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ANALYSIS OF CISANGGARUNG RIVER FLOOD IN SIDARESMI VILLAGE, PABEDILAN DISTRICT, CIREBON REGENCY USING HEC-RAS SOFTWARE

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Abstract

The eastern part of Cirebon Regency is an area that is prone to flooding because it is included in the Cisanggarung Watershed (DAS). The Cisanggarung watershed area has a high level of flood vulnerability, with the flood-prone area reaching around 3,479 hectares. This study aims to analyze flooding in Sidaresmi Village by employing the HSS Nakayasu method to calculate the flood discharge levels. This approach facilitates the estimation of peak flood discharges for a range of return periods, including Q2 or 2-year, Q5 or 5-year, Q10 or 10-year, Q25 or 25-year, Q-50 or 50-year, Q100 or 100-year. Subsequently, these discharge values are utilized in flood modeling conducted with HEC-RAS software. The modeling results using HEC-RAS software show that the Cisanggarung River in Sidaresmi Village does not have sufficient capacity to accommodate the flood discharge that occurs. With flood discharges exceeding the river's capacity, the risk of overflowing water becomes very high, which can result in flooding in surrounding areas. These findings highlight the importance of mitigation measures, such as river infrastructure improvements, to reduce the impact of flooding in the area.

Keywords: *Micro-Hydro; Dependable Flow; Thiessen Polygon; Crossflow Turbine*

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Introduction

Floods are one of the most widespread and devastating natural disasters globally, affecting millions of lives, causing major economic losses, and posing significant environmental challenges. The World Bank (2020) highlighted that more than 1.47 billion people worldwide are vulnerable to flooding, with damages estimated to exceed $650 billion annually. Urbanization, climate change, and deforestation exacerbate flood risks by altering natural hydrological patterns and increasing runoff. Advanced flood modeling and prediction technologies are critical in addressing these challenges (Dyhouse, 2003).

With its tropical climate and archipelagic geography, Indonesia is highly vulnerable to flooding. Cirebon Regency, especially Sidaresmi Village in Pabedilan District, frequently experiences flooding due to the overflowing Cisanggarung River. Local reports indicate that the village experiences repeated inundation during the rainy season, disrupting agricultural activities and endangering people’s livelihoods. Despite many structural measures, such as embankments and drainage systems, flooding continues due to inadequate flood management strategies (Wigati & Soedarsono, 2016); (Prayogo et al., 2023).

Traditional flood management approaches, while helpful, are often reactive and need more predictive capacity. Hydraulic modeling software such as the Hydrologic Engineering Center's River Analysis System (HEC-RAS) offers a robust solution by simulating river hydraulics, predicting flood extents, and evaluating mitigation strategies. Recent studies have highlighted the effectiveness of

HEC-RAS in a variety of hydrological contexts, from urban areas such as Jakarta (Pratama, 2020) to rural watersheds such as the Tabanio watershed in Kalimantan (Prayogo et al., 2023).

Although HEC-RAS has been widely applied in flood studies across Indonesia, its application in Sidaresmi Village still needs to be explored. Previous studies have focused on larger river systems or urban catchments, often neglecting smaller yet equally vulnerable rural areas. This study addresses this gap by applying HEC-RAS to analyze the flood dynamics of the Cisanggarung River in Sidaresmi Village. By combining stable and unstable flow analysis, this study aims to comprehensively understand flood behavior and inform local mitigation measures (Brunner, 1994); (Iswardoyo & Satria, 2023).

The main objective of this study is to analyze the flood pattern of the Cisanggarung River in Sidaresmi Village using HEC-RAS software. Specifically, this study seeks to Simulate flood scenarios under various hydrological conditions using HEC-RAS 5.0.7. Identify flood-prone areas and evaluate the effectiveness of existing mitigation measures. Provide actionable recommendations to improve flood management in Sidaresmi Village.

This study focuses on applying HEC-RAS to model the flood dynamics of the Cisanggarung River, considering stable and unstable flow conditions. This analysis emphasizes essential parameters such as water surface profile, floodplain area, and hydraulic structure. Data from local hydrological records, topographic surveys, and previous flood events form the basis of simulation input (Al Amin et al., 2018; Fajar, 2022).

The findings of this study have significant implications for flood management and planning in Sidaresmi Village and similar rural settings. Policy Implications The results will guide local governments in designing targeted flood mitigation policies, including constructing retention basins and embankment enhancements. Technical Implications: By demonstrating the utility of HEC-RAS, this study encourages the adoption of advanced hydraulic modeling tools in regional flood management practices. Community Implications: This study fosters community resilience by identifying vulnerable zones and informing early warning systems and evacuation plans (Rolobessy et al., 2024; Rizki, 2021).

HEC-RAS is a widely used hydraulic modeling software developed by the US Army Corps of Engineers. It enables the simulation of river hydraulics, including steady and unsteady flow, sediment transport, and water quality analysis (Brunner, 1997). Studies demonstrate its versatility in modeling various hydrological conditions, from floodplain analysis (Dyhouse, 2003) to numerical simulation of permanent and variable flow regimes (Villón Béjar, 2014).

Application of HEC-RAS in Flood Studies: Several studies highlight the efficacy of HEC-RAS in flood management: Urban Context, Pratama, et al. (2020) used HEC-RAS to simulate flood distribution in Jakarta, identify critical inundation zones, and inform infrastructure planning. Rural Watershed, Prayogo et al. (2023) applied HEC-RAS in a watershed.

Research Method

The method used in this research is quantitative, an empirical approach that focuses on collecting, analyzing, and presenting data in the form of numbers. This method is applied to obtain accurate results by relying on statistical calculations.

In this investigation, the dataset comprised both primary and secondary data sources. The primary data were directly elicited through firsthand observation of the research subject. Meanwhile, secondary data was collected from various sources relevant to the research, such as rainfall data from BBWS Cimanuk Cisanggarung and PUPR, DEMNAS maps, and land cover maps downloaded from the website Tan Hair. Indonesia.go.id and a literature review from previous studies.

This research was conducted in the Cisanggarung River, Sidaresmi Village, Pabedilan Subdistrict, Cirebon Regency, West Java Province. This location was chosen because it often experiences flooding, making it very relevant to analyze in the context of flood risk management and mitigation efforts.

