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Analyses of flood peak discharge in Cimadur river basin, Banten Province, Indonesia

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Abstract. Cimadur river basin is one of the most important catchment areas in Lebak District, Banten Province. For the past few years, the catchment has experienced floods during the rainy season. The big issue of flooding has been recorded recently in December 2019 which has caused damage and negative impacts to the local people and surrounding community. This study aims to analyze the possibility of flood peak discharges in the catchment area of the Cimadur river. The flood discharges are calculated for 2, 5, 10, 25, 50, and 100 years return period based on the daily rainfall data from the year 2011 to 2020. The rainfall and land use data are obtained from PT Saeba Consultant. In this study, the hydrological analyses are including 1) analyses of average annual rainfall using the Thiessen method; 2) analyses of rainfall distribution and estimation of design rainfall by considering three methods involving: Log-Normal, Log Pearson Type III, and Gumbel Type 1; and 3) analyses of flood discharges by adopting Nakayasu Synthetic Hydrograph Unit (SHU). The rainfall distribution analyses show that the Log Pearson Type III provided the best fit. Based on the flood peak discharges analyses, the results show that the flood discharges for the 5, 10, 25, and 50 years return period in the Cimadur river basin are 470.71 m^3/s, 560.16 m^3/s, 698 m^3/s, and 820.4 m^3/s, respectively.

1 Introduction

Flooding is the most frequent natural disaster that occurred in Indonesia in the past few decades, mostly triggered by extreme rain during the rainy season [1, 6]. However, the occurrences of flooding are not only natural but can be aggravated due to socio-economic factors such as urbanization and development activities which could result in larger flood-prone areas [7, 9].

Regarding flood risk reduction and prevention in a local region, estimation of flood peak discharges in a local area is becoming necessary [9]-[11]. Estimation of the flood peak discharges could be helpful in properly designing the various engineering structures in the river basin [12, 15].

Cimadur river basin is one of the most important catchment areas in Lebak District, Banten Province, Indonesia. The land-use change activities such as converting the forest into residential areas and rice fields around the river have triggered the flood occurrences in this catchment for the past few years (Fig. 1). One of the biggest flood events in the Cimadur river basin has been experienced in December 2019 which has caused damage and negative impacts to the local people and surrounding community.

Fig. 1. One of the flood events occurred in the Cimadur river basin

To reduce and control the flood events in the Lebak district, the local government and the local water resource managers are going to design the various engineering structures on the Cimadur river catchments. Due to the importance of flood peak discharges estimation in designing the engineering structures in the Cimadur river basin, therefore, this study aims to analyze the possibility of flood peak discharges in the catchment area of the

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Cimadur river. The flood discharges are calculated for 2, 5, 10, 25, 50, and 100 years return period.

2 Materials and Methods

2.1 Study Area

This study is carried out in the catchment of Cimadur river, Lebak District, Banten Province, Indonesia. Cimadur river catchment as shown in Fig. 2 is geographically located between 6°40” S to 6°55” S (latitudes) and 106°14” E to 106°25” E (longitudes). The total area of the Cimadur river catchment is approximately about 210 km^2. The catchment is influenced by 2 monsoon seasons during the year that is rainy season and the dry season. The area receives one cycle of rainfall during the rainy season which runs from April to October in the year.

The topography condition in the Cimadur river catchment is a moderate slope with an elevation between 0 and 500 m above MSL. Local people in this catchment are mostly making a living as a farmer [16].

