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Flood Modeling of Telomoyo Watershed in Kebumen Using HEC-RAS for Mapping Flood Risk Zones

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ABSTRACT

Flooding is a frequent natural disaster in Indonesia, especially in areas with low topography and high rainfall. The Telomoyo watershed in Kebumen Regency, with an area of 553.22 km², faces a high risk of flooding even though its water flow is controlled by the Sempor Reservoir. Geographical conditions, topography and high rainfall in the upstream area often cause inundation in the downstream area. This study modeled the flood potential in the Telomoyo watershed using HEC-RAS software, based on rainfall data and a Digital Elevation Model (DEM). The methodology includes hydrological analysis to determine peak discharge using the Nakayasu Synthetic Unit Hydrograph (HSS) method and hydraulic analysis to map flood-prone areas. The results showed that the combination of rainfall and topographic data resulted in accurate mapping of flood-prone areas. The peak discharge of the 25-year return period reached 986.177 m³/second, with inundation up to a depth of more than 3 meters in certain areas. Integration of satellite rainfall data from NASA's Giovanni with 2D hydraulics modelling based on HEC-RAS, which produced flood risk maps for the Telomoyo watershed with a high level of accuracy that was previously under-explored. The outcome of this research for flood management in the Telomoyo watershed is the provision of a scientific basis for more effective mitigation strategies, such as strengthening drainage infrastructure, and risk zone-based spatial planning. This information can be used as a basis for more effective flood mitigation planning and risk management in the Telomoyo watershed area.

INTRODUCTION

Disaster is an event or series of events that causes major damage and disruption to people's lives in various aspects, including physical, social and economic. Disasters are usually caused by natural factors, such as volcanic eruptions, floods or storms, but they can also result from human activities, such as forest fires, pollution or war. Physically, disasters can damage infrastructure, buildings, roads, bridges, and public facilities that people need for their activities. (Harsritanto & Roesmanto, 2017). Social impacts include community disruption, loss of shelter, and psychological trauma for victims. Natural disasters are natural phenomena that occur due to natural forces that cause major damage to the environment, infrastructure and human life. One of the natural disasters that often occurs in Indonesia is flooding (Chaidir A, 2023).

Flooding is a natural disaster that often occurs when rainfall is high, especially during the rainy season. Indonesia has a high potential for flooding as much of its territory consists of lowlands, basins and is surrounded by oceans. In addition, high rainfall in upstream areas often causes excessive water flow, which then triggers flooding in downstream areas. (Nugraha, 2018). Especially for areas where the ground level is lower or only a few metres above sea level. (Mardikaningsih & Muryani, 2017). One area that is vulnerable to flooding is the Telomoyo Watershed in Kebumen Regency (Nugrahanto & Limantara, 2022).

The Telomoyo watershed has varied topographical characteristics with steep slopes in the upstream and lowlands in the downstream areas, which directly affect water flow patterns, especially during high rainfall events. In addition, the complex hydrological conditions of the watershed are often exacerbated by land use change that reduces soil infiltration capacity. Factors such as rainfall intensity, slope and topography, and inadequate drainage infrastructure are the main causes of flooding (Astuti, 2018).

Telomoyo Watershed covers an area of 553.22 km^2 and is part of the Serayu-Bogowonto River Basin. Water from this watershed flows into Sempor Reservoir, which serves as the main water source for PDAM Kebumen Regency (Rustanto, 2021). Telomoyo watershed covers almost the entire area of Kebumen Regency, Central Java, and often faces hydrometeorological disasters such as floods and droughts. High rainfall upstream often increases water flow, triggering flooding in downstream areas, and posing a challenge for communities in disaster mitigation (Wahyuni, 2019). Under normal conditions, the Telomoyo River is the main source of water for agricultural irrigation and the daily needs of the surrounding communities. However, during the rainy season, the risk of flooding in the downstream area increases, mainly due to the low topography and limited flow storage capacity. Therefore, a comprehensive flood risk analysis and the implementation of effective mitigation solutions are needed to minimise the impact of flooding on the community (Rustanto, 2021).

Several studies related to flood modelling in various watersheds provide significant insights into the potential flood risk and inundation characteristics that may occur in the area. For example, in the Lukulo watershed, Kebumen Regency, flood modelling using the Nakayasu HSS method and HEC-RAS simulation showed a peak discharge of 1,642.356 m^3/sec for a 50-year return period, with a water level of 1.93 metres in the affected area. The accuracy of the model is expected to be improved with long-term rainfall data. (Bashori & Purwono, 2024). Meanwhile, flood modelling in the Cokroyasan River using the Nakayasu HSS method shows a peak discharge value for the 25-year return period of 712.733 m^3/sec (Rahmadhani dkk, 2024).