Rainfall Analysis

Flood analysis in Sidaresmi Village, Pabedilan Sub-district, Cirebon Regency using Thiessen Polygon to calculate the distribution of maximum rainfall for the last 10 years (2013-2022) from 3 rainfall stations: Darma Station, Jatiseeng Station, and Cikeusik Station.

One method that can be used in rainfall analysis is the Thiessen polygon method. The Thiessen Polygon approach assigns a weight to each station, representing the adjacent territory. It posits within a watershed that the precipitation in a specific area corresponds to that recorded at the closest station, allowing the station's rainfall data to represent that region (Nurdiyanto, 2019).

$$P = \frac{A1 \,.\, p1 + A2 \,.\, p2 + A3 \,.p3 + \cdots + An \,.\, pn}{A1 + A2 + A3}$$

Where :

P = Area rainfall (mm),
$P_1, P_2, P_3, \ldots, Pn$ = Rainfall height at post1,2,3,....n,
$A_1, A_2, A_3, \ldots, An$ = Area of influence of post1,2,3,....n.

Frequency Analysis

Frequency analysis aims to assess the severity of extreme events and ascertain their recurrence intervals or return periods using a probability distribution model (Nadia et al., 2019). Among the probability distributions frequently employed are the Normal, Gumbel, Log Normal, and Log Pearson Type III distributions.

To identify the most suitable distribution model for hydrological data, it is essential to evaluate the fit based on the statistical characteristics of the empirical data. This evaluation necessitates examining whether the statistical properties of the data, such as the coefficient of kurtosis (CK), mean, coefficient of skewness (CS), standard deviation, and CV, or the coefficient of variation align with the prerequisites of the respective probability distributions.

$$\bar{X} = \frac{\sum_{i=1}^{n} Xi}{n}$$

$$Sd = \sqrt{\frac{\sum_{i=1}^{n} (Xi - \bar{X})^2}{n-1}}$$

$$Cv = \frac{Sd}{\bar{X}}$$

$$Cs = \frac{n \sum_{i=1}^{n} (Xi - \bar{X})^3}{(n-1)(n-2) Sd^3}$$

$$Ck = \frac{n^2 \sum_{i=1}^{n} (Xi - \bar{X})^4}{(n-1)(n-2)(n-3) Sd^4}$$

Description :
$\bar{X}$ = mean rainfall value
Sd = Standard Deviation
Cv = Coefficient of Variation
Cs = Skewness Coefficient
Ck = coefficient of kurtosis
n = number of data
Xi = i-th rainfall value

Table 1. Determination of data distribution type

Type of Distribution	Terms Statistical Parameters	Statistical parameters of observation data	Description
Normal	Cs ≈ 0	-0,8615	Unqualified
	Ck ≈ 3	4,4346	Unqualified
Log-Normal	Cs = Cv^3 + 3.Cv	-0,8615	Unqualified
	Ck = $Cv^8 + 6Cv^6 + 15\ Cv^4 + 16\ Cv^2 + 3$	4,4346	Unqualified
Gumbel	Cs = 1,14	-1,0803	Unqualified
	Ck = 5,4	5,0521	Unqualified
Log Pearson III	If there is no suitable statistical parameter	-	Qualified

Source: Calculation Result

Log Pearson Type III Frequency Distribution

The Pearson Log III method uses the logarithmic value to compute return period rainfall. The determination of return period rainfall using the Log Pearson III distribution method is contingent upon the K value derived from the Reduction Frequency Table of the Pearson Log III method (Kementrian PUPR, 2018).

Mean:

$$\bar{X} = \frac{\sum_{i=1}^{n} Log\ Xi}{n}$$

Standard Deviation:

$$Sd = \sqrt{\frac{\sum_{i=1}^{n}(LogXi - Log\bar{X})^2}{n-1}}$$

Skewness Coefficient:

$$Cs = \frac{n\sum_{i=1}^{n}(LogXi - Log\bar{X})^3}{(n-1)(n-2)Sd^3}$$

Rainfall Plan log Pearson III method:

Xt = Log ($\bar{X}$ + Ktr x Sd)

Probability Distribution Test

Several methods are often used to perform distribution fit tests. Two of the most common are the Chi-Square test and the Smirnov-Kolmogorov test.

The objective of the Chi-Square test is to ascertain the adequacy of a selected distribution in representing the statistical distribution of the analyzed data sample. The analysis is deemed valid when the computed chi-square value exceeds the critical chi-square threshold.

K = 1 + 3,322 Log n

Description:
K = Number of Classes
n = The amount of data

DK = K - (P+1)

Description:
DK = Degrees of freedom
P = For normal and binominal distributions (2) and Gumbel distributions (1)

Ei = n/Cs

Description:
Ei = sum of theoretical values in subgroup I

n = number of subgroups

$$X^2 = \frac{\sum_{i=1}^{G}(Oi - \mathrm{Ei})^2}{Ei}$$

Description:
X^2 = calculated chi-square parameter
Oi = number of observation values in subgroup I

The Smirnov-Kolmogorov fit test, frequently called a non-parametric fit test, operates independently of any specific distribution function. The following outlines the procedure for its implementation:

- Sort the data (Xi) from largest to smallest
- Determine the empirical probability of each data after sorting P(Xi) with the Weibull formula: **P(Xi) = i/(n+1)**

  Notes:
  n = number of data
  i = data sequence number
- Determine the reduction variable

  F(t) = $\frac{(Xi - \overline{X})}{s}$

  Description:
  F(t) = reduction variable
  Xi = i-th data
  $\overline{X}$ = mean value
  S = standard deviation
- Determine the theoretical probability of each sorted data P' (Xi) based on the selected probability distribution. Theoretical probability = 1 - area under the standard curve corresponding to the f(t) value.
- From the two probability values, determine the difference between the observed probability and the theoretical probability.
  D = maximum (P'(Xi) - P(Xi))
- Determine whether the D value is smaller than the critical D value (Do)

Flood Discharge Analysis

The Nakayasu HSS method is commonly utilized to analyze anticipated flood discharges. Nakayasu conducted extensive research on unit hydrographs across multiple river systems in Japan. The outcomes of these studies have been encapsulated into specific equations and procedural steps for calculation. The requisite data for these computations include 24-hour rainfall (R24) measured in millimeters, river length (L) in kilometers, catchment area (A) in square kilometers, and the distribution of adequate hourly rainfall.

