

Analysis and Flood Mapping of Pekalen Watershed of Probolinggo Regency Using HEC-RAS Application

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Article Information	ABSTRACT
Article History Received : December 17, 2024 Revised : January 07, 2025 Published : January 16, 2025	Flooding is one of the natural disasters that needs attention, especially in the Pekalen watershed, Probolinggo Regency. The purpose of this research is to analyze the design flood discharge and mapping of the area potentially affected by inundation. The research stages began with arithmetic area average rainfall analysis, log pearson type III design rainfall analysis, chi squared and smirnov-kolmogorov distribution fit test, mononobe rainfall intensity, HSS Nakayasu design flood discharge analysis, and flood mapping with HEC-RAS 2D flood modeling. The design flood discharge of Pekalen watershed at 10-year return period is 421.4 m ³ /s, 25-year return period is 455.12 m ³ /s, and 50-year return period is 479 m ³ /s. The areas potentially affected by inundation at 25 years return periods are Sukomulyo, Sukokerto, Pajarakankulon, Kradenan, Tanjung, Karangbong, Temenggungan, Karanggeger, Ketompen, Petemon, Selogudigwetan, Selogudigkulon, Puspan, Braniwetan, Branilor, Sumbersecang, Satreyan, Maronkidul, Gerongan, Brabe, Condong, Racek, Pesawaran, Ranugedang, Jangkang, Segaran, Ranuagung, Tiris, Andungsari, Andungbiru, and Sumberaren.
Keywords: <i>Food analysis; Flood mapping; HEC-RAS.</i>	

INTRODUCTION

Indonesia is a country with a high level of vulnerability to natural disasters (Fariza & Handayani, 2022). Landslides, floods, flash floods, droughts, forest and land fires are hydrometeorological disasters that often occur in Indonesia (D. N. Utami, 2019). Flooding is one of the natural disasters that needs attention in Indonesia, the reason why this disaster needs attention is because its intensity in one year can reach 40% compared to other natural disasters (Muspida et al., 2021) & (Madani et al., 2022). According to the National Disaster Management Agency (BNPB), there were a total of 3,028 disasters during the period January 1 to September 30, 2023, where floods were the most frequent natural disaster with 890 incidents.

Pekalen River is one of the rivers with springs from Mount Argopuro and Mount Lemongan that passes through Probolinggo Regency (Maulana et al., 2021). In 2018, there was a flash flood disaster in Tiris sub-district which resulted in damage to buildings and bridge facilities (BPBD Probolinggo Regency, 2018). In 2019, the Probolinggo Regency Regional Disaster Management Agency (BPBD) collaborated with the East Java Provincial Public Works and Water Resources Office to carry out normalization activities on the Pekalen River located in Andungbiru village, Tiris sub-district, which is located upstream, where this effort has the aim of minimizing flood disasters to secure facilities and residential areas against subsequent flooding (Dinas Kominfo, 2019). In 2020, the Pekalen River overflowed due to high rainfall for five hours and

One of the strategic watersheds in East Java Province is the Pekalen watershed, but the simultaneous logging of sengon trees can cause erosion and is prone to flash floods (Rastanto et al., 2022). The potential for flooding in the Pekalen watershed needs to be studied more deeply to plan the mitigation process in the event of a flood. Considering that Pekalen River is a river that passes through three sub-districts sequentially, efforts that can be made for the mitigation process include flood analysis and flood mapping. The purpose of this research is to analyze the design flood discharge and mapping of the area potentially affected by inundation in the Pekalen watershed in Probolinggo Regency at 10, 25, and 50-years return period.

Research Location

The type of research used in this research is quantitative descriptive method. Quantitative descriptive method is a research method that has the aim of analyzing and drawing conclusions in accordance with the results that have been obtained during the research.

