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Flood Modeling Analysis of the Cokroyasan Watershed in Bayan District, Purworejo Regency Using HEC-RAS Software

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ABSTRACT

Floods are a frequent natural disaster in Indonesia. Heavy rainfall and poor watershed management make the Cokroyasan River Basin (DAS), Bayan District, Purworejo Regency, especially susceptible. The purpose of this study is to analyze the flood inundation area and calculate the peak discharge in the Cokroyasan Watershed using satellite rainfall data and the Digital Elevation Model (DEM). The study calculates the highest water flow during floods using the Nakayasu Synthetic Unit Hydrograph (HSS) method and examines the water flow with HEC-RAS and ArcGIS to create maps showing areas that could flood. The results showed that, using the Log Pearson Type III distribution, the design rainfall for a 25-year return period with a flow coefficient of 0.288 was 117.6711 mm. The maximum flood discharge, as determined by the Nakayasu HSS, was 1684.028 m^3/second. Hydraulic analysis was able to map the region of floods based on land cover, covering 16,200 km^2 in total. 4,961 km^2 were covered the low flood depth category (0–1 m), 3,175 km^2 the medium inundation (1–3 m), and 8,061 km^2 the high inundation (>3 m). The results of the simulation might lead to a more effective approach for managing and reducing the danger of flooding.

INTRODUCTION

Disasters, whether caused by human activity or natural causes, severely harm the environment, property, and human life. Earthquakes, floods, tsunamis, and landslides are examples of natural catastrophes that frequently strike without notice and seriously disrupt daily life and infrastructure (Putri & Saputri, 2020). However, carelessness or reckless exploitation is typically the cause of man-made disasters such as industrial accidents, environmental pollution, and forest fires (Harsritanto & Roesmanto, 2017). The negative effects of these many calamities necessitate quick action and suitable mitigation techniques to reduce damages.

Flooding is a common natural hazard in Indonesia, especially in areas with heavy rainfall. Flooding is an annual concern in Purworejo Regency, particularly in regions where the Cokroyasan River passes through. In March 2022, there was one such flooding incident in Bayan District, Purworejo Regency, which affected over 11,115 people from 2,924 families and necessitated the evacuation of 6,085 people. The floodwaters, rising to a height of 80–100 cm, submerged 2,924 homes and a number of road segments. Flooding brought on by heavy rainfall and the overflow of multiple large rivers affected 32 communities in Purworejo (Sulistyawati, 2022).

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A watershed is an area of the planet that has natural resources and water that the government must safeguard, regulate, control, and manage to ensure the prosperity of its citizens (Aryani et al., 2020). For the local populations, the Cokroyasan Watershed, which spans Wonosobo and Purworejo Regencies, is essential. Water sources from this watershed are vital for daily needs and agriculture. However, the community's social and economic circumstances deteriorate as a result of increased floods and erosion brought on by environmental deterioration and inadequate watershed management. To mitigate this and safeguard the lives of communities that depend on this river, maintenance and watershed management strategies must be enhanced right away (Setyawan et al., 2018). The Bayan District community's daily demands and irrigation can be met by the Cokroyasan River under normal circumstances. However, river capacity may be exceeded during the rainy season and when Bayan District flow management is subpar, posing a risk of flooding to nearby communities. Thus, to lessen the effects of flooding on the community, thorough flood risk assessment and the application of suitable mitigation techniques are required (Ulfiana & Sari, 2020).

Numerous studies have been conducted on flood modelling in various watersheds to forecast flood features to assess the risks and mitigate disasters in these areas. For instance, studies employing the Nakayasu SUH technique in the Ciliwung Watershed produced a peak flow of 325.4 m^3/second over a 25-year return period (Setiawan et al., 2020). With simulations that could visualise water level profiles up to 2.85 meters high at a 50-year- design flood discharge based on earlier hydrological calculations, the use of HEC-RAS software for hydraulic analysis in the Citarum Watershed produced noteworthy results (Ariani & Suryadi, 2022).

Hydrological and hydraulic modelling, including the utilisation of the Hydrologic Engineering Centre's River Analysis System (HEC-RAS) and Geographic Information System (GIS), is utilised to predict and lessen the effects of floods in the Cokroyasan Watershed, Bayan District. (Somi et al., 2020) design HEC-RAS as a software system for interactive use within its user environment. A GIS is a type of information system that uses spatial data to describe physical objects. Information technology is a key component of GIS itself, serving as a tool for data processing, analysis, storage, and presentation (Triady Ujung et al., 2019). Mapping flood-prone areas and making more precise predictions about water discharge are made possible by the integration of HEC-RAS with GIS. Researchers and the government can use this modelling to create more effective mitigation strategies and give communities early warnings. This strategy should lower the danger of flooding, increase community readiness, and provide a foundation for more effective planning of infrastructure development (Romali et al., 2018).

