Prediction of flood peak-discharges in the Raman Watershed, North Raman, Central Lampung

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Abstract. The Raman Watershed which is located in Pekalongan District covers an area of approximately 4,375 hectares of technically irrigated rice-field. The area was repeatedly hit by extreme flooding during the rainy season. The largest recorded flood occurred in December 2021, with an average daily maximum rainfall of 153 mm. This flood caused serious damage to the primary canal of the North-Raman Irrigation-Area. This research objective is to predict the flood peak-discharge in the Raman Watershed in the rainy season in December 2021. Flood discharge is calculated for various return periods based on daily rainfall-data from 2012 to 2021 obtained from BMKG Central Lampung. Hydrological analysis includes: 1) assessment of annual average rainfall-depth using the Thiessen method; 2) analysis of rainfall distribution and predictions of design rainfall using three common probability distributions; and 3) flood discharges are predicted using the Nakayasu method. Distribution analysis shows that LPT3 is the most suitable distribution. The average daily maximum rainfall recorded in December 2021 (153 mm), is in very good agreement with the design rainfall for the 25-year return period (152.58 mm). Thus, the flood peak-discharge in the Raman Watershed with average daily maximum rainfall of 153 mm is estimated at 23.27 m^3/s.

1 Introduction

In the last few decades, floods have been the most frequent natural disaster affecting Indonesia. This phenomenon is primarily triggered by extreme rainfall during the rainy season, which has intensified over time [1-6].

Previous studies have shown that while the heavy rain is a natural occurrence, the severity and frequency of flooding are not solely due to natural causes [7, 8]. Human activities, such as rapid urbanization and extensive development, have contributed significantly to the problem. These socio-economic factors have expanded flood-prone areas, making them more vulnerable and susceptible to flood damage [9-11]. As cities grow and development continues, natural drainage systems are often disrupted, leading to increased water accumulation and flooding events.

In the context of flood risk mitigation and prevention, it is essential to accurately estimate peak flood discharge for a given area [12-14]. Knowing the peak discharge level helps in understanding the potential severity of floods, thus enabling the design and construction of appropriate infrastructure to manage and reduce the impact of these events. Accurate estimates enable the development of effective flood control measures and structural designs that can better protect communities from flood damage [15, 16]. Implementing such measures is essential to reduce the impact of floods and increase resilience to future events.

In the Raman Watershed which is located in Pekalongan District, North Raman, Central Lampung, there are around 4,375 hectares of technically irrigated rice fields. A major flood event occurred in December 2021, with an average daily maximum rainfall-depth of 153 mm, causing severe damage to primary canals in the watershed. This incident has definitely had a negative impact on the economy of local residents and surrounding communities (Fig. 1).

Fig. 1. A flood event occurred in the Raman Watershed in december 2021

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Considering the importance of estimating flood peak-discharge in designing water infrastructure in the Raman Watershed, this research objective is to predict the potential flood peak-discharge in the Raman Watershed during the rainy season in December 2021.

In order to repair the primary-canal infrastructure in the North-Raman Irrigation-Area, as well as carry out flood mitigation and control measures in the Raman Watershed, Pekalongan Regency, the regional government plans to reconstruct the damaged irrigation canal and designs several other water infrastructures.

2 Methods

2.1 Research site

This research was conducted in the downstream part of the Raman Watershed, North Raman, Pekalongan Regency, Central Lampung with coordinates of 5°2'24.96" South Latitude – 105°21'41.4" East Longitude. Figure 2 shows the research site.

The total area of the Raman Watershed is approximately 86.3 km². This watershed is influenced by two seasons every year: the rainy season and the dry season. The watershed experiences a rainfall cycle that lasts from April to October.

2.2 Data collection

To predict flood peak-discharge, the data needed consist of rainfall depth data and land use data. There are two rainfall stations in the Raman Watershed, namely Bayah station and Cibeber station.

In this research, rainfall data and land use data were obtained from the River Basin Center (BBWS) - Mesuji Sekampung and PT Bumi Karya Consultant, Lampung Province. Rainfall data from both rainfall stations (Bayah and Cibeber stations) were taken for a ten-year period (2012 to 2021). Table 1 shows the maximum daily rainfall from year 2012 to 2021. This data was then analysed using the Thiessen polygon method.

