Development Of Rainfall Intensity Duration Frequency for Java Island

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Abstract. Climate change occurring in Java Island as a result of weather anomalies (La Nina) has led to more intense rainfall and higher frequencies compared to normal conditions. Phenomena perceived as extreme weather in a particular region or area can disrupt and pose a threat to water resource infrastructure, such as urban drainage networks. One optimal mitigation step that can be taken is when hydrological analysis and design are conducted using Intensity-Duration-Frequency (IDF) analysis derived from high-quality rainfall data. Developing IDF curves for future climates can be more challenging, especially for ungauged basins. This research aims to obtain rainfall intensity-duration-frequency data from 33 rain gauge stations on Java Island. The research methodology involved analyzing rainfall intensity using the Mononobe equation for various durations and return periods and then creating rainfall intensity maps (isohyets) using ArcGIS. This study's rainfall data series used in the frequency analysis is the annual maximum series. The rainfall frequency distribution chosen in this study is a Log Pearson III distribution. A total of six different durations ranging 5 minutes to 60 minutes for return period of 5 years were analyzed. The study results show that 90.9% of the daily rainfall in Java Island is in the medium category, and 9.1% is in the high category. This study indicates that rainfall intensity data from climatological rainfall stations that do not meet the hydrological criteria can be found by interpolating rainfall intensity maps from the nearest rain climatology station that meet the hydrological analysis criteria

Keywords: Flood, Mononobe, SIG.

1 Introduction

Climate change is a global phenomenon that has ushered in a new era of weather extremes that significantly affects various regions around the world. One of the consequences of climate change is the increase in intensity and frequency of rainfall, which can lead to a variety of hydrometeorological disasters, such as floods and landslides [1-3]. The Java Island, Indonesia is no exception to these changing weather patterns, experiencing increased rainfall events that have the potential to disrupt lives and livelihoods. Recognizing the urgent need to understand and manage this increasing challenge, this research endeavors to conduct a comprehensive study of rainfall intensity mapping for specific return periods on Java Island, Indonesia, using the intensity duration frequency (IDF) approach. The IDF approach is a well-established methodology in hydrology and climatology, providing valuable information on the relationship between rainfall intensity, duration, and frequency [4-6].

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The quality of rainfall data in Indonesia is generally inadequate for hydrological analysis. Since hourly rainfall data is not always available in a region, it is intriguing to explore how daily rainfall can be converted into hourly rainfall using formulas [7-8]. Hourly rainfall data is essential for transforming rainfall into peak flow (design flood) using the Rational Method. One of the hydrological parameters considered in the Rational Method is rainfall intensity, defined as the depth of rainfall per unit of time (mm per hour). When short-duration rainfall data (hourly rainfall) is unavailable, rainfall intensity can be computed using the Mononobe formula [7].

Developing Intensity-Duration-Frequency (IDF) analysis for future climate predictions can be particularly interesting, especially in ungauged basins. Currently, obtaining IDF analysis for ungauged basins involves borrowing or interpolating data from regions with similar climatological characteristics. The interpolation of hydrological data (rainfall data) can be accomplished using isohyet methods [8]. In the isohyet method, it is assumed that the rainfall in an area between two isohyets is the average value of those two isohyets. For this research, the parameter used is the Mononobe rainfall intensity from each rain gauge station, and the formation of isohyets is based on Geographic Information System (GIS) software, ArcGIS [9].

In Indonesia, research on IDF analysis using hourly rainfall data has been conducted frequently. However, due to limited access and the availability of high-quality hourly rainfall data, this study continues IDF analysis using daily rainfall data derived from the Mononobe equation. Previous research on the development of IDF analysis based on ArcGIS for predicting rainfall intensity in ungauged basins has been carried out in Vietnam [10] and Egypt [11]. The authors have conducted several research projects focused on the development of IDF curves, including the Analysis of Rainfall Characteristics and Intensity-Duration-Frequency (IDF) Curves in the Lampung Province [12], Analysis of Rainfall Characteristics in Bandar Lampung [13], Synthetic Unit Hydrograph Analysis in Flood-Prone Areas of Bandar Lampung [14], research on the development of IDF analysis at manual rain gauge stations based on GIS (ArcGIS) in the Lampung Province [15] . The results of these studies have been published in book form [16]. Based on the ongoing IDF analysis research in recent years at all rainfall recording stations in the Lampung Province (both manual and automatic rainfall measurement instruments), and research on Hydrometeorological Disaster Mitigation Through Rainfall Intensity Mapping Using IDF in Sumatera Island, Indonesia [17], the objective of this research is to develop IDF analysis for rainfall recording stations on Java Island and obtain Mononobe rainfall intensity maps for various durations and return periods for Java Island as an alternative source of hydro-meteorological disaster mitigation information.