To anticipate and reduce the impact of flooding in the Telomoyo watershed in Kebumen, hydrological and hydraulic modelling with HEC-RAS was used. This system is integrated with a Geographic Information System (GIS) to map flood-prone areas and predict water discharge accurately (Wigati, 2020). This modelling allows researchers to design more effective mitigation measures, provide early warnings to the public, and provide a basis for better infrastructure planning (Bashori & Purwono, 2024). The purpose of this research is to analyse the flood inundation area and peak discharge in the Telomoyo watershed by utilising a combination of satellite rainfall data and the Digital Elevation Model (DEM) (Anis-Athirah, 2021). The combination of these two data supports accurate flood modelling through HEC-RAS software and visualised through ArcGIS. The modelling results are expected to provide more precise and accurate information for more effective mitigation planning and flood risk management.

RESEARCH METHODS

Flood modelling consists of a series of mathematical and physical processes that map the flow of water in an area. The process receives inputs in the form of rainfall, topography and river discharge data that are used to determine water flow patterns during flood events (Z. N. Pratiwi & Santosa, 2021). The outputs of the modelling, in the form of inundation maps and estimated water volumes, are compared with historical data to test their accuracy (Anggraheni dkk, 2022). The modelling uses various hydrological and hydraulic functions to estimate the flood impact at any point within the analysed area (D. W. Pratiwi & Satria Negara, 2023).

The research method for modelling floods in the Telomoyo watershed in Kebumen using HEC-RAS involves several stages. This stage begins with data collection, where rainfall data on the Telomoyo Watershed in Kebumen is taken from Giovanni, a platform provided by NASA. This platform allows users to access and analyse climate and hydrological data from various satellite sources. By using Giovanni satellite data, researchers and practitioners can obtain accurate and up-to-date rainfall data, which is essential for flood modelling, hydrological analysis and disaster risk mitigation planning in the Telomoyo watershed area. The flow of this research is presented in Figure 1.

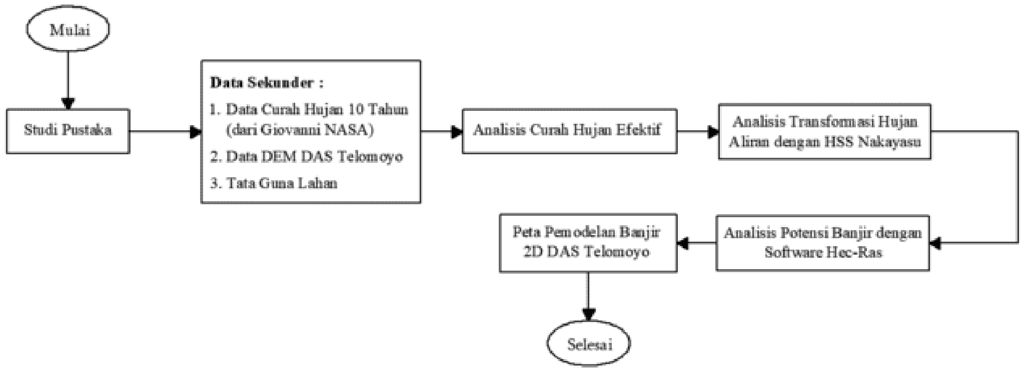

Figure 1. Research flow chart

Research Location

The research site was located in the Telomoyo River along a course of 17.643 km, with the upper reaches of the river located in Sempor Subdistrict, Kebumen Regency, Central Java Province, in the vicinity of Sempor Reservoir which serves as a water flow regulator. The lower reaches of the river are located in the Puring Subdistrict, Kebumen Regency, near the coast of the Indian Ocean. The location of the Telomoyo River can be seen in Figure 2.

