Impact of Extreme Rainfall on Flood Hydrographs

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Abstract. Extreme rainfall is the main factor triggering flooding in various regions of the world including Indonesia. The increase in intensity and duration of current extreme rainfall is predicted as a result of global climate change. This paper aims to analyze the impact of extreme rainfall to the peak discharge of flood hydrographs at a watershed outlet in Palu, Sulawesi, Indonesia. Maximum daily rainfall data for the period 1990-1999 recorded at the Palu Meteorological Station, Central Sulawesi were selected using the Annual Maximum Series Method, and grouped into two types. Type I is the maximum daily rainfall data with extreme events and Type II is the maximum daily rainfall data without extreme events. Frequency analysis was applied to the two data groups using the best distribution method of: Normal, Normal Log, Pearson III Log, and Gumbel to obtain the design rainfall of each data group. In the next stage, the design rainfall transformation into a flood hydrograph is performed using the Nakayasu Synthetic Unit Hydrograph based on a number of return periods in one of the rivers flowing into Palu Bay, namely the Poboya River. The analysis results show that the design rainfall graphs with both extreme rainfall and without extreme rainfall are identical at the low return period and divergent at the high return period with a difference of up to 21.6% at the 1000-year return period. Correspondingly, extreme rainfall has a greater impact at the peak of the flood hydrograph with increasing return periods ranging from -1.28% to 26.81% over the entire return period.

1. Introduction

The increasing intensity and frequency of floods in various regions of the world are currently considered as the impact of extreme rainfall [1], [2], [3]. In Indonesia, in the last ten years, almost all areas from Sabang to Merauke have been affected by flooding due to changes in rainfall characteristics [4], [5]. Changing the nature of the rainfall leading to extreme rainfall is one of the characteristics of climate change, which is marked by an increase in the intensity and duration of rainfall [6], [7], [8].

Extreme rainfall is rainfall with a depth of more than 100 mm/day. In general, daily rainfall in Indonesia is less than 100 mm in depth. Although there are several areas with high annual rainfall above 3000 mm/year, in fact the depth of daily rainfall is still included in the normal rainfall category. In line with the widespread impact of global climate change, currently there are many extreme rainfall events in Indonesia [9].

Studies on extreme rainfall and its impact on flood hydrographs have not been widely carried out, especially in Indonesia with the characteristics of a tropical climate. The studies that have been conducted are generally limited to prediction and projection of future extreme rainfall using a variety...
of approaches, as conducted by Rinaldi (2006, 2017), Saumi (2017), Rahmayani and Sutikno (2019), Simanjuntak and Safril (2020), and Simanjuntak et al. (2020) [10], [11], [12], [13], [14], [15]. None of these publications has examined the impact of extreme rainfall on floods, especially based on hydrographs.

In connection with the widespread impact of global climate change on extreme rainfall as a trigger for flooding, this research is very important to do with the aim of predicting the impact of extreme rainfall on peak floods. As a flood-prone area, this study will contribute to disaster mitigation programs, especially as a preliminary study and as a reference for identifying priority areas for disaster management and determining hydrological quantities for flood control.

2. Material and Methods

2.1. Data

This analysis is based on rainfall data from the Mutiara Meteorological Station, Palu, Central Sulawesi. This station is an observation station for daily climate data including: precipitation, wind speed, humidity, temperature, and sun exposure with an automatic recording system. The rainfall data used in this study are the maximum daily rainfall data for the period 1990-2019 with an observation length of 30 years.

Other data required besides rainfall data is the catchment area. The catchment area functions as a medium for transforming rainfall into discharge through the river network system in a catchment [16]. In this study, the catchment studied was the Poboya catchment, a river that passes through Palu City and has an outlet in Palu Bay. This river is interesting to study because part of the drainage system in Palu City, especially East Palu, has an outlet in the Poboya River. The river with a catchment area of around 69.82 km² is one of the rivers that is prone to flooding and plays an important role as a primary drainage channel in Palu City (Figure 1). The watershed with an elongated morphometric shape and tends to narrow downstream is located in the topography with an elevation of 5 m-1460 m.

![Figure 1. Morphometry characteristics of site area](image-url)
2.2. Methods

Maximum daily rainfall data for the period 1990-2019 were selected using the Annual Maximum Series approach. Frequency analysis was applied to 30 maximum daily rainfall data with two categories: rainfall with extreme events and without extreme events. The rainfall depth of more than 100 mm/day categorized as extreme rainfall. Four frequency distribution methods: Normal, Normal Log, Gumbel and Log Person III, are performed to determine the design rainfall using general equation:

\[ X_T = \bar{X} + K_T S \]  

\( X_T \) refers to design rainfall (mm), \( \bar{X} \) = average maximum daily rainfall (mm), \( K_T \) = frequency factor, and \( S \) = standard deviation.

Furthermore, the design rainfall is transformed into discharge using the Nakayasu Synthetic Unit Hydrograph (SUH) approach. The SUH method uses the following equations:

\[ Q_p = \frac{A R_0}{3.6(0.3T_p + \alpha T_g)} \]  
\( T_p = T_g + 0.8 \ T_r \)  
\( Q_a = \left( \frac{T}{T_p} \right)^{2.4} Q_p \ 	ext{for} 0 \leq T \leq T_p \)  
\( Q_{d1} = 0.3 \left( \frac{T-T_p}{T_0.3} \right) Q_p \ 	ext{for} T_p < T \leq (T_p + T_{0.3}) \)  
\( Q_{d2} = 0.3 \left( \frac{T-T_p+0.5T_0.3}{2T_{0.3}} \right) Q_p \ 	ext{for} (T_p + T_{0.3}) < T \leq (T_p + T_{0.3} + 1.5T_{0.3}) \)  
\( Q_{d3} = 0.3 \left( \frac{T-T_p+1.5T_0.3}{2T_{0.3}} \right) Q_p \ 	ext{for} T_p > (T_p + T_{0.3} + 1.5T_{0.3}) \)

