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Design Flood Discharge of 50 Years in Garang River Using Nakasayu Synthetic Unit Hydrograph Method

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Abstract: Various kinds of buildings in civil engineering require a careful planning. For example, the planning of a water building needed a method to calculate the design flood discharge before starting to plan the dimensions of the building to meet the effectiveness of the water structure. Design flood discharge can be determined using several hydrograph methods that have been used in water building planning in Indonesia. One of the popular hydrograph methods is the Nakayasu Synthetic Unit Hydrograph method. In this case, the design flood discharge is in the Garang watershed, precisely in Semarang, Central Java province, using rainfall data for the past 16 years. Hydrological analysis is carried out first before determining the design flood discharge with a return period of 2, 5, 10, 25, and 50 years. The results of the design flood discharge using Nakayasu method respectively were 305,522 m^3/s, 390,742 m^3/s, 447,783 m^3/s, 520,560 m^3/s, and 574,912 m^3/s.

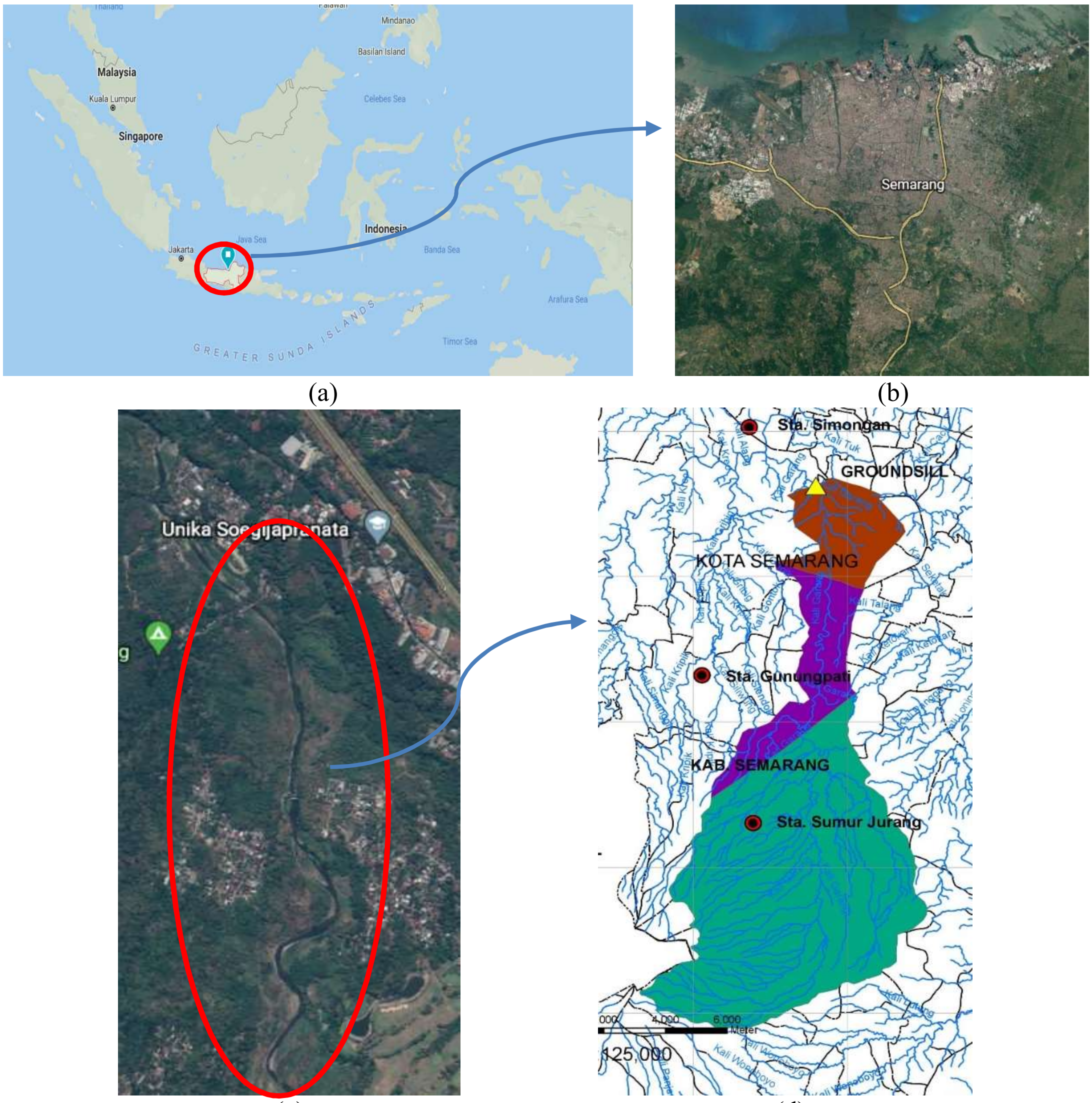
Keywords: building, flood discharge, hydrograph, method, and Nakayasu.