The purpose of this study is to analyze the flood inundation area and calculate the peak discharge in the Cokroyasan Watershed using satellite rainfall data and the Digital Elevation Model (DEM). Using HEC-RAS and ArcGIS, the study creates models for peak discharge, water levels, and flooded areas for different time periods to help improve flood risk management and planning.

RESEARCH METHODS

This study employs quantitative techniques that can be measured (Sugiyono, 2013). We conducted this study in the 19,700 kilometer long Cokroyasan River in the Bayan District of Purworejo. The region exhibits upstream features characterized by mountains in Wonosobo Regency and downstream features represented by low-lying agricultural plains and villages in Purworejo. The downstream portion of this river frequently floods during the rainy season, despite its significant role as an irrigation source. Figure 1 shows a map of the research area.

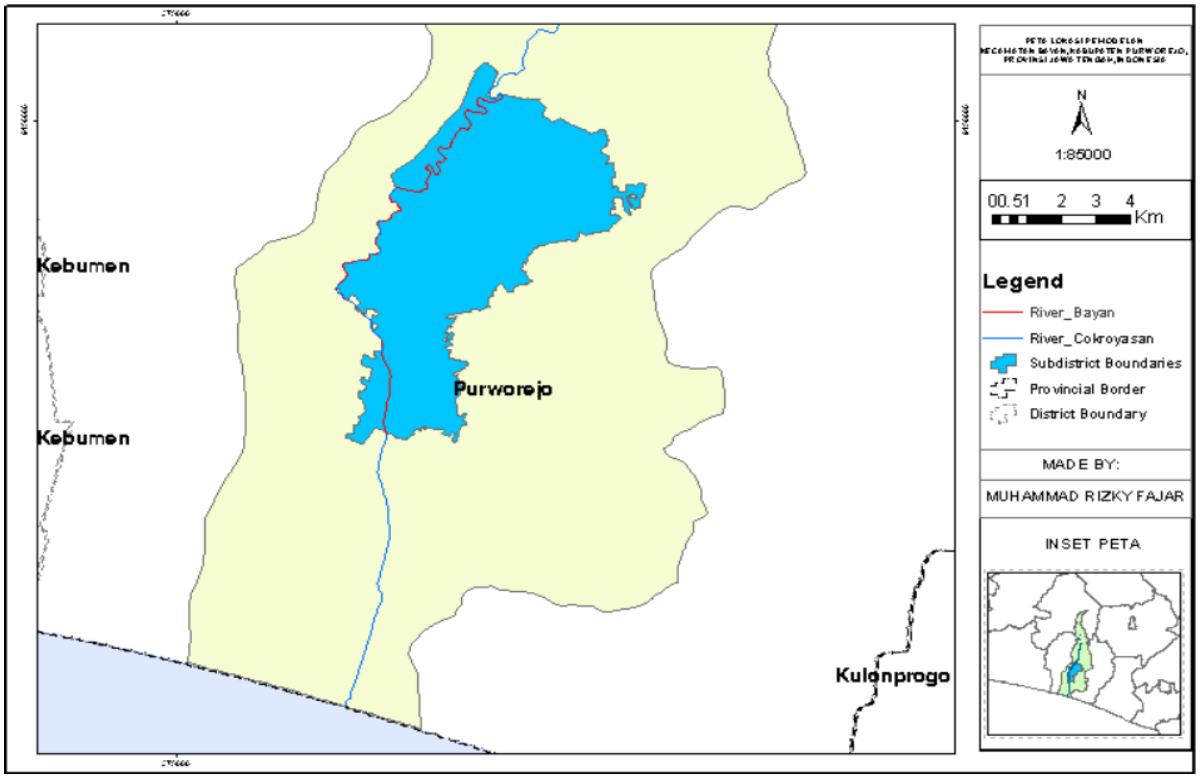

Figure 1. Map of the research area

Research Data Collection

To enable flood modeling studies, secondary data from a variety of literature sources and pertinent data types are the foundations of data collection (Permana & Dwiyanto, 2023). The paper seeks to offer compelling evidence in favor of the analysis carried out. Table 1, which summarizes the data requirements for additional analysis, displays the data used in this study.

