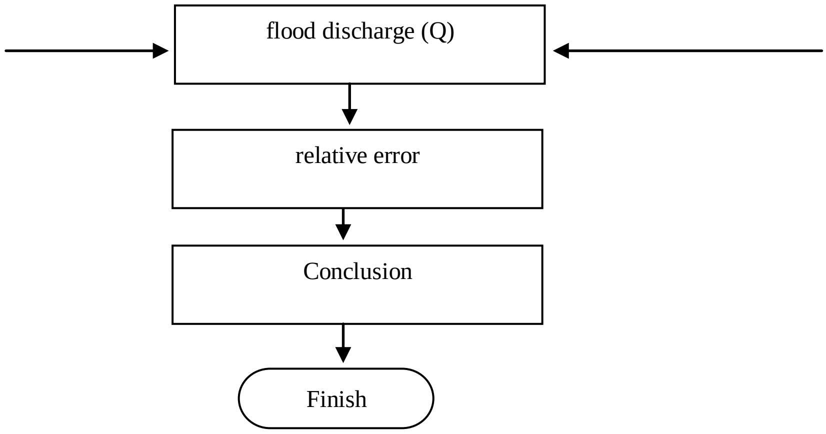


Figure 2 : Research Flowchart

Study Stages
The data processing stages are as follows:

1. The required data
   a. Monthly rainfall data
   b. Pos Duga Air monthly debit data
2. Test consistency with the multiple mass curve method
3. Analysis of the maximum daily average rainfall in the watershed using 2 calculated average methods and the Thiessen Polygon.
4. Analysis of the frequency distribution using the Log Pearson Type III method and then tested the suitability of the distribution with the Smirnov-Kolmogorov test and Chi Square.
5. Calculate the correlation coefficient and graph the relationship between the distance and the correlation value between rain stations, then determine the line equation r (o) and d (o) from the regression equation obtained.
6. Determine the required number of rain stations on the condition that the leveling (Z1) = 5% and the side length of the Kagan-Rodda net.
7. Plot the Kagan Rodda network above on the watershed map and select the station closest to the kagan node point.
8. If the station has been selected, then calculate the maximum daily average rainfall of the Kagan Rodda network using 2 methods, namely the Average Rainfall and the Thiessen Polygon.
9. Then calculate the frequency analysis and test the suitability of the distribution in accordance with what was done in a step according to the existing conditions.
10. Calculate the design rainfall for the Kagan-Rodda network using the Log Pearson Type III method.
11. Calculating the relative error of rainfall in the existing design conditions with the rainfall designed by Kagan Rodda.
12. Determine the hourly rainfall based on existing flow coefficients.
13. Calculating the design flood discharge using the Nakayasu Synthetic Unit hydrograph method.

III. RESULTS AND DISCUSSION

Rainfall data used is rainfall data from 4 rain stations in the Bondoyudo watershed. All existing data on 4 rain stations were recorded by the Lumajang Regency Spatial Planning and Water Resources Service.

TAB. 1 Data on Rain Stations in the Bondoyudo Watershed

No.	Rain Station Name	Rain Station Area	Thiessen coefficient
1	Gucialit	11.326,695 Ha	0,42
2	Senduro	3.437,155 Ha	0,127
3	Sukodono	12.225,368 Ha	0,453

Source: Department of Spatial Planning and Water Resources Kab. Lumajang (2019)

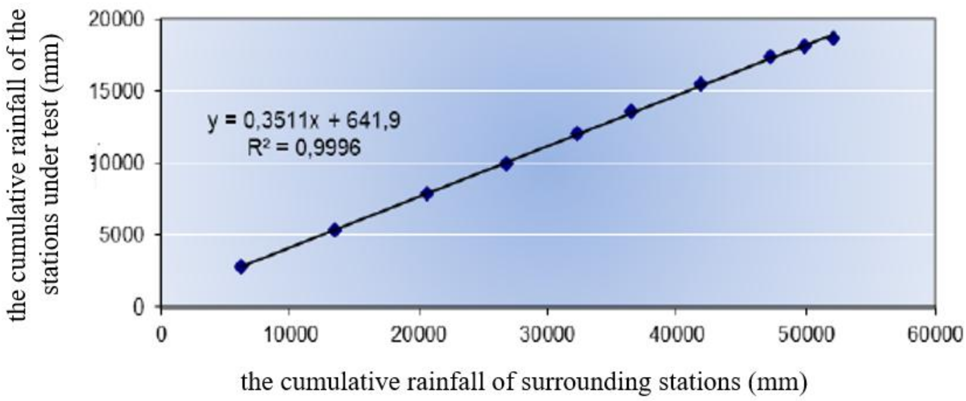
Rain Data Consistency Test

The data consistency test is intended to find out the correctness of field data. To determine the consistency of each rainfall data, the test can be carried out using multiple mass curve analysis starting from the last year