2 Methodology

This research was conducted in Java Island. The necessary data included a map of Java (Fig. 1.) and daily rainfall data over a 10-year observation period (from 2012 to 2021) collected from 33 rain gauge stations distributed across the island of Java. The data were sourced from the online records provided by the Indonesian Meteorology, Climatology, and Geophysics Agency (BMKG). The study was carried out through several stages. Firstly, collect daily rainfall data from meteorological stations equipped with rain gauges. The obtained data includes raw information on rainfall depth and rainfall events. Secondly, analyze the rainfall measurement network based on the guidelines provided by the World Meteorological Organization (WMO). Thirdly, conduct frequency analysis of annual maximum rainfall data to determine the appropriate probability distribution and conducting goodness-of-fit tests using the Chi-square and Kolmogorov-Smirnov tests. Fourthly, analyze rainfall intensity using the Mononobe method for various durations and return periods. Lastly, create rainfall intensity maps using ArcGIS software.

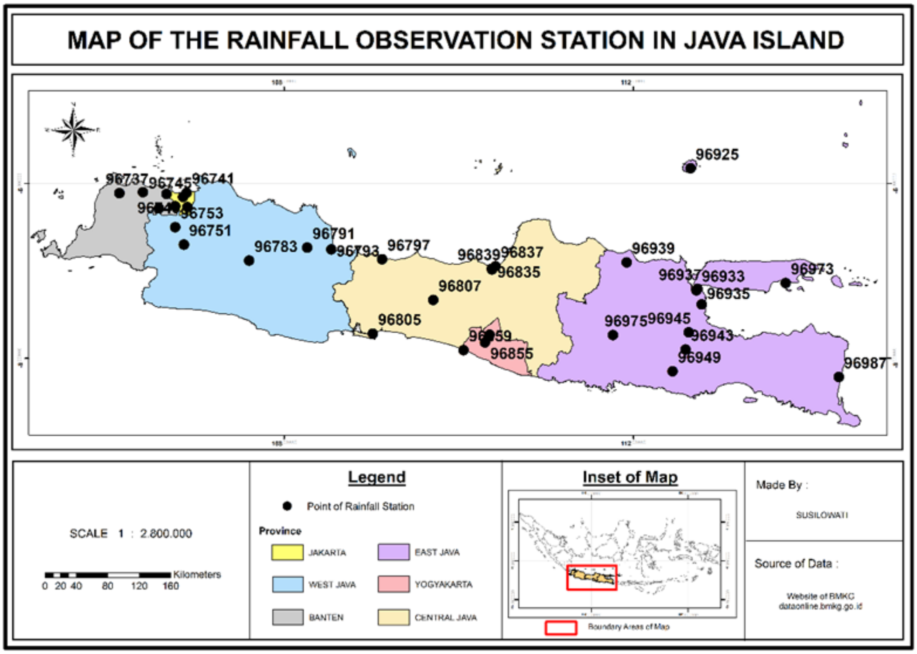

Fig. 1. Distribution Map of Rain Gauge Stations in Java Island
Source: www.bmkg.go.id.

2.1 Rainfall Measurement Network

The planning of rainfall measurement station networks is crucial in hydrology as these networks provide information on the amount of rainfall in a river basin. The World Meteorological Organization (WMO) provides guidelines on the required station density for various regions, as shown in Table 1.

Table 1. Rainfall Station Network Density [3].