Nama Data	Sumber
Monthly rainfall 2013-2023 with 5 stations (Pekalen, Pajarakan, Condong, Tiris, and Krucil)	PUPR Office of Probolinggo Regency
Watershed area and length of main river	UPT PSDA WS Welang Pekalen
Terrain	Inageoportal
Main river flow map	UPT PSDA WS Welang Pekalen
Village boundary map	PUPR Office of Probolinggo Regency
Watershed boundary map	UPT PSDA WS Welang Pekalen

The stages in this research were carried out systematically based on Figure 2 with the following steps:

- 1) Requesting the data needed in the research with the relevant agencies.
- 2) Calculating the average rainfall of the region using the Arithmetic Mean method using the following equation (Sosrodarsono & Takeda, 2003):

$$P = \frac{P_1 + P_2 + \dots + P_n}{n} \quad (1)$$

description:

P = average rainfall of the region

$P_1, P_2, \dots, P_n$ = rainfall at station 1, 2, ..., n

n = number of station

- 3) Perform calculations and adjust statistical parameters to determine the type of distribution and calculate the design rainfall analysis. The design rainfall analysis which is commonly used is log pearson type III using the following equation (Limantara, 2018) :

$$\text{Log } X_{tr} = \text{Log } \bar{X} + K_{tr} \cdot S \log \bar{X} \quad (2)$$

description:

Log X_{tr} = the rainfall amount with a T-year return period

Log $\bar{X}$ = the data's average value

K_{tr} = reduction value [K value in (Triatmodjo, 2019)]

$S \log \bar{X}$ = standard deviation

- 4) Apply the following formula to perform a distribution suitability test with Chi Square and Smirnov-kolmogorov methods (Triatmodjo, 2019):

$$\chi^2 = \sum_{f=0}^N \frac{(Of - Ef)^2}{Ef} \quad (3)$$

description:

χ^2 = calculated value of chi squared

Ef = expected frequency based on the class division

Of = frequency read in the same class

N = number of subgroups in a group

$$\Delta maks = [Pe - Pt] \quad (4)$$

description:

Pe = empirical probability

Pt = theoretical probability

- 5) Calculating rainfall intensity using the Mononobe method using the following equation (Triatmodjo, 2019):

$$I_t = \frac{R_{24}}{24} \left(\frac{24}{t} \right)^{2/3} \quad (5)$$

description:

I_t = rainfall intensity with rainfall duration t

t = length of rainfall

R_{24} = maximum rainfall for 24 hours

6) Calculating the design flood discharge using the HSS Nakayasu method using the following equation (Triatmodjo, 2019):

$$Qp = \frac{A \times Re}{3,6 (0,3 T_p + T_{0,3})} \quad (6)$$

description:

Qp = peak flood discharge

CA = river drainage area

$R0$ = rainfall unit

T_p = the amount of time between the start of the rain and the peak of the flood

$T_{0,3}$ = the amount of time needed for the peak discharge to drop to 30% of the peak discharge