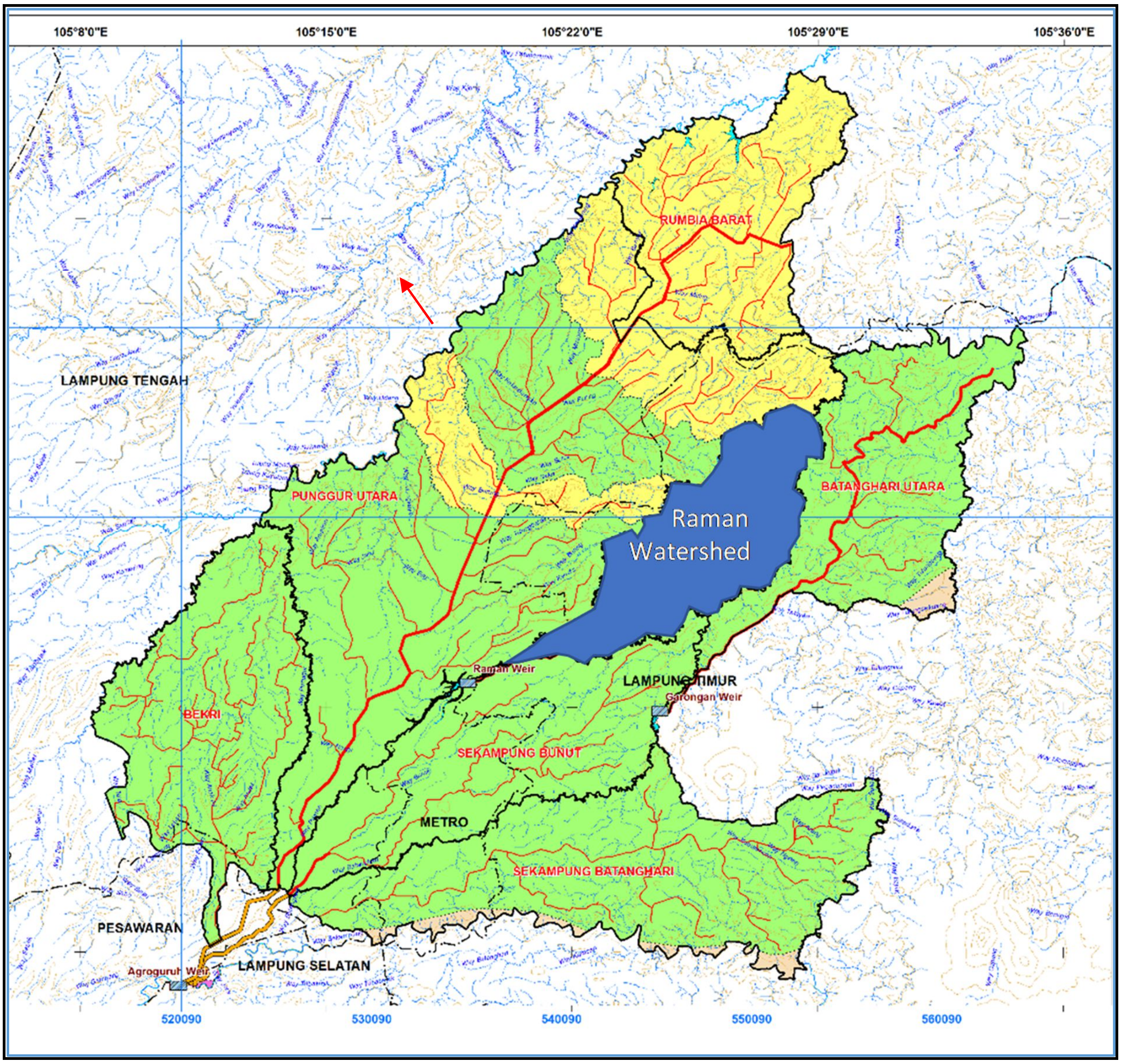

Fig. 2. Research site

Based on Table 1, there was an increasing trend in annual rainfall during the period 2012 to 2021. In particular, the highest level recorded was 180 mm at Cibeber Station in 2021, while Bayah Station experienced a peak of 167 mm in 2019. This increase in rainfall indicates a shift in local climate patterns over the years.