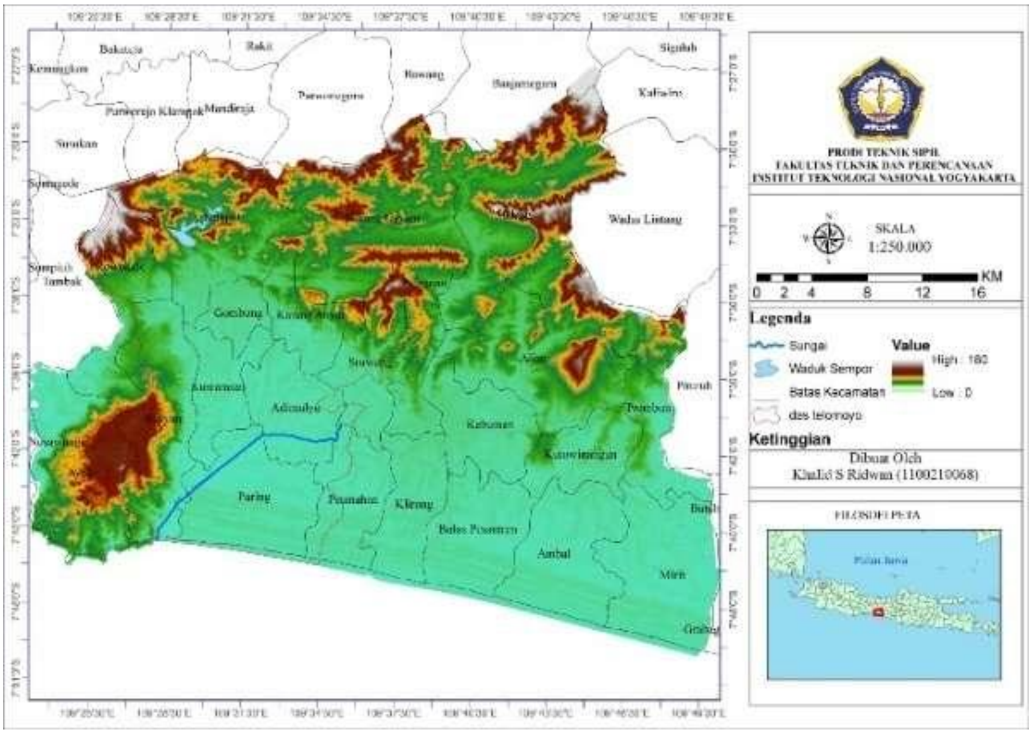

Figure 2. Location of Telomoyo River

Research Data

Data collection in this study is based on secondary data derived from various literatures and types of data relevant to support flood modelling analysis. The data used in this study can be seen in Table 1.

Table 1. Data Requirements

No	Nama Data	Jenis Data	Sumber Data
1.	10 years rainfall data	Sekunder	Giovanni NASA (*https://giovanni.gsfc.nasa.gov/giovanni/*)
2.	Digital Elevation Model (DEM)	Sekunder	Ina – Geoportal (*https://tanahair.indonesia.go.id/portal-web/unduh)*
3.	Shpfile: - Territorial boundaries - Land Cover	Sekunder	Indonesia Geospasial *(https://www.indonesia-geospasial.com/2020/05/download-data-peta-html)*

The rainfall data used in this study was obtained from NASA's Giovanni satellite data. Rainfall data can be seen in Table 2.

Table 2. 10-Year Maximum Monthly Rainfall Data from NASA Giovanni Satellite Data

Tahun	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2014	31	43	33	81	51	92	10	6	0	14	90	72
2015	37	56	78	54	21	28	1	0	1	0	47	67
2016	45	56	54	67	56	91	41	10	95	50	40	51
2017	41	29	46	54	63	14	3	0	53	50	46	37
2018	31	54	52	47	36	7	0	1	1	5	61	60
2019	75	32	49	25	14	2	1	0	0	6	31	32
2020	41	47	73	30	46	6	5	24	8	66	72	82
2021	31	53	29	30	8	36	21	5	21	34	35	30
2022	27	44	111	33	58	40	9	21	41	62	50	47
2023	27	34	42	56	64	15	6	0	0	24	40	90
2024	78	90	0	0	0	0	0	0	0	0	0	0

Data Analysis

The analyses carried out in this study include two main aspects, namely hydrological analysis and hydraulics analysis. To complete this study, a series of data processing steps have been carried out as follows:

1. Hydrological Analysis

Carry out hydrological analysis to determine the planned flood discharge using the HSS Nakayasu method, considering a return period of 25 years (Triatmojo, 2008). Based on the results of the planned rainfall calculation, a frequency distribution analysis can be carried out to obtain the rainfall intensity that will be used to find the planned flood discharge (Dewi, 2018). To understand the parameters used in frequency analysis calculations, the following are commonly used formulas:

a. Normal Distibution

$$X_t = \bar{x} + K_t \,.\, S \quad \text{(1)}$$

b. Log Normal Distibution

$$LogX_t = Log\bar{x} + K_t \,.S_{Log\,x} \quad \text{(2)}$$

c. Log Pearson Tipe III Distibution

$$X_{tr} = \bar{x} + k \,.\, S \quad \text{(3)}$$

d. Gumbel Distibution

$$X_t = \bar{x} + \frac{S}{S_n}(Y_t - Y_n) \quad \text{(4)}$$

Once the most suitable distribution is obtained, the next step is to perform statistical testing of the distribution using the Chi-squared and Smirnov-Kolmogorov methods. This test aims to ensure that the selected distribution fits the available data so that the analysis results can be more accurate (Nuzul dkk., 2021).

a. Smirnov Kolmogorov Test

The Smirnov Kolmogorov test is a statistical method used to test the suitability between the theoretical distribution and the empirical distribution of sample data (Triatmojo, 2008).