TAB. 2 Consistency Test of Badong Station to Nearby Stations

No	Year	Sukodono Station		Surrounding Station	
		R1 (mm)	$R1_{Kom}$ (mm)	R2 (mm)	$R2_{Kom}$ (mm)
1	2010	2813,00	2813,00	6176,00	6176,00
2	2011	2524,00	5337,00	7291,00	13467,00
3	2012	2524,00	7861,00	7212,00	20679,00
4	2013	2109,00	9970,00	6132,00	26811,00
5	2014	2044,00	12014,00	5520,00	32331,00
6	2015	1597,00	13611,00	4197,00	36528,00
7	2016	1889,00	15500,00	5394,00	41922,00
8	2017	1895,00	17395,00	5419,00	47341,00
9	2018	687,00	18082,00	2520,00	49861,00
10	2019	631,00	18713,00	2229,00	52090,00

Source: Calculations



Source: Calculations

Figure 3: Consistency Test of Badong Station Rain Data

The data from the curve test results look consistent, meaning that there is no curve change

Regional Average Rainfall Calculation

The calculation of the regional average rainfall uses the Polygon Thiessen method. The Thiessen Polygon method is also known as the weighted mean method. This method provides a proportion of the area of land under the influence of the rainfall post to accommodate the variability of the distance [4].

TAB. 3 Regional Average Rainfall by Thiessen Polygon Method

No	**Tahun**	**Rain Station (mm)**			**Bulk Average Rain Area (mm)**
		Gucialit	**Sukodono**	**Senduro**	
		0,31	**0,33**	**0,36**	**R**
1	2010	112,0	112,0	79,0	100,0
2	2011	83,0	83,0	83,0	83,0
3	2012	96,0	96,0	96,0	96,0

4	2013	197,0	197,0	118,0	168,4
5	2014	84,0	84,0	118,0	96,3
6	2015	108,0	84,0	118,0	103,7
7	2016	118,0	107,0	118,0	114,4
8	2017	118,0	107,0	118,0	114,4
9	2018	79,0	79,0	118,0	93,1
10	2019	79,0	79,0	118,0	93,1

Source: Calculations

Rainfall Analysis Design Frequency Distribution Log Person III

This study uses the Log Person Type III method because this method can be used for all data distributions where the skewnes price (Cs) and the kurtosis coefficient (Ck) are free. Following are the results of the calculation of the relationship between Cs and G and the calculation of rainfall for the design of the Perso Log Type III Existing Conditions:

TAB. 4 Selection Methods for Analysis of the Frequency Distribution of Watershed Rain Data

No.	Year	R_i	P	$(R_i - R)$	$(R_i - R)^2$	$(R_i - R)^3$	$(R_i - R)^4$
1	2010	100,04	9,09	-6,21	38,51	-239,01	1483,3
2	2011	83,00	18,18	-23,25	540,36	-12560,98	291987,9
3	2012	96,00	27,27	-10,25	104,97	-1075,51	11019,3
4	2013	168,37	36,36	62,12	3859,16	239739,61	14893144,2
5	2014	96,32	45,45	-9,92	98,46	-977,05	9695,2
6	2015	103,71	54,55	-2,54	6,43	-16,29	41,3
7	2016	114,37	63,64	8,13	66,05	536,82	4362,8
8	2017	114,37	72,73	8,13	66,05	536,82	4362,8
9	2018	93,13	81,82	-13,11	171,89	-2253,62	29546,7
10	2019	93,13	90,91	-13,11	171,89	-2253,62	29546,7
Total					5123,79	221437,15	15275190,2
Average/R		106,246					
	STD.DEV =	23,860					
	Cs =	2,264					
	Ck =	5,95					
	Cv =	0,225					

Source: Calculations

Information :

$$P\ (\text{plotting}) = \frac{m}{n+1} x100$$

The distribution selection requirements meet the following criteria:

Normal : CS = 0
Normal Log : CS = 2.5CV
Gumbel : CS = 1.1396; CK = 5.4002
Pearson logs : which are not included in the above terms

Based on the results of the above calculations, the Log Pearson Type III distribution is used