Table 1. Maximum daily rainfall/year from 2012 to 2021

No	**Year**	**Maximum daily rainfall**	
		Cibeber Station [mm]	**Bayah Station [mm]**
1	2012	70	61
2	2013	141	64
3	2014	134	66
4	2015	134	76
5	2016	113	92
6	2017	141	125
7	2018	112	147
8	2019	92	167
9	2020	117	144
10	2021	180	126

This finding is consistent with broader regional trends observed across Indonesia. For example, a study by Siswanto [17] reported a significant increase in extreme rainfall events over the past few decades, particularly in southern region of Sumatra. This pattern suggests that climate changes are becoming more pronounced across the country.

Our observations in the Raman Watershed are consistent with this broader trend. The evidence indicates that this region is also experiencing similar climate change, likely influenced by the same factors that influence rainfall patterns across the region. This further supports the notion of climate change, emphasizing the need for ongoing monitoring and adaptation strategies.

2.3 Hydrological analyses

In this research, hydrological analysis was carried out to predict flood peak-discharge in the Raman Watershed for return periods of 5, 10, 25, 50 and 100 years. Hydrological analysis includes several stages, they are calculation of annual average rainfall, analysis of rainfall frequency distribution, prediction of design rainfall, and analysis of flood peak-discharge.

2.3.1 Average annual rainfall

The Thiessen polygon method is used to calculate the average annual rainfall using the equation

$$P = \frac{A_1P_1+A_2P_2+A_3P_3+\cdots+A_nP_n}{A_1+A_2+A_3+\cdots+A_n} \tag{1}$$

where P denotes the average annual rainfall, $A_1, A_2, A_3, \ldots, A_n$ represent the areas influenced by each rainfall station, and $P_1, P_2, P_3, \ldots, P_n$ represent the maximum daily rainfall per year at station 1, 2, 3, … n.

Using the Thiessen method requires at least 3 rainfall stations. Meanwhile, there are only two stations in the Raman Watershed. For this reason, the nearest station which is outside the Raman Watershed is taken.

2.3.2 Rainfall distribution probabilities

In the analysis of rainfall distribution, rainfall data is tested using three probability distribution models, namely the Log-normal model, the Gumbel Type I extreme value model, and the Log Pearson Type III (LPT3) model.

The kurtosis coefficient *Ck* and skewness coefficient *Cs* are calculated to determine the most suitable models among the three. The best fit model will then be applied to predict the design rainfall for each return period.

The equation used to predict design rainfall using the Log-normal model is [16]

$$P_T = \bar{P} + kS_P \tag{2}$$

where P_T is design rainfall for *T*, *T* is return period in year, $\bar{P}$ is the average of *P*, *P* is the logarithms of rainfall data, k a coefficient factor for the normal distribution model, and S_P is standard deviation of *P*.

Equation (2) can be used to predict design rainfall for *T* using the Gumbel Type I extreme value model, but k is a coefficient factor for the Gumbel model,

$$k = \frac{X_{Tr}-X_n}{S_n} \tag{3}$$

$$X_{Tr} = -ln\left\{-ln\left[\frac{T-1}{T}\right]\right\} \tag{4}$$

where *P* is now the rainfall data (not logarithmic as used in Log-Normal model), X_n is reduced mean of Gumbel, and S_n is standard deviation of the Gumbel reduced mean.

Equation (2) can also be used to predict design rainfall for *T* using the Log-Pearson Type III model, but *P* is now the rainfall logarithmic data (as used in Log-Normal model), *k* is a frequency coefficient based on skewness values *Cs* for *T* (can be determined using a frequency factor table Haan [18].

The model that best fits rainfall distribution data to predict a design rainfall is determined based on the values of the skewness coefficient *Cs* and kurtosis coefficient *Ck* as presented in Table 2.