$$\Delta maks = maksimum\ [P(X_m) - P'(X_m)] \quad (5)$$

b. Chi-Square Test

This test method aims to determine whether the equation of the distribution of observations can be properly equated with the theoretical distribution, which means testing the correctness of the distribution used in the frequency analysis calculation. The analysis is considered acceptable if the calculated Chi-square value is smaller than the critical Chi-square value (Triatmojo, 2008). so it can be calculated by the formula :

$$X_h{}^2 = \sum_{i=1}^{G} \frac{(O_i - E_i)^2}{E_i} \quad (6)$$

2. Effective Rainfall Analysis

Effective rain is the amount of total rain that produces direct runoff, which consists of sub direct runoff and sub surface runoff (Triatmojo, 2008). Effective rainfall analysis is the process of determining the portion of total rainfall that contributes directly to surface flow. Based on effective rainfall analysis, it is necessary to know the distribution of rain that occurs every hour. The average time of rain concentration in Indonesia ranges from 5 - 7 hours (Pasir, 2017). The hourly rainfall distribution method used is the Mononobe rainfall distribution method (Triatmojo, 2008). Here is the Mononobe rainfall distribution method :

$$X_t = \left(\frac{R24}{t}\right) x (\frac{t}{T})^{2/3} \quad (7)$$

3. HSS Nakayasu

Nakayasu Synthetic Unit Hydrograph (HSS) is one of the methods in hydrology used to predict river flow hydrographs due to a rainfall event. This method is suitable to be applied in areas that have limited flow data because it is synthetic, meaning that it does not require direct river discharge data (Triatmojo, 2008). In general, the Nakayasu method is formulated as follows :

$$Qp = \frac{1}{3{,}60} \frac{A - R_o}{(0{,}30\,.Tp + T_{0,3})} \quad (8)$$

$$QB = 0{,}4715\ A^{0{,}6444} D^{0{,}9430} \quad (9)$$

4. Hydraulic Analysis

Performing Hydrological analysis to model flooding in two dimensions (2D) by utilising HEC-RAS 6.4.1 software and processing it into GIS data to be displayed in the form of spatial maps with ArcGIS 10.8 (Amalia, 2022). From the results of the spatial map, the inundation area and inundation depth as well as the flood risk index were obtained (Hengkelare & Rogi, 2021).

RESULTS AND DISCUSSION

This research applies a method that involves two main aspects, namely hydrological analysis and hydraulics analysis, in modelling floods in the Telomoyo watershed. Hydrological analysis was conducted to determine the characteristics of rainfall and river flow, as well as to calculate the peak discharge which is the main factor in flood events, using the Nakayasu Synthetic Unit Hydrograph (HSS) method to predict flood discharge based on rainfall data. Furthermore, hydraulic analyses were applied to determine the potential for water overflow in the Telomoyo watershed area. To conduct the analysis, this study used a combination of HEC-RAS 6.4.1 and ArcGIS 10.8 software, which aims to visualise flood inundation distribution maps under various rainfall scenarios. The application of this method is expected to produce accurate flood risk mapping and support flood mitigation planning in the Telomoyo watershed.

Hydrological Analysis

Hydrological analysis plays an important role in determining the amount of planned flood discharge in a flood modelling in the Telomoyo watershed. Through this analysis, an estimate of the volume of water flowing during rainfall with a certain intensity can be obtained, so as to predict how much potential flooding may occur. In addition, the hydrological analysis also aims to evaluate how much area will be affected by water runoff when a flood occurs, including the identification of areas prone to inundation.

In this study, the main data used to calculate the planned flood discharge is rainfall data obtained from NASA's Giovanni platform. The following rainfall data obtained from NASA's Giovanni platform can be seen in Figure 3.