7) Performing flood mapping using 2D flood modeling with HEC-RAS application

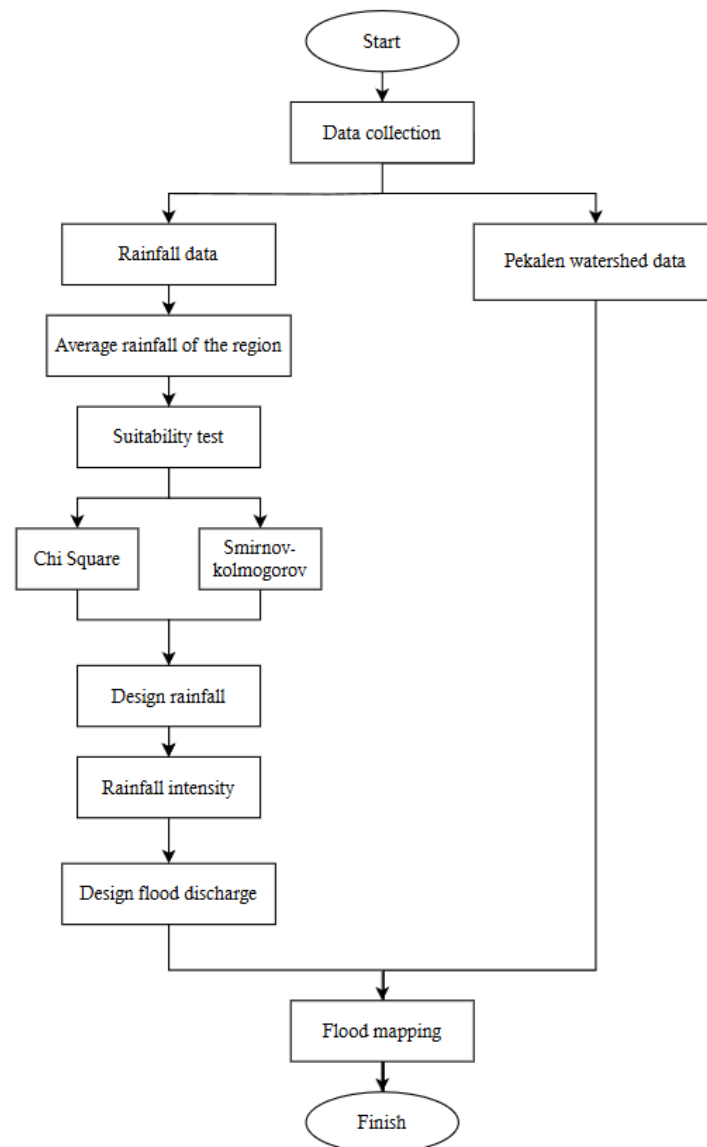


Figure 2. Flowchart

RESULTS AND DISCUSSION

Flood Discharge Analysis

Table 1 displays the findings of the regional average rainfall calculated using the arithmetic mean and equation 1. The rainfall data utilized in this analysis was obtained from the PUPR Office of Probolinggo Regency for the years 2013-2023.

Table 1. Table of average rainfall analysis results of the region

Year	Station					Result
	Pekalen	Pajarakan	Condong	Tiris	Krucil	
2013	98	90	103	177	121	117,8
2014	92	90	100	158	127	113,4
2015	119	90	109	164	139	124,2
2016	97	128	107	192	93	123,4
2017	81	140	74	145	80	104
2018	70	51	70	232	74	99,4
2019	95	95	94	96	88	93,6
2020	144	215	123	185	120	157,4
2021	101	63	105	149	130	109,6
2022	89	120	109	132	119	115,8
2023	63	65	67	103	94	83,2

The average rainfall for the region throughout the 2013-2023 period is 117.8 mm, 113.4 mm, 124.2 mm, 123.4 mm, 104 mm, 99.4 mm, 93.6 mm, 157.4 mm, 109.6 mm, 115.8 mm, and 83.2 mm, according to Table 1. The design rainfall must be examined following the completion of the regional average rainfall analysis. Calculations and adjustments with statistical parameters are required to establish the type of distribution that is utilized, Table 2 displays the results and statistical parameters.

Table 2. Table of results and statistical parameters for determining the distribution type

Distribution	Terms	Result	Description
Normal	$C_s = 0$	0,905	Not Accepted
	$C_k = 3$	5,780	Not Accepted
Log Normal	$C_s = C_v^3 + 3C_v$	0,107	Not Accepted
	$C_k = C_v^8 + 6C_v^6 + 15C_v^4 + 16C_v^2 + 3$	3,020	Not Accepted
Gumbel	$C_s = 1,14$	0,905	Not Accepted
	$C_k = 5,4$	5,780	Not Accepted
Log Pearson Tipe III	$C_s \neq 0$	0,303	Accepted

Table 2 shows that the Log Pearson Type III distribution is the distribution type used in the design rainfall analysis of this study. The Log Pearson Type III distribution can be used in this study because the results obtained from the calculation meet the requirements with a result of 0.303 with the condition that $C_s \neq 0$. Meanwhile, other types of distributions cannot be used because the results do not meet the statistical parameter requirements for determining the type of distribution. The requirements used as statistical parameters in Table 2 are based on (Triatmodjo, 2019). Equation 2 shows the Log Pearson Type III distribution equation used in this study. Table 3 shows the results of the Log Pearson Type III distribution.

Table 3. Table of result distribution log pearson type III

Period (T)	Ktr	Log Xtr	Result
10	1,28	2,14	138,07
25	1,74	2,17	149,12
50	2,04	2,19	156,8

Testing the distribution's suitability is required following the determination of the distribution type and the results obtained. There are two types of distribution appropriateness test used in this study; the Smirnov-kolmogorov test and the chi squared test. Table 4 displays the results of the distribution appropriateness test. Equation 3 and 4 contain the chi squared test equation and the Smirnov-kolmogorov test equation.

Table 4. Table of result distribution suitability test

Distribution type	X ² count	ΔPmax	Chi Square Test		Smirnov-Kolmogorov Test	
			α = 1%	α = 2%	α = 1%	α = 2%
			X ² cr = 7,815	X ² cr = 8,405	Dkritis = 0,472	Dkritis = 0,453
Log Pearson Type III	6,727	0,122 0,085	Diterima	Diterima	Diterima	Diterima

Following receipt and acceptance of the distribution suitability test result, the Mononobe method with equation 5 used to determine the intensity of the rain; the results are displayed in Figure 2.