Table 2. *Cs* and *Ck* values for each distribution method

No	**Type of Distribution**	**Rule**
1	Method of Log-Normal	$Cs = 0; Ck = 3$
2	Method of Gumbel type 1	$Cs = 1.14; Ck = 5.4$
3	Method of Log-Pearson III	others

The equations for determining *Cs* and *Ck* for *n* (the number of data) are [16]:

$$Cs = \frac{n^2}{(n-1)(n-2)}\left[\frac{\sum_{i=1}^{i=n}(P_i-\bar{P})^3}{nS^3}\right] \tag{5}$$

$$Ck = \frac{n^3}{(n-1)(n-2)(n-3)}\left[\frac{\sum_{i=1}^{i=n}(P_i-\bar{P})^3}{nS^4}\right] \tag{6}$$

2.3.3 Flood peak-discharges

Flood discharge for various return periods Q_T (5 years, 10 years, 25 years, 50 years, and 100 years) is calculated using the Synthetic Unit Hydrograph (SUH) method. In this research, the Nakayasu Synthetic Hydrograph Unit (SHU) method is used, and is represented by the following equation

$$Q_T = car_o \left\{\frac{1}{3.6\left(0.3t_p + t_{0.3}\right)}\right\} \tag{7}$$

where c is the runoff coefficient, a is the total area of the catchment or watershed (in km²), r_o denotes the design rainfall (in mm), t_p represents the time to peak (in hours), and $t_{0.3}$ is the deceleration time for discharges to reduce to 30%.

3 Results and discussion

3.1 Hydrological analyses

Data collected from three rainfall stations and analyzed using the Thiessen polygon method reveals that the area of influence within the Raman Watershed is divided evenly between two stations. Specifically, 50% of the area is influenced by Cibeber Station, while the remaining 50% falls under the influence of Bayah Station. This division allows for an accurate understanding of rainfall distribution across the watershed.

The hydrological analysis conducted for the Raman Watershed provides insights into both rainfall patterns and flood characteristics within the region. Table 3 presents the average annual maximum rainfall from 2012 to 2021 calculated using the Polygon Thiessen method. These averages show considerable variability in rainfall over the decade, with the lowest average annual rainfall being 65.5 mm in 2012 and the highest being 153 mm in 2021. The increasing trend in rainfall is very sharp, especially in 2021. This may indicate a change in rainfall patterns, and can worsen the risk of flooding in the watershed.

Table 3. Average annual rainfall from 2011 to 2020

No	Year	Cibeber P_1 [mm]	Bayah P_2 [mm]	Average annual rainfall [mm] $(0.5P_1 + 0.5P_2)$
1	2012	70	61	65.5
2	2013	141	64	102.5
3	2014	134	66	100
4	2015	134	76	105
5	2016	113	92	102.5
6	2017	141	125	133
7	2018	112	147	129.5
8	2019	92	167	129.5
9	2020	117	144	130.5
10	2021	180	126	153

3.2 Design rainfall

Table 4 presents the values of *Cs* (skewness coefficient) and *Ck* (kurtosis coefficient) that have been calculated for each distribution method.

Table 4 also shows that the Log-Pearson Type III model is the most suitable model for the rainfall data used. The data set produces a skewness coefficient *Cs* of 0.840 and a kurtosis coefficient *Ck* of 2.863. This result does not comply with the requirements for either the Log-normal or Gumbel I model. This means that the rainfall distribution in the Raman Watershed is slightly distorted, so it is very important for accurate flood frequency analysis.

Table 4. The values of *Cs* and *Ck* for each distribution model

No	Type of Distribution	Rule	Analysis results	Notes
1	Log-Normal	$Cs = 0$	0.840	Not acceptable
		$Ck = 3$	2.863	
2	Gumbel I	$Cs = 1.14$	0.840	Not acceptable
		$Ck = 5.4$	2.86	
3	Log Person III	Others	0.840	Acceptable
			2.863	

In addition, Table 5 presents design-rainfall predictions for various return periods using the Log-Pearson Type III and Gumbel models.

