Sumatra Journal of Disaster, Geography and Geography Education: December 2025. Vol.9. No.2. pp. 52-59
Disaster, Geography, Geography Education http://sjdgge.ppj.unp.ac.id/index.php/Sjdgge
ISSN: 2580 - 4030 (Print) 2580 - 1775 (Online), Indonesia

FLOOD MODELING USING HEC-RAS SOFTWARE DUE TO THE OVERFLOW OF THE BENGAWAN SOLO RIVER IN BOJONEGORO REGENCY

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ABSTRACT: The Bengawan Solo River covers an area of approximately 16,100 km² and has a length of about 660 km. Increasing and irregular rainfall patterns have led to rising water levels in the Bengawan Solo River. Therefore, by utilizing technological advancements, floodplain modeling techniques can be applied using the HEC-RAS software as a flood disaster mitigation effort. The research method used involves calculating the flood discharge using the Synthetic Unit Hydrograph (HSS) Nakayasu method, followed by hydraulic analysis with the HEC-RAS software. The resulting flood discharge for the Q_{100} year return period is 11,570.98 m³/s. Based on the Q_{100} discharge value, the existing river cross-section is unable to accommodate the flow. From this analysis, the selected mitigation method is a structural approach in the form of river normalization.

Keywords: Flood, Bengawan Solo, Hydrologic Engineering Center (HEC-RAS), Nakayasu Synthetic Unit Hydrograph (HSS), Normalization.

1. INTRODUCTION

According to the National Disaster Management Agency (BNPB), Indonesia experienced 8,808 disasters from 2021 to 2023. There were 2,136 flood events during this period, resulting in 409 people reported dead or missing. A total of 4,386,758 people were affected by the floods, with 419,162 displaced and 105,808 houses damaged [1-3].

One of the rivers in Bojonegoro Regency that frequently experiences flooding is the Bengawan Solo River. This river is the longest in Java Island, flowing through two provinces Central Java and East Java. The Bengawan Solo River Basin (DAS) covers an area of approximately 16,100 km² and stretches about 660 km. Originally, the Bengawan Solo River flowed southward into the Indian Ocean, but due to geological processes, the flow was redirected. This occurred as a result of the collision between the Asian and Australian tectonic plates [4-5].

According to the mapping by the Regional Disaster Management Agency (BPBD) of Bojonegoro Regency, 146 villages across 16 sub-districts are potentially affected by the overflow of the Bengawan Solo River. Some of the impacted sub-districts include Kalitidu, Trucuk, Dander, Kota, and Kanor. Additionally, 32 villages spread across 10 sub districts including Temayang, Tambakrejo, Sukosewu, and Kapas are considered vulnerable to flash floods.

On December 16, 2016, a flood occurred in Bojonegoro Regency, inundating 3,627 houses across 81 villages in 15 sub-districts. The evacuation involved 3,369 people, 452 people suffered minor injuries, and 4 fatalities were reported. The estimated loss from this disaster reached Rp 4,681,950,000 [3]. The largest flood disaster in the Bengawan Solo River in Bojonegoro Regency occurred in 2007–2008. According to Bojonegoro Regent M. Santoso, 12,262 hectares and 9,755 hectares of farmland experienced total crop failure due to flooding. Additionally, corn and secondary crops on 1,427 hectares were destroyed. Agricultural land along the Bengawan Solo River Basin was submerged. The total estimated losses from this flooding reached Rp 598,326,509,050, and the report was submitted to the National Development Planning Agency (Bappenas) [6-9].

Due to increasingly high and irregular rainfall patterns, the water level of the Bengawan Solo River continues to rise. Therefore, flood risks need to be evaluated, and it is essential to understand the impacts of flooding in the Bengawan Solo River. To plan for preventive measures in flood-prone areas, an estimate of the river overflow is required. By using updated rainfall data, flood modeling for the Bengawan Solo River region is necessary.