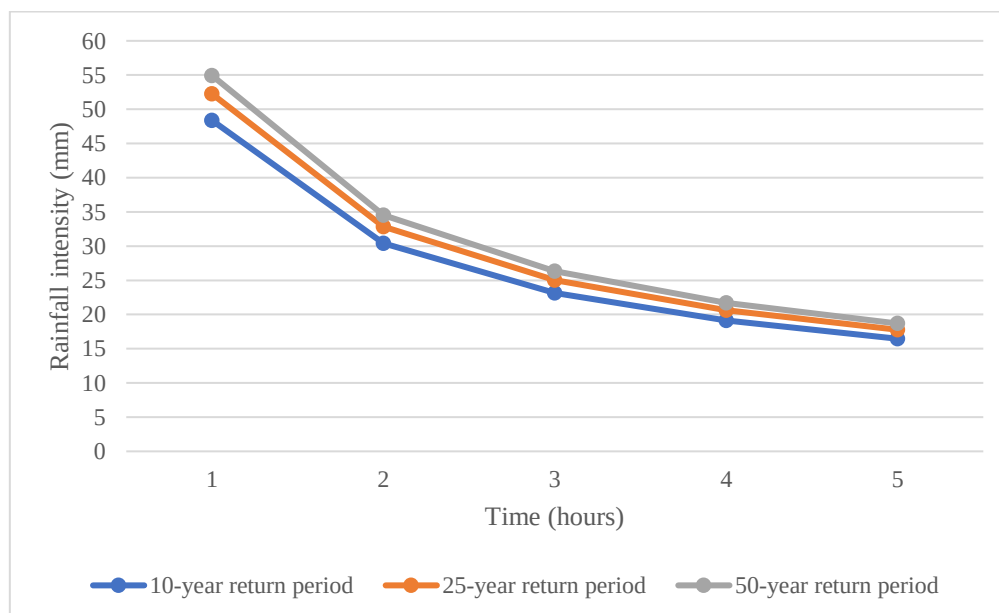


Figure 3. Rainfall intensity chart

The design flood discharge analysis in this study uses the Nakayasu Synthetic Unit Hydrograph (HSS) method. The Nakayasu HSS equation is located in equation 6. The peak flood discharge table and the total 24-hour flood discharge are shown in Table 5.

Table 5. Table of design flood discharge

Kala ulang (tahun)	10	25	50
Peak discharge	421,4	455,12	479
Total discharge	4081	4338,9	4454

Based on Table 5, it can be concluded that the results of the design flood discharge at the return periods of 10, 25, and 50 years are 421.4 m³/second, 455.12 m³/second, and 479 m³/second. While the total flood discharge for 24 hours at the return period of 10, 25, 50 years is 4081 m³/second, 4338.9 m³/second, and 4454 m³/second. Meanwhile, based on the results of research (Maulana et al., 2021), the peak flood discharge at the 10-year return period is 411.025 m³/second, the 25-year return period is 455.052, and the 50-year return period is 484.090 m³/second. And based on the results of research (Fadhilurrahman et al., 2024), the flood discharge

at the 10-year return period was 693.45 m³/second, the 25-year return period was 784.17 m³/second, and the 50-year return period was 842.66 m³/second.

According to Nugroho & Handayani (2021); Awaliyah et al. (2020), one of the factors that cause flooding is rainfall. Rainfall is an indicator of the rain intensity variable, where these two things are related in the calculation of design flood discharge. In this study, rainfall for 11 years with a period of 2013-2023 was used, while the previous study used rainfall for 20 years with a period of 1999-2018. The difference in duration and period used in the selection of rainfall is what causes differences in the results of rainfall intensity calculations, which then affects the results of the design flood discharge design.

According to Awaliyah et al. (2020); Syafitri & Rochani (2022) the internal factors that influence the occurrence of floods are topography, where topographic variables affecting the occurrence of flooding is topography, where the topography variable is included in the indicator of watershed characteristics. is included in the watershed characteristics indicator. Topography is a variable that related to the high or low contour in the upstream, middle, and downstream of a watershed. Watershed characteristics affect the value of α that is used in the calculation of design flood discharge. So that the result of the magnitude of the design flood discharge obtained in the calculation is influenced by watershed characteristics.