Regional	Minimum Network Density (km^2 /station)
Temperate, Mediterranean and tropical flat areas	
Normal Condition	600 - 900
Mountainous Region	100 - 250
Small mountainous islands (< 20,000 km^2)	25
Dry and polar regions	1.500 - 10.000

2.2 Frequency Analysis

Frequency analysis of hydrological data aims to establish relationships between the magnitude of extreme events and their frequency of occurrence using probability distributions. Frequency analysis estimates the magnitude of floods with specific recurrence intervals, such as 10-year, 100-year events, and predicts the frequency of floods of a certain magnitude that may occur during a given time period. In hydrological data analysis, statistical parameters are required, including measures of central tendency to calculate mean values and measures of dispersion to determine standard deviations, coefficient of variation, skewness, and kurtosis as numeric measures that describe data characteristics. Various continuous probability distribution functions are used in frequency analysis for hydrological data, including normal distribution, log-normal distribution, Gumbel distribution, and log Pearson III distribution.

2.3 Rainfall Intensity Analysis

Rain intensity is the height or depth of rainwater per unit time. The general characteristic of rain is that the shorter the rain lasts, the higher the intensity tends to be and the greater the return period, the higher the intensity. Table 2 shows the rain conditions and rain intensity. The table shows that rainfall does not increase proportionally with time. If the duration of time is longer, the increase in rainfall is smaller than the increase in time, because the rain can decrease or stop.

Table 2. Rainfall States and Rainfall Intensities.

Rainfall State	Rainfall Intensity (mm)	
	1 hour	24 hours
Very light Rainfall	< 1	< 5
Light Rainfall	1 - 5	5 - 20
Normal Rainfall	5 - 10	20 - 50
Heavy Rainfall	10 - 20	50 - 100
Very heavy Rainfall	> 20	> 100

Source:[3]

The relationship between intensity, rainfall duration, and rainfall frequency is typically depicted in Intensity-Duration-Frequency (IDF) curves. IDF analysis is performed to estimate peak flow based on point rainfall data (from a single rainfall station). This analysis uses short-duration rainfall data, such as 5 minutes, 10 minutes, 30 minutes, 60 minutes, or longer. This type of rainfall data can only be obtained from automatic rain gauge stations. If short-duration rainfall data is unavailable, and only daily rainfall data is accessible, rainfall intensity can be calculated using the Mononobe formula [14,16]:

$$I = \frac{R_{24}}{24}\left(\frac{24}{t}\right)^{\frac{2}{3}} \quad (1)$$

Where:

- I = rainfall intensity (mm/hour)
- t = rainfall duration (hour)
- R_{24} = maximum 24-hour rainfall (mm)

2.4 Rainfall Intensity Map

Rainfall maps depict the thickness or intensity of rainfall in a specific area. A single rainfall station can represent an area of up to 25 km^2 in flat terrain. Areas with rugged topography or high slopes require denser rainfall stations. If the research area exceeds 25 km^2, more rainfall stations are needed. To establish a network of rainfall stations, both those within and outside the research area can be utilized, provided they meet the criteria for representing the study area (less than 25 km^2 in flat areas and unobstructed by topography). Rainfall maps can be created using isohyet, Thiessen polygon, or arithmetic methods. Each method has its advantages and disadvantages, and the choice depends on field conditions and the availability and quality of data. Selecting the appropriate method will provide a more accurate representation of rainfall conditions. Rainfall maps are used for various purposes, including navigation, agriculture, mitigation, regional development planning, and climate type calculations for the region. Currently, rainfall mapping can be accomplished using ArcGIS software.

3 Results and Discussion

This study focused on analyzing rainfall data collected from 33 rainfall gauge stations distributed across Java Island. The data analysis was conducted using the Annual Maximum Series method, which selected the maximum daily rainfall data from at least 10 years of continuous data. The maximum daily rainfall values from each rainfall gauge station are presented in Fig. 2.