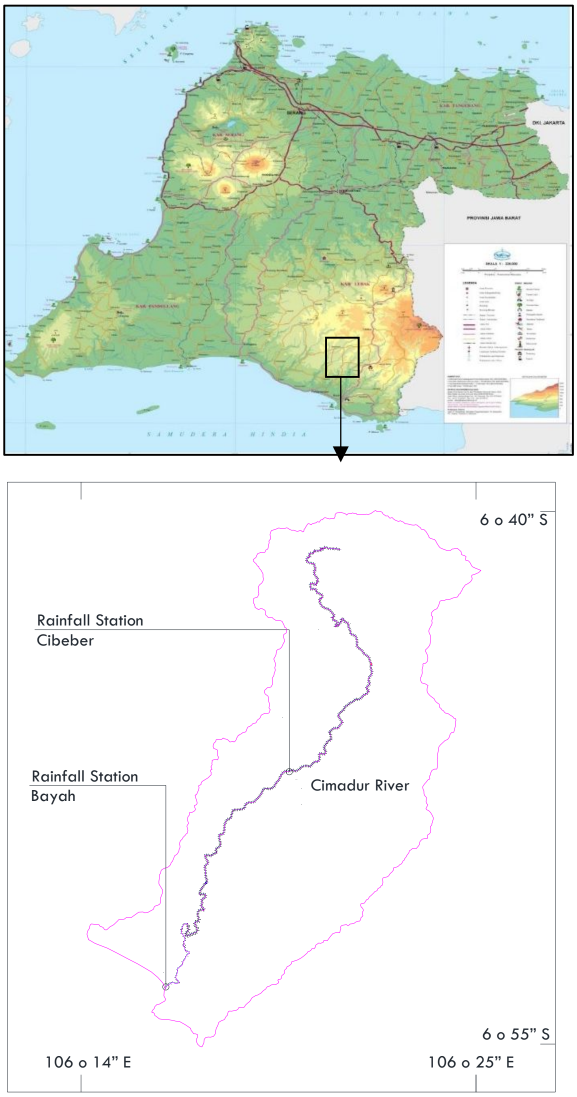

Fig. 2. Location of the study area

2.2 Data Collection

For estimation of flood peak discharges, the required data is consisting of rainfall data and land use data. There are two rainfall stations in the catchment of the Cimadur river, which are Bayah station and Cibeber station. In this study, rainfall data and land use data are obtained from PT. Saeba Konsulindo Serang, Banten. Rainfall data from both rainfall stations (Bayah station and Cibeber station) are taken for ten years period (2011 to 2020). Based on the available data, the maximum daily rainfall per year is presented in Table 1. Apart from that, Table 2 describes the land use condition in the Cimadur river basin in the year 2019 based on research done by PT Saeba Konsulindo.

Table 1. Maximum daily Rainfall per year

No	Year	Rainfall data at Bayah Station (mm), P1	Rainfall data at Cibeber Station (mm), P2
1	2011	137	75
2	2012	128	91
3	2013	185	112
4	2014	121	97
5	2015	101	71
6	2016	115	93
7	2017	120	71
8	2018	131	128
9	2019	112	201
10	2020	136	184

Table 2. Landuse Condition in Cimadur river basin in years of 2019

No	Landuse area	Area (ha)	Percentages (%)
1	forest	7284	34.65%
2	River	90	0.43%
3	residential	221	1.05%
4	ricefield	3691	17.56%
5	Mix garden	8952	42.58%
6	bush	744	3.54%
7	bare land	40	0.19%

2.3 Hydrological Analyses

In this study, hydrological analyses are carried out to estimate the flood peak discharges in the Cimadur river basin for 5, 10, 25, 50, and 100 years return period. There are several stages in hydrological analyses including analyses of average annual rainfall, analyses of rainfall frequency distribution, estimation of design rainfall, and analyses of flood peak discharges. The detailed description for those analyses are following:

2.3.1 Analysis of average annual rainfall

The average annual rainfall is analyzed by approaching the Thiessen method. Here, one rainfall station from outside of the Cimadur river basin is included to draw the polygon and to get the total areas influenced by each rainfall station. Fig. 3 shows the area division for the calculation of average annual rainfall. The calculation is further follows the equation below [17] :

$$P = \frac{A1p1+A2p2+A3p3+\cdots+Anpn}{A1+A2+A3+\cdots+An} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:

P = the average value of annual rainfall

P1, p2, ..., pn = maximum daily rainfall for each rainfall station (1, 2, ..., n)

A1, A2, A3, ... An = area influenced by each rainfall station (1, 2, ... , n.)

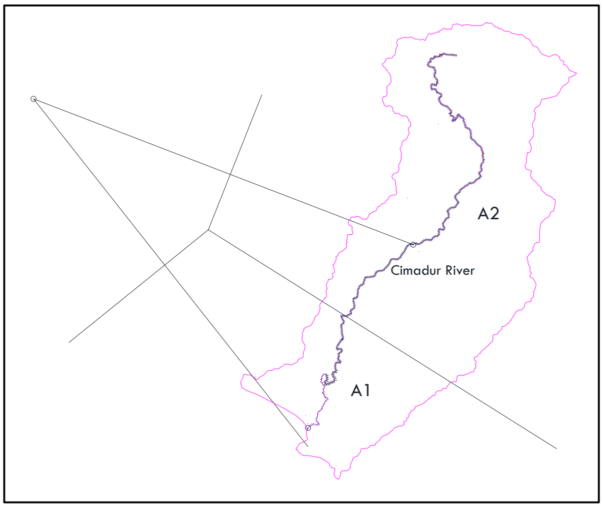

Fig. 3. Area division for each rainfall station

Based on polygon drawing, it can be described that the total area influenced by Bayah' station (A1) is 50.4 km^2 (24% from the total catchment of Cimadur), while the total area influenced by Cibeber' station (A2) is 159.6 km^2 (76% from the total catchment of Cimadur).