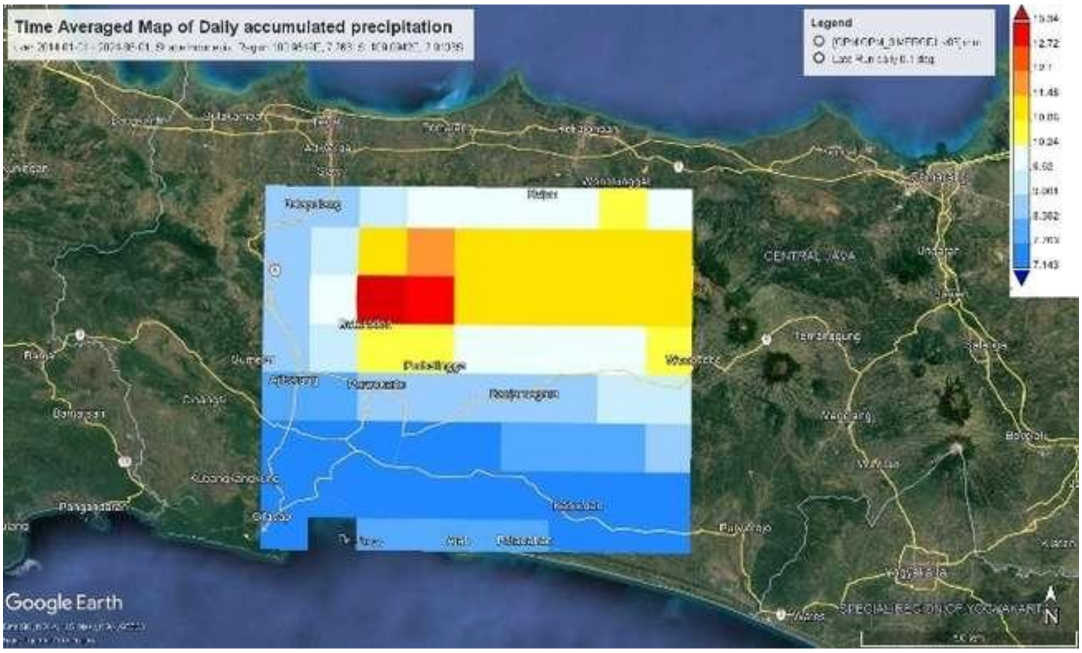

Figure 3. Average Rainfall Accumulation Map of the Telomoyo Watershed from NASA's Giovanni

Maximum Daily Precipitation

Daily rainfall data was then analysed to determine the average maximum daily rainfall based on the length of data available. In this analysis, the rainfall value used is the largest rainfall recorded during the observation period. The results of the analysis can be seen in Table 3.

Table 3. Average Annual Maximum Daily Rainfall

No	Years	Maximum Rain (Xi) (mm)	No	Years	Maximum Rain (Xi) (mm)
1	2014	92,009	6	2019	75,468
2	2015	78,127	7	2020	82,411
3	2016	94,682	8	2021	52,925
4	2017	62,530	9	2022	110,995
5	2018	61,001	10	2023	89,999

Rainfall Plan

The planned rainfall was calculated using a frequency distribution, starting with a frequency analysis to determine the appropriate distribution for the rainfall data. This process involves calculating statistical parameters such as the mean, standard deviation, and coefficient of variation of the historical data based on the maximum daily rainfall obtained from Table 4. The following results of statistical parameter calculations can be seen in Table 4.

Table 4. Statistical Parameters

No.	Years	Max Rain (Xi)	Xi-x	$(Xi-x)^2$	$(Xi-x)^3$	$(Xi-x)^4$
1	2021	52,925	-27,091	733,924	-19882,754	538644,280
2	2018	61,011	-19,005	361,173	-6863,921	130445,682
3	2017	62,530	-17,485	305,736	-5345,879	93474,280
4	2019	75,468	-4,548	20,681	-94,048	427,691
5	2015	78,127	-1,888	3,566	-6,734	12,716
6	2020	82,411	2,395	5,737	13,740	32,908
7	2023	89,999	9,983	99,664	994,958	9932,834
8	2014	92,009	11,993	143,829	1724,922	20686,767
9	2016	94,682	14,667	215,110	3154,934	46272,234
10	2022	110,995	30,979	959,702	29730,652	921027,455
Jumlah		800,157	0,00	2849,119	3425,872	1760956,846

The selection of the frequency distribution type is done by comparing the calculated statistical coefficients and the distribution type requirements. The frequency distribution parameters to determine the type of distribution to be selected can be seen in Table 5.

Table 5. Frequency Distribution Parameters

No	Distribution	Parameters
1	Normal	Cs ≈ 0 Ck ≈ 3
2	Log Normal	$Cs = Cv^3 + .Cv = 0{,}679$ $Ck = Cv^8 + 6Cv^6 + 15$ $Cv^4 + 16Cv^2 + 3 = 3{,}168$
3	Gumbel	Cs = 1,14 Ck = 5,4
4	Log pearson III	Selain dari nilai diatas

The Log Pearson Type III distribution was chosen because it best fits and accurately describes the distribution of extreme rainfall data. With this method, the value of the rainfall plan (Xt) for various return periods can be determined. The following are the results of the calculation of the rainfall plan using the Log Pearson Type III method presented in Table 6.

Table 6. Rainfall Analysis Log Pearson Type III Distribution Method

No	Return Period	Opportunities (%)	K	K x S1	Log Xt	Xt (mm)
1	25	4	1,7087	0,0233	1,9164	115,7021

Kolmogorov-Smirnov Test

This test is performed by plotting the data on Log Pearson Type III probability paper, then calculating the largest deviation distance (Δmax) between the actual data and the theoretical distribution. The Δmax value must be smaller than Δcritical for the distribution equation to be acceptable. The Log Pearson Type III probability paper data plot can be seen in Figure 3.

From the test results in the probability paper, Δmax was obtained = 18,182% = 0,182

To :

N = 10, and a = 5 % = 0,050

Δcritical = 0,41 (seen in Table 2 Critical Values of the Smirnov Kolmogorov Test)

Δmax = 0,183 < 0,41, this means that the distribution with the Log Pearson Type III method is acceptable.