According to Awaliyah et al. (2020) another external factor is the shape of the watershed. The shape of the watershed has an influence on the occurrence of floods, because the shape of a watershed can affect the speed of water flow. watershed can affect the speed of water flow. Watershed shape variables are included into an indicator of watershed characteristics. Watershed characteristics have an influence on the α value used in the calculation of the design flood discharge. Based on the previous sentence, it can be concluded that the watershed characteristics affect the on the result of the design flood discharge.

Flood Mapping

After the results of the design flood discharge are obtained using the Nakayasu HSS, it is necessary to do flood mapping to find out the areas that will be affected by inundation. Flood mapping is carried out using 2D modeling of the HEC-RAS application. The data used in this process are terrain data, watershed boundaries, village boundaries, and main river maps. The 10, 25, and 50-year return period flood mapping is shown in Figure 4, Figure 5, and Figure 6.

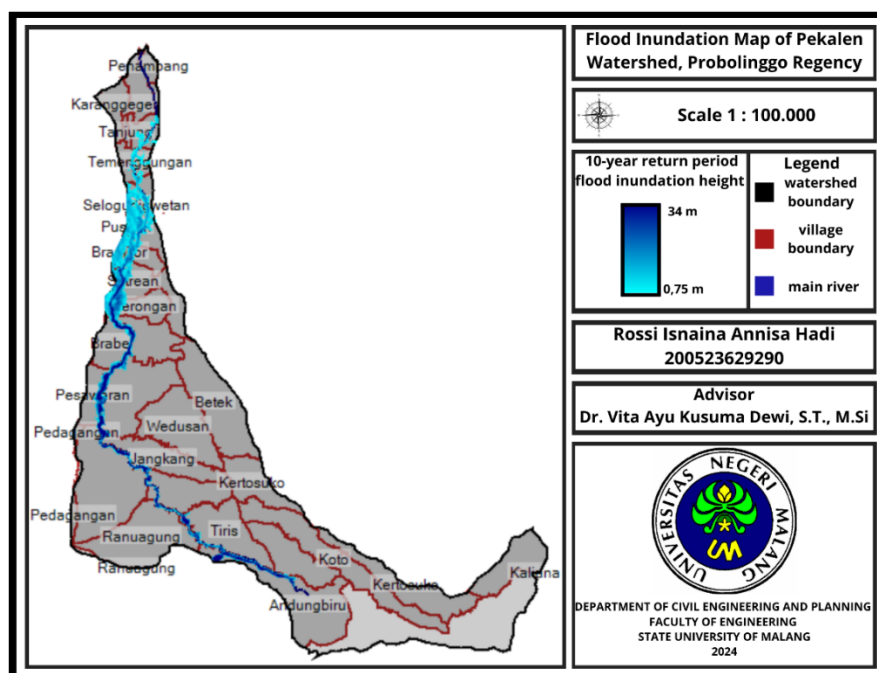


Figure 4. 10-year return period inundation map

Based on Figure 4, it can be concluded that the areas impacted by floods with a 10-year return period flood discharge are the villages of Pajarakan kulon, Kradenan, Karangbong, Temenggungan, Ketompen, Petemon, Selogudig wetan, Selogudig kulon, Puspan, Brani wetan, Brani lor, Condong, Racek, Pesawaran, Ranu gedang, Jangkang, Segaran, Ranu agung, Tiris, Andung sari, Andung biru, and Sumber aren. The village that experienced the highest maximum inundation was Andung sari where the height reached 34.4 m when the peak flood discharge occurred.