2.3.2 Analyses of rainfall frequency distribution and estimation of design rainfall

Concerning the estimation of design rainfall and analyses of rainfall frequency distribution, three methods are considered to be examined in this study including the Log-normal method, extreme Gumbel type 1 method, and Log person type III method.

The equation used for calculation of design rainfall in the Log-normal method is as follows [17]:

$$\text{Log } X_T = \text{Log } \bar{X} + \text{k.Sx.LogX} \ldots\ldots\ldots\ldots\ldots (2)$$

Where:

Log X_T = design rainfall for T years return period

Log $\bar{X}$ = the logarithms average of rainfall data

$\bar{k}$ = coefficient factor

SxLogX = standard deviation

Further, the equation used for calculation of design rainfall in the Gumbel type 1 method is as follows [17]:

$$X_T = \bar{X} + S.K \ldots\ldots\ldots\ldots\ldots (3)$$

Where:

X = design rainfall for T years return period

$\bar{X}$ = the mean value of rainfall data

K = the frequency factor for extreme Gumbel method

S = standard deviation

$$K = \frac{Ytr-Yn}{Sn} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$Ytr = -In\left\{-In\frac{Tr-1}{Tr}\right\} \ldots\ldots\ldots\ldots (5)$$

Where:

Tr = The function of time

Yn = Gumbel' reduced mean

Sn = Gumbel' reduced standard deviation

Besides, the equation used for calculation of design rainfall in the Log-Pearson type III method is as follows (15):

$$Log\ X_T = \overline{Log\ X} + ktr.S1 \ldots\ldots\ldots\ldots (6)$$

Where:

Log X_T = design rainfall for T years return period

Log X = the logarithms average of annual rainfall at station

S1 = standar deviation,

Ktr = frequency coefficient based on skewness values (Cs) for T years return period (can be determined using a frequency factor table (Haan, 1977)

However, the best fit method that can be applied for design rainfall is based on the values of skewness coefficient (Cs) and kurtosis coefficient (Ck). Table 3 describes the values of Cs and Ck that must be fulfilled as a rule in choosing the fittest method for the calculation of design rainfall.

Table 3. Cs and Ck values for each distribution method

No	Type of Distribution	Rule
1	Log-Normal method	Cs = 0 Ck = 3
2	Gumbel type 1 method	Cs = 1,14 Ck = 5,4
3	Log-Pearson type III	others

The equations for Cs and Ck are following [17]:

$$Cs = \frac{n^2}{(n-1)(n-2)}\left[\frac{\sum_{i=1}^{i=n}(Xi-\overline{X})^3}{nS^3}\right] \quad ....(7)$$

$$Ck = \frac{n^3}{(n-1)(n-2)(n-3)}\left[\frac{\sum_{i=1}^{i=n}(Xi-\overline{X})^3}{nS^4}\right] \quad ....(8)$$

Where:
$\bar{X}$ = the mean value of data
n = number of data
S = standard deviation
Xi = variate value of data

2.3.3 Analysis of flood peak discharges

Flood peak discharges are analyzed based on the results of design rainfall. In this study, flood peak discharges are estimated for 5, 10, 25, 50, and 100 years return period by adopting Nakayasu Synthetic Hydrograph Unit (SHU) method (17) as follows:

$Q_{max} = C * A * Ro * (1/ (3.6\ (0.3Tp+T_{0.3}))$

Where :
Tp is peak time (hour)
C is runoff coefficient
Ro is designed rainfall (mm)
A is the catchment area (km^2)
$T^{0.3}$ is the time of slowdown the discharge (until 30%)

3 Results and Discussion

3.1 Analysis Results of Average Annual Rainfall

Table 4 presents the average annual rainfall calculated using the Thiessen method.

Table 4. Analysis results of average annual rainfall

No	Year	Rainfall at Bayah Station (24%)	Rainfall at Cibeber Station (76%)	Average Annual Rainfall (mm)
1	2011	32.88	57	89.88
2	2012	30.72	69.16	99.88
3	2013	44.4	85.12	129.52
4	2014	29.04	73.72	102.76
5	2015	24.24	53.96	78.2
6	2016	27.6	70.68	98.28
7	2017	28.8	53.96	82.76
8	2018	31.44	97.28	128.72
9	2019	26.88	152.76	179.64

3.2 Estimation of Design Rainfall

Table 5 shows the values of Cs and Ck that have been calculated from each distribution method.