TAB. 5 Calculation of rainfall plan method Log Pearson III

No	Year	R (mm)	LogR	Log R -Log Rr	(Log R -LogRr)^2	(LogR -LogRr)^3	Calculation Results	Infor.
1	2004	100,0	2,000	-0,018	0,000	0,000	Log Rr = 2,0182	
2	2005	83,0	1,919	-0,099	0,010	-0,0010	S = 0,0843	
3	2006	96,0	1,982	-0,036	0,00129	-0,0000465	Cs = 1,8147	
4	2007	168,4	2,226	0,208	0,043	0,009	G(2) = -0,0299	Table
5	2008	96,3	1,984	-0,034	0,0012	-0,000041	G(5) = 0,8311	Table
6	2009	103,7	2,016	-0,002	0,000	0,0000	G(10) = 1,2992	Table
7	2010	114,4	2,058	0,040	0,002	0,0001	G(25) = 1,8118	Table
8	2011	114,4	2,058	0,040	0,002	0,0001	G(50) = 2,1490	Table
9	2012	93,1	1,969	-0,049	0,002	-0,0001	G(100) = 2,4585	Table
10	2013	93,1	1,969	-0,049	0,002	0,000		
n =	10							
Total			20,182	0,000	0,064	0,008		
Average		Log Rr	2,018					

Source: Calculations

$$S_y = \sqrt{\frac{\Sigma(\text{Log R} - \text{Log Rr})^2}{n-1}}$$

S_y = 0,0843

$$Cs = \frac{n \cdot \Sigma(\text{Log R} - \text{Log Rr})^3}{(n-1)\cdot(n-2)\cdot Sy^3} \qquad G = \frac{\Sigma(\text{Log R} - \text{Log Rr})^3}{(n-1)\cdot(n-2)\cdot Sy^3}$$

Cs = 1,8147 G = 0,1815

From Equation

Log Rt = Log Rr + G. S_y
Log Rt = 2.014 + G. 0.1183

TAB. 6 Rainfall Design Pearson Log Type III Existing Conditions

Time to Repeat	G	From Table		K
		Coef	% Opportunity	
2	0,1815	0,20	-0,033	-0,0299
		0,00	0,000	
5	0,1815	0,20	0,830	0,8311
		0,00	0,842	
10	0,1815	0,20	1,301	1,2992
		0,00	1,282	
25	0,1815	0,20	1,818	1,8118
		0,00	1,751	
50	0,1815	0,20	2,159	2,1490
		0,00	2,051	
100	0,1815	0,20	2,472	2,4585
		0,00	2,326	

Source: Calculations

Conclusion:
Dmax <Do (5%) The distribution equation is acceptable
Dmax> Do (1%) The distribution equation is unacceptable
From the table above, it can be seen that Dmax <Dcritical so that it can be concluded that the selection of the Log Person Type III frequency distribution can be applied.

Chi Square test

TAB. 8 Chi Square Test Class Limits

Pr	G	G*S		Log Rt	Rt
75	-0,618	-0,052		1,966	92,4956
50	0,139	0,012		2,030	107,1367
25	0,735	0,062		2,080	120,2770

Source: Calculations

TAB. 9 Chi Square Test

X			Oi	Ei	Oi - Ei	$(Oi-Ei)^2/Ei$
0	-	92,50	3	2,31	0,69	0,20
92,50	-	107,14	3	2,31	0,69	0,20
107,14	-	120,28	1	2,31	-1,31	0,75
	>	120,28	3	2,31	0,69	0,20
			10	9,25		1,36

Source: Calculations

For a = 5% → X2 = 1,36
For a = 1 % → X2 = 2,35
Conclusion : because X2 hit < X2 critis so distribution fulfills

Design Flood Discharge
To determine design flooding, if the discharge data in the desired area is sufficient, it can be directly used to determine design flooding with frequency analysis. If in the area the discharge data is very limited, then rain data can be used [5]. This study is to find the value of the design flood discharge using rain data

Hourly Rain Distribution
In Indonesia there is no more than 7 hours of concentrated rain, so in this calculation it is assumed that the maximum concentrated rain is 6 hours a day. The hourly rain distribution is calculated by the Mononobe formula:

$$R_t = \frac{R_{24}}{24}\left(\frac{24}{t}\right)^{\frac{2}{3}}$$

With:
Rt = average rainfall intensity in t hours (mm / hour)
R24 = effective rainfall in 1 day
t = rain time based on this equation, the results of the ratio of the distribution of rain and distribution of rain for 6 hours are as follows:

TAB. 10 Distribution of Hourly Rain

Time	Ratio	Hourly Rain			
		10	25	50	100
1	0,5438	24,0820	26,6012	28,4007	30,1591
2	0,1445	6,3999	7,0695	7,5477	8,0150
3	0,1017	4,5056	4,9770	5,3136	5,6426
4	0,0812	3,5952	3,9713	4,2399	4,5024
5	0,0687	3,0411	3,3593	3,5865	3,8086
6	0,0601	2,6619	2,9403	3,1392	3,3336
Effective rain		44,2857	48,9185	52,2276	55,4613
Flow coefficient		0,33	0,33	0,33	0,33
Rain plan		134,1991	148,2379	158,2655	168,0645

Source: Calculations

Nakayasu Synthetic Unit Hydrograph

Unit hydrograph is used in the calculation of the design flood discharge in a watershed if there is no discharge measuring device in the watershed. Several methods of calculating the unit hydrograph have been developed, either using flood data in the river or using syntetic unit hydrographs such as Snyder, Nakayasu, Gama I and others. In this study, the Najayasu sitetic unit hydograph was used. Unit hydrograph is a hydrograph of direct runoff produced by effective rain that occurs evenly throughout the watershed with a constant intensity in a set time unit. There are two main assumptions in the master hydrograph, namely evenly distributed rain and constant rain intensity [6]. According to [7] in his research, it was said that the selected flood hydrograph was the result of the HSS Nakayasu method, where the peak flood time was more in accordance with the characteristics. The calculation of flood discharge using the HSS method is more appropriate for planning water structures because the Nakayasu HSS diagram provides an overview of the discharge when the rain begins, when the flood ends and the flood ends [8].

From the hourly distribution table, the calculation of the Nakayasu synthetic unit hydrograph can be continued with the following parameters:

TAB 11. Nakayasu Synthetic Unit Hydrograph Ordinate

t (hour)	Q (m3/dt)	Keterangan
0,0	0,0000	the curved part goes up for t < Tp
2,0	12,4728	
2,5	**20,4443**	**peak discharge**
4,0	14,6992	for Tp < t < Tp+T0.3
6,0	9,5841	
8,0	6,2490	
10,0	3,6996	Tp+T0.3 < t < Tp+2.5T0.3
12,0	2,9874	
14,0	2,4122	
16,0	1,9478	
18,0	1,5728	
20,0	1,1224	curved section down for t > Tp+2.5T0.3
22,0	0,8439	
24,0	0,6346	
26,0	0,4771	
28,0	0,3588	
30,0	0,2698	
32,0	0,2028	
34,0	0,1525	
36,0	0,1147	
38,0	0,0862	
40,0	0,0648	
42,0	0,0488	
44,0	0,0367	
46,0	0,0276	
48,0	0,0207	
50,0	0,0156	

Source: Calculations

TAB. 12 Recapitulation of Design Flood Discharge Hydrograph Calculation Using the Nakayasu Method

HOUR	10 YEAR	25 YEAR	50 YEAR	100 YEAR
0,00	0,000	0,000	0,000	0,000
2,00	300,371	331,793	354,237	376,170
2,46	**572,164**	**632,019**	**674,772**	**716,551**
8,00	337,528	372,837	398,058	422,704
14,00	240,527	265,689	283,662	301,225
16,00	203,391	224,668	239,865	254,717
18,00	178,148	196,785	210,096	223,104
20,00	128,273	141,692	151,277	160,644
22,00	65,897	72,791	77,715	82,527
24,00	44,057	48,666	51,958	55,175
26,00	33,113	36,577	39,052	41,470
28,00	24,973	27,586	29,452	31,275
30,00	18,778	20,742	22,145	23,517
32,00	14,119	15,597	16,652	17,683
34,00	10,617	11,727	12,521	13,296
36,00	7,983	8,818	9,415	9,997
38,00	6,003	6,630	7,079	7,517
40,00	4,513	4,986	5,323	5,652
42,00	3,394	3,749	4,002	4,250
44,00	2,552	2,819	3,009	3,196
46,00	1,919	2,119	2,263	2,403
48,00	1,443	1,594	1,701	1,807
50,00	1,085	1,198	1,279	1,359