Qp = $\frac{1}{3{,}6}\left(\frac{C.\ A\ .\ Re}{0{,}3\ Tp + T0{,}3}\right)$

Description:
Qp = peak flood discharge (m3/det),
Re = rainfall unit (mm),
Tp = grace time from the beginning of the rain to the peak of the flood (hour),
T0,3 = time required by the decrease in discharge from the peak to 30% of the peak discharge
A = catchment area to the outlet,
C = conveyance coefficient.
To determine Tp and T0,3, the following formula approach is used:
Tp = tg + 0.8 tr

$T0.3 = \alpha\ tg$

tg represents the time lag, defined as the interval in hours between rainfall and the peak flood discharge.

Rivers with channel length L > 15 km:

$tg = 0.4 + 0.058\ L$

Rivers with a channel length of L < 15 km:

$tg = 0.21\ L^{0.7}$

Notes:

Tr = rainfall time unit (hour)

α = watershed characteristic coefficient

- On an upward curve (0 < t < Tp)

  $Qt = Qp\ (-TTP)^{2,4}$

  Notes:

  Q(t) = runoff before finding peak discharge (m3),

  t = time (hour).

- On the downward curve, Pada Kurva Turun

  (Tp < t < Tp + T0,3)

  $Q = Qp \times 0,3^{\frac{T-Tp}{T0,3}}$

  (Tp + T0,3 < t < Tp + T0,3 + 1,5 T0,3)

  $Q = Qp \times 0,3^{\frac{(T-Tp)+0,5\ T0,3}{1,5\ T0,3}}$

  (t > Tp + T0,3 + 1,5 T0,3)

  $Q = Qp \times 0,3^{\frac{(T-Tp)+0,5\ T0,3}{2\ T0,3}}$

ArcGIS

ArcGIS is a robust platform for constructing and deploying Geographic Information Systems (GIS). It enables disseminating geographic data to a global audience across diverse disciplines. This platform comprises an array of tools and software that furnish comprehensive GIS functionalities.

Coordinated application interfaces on this platform facilitate a wide range of GIS tasks, from the most basic to the most complex, including visualization, spatial processing, mapping, management, data editing, and geographic analysis (Zhang, 2021). GIS demonstrates its utility and efficiency by facilitating integrated spatial and attribute data analysis, including hydrology, land use, topography, and population demographics. This data is processed and analyzed to extract the specific information needed for various applications (Zardari et al., 2019).

HEC-RAS

Initiated in the early 1990s by the Hydrologic Engineering Center, HEC-RAS represents the inaugural application within a suite of Windows-based software tailored for hydrologic engineering. Officially launched in July 1995, HEC-RAS has emerged as HEC's premier software, supplanting HEC-2 with its ability to execute calculations for determining water surface profiles (Alzahrani, 2017).

HEC-RAS has garnered widespread utilization for river flow modeling, extending to analyses of floodplains, sediment transport, dam breaches, and water quality. Historically prominent for its one-dimensional (1D) river hydraulic modeling, HEC-RAS has developed a significant two-dimensional (2D) modeling capability, responding to the growing need for precise floodplain mapping and flood hazard evaluations. The 2D functionality of HEC-RAS enables the modeling of expansive and intricate river systems, facilitating the simulation of water movements across both horizontal and vertical dimensions (Ansori et al., 2023).

RESULT AND DISCUSSION

Rainfall Analysis

Flood analysis in Sidaresmi Village, Pabedilan Sub-district, Cirebon Regency, using Thiessen Polygon to calculate the distribution of maximum rainfall for the last 10 years (2013-2022) from 3 rainfall stations: Darma Station, Jatiseeng Station, and Cikeusik Station. This method was chosen because the Cisanggarung watershed has a relatively medium area, between 500 and 5000 km².

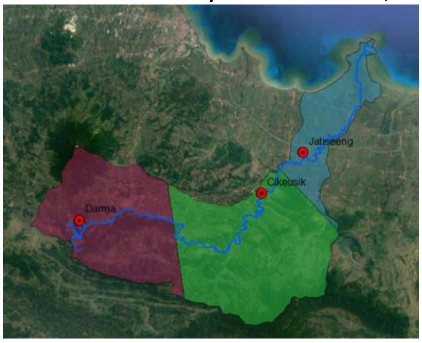

Figure 1. Thiessen Polygon Map

The following is the Area (A) of each rain station area:

Darma Station: 359.015 km²

Cikeusik Station: 468.243 km²

Jatiseeng Station: 170.966 km²

Table 2. Thiessen Polygon Rainfall Calculation

Year	Station						Average Rainfall (Xmax)
	Darma		Cikeusik		Jatiseeng		
	X (mm)	X.A	X (mm)	X.A	X (mm)	X.A	
2013	104	37337,56	90	42141,87	103	17609,498	97,26
2014	128	45953,92	92	43078,356	92	15728,872	104,95
2015	103	36978,545	97	45419,571	92	15728,872	98,30
2016	136	48826,04	90	42141,87	115	19661,09	110,83
2017	137	49185,055	110	51506,73	77	13164,382	114,06
2018	108	38773,62	117	54784,431	72	12309,552	106,06
2019	107	38414,605	126	58998,618	87	14874,042	112,49
2020	96	34465,44	103	48229,029	86	14703,076	97,57
2021	100	35901,5	131	61339,833	107	18293,362	115,74
2022	75	26926,125	85	39800,655	95	16241,77	83,12

Source: Calculation Result

Log Pearson Type III Frequency Distribution

Table 3. Smirnov-Kolmogorov Calculation Results

No	Tahun	Xmax (mm)	Xi (mm)	Log Xi	Log (Xi-Xt)	Log (Xi-Xt)²	Log (Xi-Xt)³
1	2013	97,26	115,74	2,0635	0,0482	0,0023	0,0001
2	2014	104,95	114,06	2,0571	0,0419	0,0018	0,0001
3	2015	98,30	112,49	2,0511	0,0359	0,0013	0,0000
4	2016	110,83	110,83	2,0446	0,0294	0,0009	0,0000
5	2017	114,06	106,06	2,0255	0,0103	0,0001	0,0000
6	2018	106,06	104,95	2,0210	0,0057	0,0000	0,0000
7	2019	112,49	98,30	1,9926	-0,0227	0,0005	0,0000
8	2020	97,57	97,57	1,9893	-0,0259	0,0007	0,0000
9	2021	115,74	97,26	1,9879	-0,0273	0,0007	0,0000