Table 5. Design-rainfall summary

No	Return Period [year]	Gumbel I [mm]	Log Person III [mm]
1	2	111.75	117.77
2	5	141.29	137.48
3	10	160.86	145.63
4	25	185.57	152.58
5	50	203.91	156.14
6	100	222.11	158.75

Based on Table 5, the Log-Pearson Type III model consistently produces higher rainfall estimates for all return periods, thereby resulting in more conservative flood management strategies. Notably, the 25-year return period rainfall of 152.58 mm agrees well with the observed average rainfall of 153 mm during the December 2021 flood event, thus validating the reliability of our analysis.

3.3 Flood peak-discharges

Table 6 presents the flood peak-discharge in the Raman Watershed at return periods of 2, 5, 20, 25, 50 and 100 years using the Nakayasu method. There is a non-linear relationship between the return period and flood peak-discharge. The estimated flood peak-discharge with a return period of 25 years is 23.27 m³/s.

Table 6. Flood peak-discharges

Return period [year]	Flood discharges [m³/s]
2	17.96
5	20.96
10	22.21
25	23.27
50	23.81
100	24.21

Aligning the December 2021 flood (averaging 153 mm) with our calculated 25-year return period (152.58

mm) provides valuable context regarding the severity of this flood. Interestingly, these findings are different from several recent studies in other regions in Indonesia. For example, Ningrum [19], who studied the Ciliwung Watershed in Jakarta, found that flood events that historically occurred over 25 years were occurring more frequently, approaching 10-year intervals. These differences highlight the spatial variability of climate change impacts and the need for local studies.

This finding is very important because it shows that flooding in 2021 is indeed a relatively rare event, occurring on average once every 25 years. However, it is important to note that climate change may alter these probabilities, potentially making similar events more common in the future.

These results have important implications for flood management in the Raman Watershed. The close correspondence between the 25-year flood calculations and the events that occurred in December 2021 underscores the need for robust flood mitigation measures designed to handle at least this level of flooding. Additionally, increasing trends in annual rainfall suggest that flood risk may be increasing, necessitating adaptive management strategies.

4 Conclusion

This research provides important insights into flood characteristics in the Raman Watershed, with a particular focus on the major flood event in December 2021. Through comprehensive hydrological analysis, we have determined that:

1) The Log-Pearson Type III probability distribution model best describes rainfall depth patterns in Raman Watershed, thereby producing the most accurate design-rainfall estimates;
2) The flood event in December 2021, with an average daily maximum rainfall-depth of 153 mm, is closely related to the 25-year return period event based on our analysis; and
3) The estimated flood peak-discharge for the 25-year return period is 23.27 m3/s, and represents a significant flood-risk in the area.

These findings have important implications for flood management in the Raman Watershed. The close alignment between 25 years of flood calculations and recent events in 2021 validates our methodology while highlighting the severity of the flood risk faced by local communities. This underscores the urgent need for flood mitigation measures designed to handle at least flood levels of this magnitude.

However, it is important to note that our analysis is based on historical data and assumes stationarity of climate patterns. As climate change has the potential to alter rainfall patterns, the frequency and intensity of extreme events may increase in the future. These limitations highlight the need for ongoing monitoring and regular reassessment of flood risk.

Future research should focus on incorporating climate change projections into analyses of flood frequency in the region. In addition, hydrodynamic models with more detailed variables can provide insight into the spread of floods and inundation patterns, thereby providing further information regarding flood management strategies.