Source: Calculations

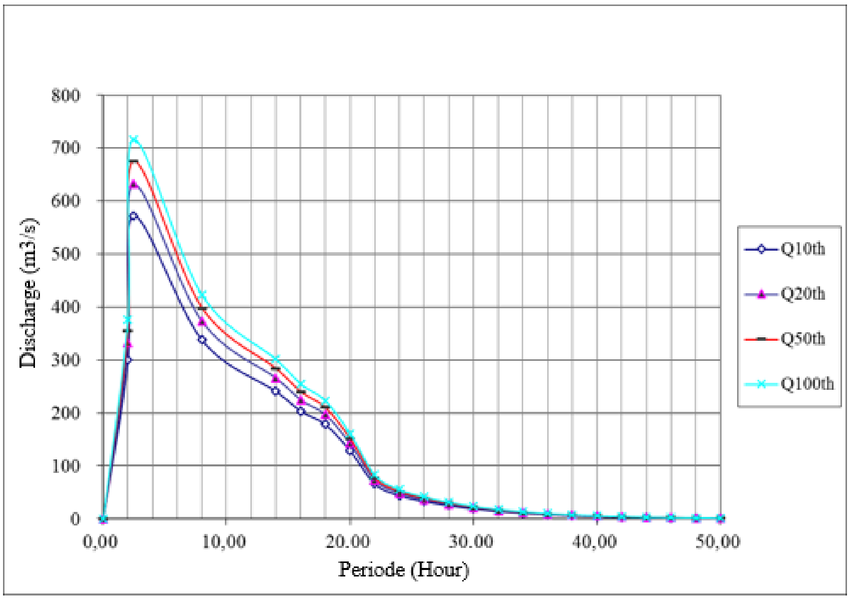


Figure 4 : Designed Flood Hydrograph Graph with various timescales

Combined Rain Station Network Using Other Methods
The network density method can be used as an alternative combination

Table 13. Recapitulation of Network Density

No	Standart	Approach	Total of Station
1	WMO	Empirical	2
2	Sugawara	Empirical	10/15
3	Bleasdale	Empirical	4

4	Varshney	statistics	8

Source: Calculations, 2017 (14-42-1-PB)

In general, all methods show relatively the same results, namely the reduction of rain stations, except for Sugawara. Sugawara's method is considered unsuitable because it does not pay attention to area.

The WMO method is considered the most suitable, because it is ideal and more practical, as well as applicative to be applied. Using the WMO method as the lower limit (2 stations), there are 12 networks that can be analyzed.

TAB. 14 Combination of New Station Networks

No.	Station Elimination	Total of Stations	Total of Combinations
1	1	3	3
2	2	2	6
3	3	1	3
Total			12

Source: Calculation Results (3566-8355-1-PB)

IV. CONCLUSIONS AND SUGGESTIONS

Conclusion

1. The condition of the distribution of rain stations in the Bondoyudo watershed is relatively large, where currently there are 16 rain stations in a watershed area of 267.3 km2. According to WMO standards, 2 stations are represented, whereas Bleasdale suggests 4 stations. Varshney set the number of 8 stations as the ideal number, then Sugawara suggested 10 or 15 stations.
2. Artificial neural networks offer an alternative to selecting a new rain station network by experimenting with each combination of station networks that can be formed, then modeling the river discharge and then comparing it with the original data. With the existing network density method, the new combination of stations is limited from 2 to 3 stations, with a total combination of 12 units.
3. The strongest relationship between topographic aspects of rainfall is the height difference to rainfall ($R = 0.918$), where the higher the elevation of the rain station (the greater the height difference to AWLR), the higher the rainfall will be.

Suggestion

1. The condition of the existing rain station network is currently too excessive and ineffective, so that stations that say they are less representative cannot be moved to another point in the Bondoyudo watershed or can also be moved to another watershed where the network density is still low in the Lumajang region. the working area of the Lumajang Regency Office).
2. ANN analysis has not been widely used in the analysis of rain station networks, so further research is needed to ensure its accuracy. However, the ANN method is considered time-consuming. The studies carried out include a lot of rain stations, so it may be more suitable and only suitable for small watersheds with not too many stations.
3. In practice, the relationship between the occurrence of discharge originating from rain is not as simple as one might imagine. In order for ANN analysis to be able to model discharge properly, of course, it requires more complete data (not only rainfall data), for example data on land use, vegetation cover, topography, and soil types. However, in reality the data is difficult to obtain, so the analysis is limited to rainfall - discharge modeling.
4. In addition, the relationship (relationship) between each rain and discharge must also be good enough. If this is not the case, then it is understandable that the results of the analysis are ultimately unsatisfactory. Another factor that is also thought to have an effect is the time lag or time lag, but it seems that this factor is very dominant in the daily database. Meanwhile, the monthly data can be ignored (not too big).
5. The relationship between topographical aspects of rainfall in this study is hypothetical and empirical for the watershed area studied, so it is necessary to obtain a lot of comparisons from other watersheds in order to strengthen the arguments held.

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