10	2022	83,12	83,12	1,9197	-0,0956	0,0091	-0,0009
Total		**Σ**	**1040,37**	**20,1524**	**0,0000**	**0,0174**	**-0,0007**
Amount of Data		**n**			**10**		
Average		**R̄**	**104,04**	**2,0152**	**0,0000**	**0,0017**	**-0,0001**
Standard Deviation		**S**			**0,0440**		
Coef. Asymmetry		**Cs**			**-1,1**		

Source: Calculation Result

Table 4. Rainfall Calculation for return periods of 2, 5, 10, 25, and 100 years

Tr (Year)	KTr	XTr (mm)
100	1,519	120,80
50	1,436	119,79
25	1,324	118,44
10	1,107	115,87
5	0,848	112,87
2	0,180	105,47

Source: Calculation Result

Probability Distribution Test

- Chi-square

Table 5. Rainfall Return Period Rating

No	Year	Xmax (mm)	Xi (mm)	Log Xi
1	2013	97,26	115,74	2,06348
2	2014	104,95	114,06	2,05713
3	2015	98,30	112,49	2,05110
4	2016	110,83	110,83	2,04464
5	2017	114,06	106,06	2,02554
6	2018	106,06	104,95	2,02097
7	2019	112,49	98,30	1,99256
8	2020	97,57	97,57	1,98932
9	2021	115,74	97,26	1,98794
10	2022	83,12	83,12	1,91969
Total		**Σ**	**1040,37**	**20,15**

Source: Calculation Result

Calculating the number of classes (K)

K = 1 + 3.322 Log n

K = 1 + 3,322 Log 10 = 4,322

Calculating degrees of freedom (Dk)

DK = K - (P+1)

DK = 4.322 - (2+1) = 1.322

Table 6. Chi-Square Calculation Results

Class	Limit Value of Each Class			Ef	Of	((Ef-Of)^2)/Ef
1		>	110,34	2,5	4	0,9
2	105,44	-	110,34	2,5	1	0,9
3	86,814	-	105,44	2,5	4	0,9
4		<	86,81	2,5	1	0,9
	Total			**10**	**10**	**3,6**

Source: Calculation Result

From the table above, it is known that the calculated chi-squared value is 3.6. As for the critical value with degrees of freedom (DK) = 1.322 and degrees of confidence α = 5%, the critical chi value is 4.534. Thus, the calculated chi value is smaller than the critical chi value, so the log Pearson type III probability distribution is acceptable for analyzing rainfall data.

- Smirnov-Kolgomorov

The following are the results of the Smirnov-Kolmogorov test calculation using the Log Pearson III distribution.

Table 7. Smirnov-Kolmogorov Calculation Results

No	Rainfall	Log Xi	P(xi)	f(t)	P'(Xi)	ΔP
1	115,74	2,06	0,09	1,10	0,11	0,01
2	114,06	2,06	0,18	0,95	0,16	0,02
3	112,49	2,05	0,27	0,81	0,22	0,06
4	110,83	2,04	0,36	0,67	0,28	0,08
5	106,06	2,03	0,45	0,23	0,47	0,02
6	104,95	2,02	0,55	0,13	0,51	0,04
7	98,30	1,99	0,64	-0,52	0,62	0,02
8	97,57	1,99	0,73	-0,59	0,63	0,10
9	97,26	1,99	0,82	-0,62	0,64	0,18
10	83,12	1,92	0,91	-2,17	0,90	0,01
					D	**0,18**

Source: Calculation Result

From the table above, it can be seen that the maximum calculated D value is 0.18. With the number of data 10 and 5% confidence degree, the critical D value is 0.41. Thus, the calculated maximum D value is smaller than the essential D value, so the log Pearson type III probability distribution is acceptable for analyzing rainfall data.

Flood Discharge Analysis

The following are the steps in analyzing the HSS Nakayasu plan flood discharge:

1) Rain intensity calculation

$$I = \frac{R24}{24}\left[\frac{24}{tc}\right]^{\frac{2}{3}}$$

Description:
I = Rainfall intensity (mm/hour)
R24 = Maximum rainfall (mm)
Tc = Concentration time (hour)

Table 8. Rain Intensity Calculation

T (Minute)	Tc (Hour)	Periods					
		2	5	10	25	50	100
5	0,0833	191,66	205,09	210,54	215,23	217,67	219,51
10	0,1667	120,74	129,20	132,63	135,58	137,12	138,28
20	0,3333	76,06	81,39	83,55	85,41	86,38	87,11
40	0,6667	47,91	51,27	52,64	53,81	54,42	54,88
60	1	36,57	39,13	40,17	41,06	41,53	41,88
90	1,5	27,90	29,86	30,65	31,34	31,69	31,96
120	2	23,03	24,65	25,30	25,87	26,16	26,38
150	2,5	19,85	21,24	21,81	22,29	22,55	22,74
180	3	17,58	18,81	19,31	19,74	19,96	20,13
210	3,5	15,86	16,97	17,43	17,81	18,01	18,17
240	4	14,51	15,53	15,94	16,30	16,48	16,62
270	4,5	13,42	14,36	14,74	15,06	15,24	15,36
300	5	12,51	13,38	13,74	14,04	14,20	14,32
360	6	11,07	11,85	12,17	12,44	12,58	12,68
390	6,5	10,50	11,23	11,53	11,79	11,92	12,02

T (Minute)	Tc (Hour)	Periods					
		2	5	10	25	50	100
420	7	9,99	10,69	10,98	11,22	11,35	11,44
450	7,5	9,54	10,21	10,48	10,72	10,84	10,93
480	8	9,14	9,78	10,04	10,27	10,38	10,47
510	8,5	8,78	9,39	9,64	9,86	9,97	10,06
540	9	8,45	9,04	9,28	9,49	9,60	9,68

Source: Calculation Result

2) Calculating Hourly Rain Distribution

Hourly rainfall distribution is planned by estimating the rainfall duration and intensity, which changes every hour. The hourly rainfall distribution analysis is calculated based on the rainfall intensity in one day, with a total rainfall duration of 6 hours.