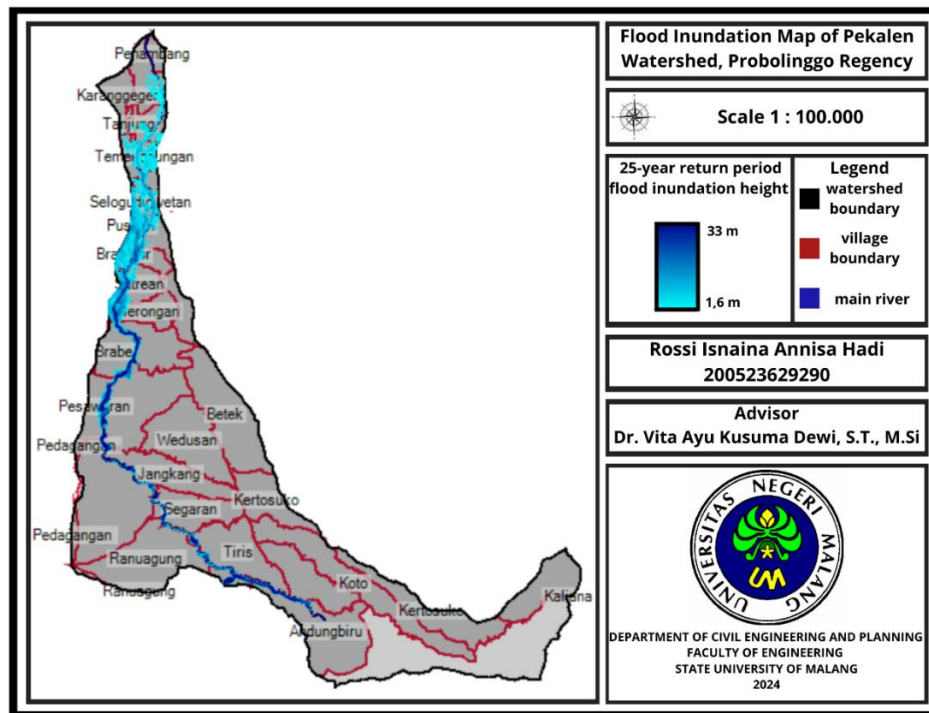


Figure 5. 25-year return period inundation map

Based on Figure 5, it can be concluded that the areas impacted by floods with a 25-year return period flood discharge are the villages of Sukomulyo, Sukokerto, Pajarakan kulon, Kradenan, Tanjung, Karangbong, Karanggeger, Temenggungan, Ketompen, Petemon, Selogudig kulon, Brani wetan, Puspan, Brani lor, Sumber secang, Satreyan, Maron kidul, Gerongan, Brabe, Condong, Racek, Pesawaran, Ranu gedang, Jangkang, Segaran, Ranu agung, Tiris, Andung sari, Andung biru, and Sumber aren. The maximum flood inundation with a 25-year return period flood discharge occurs in Andung sari village where the height reaches 33 m during the peak flood discharge.

Based on Figure 6, it can be concluded that the areas impacted by floods with a 50-year return period discharge are the villages of Sukomulyo, Sukokerto, Pajarakan kulon, Kradenan, Temenggungan, Tanjung, Karangbong, Ketompen, Selogudig wetan, Selogudig kulon, Puspan, Brani wetan, Brani lor, Sumber secang, Satreyan, Maron kidul, Gerongan, Condong, Brabe, Racek, Pesawaran, Ranu gedang, Jangkang, Segaran, Ranu agung, Tiris, Andung sari, Andung biru, and Sumber aren. The highest maximum flood inundation occurred in Andung sari village with a 50-year return period flood discharge as high as 34.6 m when the peak flood discharge occurred.