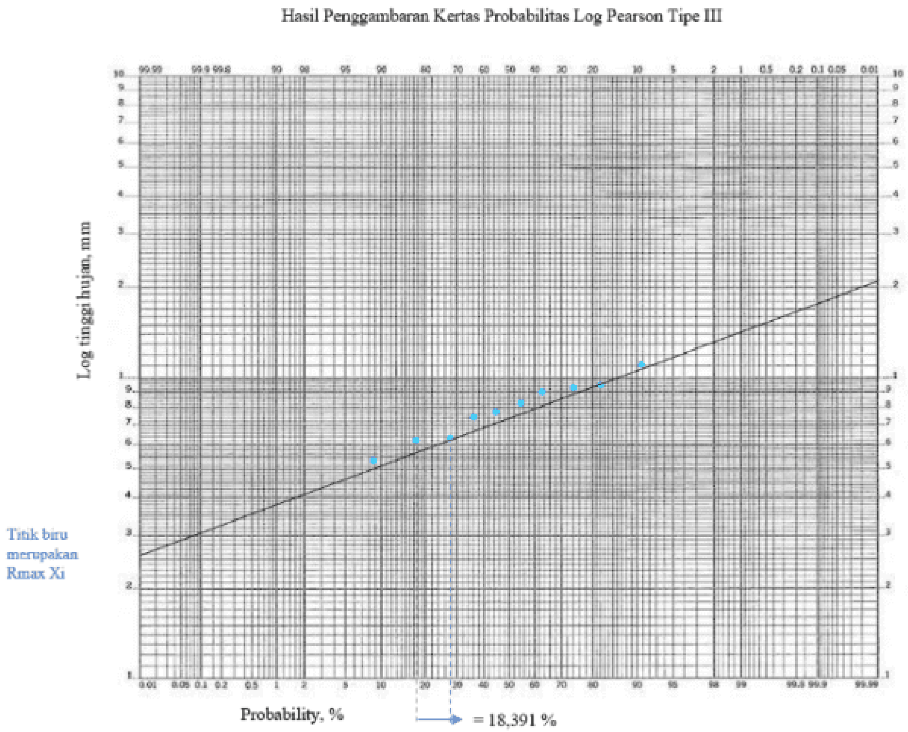

Figure 3. Plotting Data on Log Pearson Type III Probability Paper

Chi-Square Test

The Chi-Square test is acceptable if the Chi-Square value obtained (X^2) is greater than the critical Chi-Square value at a predetermined significance level. In this case, after performing the Chi-Square test calculation, the X^2 value obtained is 4,5. Based on the Chi Kuadrat distribution table, for degrees of freedom = 2,5 and significant level of 5% (α = 0,05), the corresponding critical Chi-Square value is 5,991.

Because the calculation results show that X^2 = 4,5 is smaller than the critical value 5,991, then we can conclude that there is not enough evidence to reject the null hypothesis (H_0). Therefore, the Log Pearson type III distribution used in this analysis is acceptable or suitable for the data analysed. The results of the chi-square test analysis can be seen in Table 7.

Table 7. Chi-Square Test Analysis Results

Data Range			Ef	Of	Ef-Of	$(Ef-Of)^2/Ef$
43,246	< x <	62,603	2,5	2	0,5	0,1
62,603	< x <	81,960	2,5	3	-0,5	0,1
81,960	< x <	101,316	2,5	4	-1,5	0,9
101,316	< x <	120,673	2,5	1	1,5	0,9
	x >	120,673	2,5	0	2,5	2,5
	Total		**12,5**	**10**		**4,5**

Effective Rainfall Analysis

Flow coefficient in the Telomoyo Watershed was determined through the incorporation of various land cover variations in the area. Based on the results of the analysis, the conveyance coefficient obtained is C = 0.183. Effective rainfall was calculated by multiplying the planned rainfall by this conveyance coefficient. From the calculation, a daily effective rainfall of Reff = 21,173 mm for a 25-year return period was obtained. Centralised rainfall in Indonesia is determined to be 5 hours. The following hourly rainfall distribution graph can be seen in Figure 4.