Table 1. Data Requirements Table

No	Data Name	Data Type	Data Source
1.	10 years rainfall data	Seconds	Geovani NASA (https://giovanni.gsfc.nasa.gov/giovanni/)
2.	Digital Elevation Model (DEM)	Seconds	Ina - Geoportal (https://tanahair.indonesia.go.id/portal-web/unduh)
3.	Shp file: Territorial boundaries Land cover	Seconds	Indonesia Geospatial (https://www.indonesia-geospasial.com/2020/05/download-data-peta.html)

Frequency Distribution Analysis

Frequency distribution analysis is important when it comes to identifying the most suitable distribution type for rainfall data. Choosing the correct distribution enhances computation accuracy and reduces forecast errors. The frequency analysis of hydrological data seeks to find the relationship between how often extreme events happen and how often they occur using probability distributions (Triatmojo, 2008).

Frequency distribution analysis includes different types of distributions, such as normal distribution, log-normal distribution, Gumbel distribution, and Pearson type III distribution, as shown in Table 2. The distribution calculation can be effectively executed with the formulaic approach outlined in Equations 1 to 4.

Table 2. Selection of Distribution Type

No	Distribution	Requirement
1.	Normal	$Cs \approx 0$ $Ck \approx 3$
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	Apart from the above values

Here are some often-used formulas for understanding the parameters utilized in frequency analysis calculations.

1. Normal Distribution

$$X_T = \bar{x} + K \cdot S \quad (1)$$

2. Normal log distribution

$$\text{Log } X_T = \log\bar{x} + k \cdot S_{(\log x)} \quad (2)$$

3. Gumbel

$$X_T = \bar{x} + \frac{s}{s_n}(Y_T - Y_n) \quad (3)$$

4. Log Pearson III

$$X_{tr} = \bar{x} + k \,.\, S \quad (4)$$

Distribution Compatibility Test

The distribution selected for evaluating parameter fitness is the Log Pearson III . This fitness test can be conducted using the Smirnov-Kolmogorov and Chi-square methods, which are designed to verify whether the distribution is a suitable representation (Suripin, 2004).

1. Chi-square test
2. This test is used to assess the deviation vertically by examining the extent of the difference between the expected and observed frequencies. All observations were conducted separately, and the sample size was optimally greater than forty. The subsequent formula can be employed to ascertain the value of chi-squared (Wahyudi Dedi et al., 2023).

$$X_h{}^2 = \sum_{i=1}^{m} \frac{(O_i - E_i)^2}{E_i} \quad (5)$$

3. Smirnov-Kolmogorov Test

The Smirnov-Kolmogorov test (Ananta et al., 2024) checks if the distribution is suitable for horizontal deviations by looking at these deviations without relying on a specific distribution function. This test seeks to quantify the maximum divergence between empirical probability and theoretical probability. The equation for the Smirnov-Kolmogorov Test calculation is as in Equation 6.

$$D = \max_x [Fa(x) - Fe(x)] \quad (6)$$

Effective Rainfall Analysis

Effective rainfall, also referred to as excess rainfall, is defined as the segment of precipitation that contributes to direct flow in rivers (Triatmojo, 2008). The calculation of effective rainfall necessitates the runoff coefficient (C) and the design rainfall height. We conduct an analysis of the hourly rainfall ratio after acquiring the effective rainfall. This analysis assumes that rainfall is concentrated over a 5-hour observation period, as the duration of concentrated rainfall in Indonesia typically does not exceed 7 hours (Pitaloka & Lasminto, 2017). The effective rainfall analysis equation can be seen in Equation 7, land cover table can be seen in table 3, the runoff coefficient analysis equation can be seen in Equation 8, the rainfall event percentage analysis

equation can be seen in Equation 9, and the rainfall distribution equation can be seen in Equation 10.

$$R_{eff} = C \times X_t \quad (7)$$

$$C = \frac{\sum C.A}{\sum A} \quad (8)$$

$$I = \frac{R_{24}}{t} \left(\frac{t}{T}\right)^{\frac{2}{3}} \quad (9)$$

$$Xt = t \times Xt - (t-1)(Xt-1) \quad (10)$$

Table 3. Bayan District Land Cover Table

No	Land Cover Types	Flow Coefficient
1	Settlement	0,6
2	Dryland Agriculture	0,1
3	Mixed Dryland Agriculture	0,1
4	ricefield	0,15