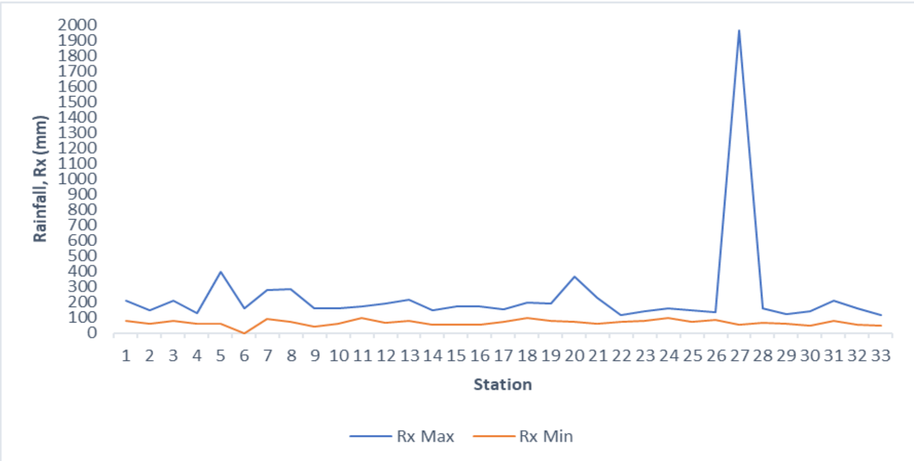

Fig. 2. Maximum Daily Rainfall Magnitude of each Rain Gauge Station.
Source: Researcher Analysis, 2022.

According to BMKG, normal rainfall is categorized as follows: low (0 – 100 mm), moderate (100 – 300 mm), high (300 – 500 mm), and very high (>500 mm). Fig. 2. shows the maximum daily rainfall at the 33 rain gauge stations on Java Island. Out of these, 30 stations (90.9%) fall into the medium rainfall category, while 3 stations (9.1%) fall into the high rainfall category. The highest maximum daily rainfall is recorded at the Banyuwangi Meteorological Station (station number 27) at 1965.5 mm, while the lowest maximum daily rainfall is recorded at the Halim Perdana Kusuma Jakarta Station.

The World Meteorological Organization (WMO) stated that in tropical regions like Indonesia, a minimum rain gauge station network density of 100-250 km^2 is required for normal conditions. For challenging physical conditions, a density of 250-1000 km^2 is recommended [18]. The area coverage of the 33 rain gauge stations on Java Island can be seen in Table 3 and Fig. 3.

Table 3. Coverage Area of rain gauge stations in Java Island.

No.	WMO Station Code	Coverage Area (km^2)	No.	WMO Station Code	Coverage Area (km^2)
1	96739	2400.4	18	96805	3203.5
2	96735	1114.46	19	96797	6670.79
3	96733	250.98	20	96855	1771.66
4	96737	5434.35	21	96851	1146.99
5	96749	462.78	22	96859	251.56
6	96747	265.70	23	96949	4315.83
7	96745	286.74	24	96975	11527.82
8	96741	109.07	25	96945	3959.99
9	96793	931.97	26	96943	2520.59
10	96783	8487.21	27	96987	10798.44
11	96753	5497.35	28	96935	684.94
12	96751	92.41	29	96937	1545.05
13	96791	20368.74	30	96933	684.94
14	96807	8671.19	31	96925	4030.74
15	96835	3203.50	32	96973	3442.78
16	96839	3014.0	33	96939	239.76
17	96837	8037.72			

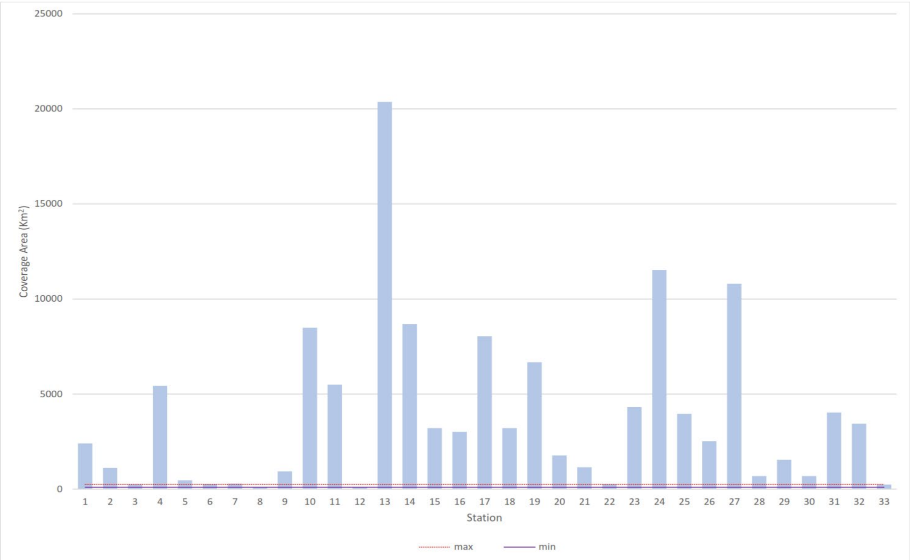

Fig. 3. Coverage Area of rain gauge stations in Java Island.