INTRODUCTION

The calculation of design flood discharge is the most important aspect of planning the water structure. Design flood discharge is a component which is needed to determine the magnitude of peak flow discharge in a Watershed. This flood discharge will be used in calculating the dimensions of water structures such as dams, groundsill, and so on. Design flood discharge can be calculated using rational methods and several hydrograph methods that previously have been used in the planning of water structures in Indonesia.

Hydrograph is a method that uses diagrams to illustrate the relationship between flow rate and time. A hydrograph must be adjusted by observing and analyzing hydrology to determine the characteristics in a watershed. Some popular hydrograph methods include ITB, GAMA-1, SCS, ITS-1, ITS-2 and Nakayasu [1]. The method used in this study is Nakayasu Synthetic Unit Hydrograph method.

The calculated flood discharge is 2, 5, 10, 25, and 50 years. The location chosen for research is in the Garang watershed, starting from the head of the river to the coordinates 7° 1' 40.444" S and 110° 24' 7.999" E where it is known with its fast flow in a short time [2]. Therefore, the determination of design flood discharge is needed especially for the advantage of the local society if they want to plan the building's construction around the river. The research location is shown in the figure 1:



(a) (b)

(c) (d)

FIGURE 1. Map of research location
(source: earth.google.com and tanahair.indonesia.go.id)

Before drawing a hydrograph curve, the first step is to look for its constituent components, such as rainfall intensity and base flow. Rain intensity is the level of rainfall per unit of the time, it can be calculated using the Manonobe method which is described as follows [3]:

$$I = \frac{R_{24}}{24}\left(\frac{24}{t}\right)^{\frac{2}{3}} \quad \text{a)}$$

where :

I = rain intensity (mm/hour)
t = rain duration (hours)
R_{24} = maximum rainfall (mm)

The base flow which has a meaning as groundwater flow due to rainfall that come through infiltration and percolation can be searched with the following formula[4]:

$$Qb = 0{,}4751\,.A^{0{,}6444}.D^{0{,}943} \quad \text{b)}$$

where :

Qb = base flow (m^3/s)
A = watershed area (km^2)

D = drainage density (km/km^2)

The Nakayasu Synthetic Unit Hydrograph method is the first hydrograph method developed in Japan[5]. This method has been applied several times in water structures in East Java. Sutapa [6] opined that until now the use of the Nakayasu method has given satisfactory results. The equation used to draw a hydrograph is as follows[7]:

$$Qp = \frac{C\,.\,A\,.\,R_O}{36\ .(0{,}3\,Tp) + T_{0,3}} \qquad \text{c)}$$

$$Tp = Tg\ +\ 0{,}8\,.Tr \qquad \text{d)}$$

$$Tg = 0{,}21.L^{\,0,7} \qquad \text{if } L < 15 \text{ km} \qquad \text{e)}$$

$$Tg = 0{,}4 +\ 0{,}058\,.L \qquad \text{if } L > 15 \text{ km} \qquad \text{f)}$$

$$Tr = 0{,}5\ s/d\ 1\,.Tg \qquad \text{g)}$$

$$T_{0,3} =\ \alpha\,.Tg \qquad \text{h)}$$

Meanwhile, drawing Nakayasu hydrograph curve is divided into 3 conditions which are described as follows:

$$Qt = Qp\ .\ 0{,}3^{\frac{t-Tp}{T_{0,3}}} \qquad Tp < t \le (Tp + T_{0,3}) \qquad \text{i)}$$

$$Qt = Qp\ .\ 0{,}3^{\frac{(t-Tp)(0{,}5T_{0,3})}{1{,}5T_{0,3}}} \qquad (Tp + T_{0,3}) \le t \le (Tp + T_{0,3} + 1{,}5T_{0,3}) \qquad \text{j)}$$

$$Qt = Qp\ .\ 0{,}3^{\frac{(t-Tp)(0{,}5T_{0,3})}{2T_{0,3}}} \qquad t > (Tp + T_{0,3} + 1{,}5T_{0,3}) \qquad \text{k)}$$

where :