Flood Discharge Analysis

The Nakayasu Synthetic Unit Hydrograph (HSS) is a popular tool in hydrology used to study flood patterns and predict how rivers will flow after it rains (Margini et al., 2017). This method employs the concept of a synthetic unit hydrograph, which represents river flow generated by a single unit of rainfall. Nakayasu HSS Curve derived from the book (Triatmojo, 2008)can be seen in Figure 2. The general formula for the Nakayasu synthetic unit hydrograph can be seen in Equation 11, and the formula for base flow can be seen in Equation 12.

$$Qp = \frac{A - R_o}{3{,}6(0{,}3Tp + T_{0,3})} \quad (11)$$

Information:

Qp : Peak discharge of floods (m^3/dt)

A : watershed area (km^2)

R_o : Effective Rainfall (mm)

Tp : time from the beginning of the flood to the peak of the hydrograph (hours)

$T_{0,3}$: time from peak flood to 0.3 times peak discharge (hours)

$$QB = 0{,}4715\, A^{0{,}6444} D^{0{,}9430} \quad (12)$$

Information:

QB : Basic Flow (m^3/dt)

D : the density of the drainage network, the number of river lengths of all levels per unit area of the watershed

The Nakayasu Synthetic Unit Hydrograph Curve, depicted in Figure 2, is used for flood analysis in regions with insufficient discharge data. The graph illustrates the correlation between discharge (Q) and time (t), with a steep ascent to peak discharge (Qp) followed by three subsequent falling phases. The primary characteristics comprise peak time (Tp), concentration time (Tg), and decline time (T0.3). This model is crucial for calculating the flood flow during the designing of various water control structures.

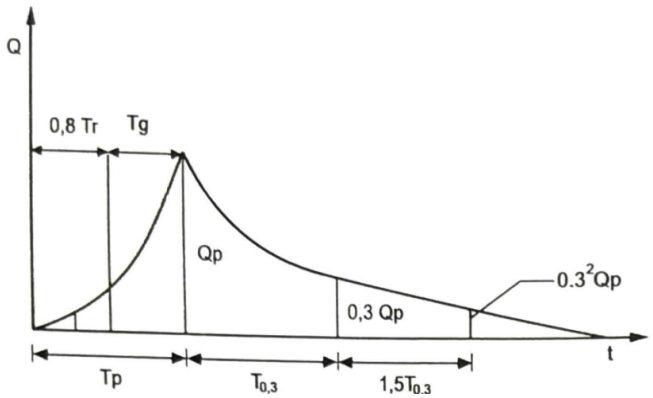

Figure 2. Nakayasu HSS Curve

Hydraulic Analysis

Once we determine the peak flood discharge, we conduct a hydraulic analysis using HEC-RAS 6.4.1 software to model the flood in two dimensions (2D). We then process the obtained data into GIS format and display it as spatial maps using ArcGIS 10.8. The categorization of inundation depth levels in flood visualization adheres to the stipulations outlined in PERKA BNPB No. 02 of 2012 concerning General Guidelines for Disaster Risk Assessment (BNPB No.2 Tahun 2012, n.d.). Information pertaining to the inundation area, the inundation depth, and the flood risk index is derived from the spatial map. Information pertaining to the inundation area, the inundation depth, and the flood risk index is derived from the spatial map.

RESULTS AND DISCUSSION

Maximum Rainfall Data

This study used rainfall data from NASA's Giovanni satellite over the period 2014–2023, with the objective of identifying the maximum daily rainfall. We examined the daily data to determine the average maximum rainfall and identify the peak values during the observation period. The study of daily rainfall data groupings led to the derivation of the maximum data presented in Table 4, which illustrates the annual rainfall trend. Additionally, we derive the maximum rainfall figure for each year from the aggregated data.

Table 4. Average Annual Maximum Daily Rainfall

No	Year	Maximum Rain (X1) (mm)
1	2014	106.184
2	2015	89.883
3	2016	88.272
4	2017	93.305
5	2018	78.732
6	2019	66.528
7	2020	109.950
8	2021	59.025
9	2022	81.461
10	2023	63.827

Frequency Distribution Analysis

The calculation of the probability distribution of rain frequency is carried out to determine the planned rainfall value, which is used in the analysis of flood potential. The data used is the annual maximum rainfall data, which is the largest data that occurs for one year, which is measured over several years. The determination of the distribution type is based on statistical

parameters with corresponding results between the requirements in Table 2 and the calculation results, as shown in the following 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	Apart from the above values

The Pearson Log Type III technique was selected due to its compliance with the requisite criteria, rendering it appropriate for analysis, but the normal methods, normal logs, and Gumbel distributions are unsuitable as their calculation outputs are unqualified. The Pearson Type III Log Method effectively handles data that doesn't follow a normal distribution and provides accurate estimates for extreme values, such as expected rainfall. The outcomes of the scheduled precipitation computation are displayed in Table 6.