For normal condition, only 2 stations meet the WMO standards for rain gauge station network density, however for challenging physical conditions there were 5 stations that met WMO standards.

Coverage Area Map of Rainfall in East Java Province The next stage of the research, the frequency analysis of rain data from 33 rain gauge stations, the appropriate distribution type is the Log Pearson III distribution. Then the goodness of fittest test was conducted on the frequency distribution of the data samples against the probability distribution function that is expected to describe or represent the frequency distribution. The tests used are the chi-squared test and the Smirnov Kolmogorov test.

Rainfall intensity or rainfall depth per unit of time is typically recorded in millimeters per hour (mm/hour). If daily rainfall data is available, the Mononobe equation is used to calculate rainfall intensity. Table 4 presents the results of the Mononobe rainfall intensity analysis for a 5-year return period for various short-duration rainfall events (15 minutes, 30 minutes, 45 minutes, 60 minutes). Based on this research, these intensity values can be used to estimate peak flows for drainage design in small catchment areas, considering intense short-duration rainfall events occurring at multiple points within the catchment simultaneously [19-21].

Table 4. Rainfall Intensity for a 5-Year Return Period.

No.	WMO ID	Rainfall Intensity (mm/hour), Return Period 5 Year					
		5’	10’	15’	30’	45’	60 ‘
1	96739	221.2	139.3	106.3	67.0	51.1	42.2
2	96735	232.4	146.4	111.7	70.4	53.7	44.3
3	96733	230.7	145.3	110.8	69.8	53.3	44.0
4	96737	176.7	111.3	85.0	53.5	40.8	33.7
5	96749	407.2	256.5	195.8	123.3	94.1	77.7
6	96747	371.8	234.2	178.7	112.6	85.9	70.9
7	96745	375.4	236.5	180.5	113.7	86.8	71.6
8	96741	347.7	219.0	167.2	105.3	80.4	66.3
9	96793	209.3	131.8	100.6	63.4	48.4	39.9
10	96783	186.6	117.6	89.7	56.5	43.1	35.6
11	96753	274.4	172.9	131.9	83.1	63.4	52.4
12	96751	268.5	169.1	129.1	81.3	62.1	51.2
13	96791	314.2	197.9	151.1	95.2	72.6	60.0
14	96807	211.4	133.2	101.6	64.0	48.9	40.3
15	96835	251.1	158.2	120.7	76.0	58.0	47.9
16	96839	244.2	153.9	117.4	74.0	56.5	46.6
17	96837	248.3	156.4	119.4	75.2	57.4	47.4
18	96805	324.0	204.1	155.8	98.1	74.9	61.8
19	96797	259.0	163.1	124.5	78.4	59.9	49.4

Table 4. Rainfall Intensity for a 5-Year Return Period (continued).

No.	WMO ID	Rainfall Intensity (mm/hour), Return Period 5 Year					
		5’	10’	15’	30’	45’	60 ‘
20	96855	300.3	189.2	144.4	90.9	69.4	57.3
21	96851	258.8	163.1	124.4	78.4	59.8	49.4
22	96859	186.9	117.7	89.8	56.6	43.2	35.6
23	96949	190.5	120.0	91.6	57.7	44.0	36.4
24	96975	270.5	170.4	130.0	81.9	62.5	51.6
25	96945	267.3	168.4	128.5	81.0	61.8	51.0
26	96943	207.6	130.8	99.8	62.9	48.0	39.6
27	96987	375.4	236.5	180.5	113.7	86.8	71.6
28	96935	223.1	140.5	107.2	67.6	51.6	42.6
29	96937	214.5	135.1	103.1	65.0	49.6	40.9
30	96933	240.7	151.6	115.7	72.9	55.6	45.9
31	96925	275.6	173.6	132.5	83.5	63.7	52.6
32	96973	207.6	130.8	99.8	62.9	48.0	39.6
33	96939	196.4	123.7	94.4	59.5	45.4	37.5