Rt = t x I - (t - 1) x I(t - 1)

Description:
Rt = rainfall height at hour t (mm)
I = rainfall intensity at hour t (mm)
I(t - 1) = rainfall intensity before hour t (mm)
T = time of concentration (hour)

Table 9. Hourly rainfall distribution calculation

2-Year Return Period				**5-Year Return Period**				**10-Year Return Period**			
Hours -				**Hours -**				**Hours -**			
1	I	36,57	mm/hour	1	I	39,13	mm/hour	1	I	40,17	mm/hour
	Rt	36,565	mm		Rt	39,13	mm		Rt	40,17	Mm
2	I	23,03	mm/hour	2	I	24,65	mm/hour	2	I	25,30	mm/hour
	Rt	9,504	mm		Rt	10,17	mm		Rt	10,44	Mm
3	I	17,58	mm/hour	3	I	18,81	mm/hour	3	I	19,31	mm/hour
	Rt	6,6669	mm		Rt	7,13	mm		Rt	7,32	Mm
4	I	14,51	mm/hour	4	I	15,53	mm/hour	4	I	15,94	mm/hour
	Rt	5,3075	Mm		Rt	5,68	mm		Rt	5,83	Mm
5	I	12,51	mm/hour	5	I	13,38	mm/hour	5	I	13,74	mm/hour
	Rt	4,482	Mm		Rt	4,80	mm		Rt	4,92	Mm
6	I	11,07	mm/hour	6	I	11,85	mm/hour	6	I	12,17	mm/hour
	Rt	3,9178	Mm		Rt	4,19	mm		Rt	4,30	Mm
25-Year Return Period				**50-Year Return Period**				**100-Year Return Period**			
Hours -				**Hours -**				**Hours -**			
1	I	41,06	mm/hour	1	I	41,53	mm/hour	1	I	41,88	mm/hour
	Rt	41,06	mm		Rt	41,53	mm		Rt	41,88	Mm
2	I	25,87	mm/hour	2	I	26,16	mm/hour	2	I	26,38	mm/hour
	Rt	10,67	mm		Rt	10,79	mm		Rt	10,89	Mm
3	I	19,74	mm/hour	3	I	19,96	mm/hour	3	I	20,13	mm/hour
	Rt	7,49	mm		Rt	7,57	mm		Rt	7,64	Mm
4	I	16,30	mm/hour	4	I	16,48	mm/hour	4	I	16,62	mm/hour
	Rt	5,96	mm		Rt	6,03	mm		Rt	6,08	Mm
5	I	14,04	mm/hour	5	I	14,20	mm/hour	5	I	14,32	mm/hour
	Rt	5,03	mm		Rt	5,09	mm		Rt	5,13	Mm
6	I	12,44	mm/hour	6	I	12,58	mm/hour	6	I	12,68	mm/hour
	Rt	4,40	mm		Rt	4,45	mm		Rt	4,49	Mm

Source: Calculation Result

3) Flow Coefficient

Land surface conditions or land use influence the conveyance coefficient (C).

Table 10. Flow coefficient result

Area Categories	**A (km2)**	**C**	**AC**
Settlement	89,522	0,7	62,67
Paddy fields	302,42	0,7	211,69
River	10,237	0,5	5,12

Industrial Area	0,081	0,8	0,06
Cultivated land	365,15	0,45	164,32
Forest	188,28	0,5	94,14
Total	**955,69**		**443,86**

Source: Calculation Result

From the table above, we can find the value of the flow coefficient with the following equation:

$$\mathbf{C} = \frac{\sum_{i=1}^{n} CiAi}{\sum_{i=1}^{n} Ai}$$

$$C = \frac{443{,}86}{955{,}69} = 0{,}46$$

4) Effective rainfall
Here is the equation for calculating adequate rainfall;
Re = Rt x C
Description:
Re = adequate rain (mm)
Rt = hourly rainfall distribution (mm)
C = flow coefficient

Figure 2. Effective rainfall calculation

2-Year Return Period Rainfall			5-Year Return Period Rainfall			10-Year Return Period Rainfall		
Hour	ΔRt (mm)	Re (mm)	Jam ke-	ΔRt (mm)	Re (mm)	Hour	ΔRt (mm)	Re (mm)
1	36,565	16,982	1	39,128	18,173	1	40,169	18,656
2	9,504	4,414	2	10,170	4,723	2	10,441	4,849
3	6,667	3,096	3	7,134	3,313	3	7,324	3,402
4	5,307	2,465	4	5,680	2,638	4	5,831	2,708
5	4,482	2,082	5	4,796	2,228	5	4,924	2,287
6	3,918	1,820	6	4,192	1,947	6	4,304	1,999

25-Year Return Period Rainfall			50-Year Return Period Rainfall			100-Year Return Period Rainfall		
Hour	ΔRt (mm)	Re (mm)	Jam ke-	ΔRt (mm)	Re (mm)	Hour	ΔRt (mm)	Re (mm)
1	41,062	19,071	1	41,528	19,288	1	41,879	19,451
2	10,673	4,957	2	10,794	5,013	2	10,885	5,056
3	7,487	3,477	3	7,572	3,517	3	7,636	3,546
4	5,960	2,768	4	6,028	2,800	4	6,079	2,823
5	5,033	2,338	5	5,090	2,364	5	5,133	2,384
6	4,400	2,043	6	4,450	2,067	6	4,487	2,084

Source: Calculation Result

5) Base Flow Calculation
Base flow is water that originates below the ground surface and flows back into the river. It ensures that the river continues to flow from one rainfall event to the next.
Here is the equation for calculating base flow:
QB = 0.4751 x A^(0.6444) x D^(0.9430)
QB = 0.4751 x 955.688^(0.6444) x 0.7^(0.9430)
QB = 3.02 m^3/s
Description:
QB = base flow (m3/s)
A = watershed area (km3)
D = drain network density (km/km2)
D = L/A
L = river length (km)