Table 5. The values of Cs and Ck for each distribution method

No	Type of Distribution	Rule	Analysis results	Notification
1	Log-Normal	Cs = 0	0,7860	Not acceptable
		Ck = 3	3,0005	
2	Gumbel 1	Cs = 1,14	0,7860	Not acceptable
		Ck = 5,4	3,0005	
3	Log Person III	Others	0,7860	Acceptable
			3,0005	

Based on Table 5, it can be concluded that the method of Log-Pearson type III is the most suitable fit method that can be applied to determine the design rainfall in the Cimadur river basin. The values of design rainfall for the estimated T-year return period based on the Log-Pearson type III method are presented in Table 6.

Table 6. Design rainfall using Log-Pearson Type III method

No	Years return period	The values of design Rainfall
1	2	100.20
2	5	128.92
3	10	153.42
4	25	191.19
5	50	224.70
6	100	263.30

3.3 Analysis Results of Flood Peak Discharges

Fig. 4 shows the estimation of flood peak discharges for 2, 5, 10, 25, 50, and 100 years return period by adopting Nakayasu Synthetic Hydrograph Unit (SHU) method (Fig. 4).

Based on Fig. 4, it can be demonstrated that the flood peak discharges in the catchment of Cimadur river for 2, 5, 10, 25, 50, and 100 years return periods are 398 m^3/s, 470.71 m^3/s, 560.16 m^3/s, 698 m^3/s, 820.4 m^3/s, and 1017.04 m^3/s, respectively. The flood peak discharges are found to be high even for 5 years return period of design rainfall. The results also show that the peak discharges occur after 4-hour rain continuously.

As reported by RPJMD Lebak district (14), local people in the Cimadur river basin mostly make a living as a farmer. Freshwater is always becoming a necessary thing for agriculture activities by local people in the Cimadur catchment, but the freshwater also could cause harvest failure if the farm is flooded with water (for example flooding occurrences around the agriculture areas during the rainy season).

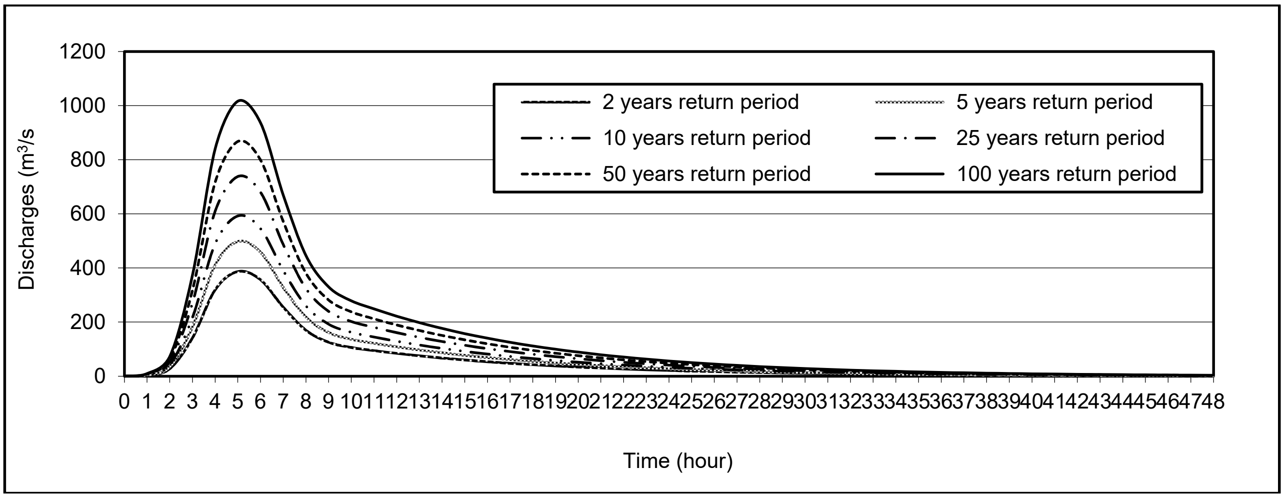

Fig. 4. Flood peaks discharge for 2 years to 100 years return period

Therefore, we have to make sure that the water supply is enough for agriculture activities during the dry season, but no flooding during the rainy season. For this, the local government must think about how to manage and store the excess water during the rainy season to be useful for the farmer during the dry season. The local government may consider constructing an engineering structure that can store and control the excess water discharge during the rainy season.

4 Conclusion

Flood is the major natural disaster in the catchment of the Cimadur river for the past few years. Converting the forest to become residential and agricultural areas has triggered more frequency of flooding events. During the rainy season, the flood peak discharges can reach 560.16 m^3/s for 10 years return period of design rainfall.

However, the agricultural areas in this district will need more water supply during the dry season. High frequency of the water during the rainy season may be utilized for water supply during the dry season. For this, purpose, the local government must think carefully about how to reduce and control the flood problem in the Cimadur catchment and also could plan how to restore the excess water during the rainy season.

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