Based on the rainfall intensity criteria in Table 2, the rainfall intensity for a 5-year return period with a 1-hour (60-minute) duration at 33 rain gauge stations on Java Island falls into the category of very heavy rainfall (>20 mm). Such high-intensity rainfall events, especially during short durations, need to be considered when planning for peak flows (design runoff) in small catchment areas. This is a critical observation for water resource management and disaster mitigation, as it emphasizes that the intensity of short-duration rainfall events may be more predictable and uniform across different regions of Java. On the contrary, longer-duration events exhibit more significant spatial variability [22-25]. Furthermore, the intensity values for the 5-year return period and various durations (refer to Table 4) were used to create rainfall intensity maps using ArcGIS (Fig. 4.).

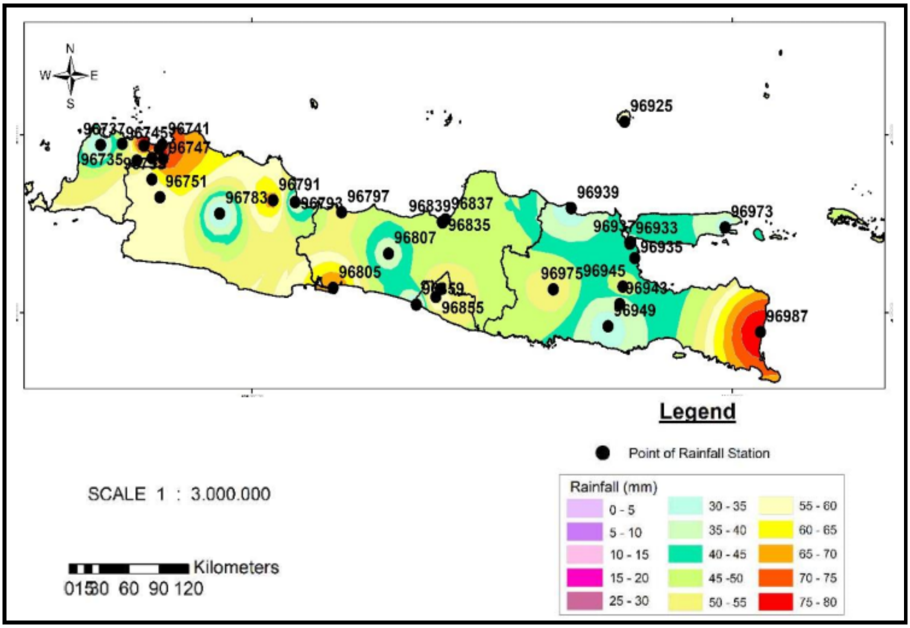

Fig. 4. Rain intensity map of Java Island at 5-year return duration 60 minutes.

Fig. 4. illustrates the expected intensity of rainfall for 60 minutes, which is likely to occur once every five years. The map color gradient effectively differentiates between areas of varying rainfall intensities, with darker colors indicating higher intensities. This detailed mapping is crucial to identify regions at increased risk of experiencing significant rainfall within a relatively short period, which is critical in managing flood risks and designing adequate stormwater facilities. The map shows a transparent gradient of rainfall intensity, with specific zones exhibiting a higher propensity for intense rainfall. These areas are particularly interesting for infrastructure development and emergency planning, as the five-year return period suggests a moderate frequency of occurrence with potentially high impact.

4 Conclusion

Based on the research conducted, the following conclusions were drawn:

- The study results show that 90,9% of the daily rainfall in Java Island is in the medium category, and 9,1% is in the high category.
- The rainfall frequency distribution chosen in this study is a Log Pearson III distribution
- The rainfall intensity for a 5-year return period with a 1-hour (60-minute) duration at 33 rain gauge stations on Java Island falls into the category of very heavy rainfall (>20 mm).
- This study presents the Rainfall Intensity Map for Mononobe in Java Island for a 5-Year Return Period with a 60-Minute Duration.

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