Qp = flood peak flow rate (m^3/s)
C = runoff coefficient
A = watershed area (km^2)
R_o = unit rain (1 mm)
Tp = time interval from the beginning of the rain until the flood's peak unit
Tg = concentration time
Tr = rain time unit
$T_{0,3}$ = the time required by a decrease of peak discharge up to 30% of peak discharge.

METHODOLOGY

This case used several methods including the method of observation by direct observation of the study site to determine the conditions around the area and other components needed in the study. Documentation methods were also carried out by collecting data, such as rainfall data from the three nearest rain stations and concerning data of watersheds such as topography, area, and length. Last is the literature method by taking references from journals, modules, books that are supporting research.

The initial step to solve this case is to observe the research location and data collection. The step is continued by proceeding data such as regional rainfall analysis, frequency and probability analysis, data compatibility test, rainfall intensity analysis and design flood discharge analysis.

RESULT AND DISCUSSION

The rainfall data used 16 years of data from the nearest rain station, which is Sumurjurang, Simongan, and Gunungpati using the polygon-Thiessen method. The results of the regional rainfall analysis are provided below:

TABLE 1. Result of regional rainfall analysis

Years	R Max	Year	R Max
2003	149.88	2011	104.80
2004	116.17	2012	64.13
2005	80.85	2013	125.62
2006	92.10	2014	88.90
2007	61.97	2015	94.14
2008	158.23	2016	93.78
2009	66.25	2017	80.65
2010	125.97	2018	80.47

The distribution selection results using the log-Pearson III distribution method with rain return periods of 2, 5, 10, 25 and 50 years are described as follows:

TABLE 2. Result of log-Pearson III distribution

Log-Person III	
Average	98.9943
St. Dev	0.1243
Skewness	0.2393
Kurtosis	-0.7295
Variant	0.5195

TABLE 3. Rain return period of 2, 5, 10, 25, and 50 years

Years	k	Log Xt (mm)	Xt (mm)
2	-0.0381	1.9740	94.180
5	0.8259	2.0814	120.605
10	1.3041	2.1408	138.291
25	1.8322	2.2064	160.857
50	2.1803	2.2497	177.710

The results of the data validity test using the chi-square method by dividing class intervals of 5 classes are presented in the following table:

TABLE 4. Result of chi-square test

Classes	Limit Value for Each Class			Ei	Oi	Oi-Ei	$(Oi-Ei)^2$ / Ei
1	138.97	< Xi <	158.23	3.20	2	-1.20	0.450
2	119.72	< Xi <	138.97	3.20	2	-1.20	0.450
3	100.47	< Xi <	119.72	3.20	2	-1.20	0.450
4	81.22	< Xi <	100.47	3.20	4	0.80	0.200
5	61.97	< Xi <	81.22	3.20	6	2.80	2.450

The value of the chi-square test was 4, while the critical value in the table was 7,81. Then, it can be concluded that the tested data represent some or all the existing data.

While the results of rainfall intensity analysis using the manonobe method for 24 hours are described as follows:

TABLE 5. Rainfall intensity of 2, 5, 10, 25, and 50 years

Return Periods (t)	2	5	10	25	50
1	32.651	41.811	47.943	55.766	61.609
2	20.569	26.339	30.202	35.130	38.811
3	15.697	20.101	23.049	26.810	29.618
4	12.957	16.593	19.026	22.131	24.449
5	11.166	14.299	16.396	19.072	21.070
6	9.888	12.663	14.520	16.889	18.658
7	8.923	11.426	13.102	15.240	16.836
8	8.163	10.453	11.986	13.942	15.402
9	7.546	9.663	11.081	12.889	14.239
10	7.034	9.008	10.329	12.014	13.273
11	6.601	8.453	9.693	11.275	12.456
12	6.229	7.977	9.147	10.639	11.754
13	5.906	7.562	8.672	10.087	11.143
14	5.621	7.198	8.254	9.600	10.606
15	5.368	6.874	7.882	9.169	10.129
16	5.142	6.585	7.551	8.783	9.703
17	4.938	6.324	7.251	8.435	9.318
18	4.754	6.088	6.980	8.119	8.970
19	4.586	5.872	6.733	7.832	8.652
20	4.431	5.675	6.507	7.569	8.362
21	4.290	5.493	6.299	7.326	8.094
22	4.159	5.325	6.106	7.103	7.847
23	4.037	5.170	5.928	6.895	7.618
24	3.924	5.025	5.762	6.702	7.405

The width of the watershed and the length of the river are obtained through the analysis of the ArcGIS software. So, the results obtained from the base flow that have been calculated are described as follows:

TABLE 6. Result of base flow

Parameters	Values
Watershed area (A)	80.22
River length (L)	16.303
Drainage density	0.203
Base flow	1.784

Design flood discharge analysis curve using Nakayasu Synthetic Unit Hydrograph with a return period of 2, 5, 10, 25, and 50 years is presented in the following figure:

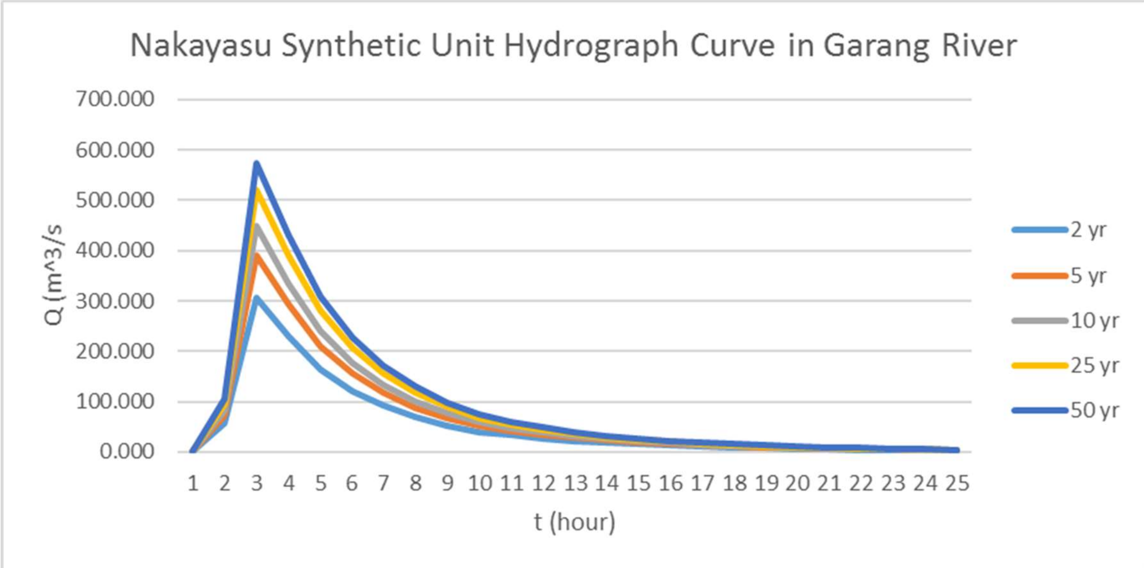


FIGURE 2. Hydrograph curve return period of 2, 5, 10, 25, and 50 years

The hydrograph curve shows that the design flood discharge increases as time goes on. The design flood discharge values obtained in the return periods of 2, 5, 10, 25, and 50 years were 305.522 m^3/s, 390.742 m^3/s, 447.783 m^3/s, 520.560 m^3/s and 574.912 m^3/s.

CONCLUSION

Based on the results of the discussion, it can be concluded that in the case of Garang watershed using rainfall data for 16 years with several hydrograph methods. One of them is using the Nakayasu Synthetic Unit Hydrograph. The values obtained were 305.522 m^3/s for the 2-years return period, 390.742 m^3/s for the 5-years return period, 447.783 m^3/s for the 10-years return period, 520.560 m^3/s for the 25-years return period and 574.912 m^3/s for the 50-years return period.

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