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References

1. A. Fitri, M.S.N. Hadie, A. Agustina, D. Pratiwi, S. Susarman, G. Pramita, H.A. Salah, Analyses of flood peak discharge in Cimadur river basin, Banten Province, Indonesia. EDP Sciences, **331**, 08006 (2021)
2. K.N.A. Maulud, A. Fitri, W.H.M.W. Mohtar, W.M. Jaafar, N.Z. Zuhairi, M.K.A. Kamarudin, A study of spatial and water quality index during dry and rainy seasons at Kelantan River Basin, Peninsular Malaysia. Arabian Journal of Geosciences, **14**, (2021)
3. D. Pratiwi, A. Fitri, A. Phelia, N.A. Adma, K. Kastamto, Analysis of urban flood using synthetic unit hydrograph (SUH) and flood mitigation strategies along way Halim River: A case study on Seroja street, Tanjung Senang District. EDP Sciences, **331**, 07015 (2021)
4. S. Shi, X. Tao, X. Chen, H. Chen, A. Fitri, X. Yang, Evaluation of urban water security based on DPSIR model. IOP conference series: Earth and environmental science, **880**, 012023 (2021)
5. K. Kastamto, A. Fitri, M.S.N. Hadie, D. Safitri, S. Susarman, D. Pratiwi, Flood analyses at downstream of Cimadur River in Upper Cimadur Basin using HEC-RAS. EDP Sciences, **464**, 02009 (2023)
6. A. Fitri, R. Hashim, S. Abolfathi, K.N.A. Maulud, Dynamics of sediment transport and erosion-deposition patterns in the locality of a detached low-crested breakwater on a cohesive coast. Water (Switzerland), **11**, (2019)
7. S. Hutapea, Biophysical characteristics of Deli River Watershed to know potential flooding in Medan City, Indonesia. J Rangel Sci, **10**, (2020)
8. A. Fitri, Z.A Hasan, A. A. Ghani, Determining the Effectiveness of Harapan Lake as Flood Retention Pond in Flood Mitigation Effort. In Proceedings of 2011: 4th International Conference on Environmental and Computer Science (ICECS 2011), **34**, (2011)
9. A. Fitri, H. Chen, L. Yao, K. H. Zheng, F. Rossi, Y. Yin, Evaluation of the groundsill's stability at downstream of "Citorek" bridge in Cimadur River, Banten Province, In IOP Conference Series: Earth and Environmental Science, **880**, 012029, IOP Publishing (2021)
10. L. Yao, X. Huang, A. Fitri, Influence scope of local loss for pipe flow in plane sudden expansions, In: IOP Conference Series: Earth and Environmental Science, 12056, (2019)
11. A. Fitri, K.N.A. Maulud, D. Pratiwi, A. Phelia, F.

Rossi, N.Z. Zuhairi, Trend of water quality status In Kelantan River Downstream, Peninsular Malaysia. J Rekayasa Sipil, (2020)

12. A. Fitri, K. Nizam, A. Maulud, F. Rossi, F. Dewantoro, N.Z. Zuhairi, Spatial and temporal distribution of dissolved oxygen and suspended sediment in Kelantan River Basin. 4th International Conference on Sustainable Innovation 2020, Technology, Engineering and Agriculture (ICoSITEA 2020), (Atlantis Press, Dordrecht, 2021)
13. S.H Lai, A. Fitri, Application of SWAT hydrological model to upper Bernam River Basin (UBRB), Malaysia. IUP J Environ Sci. **5**, (2011)
14. G. Villarini, J.A. Smith, F. Serinaldi, A.A. Ntelekos, Analyses of seasonal and annual maximum daily discharge records for central Europe. J Hydrol, **399**, (2011)
15. R. Prasad, J. Rishideo, Peak discharge analyses for flood management in lower Gandak Basin. Climate Change, Extreme Events and Disaster Risk Reduction, (2018)
16. I.L.M Limantara, Hydrological engineering: revised edition, (Penerbit Andi, Yogyakarta, 2018)
17. S. Siswanto, G.J. van Oldenborgh, G. van der Schrier, R. Jilderda, B. van den Hurk, Temperature, extreme precipitation, and diurnal rainfall changes in the urbanized Jakarta city during the past 130 years. International Journal of Climatology, **36**, (2016)
18. L. De Haan, and Resnick, S. I., Limit theory for multivariate sample extremes. Zeitschrift für Wahrscheinlichkeitstheorie und verwandte Gebiete, **40**, (1977)
19. W. Ningrum, R. Boer, Statistical assessment of high-resolution climate model rainfall data in the Ciliwung Watershed, Indonesia. Agromet, **37**, (2023)