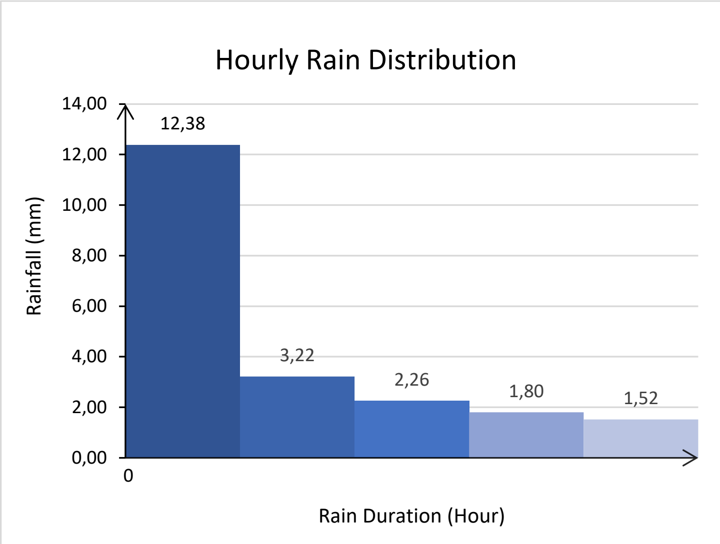

Figure 4. Hourly Rain Distribution Chart

Calculation of Plan Flood Discharge

Determination of the plan flood discharge in flood modelling is carried out using a 25-year return period, according to the guidelines of SNI 2415:2016 on the Procedure for Calculating Flood Discharge. In this process, the calculation of the planned flood discharge is done by multiplying the ordinate value of the Nakayasu Synthetic Unit Hydrograph (HSS) with the hourly rainfall distribution. Watershed parameters are the main elements in the Nakayasu HSS method analysis. The results of this calculation show that the peak discharge **value of the planned flood is as follows Qp = 986,177 m³/second and base flow discharge of QB = 9,5 m³/detik**, obtained by using a 25-year return period. The Nakayasu Hydrograph of the Telomoyo watershed can be seen in Figure 5.

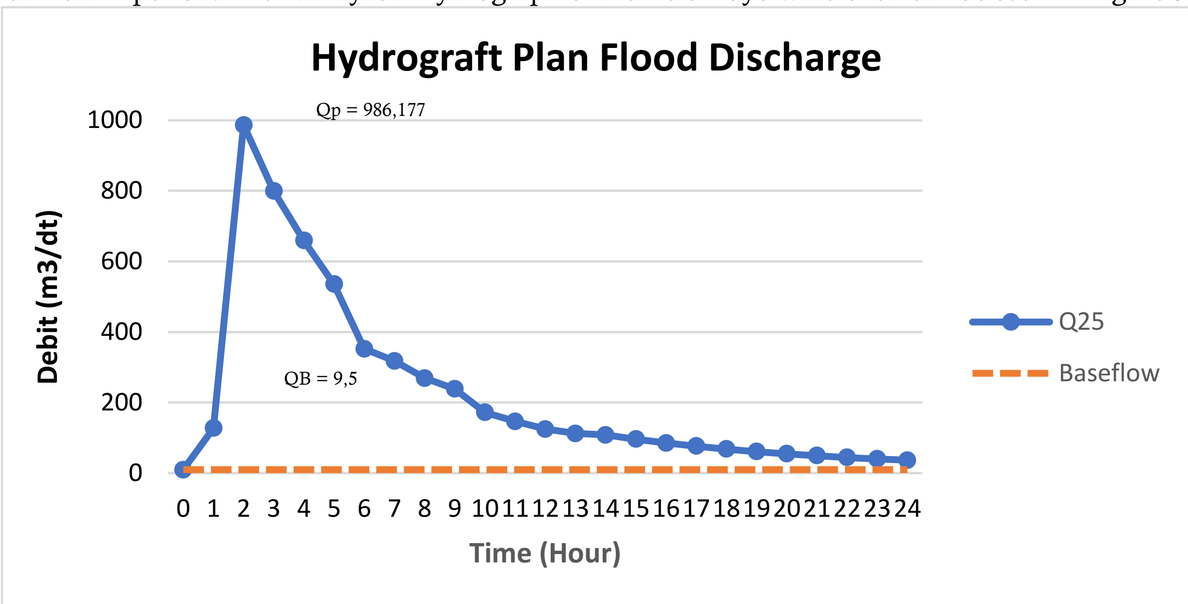

Figure 5. Hydrograph of the Nakayasu HSS method 25-year return period flood discharge

Analisis Hydraulics

Hydraulic analysis aims to determine the river's capacity to cope with floods, which is later used for the design and simulation of possible flood flows. This research makes use of the HEC-RAS software version 6.4.1, particularly through the Ras Mapper feature, to produce two-dimensional (2D) flood modelling. The following are the results of flood modelling in the Telomoyo river using HEC-RAS 6.4.1 which can be seen in the figure 6.

Figure 6. Results of Flood Modelling using HEC-RAS 6.4.1

Furthermore, the flood modelling results were analysed and mapped using ArcGIS 10.8 software. The following analysis and mapping results from Arcgis 10.8 can be seen in Figure 7 and Table 7.