Therefore, by utilizing technological advancements, floodplain modeling techniques can be applied through the HEC-RAS software. This modeling can identify flood-prone areas and estimate potential floods or river overflows. With an appropriate model, HEC-RAS can provide a clear representation to analyze water flow conditions in both 1D (one-dimensional) and 2D (two-dimensional) formats. It is highly useful in designing flood mitigation strategies and improving infrastructure. Thus, the objective of this study is to obtain flood inundation distribution and flow patterns in the Bengawan Solo River area of Bojonegoro Regency.

2. METHODS

The research began with a literature review, which involved collecting various references or knowledge sources related to the topic or issue under investigation. The researcher utilized literature obtained from online sources, previous studies, academic papers, and other relevant materials.

This study was conducted in the Bengawan Solo River region, located in Bojonegoro Regency. The research applied a quantitative method, with data collected from the Bengawan Solo River Basin Authority (Balai Besar Wilayah Sungai – BBWS Bengawan Solo). The scope of the research is outlined as follows:

1. The study uses several types of data, including topographic data, rainfall data, and river discharge data over a specific time period.
2. The research focuses on the flood distribution of the Bengawan Solo River within Bojonegoro Regency.
3. The objective of the study is to assess the effectiveness of the HEC-RAS model in evaluating flood risk mitigation efforts.

2.1 Hydrological Analysis

Hydrological analysis is an evaluation process aimed at calculating the flood potential in a given area so that it can be utilized according to the needs of the local population. This analysis serves as an initial step in planning water resource utilization and designing flood control measures.

Design Rainfall Calculation

According to [10-11], frequency analysis is a type of analysis used to estimate how likely rainfall will occur in a certain area, meeting the condition that the rainfall amount is equal to or exceeds a certain value within a specific period of time.

This calculation is carried out using several methods, each of which has its own distinct characteristics. For every set of hydrological data, a goodness of fit test must be conducted to determine the most suitable distribution based on its statistical characteristics. This calculation is carried out using several methods, each of which has its own distinct characteristics. For every set of hydrological data, a goodness of fit test must be conducted to determine the most suitable distribution based on its statistical characteristics. Table 1 below shows the factors influencing each distribution:

Table 1 Guidelines for the Selection of Frequency Methods

Method	Condition
Normal Distribution	$Cs \approx 0$ $Ck = 3$
Normal Log Distribution	$Cs \approx 3$ $Cv + Cv^2 = 3$ $Ck = 5{,}383$
Gumbel Distribution	$Cs \leq 1{,}1396$ $Ck \leq 5{,}4002$
Log Pearson Tipe III Distribution	$Cs \neq 0$

Source: Ministry of Public Works and Housing (PUPR)

Distribution Goodness of Fit Test

Hydrological data from frequency analysis may not necessarily match the distribution to be used in further calculations. Therefore, to determine the most appropriate distribution, the Chi-Square test and the Smirnov-Kolmogorov test must be applied. These tests help identify which distribution can be selected and accepted based on the smallest deviation value.

Chi-Square Test

$$X_h{}^2 = \sum_{i=1}^{G} \frac{(Oi - Ei)^2}{Ei} \quad \text{..............................(1)}$$

Smirnov – Kolmogorof Test

$$\Delta maks = [Pe - Pt] \quad \text{................................(2)}$$

Hourly Rainfall Distribution

The hourly rainfall distribution analysis for each return period is used to determine the rainfall intensity pattern of effective rainfall, which will be applied in the design flood discharge calculation. The hourly rainfall distribution in this study is obtained using the Mononobe equation, as follows:

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

After obtaining the hourly rainfall values, the next step is to calculate the rainfall distribution ratio using the following equation:

$$Rt = t.R_T - (t-1).R_{(T-1)} \quad \text{....................(4)}$$

Effective Rainfall Calculation

This calculation is used in the analysis of design flood discharge for a specific return period. The effective rainfall is calculated by multiplying the design rainfall value by the runoff coefficient (C), based on the surface condition of the catchment area.

$$Re = Rt \times C \quad (5)$$

Design Flood Discharge Analysis

The design flood discharge analysis in this study is conducted using the Nakayasu Synthetic Unit Hydrograph Method. This method is used to calculate the peak discharge resulting from rainfall by considering the characteristics of the watershed (DAS) as well as the ongoing rainfall intensity.