6) Nakayasu calculation

In the calculation of HSS, Nakayasu required watershed parameter characteristics, namely:
Watershed area (A) = 955.688 km2
Main river length (L) = 62.5 km

- Calculating Time lag (tg)
  tg is the time lag, which is the time between rainfall and peak flood discharge.
  tg = 0.4 + 0.058 L
  tg = 0.4 + 0.058 x 62.5
  tg = 4.03 hours
- Calculating rain duration (tr)
  tr = 0.75 x tg
  tr = 0.75 x 4.03
  tr = 3.02 hours
- Calculating the peak flood time (tp)
  TP is the time from the rain's beginning to the flood's peak.
  Tp = tg + 0.8 tr
  Tp = 4.03 + 0.8 3.02
  Tp = 6.44 hours
- Calculating watershed characteristic coefficient (α)

  $$\alpha = \frac{(\mathbf{0{,}47}\ x\ (A\ x\ L)^{\mathbf{0{,}25}}}{tg}$$

  $$\alpha = \frac{(0{,}47\ x\ (955{,}688\ x\ 62{,}5)^{0{,}25}}{4{,}03}$$

  α = 1,83 Hours

- Flood peak reduction up to 30% (T_0.3)
  $T_{0,3}$ = α x tg

  $T_{0,3}$ = 1,83 x 4,03

  $T_{0,3}$ = 7,53 hours

- Calculating Nakayasu peak discharge

$$Qp = \frac{1}{3{,}6}\left(\frac{C.\ A\ .\ Re}{0{,}3\ Tp + T0{,}3}\right)$$

$$Qp = \frac{1}{3{,}6}\left(\frac{0{,}46\ x\ 955{,}688\ x\ 1}{0{,}3\ x\ 6{,}44 + 7{,}53}\right)$$

Qp = 13,29 m^3/s

- Calculating rising and falling curves
  Rising curves (0 < t < Tp)
  (0 < t < 6,44)
  Qa = Qp $(\frac{t}{Tp})$

Table 12. Rising curve calculation

t (hours)	Q (m^3/Sec)
0	0,00
1	0,15
2	0,80
3	2,12
4	4,24
5	7,24

6	11,21
6,44	13,29

Source: Calculation Result

Falling curves (Tp < t < Tp + T_0,3)
(6,44 < t < 13,79)

$Q = Qp \times 0,3^{\frac{T-Tp}{T_{0,3}}}$

Table 13. Falling curves 1

t (hours)	Q (m³/sec)
7	12,12
8	10,29
9	8,73
10	7,41
11	6,29
12	5,34
13	4,54
13,79	3,99

Source: Calculation Result

Falling curves (Tp + $T_{0,3}$ < t < Tp + $T_{0,3}$ + 1,5 $T_{0,3}$)

(13,79 < t < 24,81)

$Q = Qp \times 0,3^{\frac{(T-Tp)+0,5\,T_{0,3}}{1,5\,T_{0,3}}}$

Table 14. Falling curves 2

t (Hours)	Q (m³/sec)
14	3,89
15	3,49
16	3,13
17	2,81
18	2,52
19	2,26
20	2,02
21	1,81
22	1,63
23	1,46
24	1,31
24,81	1,20

Source: Calculation Result

Falling curves (t < Tp + $T_{0,3}$ + 1,5 $T_{0,3}$)

(t < Tp + 24, 81)

$Q = Qp \times 0,3^{\frac{(T-Tp)+0,5\,T_{0,3}}{2\,T_{0,3}}}$

Table 15. Falling curves 3

t (hours)	Q (m³/sec)
25	1,17
26	1,05
27	0,94
28	0,84

Source: Calculation Result

Table 16. Hydrograph of direct runoff during rainfall

t	Q2	Q5	Q10	Q25	Q50	Q100
Hours	m³/sec	m³/sec	m³/sec	m³/sec	m³/sec	m³/sec
0	3.02	3.02	3.02	3.02	3.02	3.02
1	8.33	8.70	8.85	8.98	9.05	9.10
2	38.29	40.76	41.76	42.63	43.08	43.41
3	109.85	117.34	120.38	122.98	124.35	125.37
4	237.54	253.98	260.65	266.38	269.37	271.62
5	434.60	464.85	477.13	487.67	493.18	497.32
6	713.40	763.19	783.41	800.76	792.96	816.64
6.44	844.90	903.91	927.87	948.44	950.37	967.26
7	771.09	824.93	846.78	865.55	880.29	882.72
8	655.00	700.70	719.26	735.19	751.28	749.76
9	556.47	595.26	611.01	624.53	638.19	636.90
10	472.82	505.75	519.12	530.59	542.19	541.10
11	401.81	429.77	441.12	450.86	460.70	459.77
12	341.54	365.27	374.90	383.17	391.53	390.74
13	290.38	310.52	318.70	325.72	332.81	332.14
13.79	255.59	273.29	280.48	286.65	292.20	292.29
14	249.79	267.09	274.11	280.14	283.68	285.66
15	224.26	239.76	246.06	251.46	256.00	256.41
16	201.36	215.27	220.91	225.76	229.82	230.19
17	180.84	193.30	198.36	202.71	206.35	206.68
18	162.44	173.61	178.15	182.04	185.31	185.61
19	145.94	155.96	160.03	163.52	166.44	166.71
20	131.15	140.13	143.78	146.91	149.53	149.77
21	117.89	125.94	129.21	132.02	134.37	134.59
22	106.00	113.22	116.15	118.67	120.78	120.97
23	95.35	101.82	104.45	106.70	108.59	108.77
24	85.79	91.59	93.95	95.97	97.67	97.82
24.81	78.79	84.10	86.26	88.11	89.55	89.80
25	77.23	82.43	84.54	86.35	87.41	88.01
26	69.55	74.21	76.11	77.73	79.09	79.22
27	62.66	66.84	68.54	70.00	71.22	71.33
28	56.49	60.24	61.76	63.07	64.16	64.26