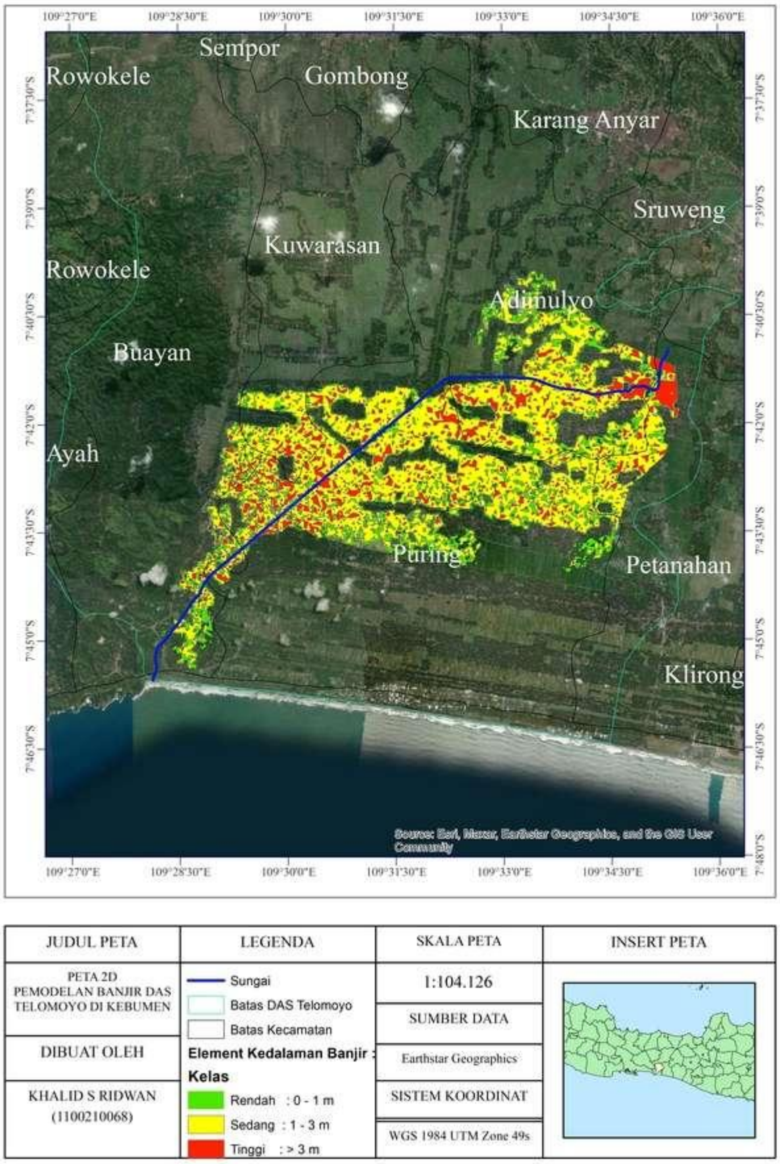

Figure 7. 2D Flood Modelling Map of Telomoyo Watershed

Table 8. Inundation area of Telomoyo watershed

No	Sub-District	Class	Inundation Depth (m)	Extent of Inundation (km2)
1	Puring	Low	0 - 1	4,247
		Medium	1 - 3	13,970
		High	> 3	2,998
		Total		**21,215**
2	Adimulyo	Low	0 - 1	2,374
		Medium	1 - 3	7,138
		High	> 3	1,556
		Total		**11,068**
3	Kuwarasan	Low	0 - 1	0,361
		Medium	1 - 3	1,692
		High	> 3	0,371
		Total		**2,424**
4	Buayan	Low	0 - 1	0,971
		Medium	1 - 3	1,667
		High	> 3	0,344
		Total		**2,982**
5	Petanahan	Low	0 - 1	0,315
		Medium	1 - 3	1,581
		High	> 3	0,748
		Total		**2,644**
Total Area				**40,333**

From the results of flood modelling of the Telomoyo watershed, the areas affected by flood inundation include several sub-districts, namely Puring sub-district with a total area of 21,215 km^2, Adimulyo sub-district with a total area of 11,068 km^2, Adimulyo sub-district with a total area of 2,424 km^2, Buayan sub-district with a total area of 2,982 km^2, Petanahan sub-district with a total area of 2,644 km^2. The following inundation area of the Telomoyo watershed can be seen in Table 8.

CONCLUSION

This research shows the importance of managing the Telomoyo watershed, especially to reduce flood risk in the Kebumen Regency. Using rainfall data and the Digital Elevation Model (DEM) allows for accurate modelling to determine flood risk zones in the Telomoyo watershed. Through hydrological and hydraulic modelling using HEC-RAS and ArcGIS tools, this research successfully mapped flood-prone areas predicted peak discharges, and visualised flood inundation areas. The modelling results provided information on the area affected by floods in the Telomoyo watershed of 40,333 km^2 in the five affected sub-districts. Analysis using the Nakayasu Synthetic Unit Hydrograph (HSS) method successfully predicted the peak flood discharge with a design discharge for a 25-year return period of 986,177 m^3/second. This research provides important information to identify flood risk areas and support more effective and sustainable flood risk mitigation and management planning in the Telomoyo watershed.

SUGGESTION

To improve the accuracy of flood modelling in the Telomoyo watershed and adapt it to the characteristics of watersheds in Indonesia, several other methods are suggested in addition to the Nakayasu HSS. These include the Gama I HSS, which is more suited to local conditions, as well as the Snyder method which is effective in watersheds with complex topography. In addition, Hec-HMS or SWAT provide more detailed spatial distribution-based modelling. Combining these methods will result in more precise flood discharge projections and support more effective flood mitigation.

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