Table 6. Rainfall Analysis Pearson Log Pearson Type III Method

Re-Period (Year)	Opportunities (%)	K	K x S1	Log Xt	Xt (mm)
25	95	1.7089	0.0186	1.9328	117,6711

Chi Square Test

The Chi-squared test yielded a value of 2.900 with one degree of freedom and a 5% confidence level, resulting in a critical value of 2.900. Given that the crucial Chi-squared value (2.900) is less than the critical Chi-squared value (5.991), it can be inferred that a type III Pearson log distribution is applicable. The table of the results of the Chi Square test analysis can be seen in table 7.

Table 7. Results of Chi Square Test Analysis

Interval	Ef	Of	If - Too	$(Ef - Of)^2$	$(Ef - Of)^2$ / Ef
51,165 < x < 66,884	2,5	2	0,5	0.25	0,100
66,884 < x < 82,604	2,5	3	-0,5	0.25	0,100
82,604 < x < 98,324	2,5	3	-0,5	0.25	0,100
98,324 < x < 114,044	2,5	2	0,5	0.25	0,100
x > 114,044	2,5	0	2,5	6,25	2,500
Sum	12,5	10			2.900

Uji Kolmogorov-Smirnov

The Kolmogorov-Smirnov test findings, utilising Aprob software, as depicted in Figure 3, yielded a Δmax value of 0.113. We then compare the result to the criticism at the 5% confidence level for a sample size of n=10, which comes out to 0.41. As the Δmax value (0.113) is less than the Δcritical value (0.41), the Pearson Log type III distribution is deemed suitable for subsequent investigation.

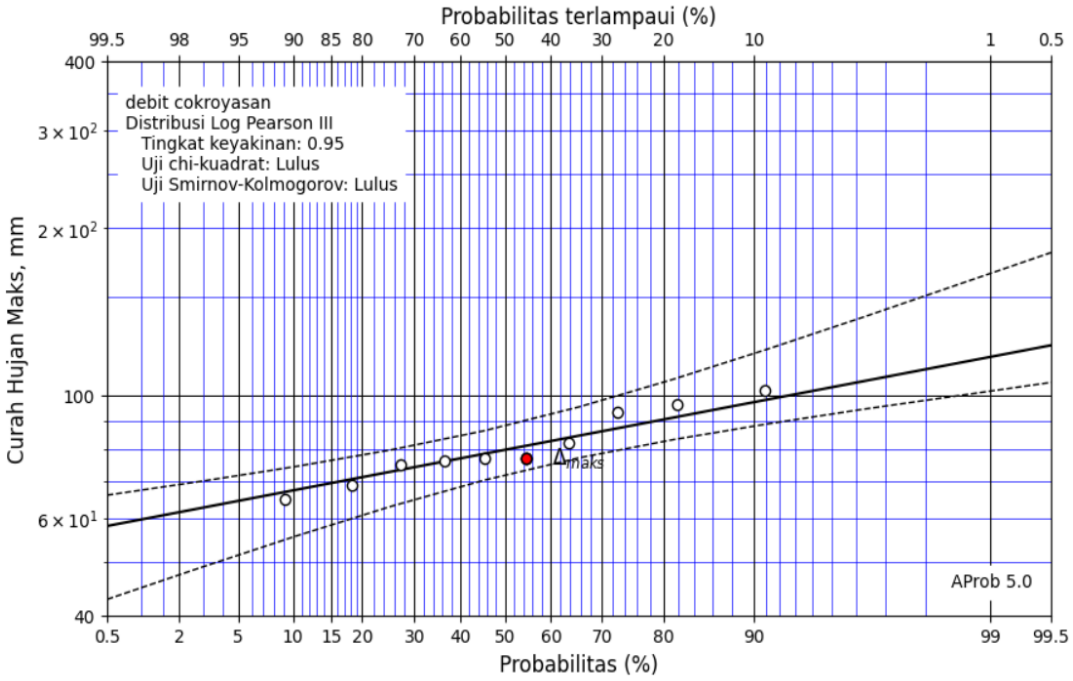

Figure 3. Kolmogorov-Smirnov Test Results

Effective Rainfall Analysis

The runoff coefficient in the Cokroyasan watershed is found by evaluating differences in land cover. Upon acquiring the land cover values, a calculation is performed to ascertain the runoff coefficient. This value is derived from the sum of the products of the flow coefficient (C) for each land cover type and its corresponding area (A), divided by the total area of the entire region. This step is an example of computing runoff coefficients:

$$C = \frac{\sum(CxA)}{\sum A} = \frac{12{,}885}{44{,}470} = 0{,}288$$

The runoff coefficient is 0.288, which corresponds to 2,88% when expressed as a percentage. The calculation of effective rainfall is derived from the product of the flow coefficient and the anticipated rainfall. This is an illustration of an efficient precipitation computation:

Reff = C × Xt = 0.288 × 117.6711 = 33.890 mm

The calculated daily effective rainfall amounts to 33.890 mm for the 25-year renewal period. Upon acquiring effective rainfall, the distribution of rainfall hours is computed utilising the percentage of rain incidence approach grounded in the Mononobe formula. The cumulative rainfall percentage (Rt) relative to daily rainfall (R24) is computed using the formula for the distribution of rainfall during the specified periods:

$$I = \frac{R_{24}}{t}\left(\frac{t}{T}\right)^{\frac{2}{3}} = \frac{R_{24}}{5}\left(\frac{5}{1}\right)^{\frac{2}{3}} = 0{,}585\ R24$$

Furthermore, to find out the distribution of rain at each hour, the difference between the cumulative rain at the t-hour and the cumulative rainfall at the 1st hour was calculated using the equation:

Xt = t × Xt – (t – 1) (Xt – 1) = 1(0.585 R24) – (1 – 1)(X1 – 1) = 0.585 R24

So, the total effective daily rainfall is 0.585 × 33,890 = 19,819 mm. The hourly rain distribution chart can be seen in Figure 4.

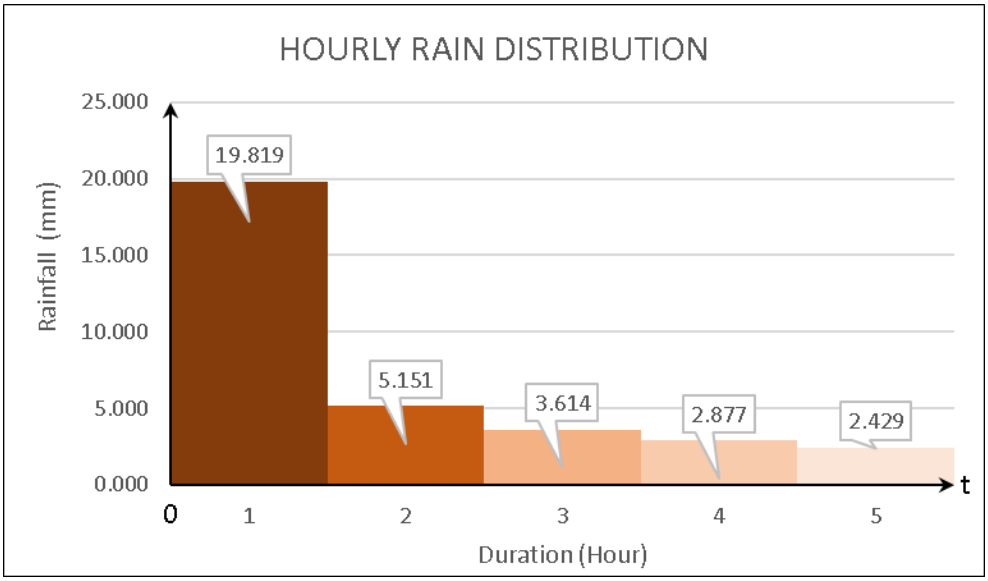

Figure 4. Hourly Rain Distribution Chart

Flood Discharge Analysis

The anticipated flood discharge is computed to assess the greatest discharge that may occur within a specified return period. This study employed a 25-year replay period for flood modelling, in accordance with SNI 2415:2016 on Flood Discharge Calculation Procedures. The employed approach is the Nakayasu Synthetic Unit Hydrograph (HSS), wherein the computation is executed by multiplying the Nakayasu HSS value by the rainfall distribution over the periods. The analysis conducted using the formulas in equations 11 and 12 yielded a maximum flood discharge of QP = 1387.844 m³/second for a 25-year return period, with a base flow of QB = 4 m³/second. The hydrographic graph of the Nakayasu Cokroyasan watershed can be seen in Figure 5.