Source: Calculation Result

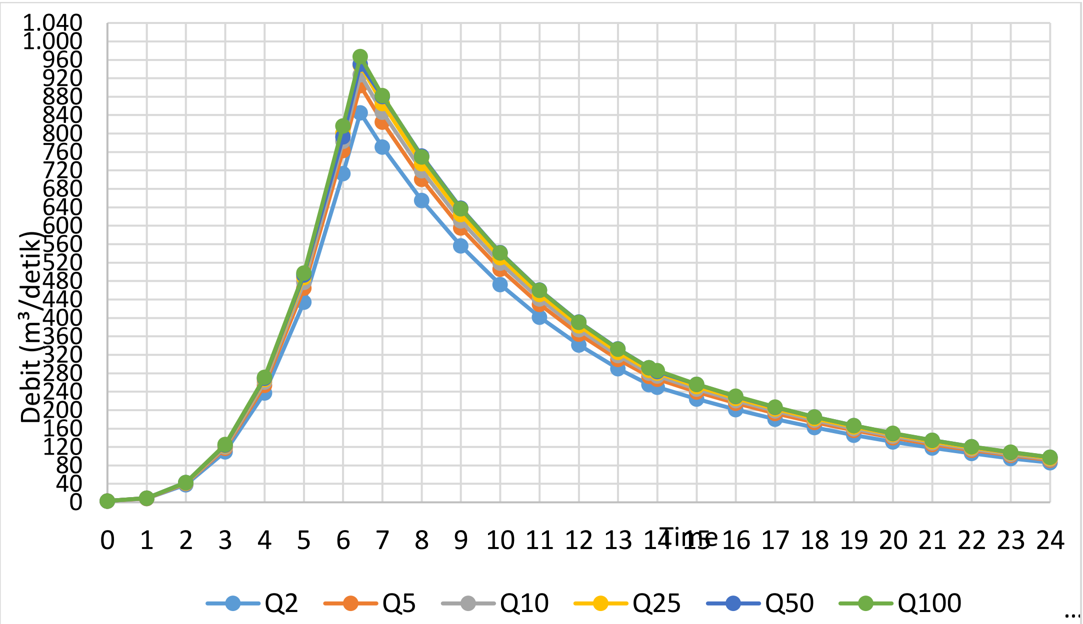

Figure 3. HSS Nakayasu Chart

Flood Simulation

In flood modeling, researchers used the HEC-RAS 6.5 application for 2D modeling under unsteady flow conditions. The required data includes boundary conditions upstream and downstream of the river, information on the slope of the channel bed, a manning coefficient to calculate the channel's roughness, and Digital Elevation Model (DEM) data.

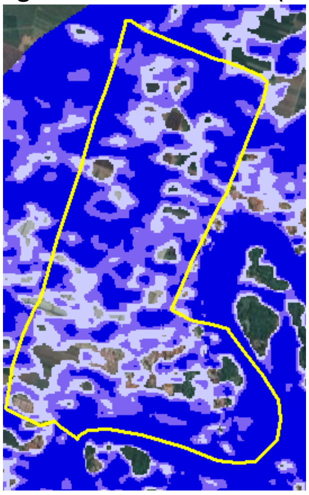

Figure 4. Flood in Sidaresmi Village

Source: Modeling results

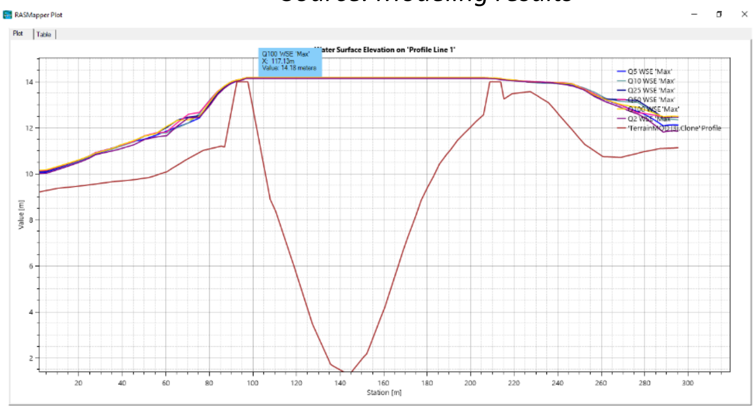

Figure 5. Water surface elevation profile line 1

Source: Modeling results

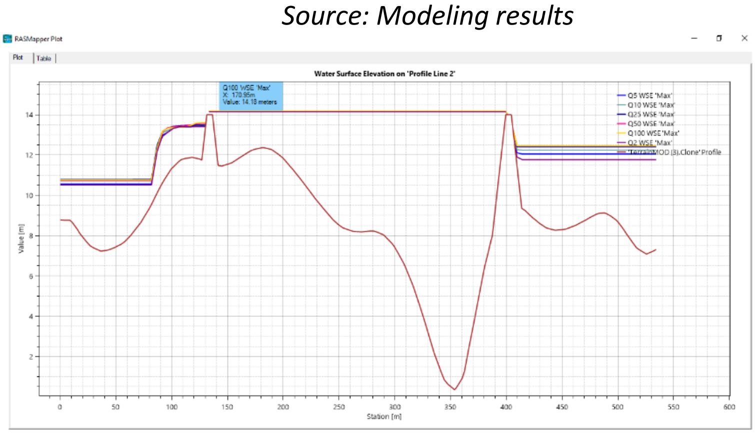

Figure 6. Water surface elevation profile line 2
Source: Modeling results

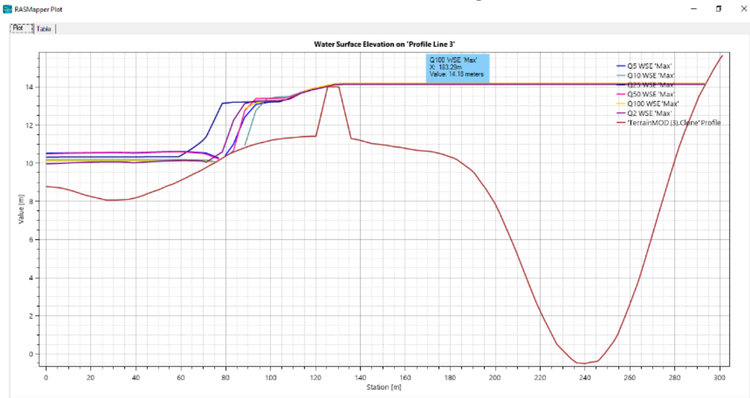

Figure 6. Water surface elevation profile line 3
Source: Modeling results

Flood modeling results for return periods Q2, Q5, Q10, Q25, Q50, and Q100 revealed that the capacity of the Cisanggarung River in Sidaresmi Village is insufficient to accommodate the planned flood discharge in various scenarios. The flood discharges that occur at these return periods exceed the river's capacity, meaning that the river has the potential to overflow and cause flooding in the surrounding area. Based on Heart's modeling, the total flooding area in Sidaresmi village is 1,37 km². This condition highlights the need for more severe mitigation measures, such as upgrading flood control infrastructure or building additional barriers to prevent further losses.