Nakayasu Synthetic Unit Hydrograph

Peak Discharge of Design Flood

$$Qp = \frac{C.A.R0}{3{,}6\,(0{,}3\,Tp + T_{0,3})} \quad (6)$$

Time to Peak

$$T_P = T_g + 0{,}8\,T_r \quad (7)$$

Time to Peak and Peak Discharge Relationship

$$T_r = 0.75 \times T_g \quad (8)$$

Time When Discharge Equals 0.3 × Peak Discharge

$$T_{0,3} = \alpha \times T_g \quad (9)$$

Time Lag

If L > 15 km

$$T_g = 0{,}4 + 0{,}058 \times L \quad (10)$$

2.2. Hydraulic Analysis

The purpose of the river hydraulic analysis is to evaluate the cross-sectional capacity of the river and to model the flood water surface profile using the HEC-RAS software. The following data must be input into the HEC-RAS software:

1. Input topographic map data
2. Define the river area and cross-section boundaries
3. Create cross sections
4. Input design flood discharge data
5. Run the simulation using HEC-RAS software

3. RESULTS AND DISCUSSION

3.1 Hydrological Analysis

Design Rainfall Calculation

In hydrological analysis, this test is used to determine the probability distribution that best fits the rainfall and river discharge data. Commonly used distributions include the Normal, Log-Normal, Gumbel, and Log-Pearson Type III distributions. To assess the suitability of each distribution, two methods are applied: the Chi-Square Test and the Smirnov–Kolmogorov Test.

Distribution Goodness of Fit Test

Table 2 and table 3 below presents the results of the distribution conformity tests using the Chi-Square and Smirnov–Kolmogorov methods:

Table 2 Recapitulation of Chi-Square Test Results

No	Distribution Method	Calculated X^2 Value	Critical X^2 Value	Description
1	Gumbel Distribution	3	5,991	Accepted
2	Normal Distribution	3	5,991	Accepted
3	Log Normal Distribution	3	5,991	Accepted
4	Log Person Type III Distribution	3	5,991	Accepted

Source: Processed by the Author

Table 3 Recapitulation of Smirnov–Kolmogorov Test Results

No	Distribution Method	Δ_{max} Value	Δ_{cr} Value	Description
1	Gumbel Distribution	3	5,991	Accepted
2	Normal Distribution	3	5,991	Accepted
3	Log Normal Distribution	3	5,991	Accepted
4	Log Person Type III Distribution	3	5,991	Accepted

Source: Processed by the Author

Based on the Chi-Square test requirement where $X_2Calc < X_2cr$, all four distributions meet the criteria and are therefore accepted. Meanwhile, according to the Smirnov–Kolmogorov test requirement, where $\Delta_{max} < \Delta_{cr}$, it can be concluded that only three distributions satisfy the condition, with the Log-Pearson Type III distribution not meeting the requirement. Therefore, in this study, the Gumbel distribution is selected for calculating the design flood discharge.

Effective Rainfall Calculation

Table 4 below presents the results of the effective rainfall calculation:

Table 4 Effective Rainfall

Hour		Return Period (years)						
		2	5	10	20	25	50	100
1	ΔRt (mm)	106,13	106,67	107,56	108,78	109,28	110,97	113,01
	Re (mm)	74,29	74,67	75,29	76,15	76,49	77,68	79,11
2	ΔRt (mm)	27,58	27,73	27,96	28,28	28,40	28,84	29,37
	Re (mm)	19,31	19,41	19,57	19,79	19,88	20,19	20,56
3	ΔRt (mm)	19,35	19,45	19,61	19,83	19,92	20,23	20,61
	Re (mm)	13,54	13,61	13,73	13,88	13,95	14,16	14,42
4	ΔRt (mm)	15,40	15,48	15,61	15,79	15,86	16,11	16,40
	Re (mm)	10,78	10,84	10,93	11,05	11,10	11,28	11,48
5	ΔRt (mm)	13,01	13,07	13,18	13,33	13,39	13,60	13,85
	Re (mm)	9,11	9,15	9,23	9,33	9,38	9,52	9,70
6	ΔRt (mm)	11,37	11,43	11,52	11,66	11,71	11,89	12,11
	Re (mm)	7,96	8,00	8,07	8,16	8,20	8,32	8,48