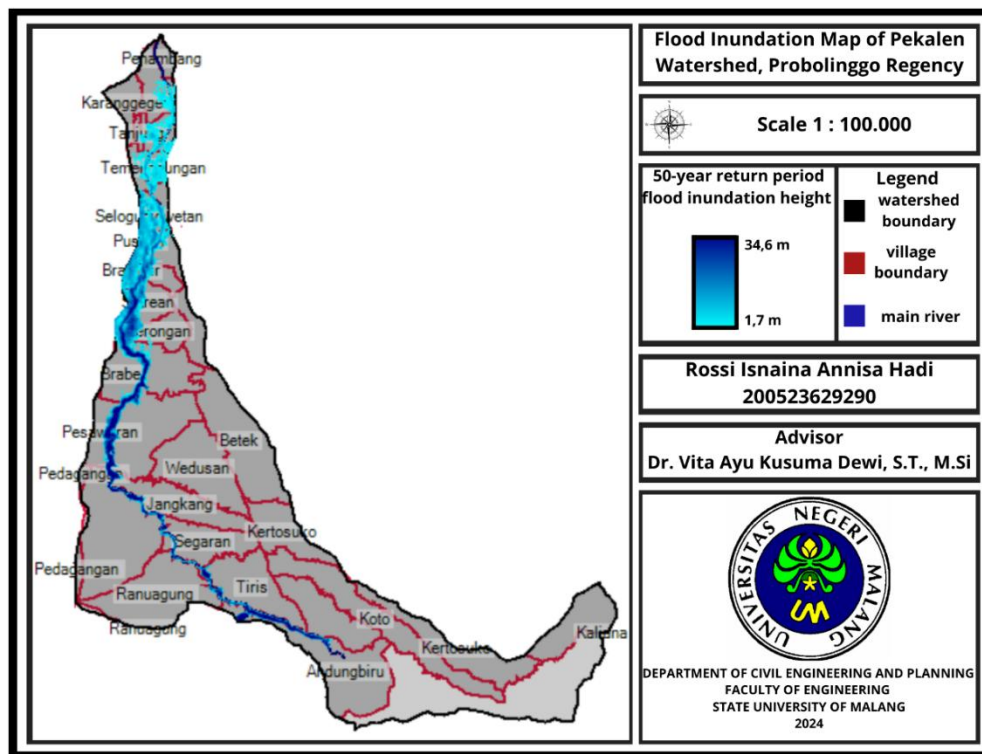


Figure 6. 50-year return period inundation map

Based on the results of the analysis in the study, it was found that the villages that experienced the highest inundation were Andungsari village with a height of 34.4m with a 10-year return period, 33m with a 25-year return period, and 34.6m with a 59-year return period. with a 10-year return period, 33m with a 25-year return period, and 34.6m with a 59-year return period. year. Meanwhile, according to the research of Fadhlurrahman et al. village that experienced the highest inundation was Sukokerto village with a height of 1.5m with a return period of 2 years. with a return period of 2 years. The village with the lowest maximum inundation in this study is Rondokuning village with a height of 0.75m at a return period of 10 years, 1.6m at the 25-year return period, and 1.7m at the 50-year return period. Meanwhile, according to Fadhlurrahman et al.'s research (2024), the village that experienced the lowest maximum inundation was Kreitung. the lowest maximum inundation is Kregen with a height of 0.38m at the 2-year return period. at the 2-year return period.

The difference between the results of this study and previous studies is the village or area that will be affected by flooding in a certain return period. According to Nugroho & Handayani (2021); Awaliyah et al. (2020) one of the factors that can cause flooding is rainfall. The difference between rainfall in this study and previous studies is in the period used, namely the rainfall used in this study for 11 years (2013-2023) while in previous studies using rainfall for 10 years (2013-2023). previous research used rainfall for 10 years (2012-2021). The high rainfall in 2018 at the Tiris rain station resulted in floods that have an impact on damage to buildings and bridges.

Another factor that affects the mapping of floods or areas that will be affected by flooding is terrain data. Terrain data is the elevation data of an area used in 2D HEC-RAS modeling. According to Awaliyah et al. (2020); Syafitri & Rochani (2022), the internal factors that influence the occurrence of floods are topography or elevation, which is related to the high or low level of flooding. Flooding is related to the high or low contour where the lower the contour of an area, the greater the potential for flooding. flood prone. The downstream area of the Pekalen River Basin has a low contour, causing the downstream area of the Pekalen River Basin to be prone to flooding. low contours, which is why the downstream areas in the mapping had many areas that are inundated.

CONCLUSION

The design flood discharge of Pekalen watershed at 10-year return period is 421.4 m³/s, 25-year return period is 455.12 m³/s, and 50-year return period is 479 m³/s. The areas potentially affected by inundation at 25-years return periods are Sukomulyo, Sukokerto, Pajarakan kulon, Kradenan, Tanjung, Karangbong, Temenggungan, Karanggeger, Ketompen, Petemon, Selogudig wetan, Selogudig kulon, Puspun, Brani wetan, Brani lor, Sumber secang, Satreyan, Maron kidul, Gerongan, Brabe, Condong, Racek, Pesawaran, Ranu gedang, Jangkang, Segaran, Ranu agung, Tiris, Andung sari, Andung biru, and Sumber aren. Suggestions for reducing the area impacted by flooding are the construction of reservoirs or retention ponds in low topography areas and the addition of green space or to enhance infiltration and store water in the ground.

ACKNOWLEDGEMENTS

Thank you to the advisor, Dr. Vita Ayu Kusuma Dewi, S.T., M.Si. who has helped and provided advice in the work of this journal. Thanks also to the agencies that have helped the author in obtaining data, namely the PUPR Office of Probolinggo Regency and UPT PSDA WS Welang Pekalen.

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