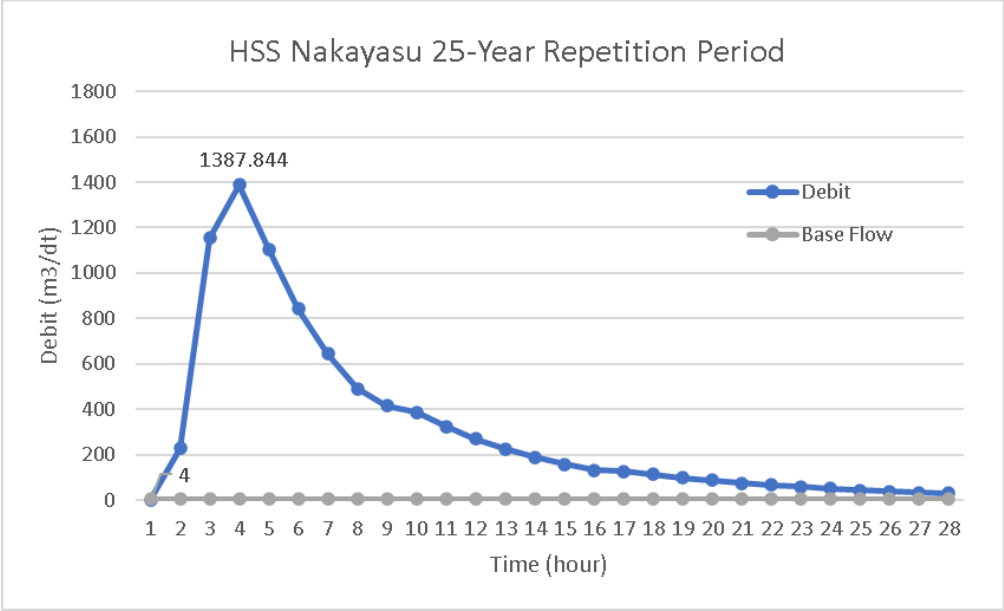

Figure 5. HS Nakayasu

Hydraulic Analysis

Hydraulic analysis uses HEC-RAS 6.4.1 with the Ras Mapper feature for 2D flood modelling and ArcGIS 10.8 for mapping, where the process starts from collecting topographic, hydrological, and cross-sectional data of the river, which is then simulated to produce a profile of water flow and inundation areas that can help flood mitigation planning.