Source: Processed by the Author

Nakayasu Synthetic Unit Hydrograph

Based on the obtained calculation results, table 5 below presents the summary of peak discharge values for the design flood at each return period:

Table 5 Summary of Design Flood Discharge Using Nakayasu Method

Rekapitulasi Debit Banjir Rancangan Metode Nakayasu	
Return Period (years)	Peak Discharge (m^3/s)
2	10866,48
5	10922,10
10	11013,30
20	11138,40
25	11188,71
50	11362,22
100	11570,98

Source: Processed by the Author

Figure 1 shows the summary graph of design flood discharge for each return period using the

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Nakayasu method:

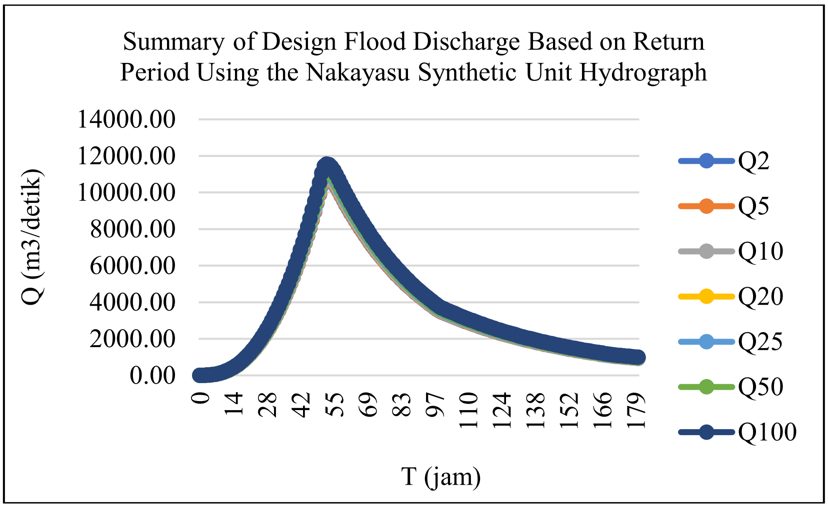

Fig 1 Design Flood Discharge Based on Nakayasu Synthetic Unit Hydrograph

3.2 Hydraulic Analysis

In this analysis, a model of the Bengawan Solo River in Bojonegoro Regency was developed using the HEC-RAS software. This analysis aims to determine whether the river cross-section is capable of handling the flow discharge or not.

HEC-RAS Modeling

At this stage, the input data includes topographic maps. Subsequently, the river alignment, riverbank boundaries, and cross sections are created to determine the river's cross-sectional profile.

Fig 2 Schematic Model Representation

Geometric Data

In the Profile column, input is based on the return period of the design flood discharge used in the study. Then, in the Reach Boundary Conditions section, the Downstream column is filled using the Normal Depth method.

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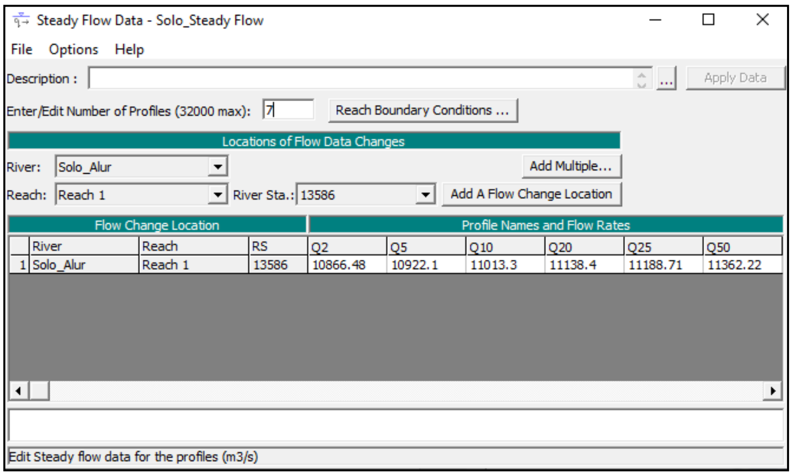