Flood Mitigation

The primary source of flooding in Sidaresmi Village has been identified as the breaching of the embankment due to the overflow of the Cisanggarung River, which inundated residential areas.

In response, the government has initiated the construction of gabions to restore the compromised barrier. Despite these efforts, flood modeling analyses reveal that the current embankment structure must be improved to contain the floodwaters effectively. Therefore, in this study, HEC-RAS modeling was carried out to elevate the embankment in Sidaresmi Village.

In the HEC-RAS modeling for flood mitigation, a 2-meter-high embankment was raised upstream and downstream along the Cisanggarung River in Sidaresmi Village. Then, an unsteady flow analysis was conducted using flow hydrograph data with a return period of Q25.

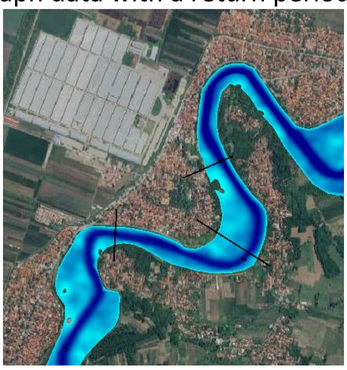

Figure 7. Simulation results of embankment elevation
Source: Modeling results

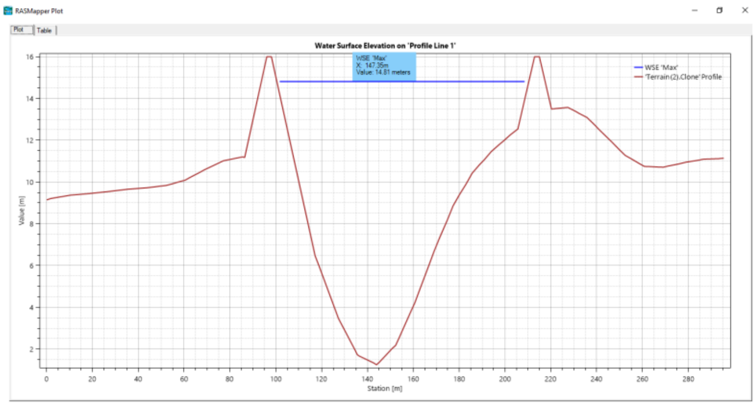

Figure 8. Water surface elevation embankment raising 1
Source: Modeling results

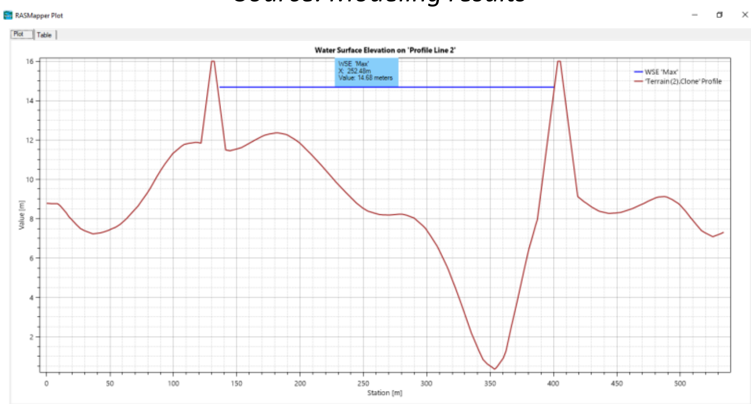

Figure 9. Water surface elevation embankment raising 2
Source: Modeling results

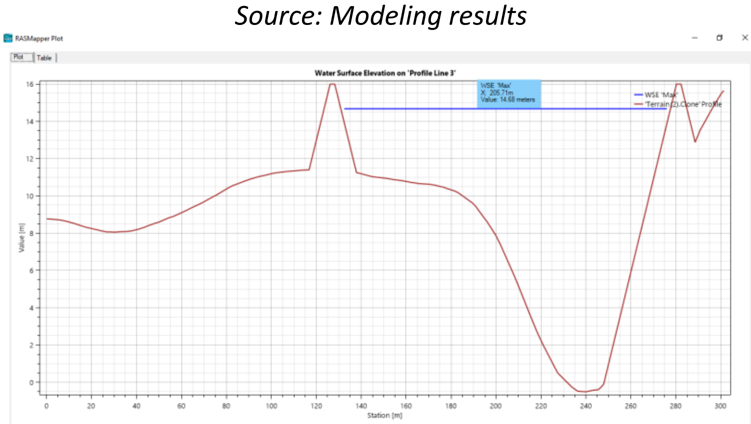

Figure 10. water surface elevation embankment raising
Source: Modeling results

CONCLUSION

Utilizing the HSS Nakayasu method to compute flood discharge, peak discharge values for varying return periods have been established. The calculated maximum flood discharges are as follows: for a 2-year-return period (Q2), 844.9 m^3/s; for a 5-year-return period (Q5), 903.91 m^3/s; for a 10-year-return period (Q10), 927.87 m^3/s; for a 25-year-return period (Q25), 948.44 m^3/s; for a 50-year-return period (Q50), 950.37 m^3/s; and for a 100-year return period (Q100), 967.26 m^3/s.

Further analysis through flood modeling with HEC-RAS software indicates that the Cisanggarung River in Sidaresmi Village cannot handle the projected flood discharge. However, after implementing a model with a 2-meter increase in embankment height, the results demonstrated that the barrier can successfully manage the flood discharge per the calculated specifications. This gives confidence that the dam will effectively prevent potential flooding in the protected area.

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