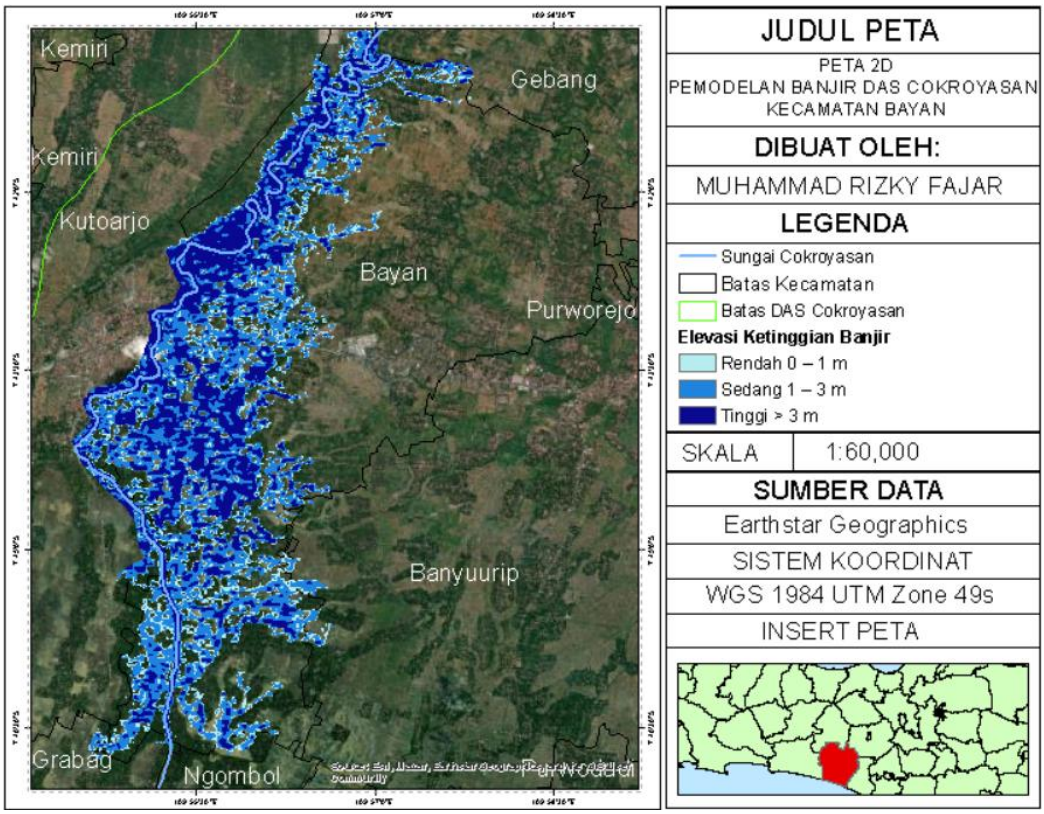

Figure 6. 2D Flood Modeling of the Cokroyasan River

Based on the results of the analysis that has been carried out, two-dimensional flood modelling in the Cokroyasan Watershed (DAS) in Bayan District, with a 25-year re-period (Q25), produces a flood inundation area in the Cokroyasan watershed, Bayan District. The visualization of the results of flood inundation modeling can be seen in Figure 6.

The information on the inundation area in the Cokroyasan watershed, Bayan District, is shown in Table 8. This information is based on the land cover that was impacted by the flood. On this chart, the depth of the inundation is broken down into three distinct categories: low, medium, and high. Additionally, the table displays the region that is impacted by each of these depth categories. The data shown here paints a clear picture of the extent to which the land has been inundated as a result of flooding.

Table 8. Inundation Area of the Cokroyasan Watershed, Bayan Distric

No	District	Land Cover	Class	Inundation Depth (m)	Inundation Area (km2)
1	Bayan	Settlement	Low	0 – 1	1,013
			Medium	1 – 3	0,367
			High	> 3	1,089
			Total		2,469
2		Dry Land Agriculture	Low	0 – 1	1,819
			Medium	1 – 3	0,778
			High	> 3	2,547
			Total		5,144
3		ricefield	Low	0 – 1	2,129
			Medium	1 – 3	2,029
			High	> 3	4,429
			Total		8,587

Based on the analysis of flood modelling in the Cokroyasan watershed, Bayan District, it shows that flood modelling of the Cokroyasan watershed using the Pearson Log Type III method produced a planned rainfall of 117.6711 mm for a 25-year re-period with a flow coefficient of 0.288. Analysis with the Nakayasu HSS yielded a peak discharge of 1684.028 m^3/s. Hydraulic modelling with HEC-RAS and ArcGIS mapped an inundation area of 16,200 km^2, consisting of shallow inundation (0-1 metre) covering an area of 4,961 km^2, moderate inundation (1-3 metres) covering an area of 3,175 km^2, and deep inundation (>3 metres) covering an area of 8,064 km^2.

CONCLUSION

This study succeeded in achieving the goal of analysing the area of flood inundation and calculating peak discharge in the Cokroyasan watershed by utilising a combination of rainfall data from NASA's Giovanni satellite and Digital Elevation Model (DEM). The application of the Nakayasu Synthetic Unit Hydrograph (HSS) method resulted in the calculation of the peak discharge of the flood with a 25-year re-enactment period of 1684.028 m^3/second, a significant value and a need to be considered in watershed management planning. Hydraulic analysis using HEC-RAS modelling and ArcGIS managed to map a total inundation area of 16,200 km^2, consisting of three depth classifications: low inundation (0-1 meter) covering an area of 4,961 km^2, moderate inundation (1-3 meters) covering an area of 3,175 km^2, and high inundation (>3 meters) covering an area of 8,064 km^2. The integration of satellite rainfall data with 2D hydraulic modelling results in accurate and comprehensive visualisation of flood-prone areas, showing high-risk areas in multiple locations with water depths of more than 3 metres. The modelling and mapping results obtained in this study can be an important information basis to identify high-risk areas in the Cokroyasan watershed and support the development of more effective and sustainable flood risk mitigation strategies and management in Bayan District, Purworejo Regency.

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