Fig 3 Design Flood Discharge Input Data Using the Nakayasu HSS Method

Cross Section Analysis under Existing Conditions of the Bengawan Solo River

Based on the simulation results using design flood discharges for return periods of 2, 5, 10, 20, 25, 50, and 100 years, the river cross section profile indicates that almost all points experienced river overflow with varying overflow heights. This occurred because the water overtopped the levee (Bank Station), as shown by the HEC-RAS software simulation results.

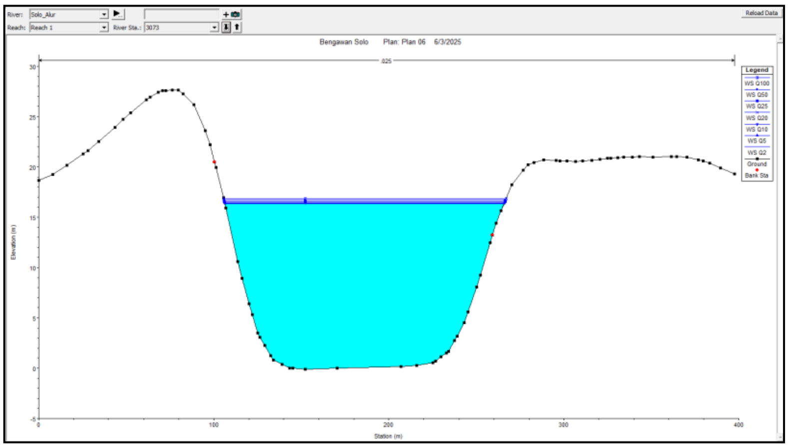

Fig 4 Example of Cross-Sectional Profile Result of the River at STA +3073

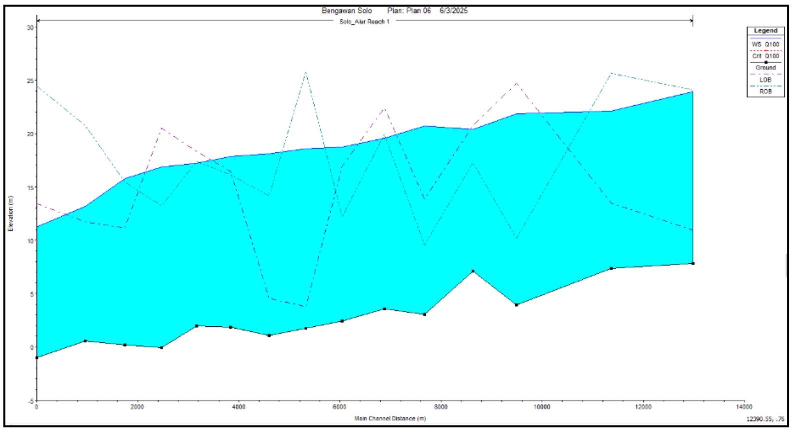

Fig 5 Hasil Profil Melintang Sungai Q_{100}

Disaster Mitigation Efforts

Since the river is unable to accommodate the design flood discharge, river normalization is required in the form of improving the cross-section so that it can convey water according to the design flood discharge, as an effort in disaster mitigation. Based on the hydraulic analysis normalization using HEC-RAS modeling, a comparison of the cross-section before and after the planned normalization is shown in Figure 6 and Figure 7:

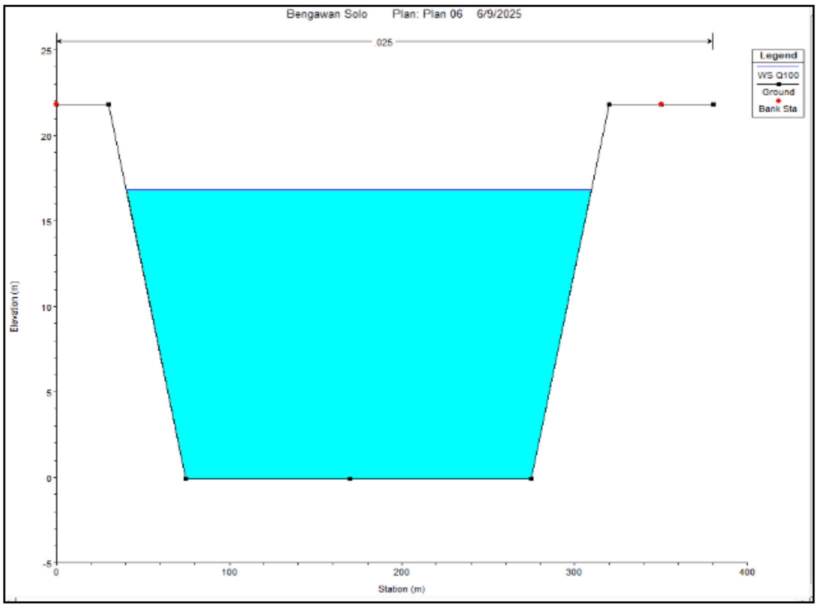

Fig 6 Example of River Normalization Result at STA +3073

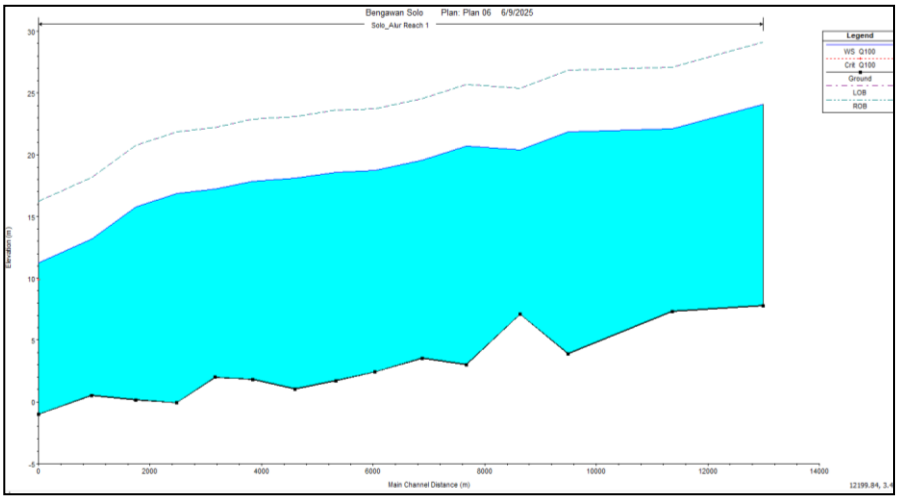

Fig 7 Cross-Sectional Profile Result of the River for Q_{100} After Normalization

Based on the normalization results of the Bengawan Solo River using HEC-RAS software, a difference can be observed between the existing river cross-section before normalization and the river cross-section after normalization. After the river was normalized, the water surface elevation decreased from upstream to downstream, no longer overflowing the left or right riverbanks.

It can therefore be concluded that with the normalized river cross-section, the Q100 return period condition is safe and no overflow occurs. This confirms that to address the existing problems, it is not necessary to redesign the existing channels. Thus, the most effective action is to normalize the channel.

4. CONCLUSION

Based on the research analysis and the processed data results described, several conclusions can be drawn: the cross sectional profiles of the Bengawan Solo River under flood discharge conditions for return periods of 2, 5, 10, 20, 25, 50, and 100 years all indicate overflow. Therefore, river normalization is necessary by enlarging the cross sectional dimensions of the river. The flood affected area distribution map can be used as a basis for disaster mitigation preparedness efforts.

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