where: \( Q_p \) = peak flow (m³/s), \( A \) = watershed area (km²), \( R_0 \) = unit rainfall (mm), \( T_p \) = peak time (hour), \( \alpha \) = run-off coefficient, \( T_g \) = time of concentration (hour), and \( T_r \) = rainfall duration (hour). \( T_{0.3} \) is time required to reach 30% of peak discharge from the hydrograph peak (hour). \( Q_a \) = discharge on the rising side of the hydrograph (m³/s). \( Q_{d1}, Q_{d2}, \) and \( Q_{d3} \) are the discharge corresponding to \( T_{0.3}, 1.5T_{0.3}, \) and \( 2T_{0.3} \), respectively (m³/s).

The effect of extreme rainfall to the peak of the flood hydrograph is calculated by comparing the difference between the hydrograph peak discharge from the two data groups at each return period with the hydrograph peak discharge without extreme events. The equation applied is as follows:

\[ \Delta = \left( \frac{Q_p-Q_0}{Q_0} \right) 100\% \]

where \( \Delta \) is the impact of extreme rainfall to the peak of the flood hydrograph (%), \( Q_e \) and \( Q_0 \) are the peak of the hydrograph due to both with extrem rainfall and without extrem rainfall, respectively (m³/s).

3. Result and Discussion

3.1. Extreme Rainfall

Identification of maximum daily rainfall data in the study area for the period 1990-2009, 30 data were selected. This data includes the maximum daily rainfall which represents each year of the data. Evaluation of all of these data indicates that during that period there was extreme rainfall. The maximum rainfall as shown in Figure 2, actually shows a regular sinusoidal graph over the observation period. The extreme rainfall with a frequency of one event in 2009 tends to influence the trend of the graph. In fact, in 1996 there was also high intensity rain approaching the extreme rainfall, which also affected the maximum rainfall pattern.
The frequency analysis of the 30 rainfall data which is clustered into two groups results in a design rainfall as illustrated in Figure 3. The pattern of increasing rainfall of the two data groups shows a similar trend, especially in the low return period. Trend changes enlarge with increasing return periods. Another thing that can be observed in Figure 3 is the difference in design rainfall based on extreme events and without extreme events. Rainfall extremes affect the increase in design rainfall by up to 21.6% in the 1000-year return period. This indicates that the extreme event has a major impact on design rainfall.

Figure 3. Design rainfall predicted with and without extreme event

3.2. Flood Hydrograph

Based on the two design rainfall groups as shown in Figure 3, then using the Nakayasu approach can be determined the flood hydrograph in the Poboya River. The flood hydrograph was determined based on the current land cover condition of the Poboya catchment, where the land cover in the middle and downstream segments had been degraded. Traditional gold mining in the middle segment of this catchment has contributed greatly to the decline in catchment carrying capacity in response to rainfall. Likewise, the development of urban settlements in the downstream segment is also predicted to trigger an increase in discharge in rivers. Changes in land cover in the two catchment segments have been deemed to have triggered flooding in this river apart from being a result of extreme rainfall.

The flood hydrograph resulting from the hydrograph based transformation is shown in Figure 4. Two groups of graphs with significant differences between Figure 4a and Figure 4b. The graph in Figure 4b is a hydrograph as a result of the rainfall extreme. The peak of the flood hydrograph without extreme rain reached 145.67 m$^3$/s in the 1000 year return period. In the same return period, the
hydrograph peak discharge with extreme rain reached 184.60 m$^3$/s. This proves that the peak of the flood hydrograph is very much influenced by the depth of the rainfall, especially the rainfall extremes.

![Flood hydrograph transformed from design rainfall. (a) without extreme rainfall, (b) with extreme rainfall](image)

**Figure 4.** Flood hydrograph transformed from design rainfall. (a) without extreme rainfall, (b) with extreme rainfall

| Return Period (year) | Peak Flood (m$^3$/s) | Change (%) |
|----------------------|----------------------|------------|
|                      | Without Extreme Data | With Extreme Data |
| 1                    | 38.17                | 37.68      | -1.28      |
| 2                    | 63.89                | 63.53      | -0.56      |
| 5                    | 85.60                | 88.60      | 3.50       |
| 10                   | 95.07                | 101.40     | 6.67       |
| 20                   | 102.57               | 112.63     | 9.81       |
| 50                   | 110.52               | 125.88     | 13.90      |
| 100                  | 115.45               | 135.03     | 16.95      |
| 500                  | 124.43               | 154.14     | 23.89      |
| 1000                 | 127.48               | 161.65     | 26.81      |

Quantitatively, the influence of extreme rainfall on the hydrograph peak can be expressed as a percentage. Table 1 shows the change in the hydrograph peak discharge in the two data groups based on the return period. The change in peak discharge increases with increasing return period. Based on Table 1, the change in discharge at the largest return period reached 26.81%.

**4. Conclusion**
The effect of extreme rainfall at the peak of the flood hydrograph in the Poboya River, Palu, Central Sulawesi based on two groups of maximum daily rainfall data for the period 1990-1999 has been evaluated. Two data groups were classified based on the presence or absence of extreme events in the data group.
The results indicated that extreme rainfall significantly affected the hydrograph peaks. Extreme rainfall has a greater impact at the peak of the flood hydrograph with increasing return periods ranging from -1.28% to 26.81% over the entire return period. However, the results of this analysis need to be compared with other data in other areas by involving a more diverse number and distribution of data to get conclusions that can represent a wider area.

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