Application of TRMM in Deriving Intensity-Duration-Frequency Curve in Bandung Area

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Abstract. A rainfall Intensity-Duration-Frequency curve serves vital purposes in urban water management, typically generated using a long historical rainfall record. In most cases, such measurement is often sparse or poorly done. Hence it becomes a significant challenge to derive this curve. However, many studies have demonstrated the use of satellite rainfall measurement to cope with this data shortage. One of them is TRMM 3B42 Daily, which is employed in this study. This paper presents the application of TRMM to derive a better IDF curve in a data-scarce region for urban water management. It takes place in Bandung, where most of the upstream catchment area has limited rainfall records. The result shows that the TRMM-derived IDF curve demonstrates underestimated rainfall intensity compared to the ground measurement one. Consequently, the correction of daily data TRMM is necessary to improve the performance of TRMM-derived IDF. The correction of daily TRMM has statistically improved the performance of IDF. It is exhibited by the decreasing value of RMSE and RE. This analysis was culminated by producing an updated IDF curve using TRMM data from 1998-2019 for Bandung City. There is no significant trend that appears in rainfall intensity from 2016-2019.

1. Introduction
An Intensity-Duration-Frequency (IDF) rainfall curve plays an essential role in urban water management. One of such is in designing urban drainage infrastructure for storm events. This method has been widely used since its first introduction in 1932 and has been developed ever since [1]. The IDF curve construction exploits a long record of storm events, usually in a short period. Consequently, the installed instrument should be able to record a sub-daily rainfall. On the contrary, such instruments are hardly found in many developing countries, not to mention Indonesia. If any, those are also sometimes poorly done due to lack of maintenance. Hence, it inevitably affects the reliability of the IDF curve.

Alternatively, to cope with such data shortage, many studies have been conducted using satellite rainfall products in deriving IDF curves [2]. The satellite rainfall product that is employed in this study is TRMM (Tropical Rainfall Measuring Mission) 3B42 daily. Therefore, this study discusses the application of satellite product performance to derive an IDF curve, which is beneficial for a region with poor or scarce sub-daily records. The performance will be evaluated by comparing the storm events record. Moreover, this study also applies a practical method to construct the IDF curve with a meaningful result. In the later section, an update on the satellite precipitation data will also be presented to see any changing rainfall pattern captured from the IDF curves.
2. Data and Methods

2.1. Study Location and Data
Located in West Java, Indonesia, Greater Bandung has an annual rainfall of 2,500 mm and an average temperature of around 23°C. The climate is classified as tropical rainforest climate [3]. Bandung is a home for almost 2.5 million population [4], and the urbanized space has been very intensively built over the decade. A study also demonstrates a significant change to a build-up area from 2006 to 2012 on Bandung's northern part (West Bandung District) [5]. It will cause a serious problem if urban planning is overlooked, primarily if it affects the water catchment runoff.

![Figure 1. Location of rainfall ground stations and grid of TRMM 3B42 for this research study](image)

Figure 1 illustrates the distribution of rainfall gauges within the Greater Bandung. However, less are located on the northern part of the city, and merely one station within the city which records the sub-daily rainfall (storm events) is Cemara Station (red symbol in Figure 1). The available sub-daily data in Bandung City recorded from 1984 until 2016. As previously mentioned, the satellite rainfall product used in this study is TRMM 3B42 Daily. TRMM [6] is a satellite rainfall product measurement launched by NASA in 1997. The spatial resolution of TRMM is 0,25 x 0,25 in degrees or around 28 x 28 km near the tropical areas (see the red box in Figure 1. TRMM 3B42 daily is available within the period year 1998-2019.

2.2. General Step Deriving IDF Curves
Since the data period is different between TRMM and Ground station, this study utilizes both data period from 1998-2016. The derivation of the IDF curve using satellite data is processed under several steps, proposed by [2]. It starts with retrieving the annual maxima rainfall from satellite products, which is TRMM 3B42 daily. Having the annual maxima rainfall, we can fit the data into EV-1 distribution and express the distribution for different return periods, viz, 2, 5, 10, 25, 50, and 100-year. The rainfall
intensity for each duration can be obtained by transforming the fitted data using empirical formulas. The process is culminated by constructing the IDF curve using a regression formula.

2.3. Extreme Value Distribution

In order to express the rainfall data into several return periods, Extreme Value (EV) Type-1 (Gumbel) distribution is selected in this study. The EV1 has two parameters: concentration parameter \((a)\) and measure of central tendency \((b)\). The following formula is the cumulative distribution function for EV1 [7]:

\[
F(x) = e^{-e^{y}} \tag{1}
\]

\[
y = a(b - x) \tag{2}
\]

where parameter \(a > 0\) and parameter \(b\) \((-\infty < b < x)\), \(y\) is the reduced variate. In this study, the parameters were estimated using the method of moments proposed by Chow [8]. The following equations are used to fit the EV1 distribution:

\[
x_T = \bar{x} + K(T) \cdot S_X \tag{3}
\]

\[
K(T) = -0.45 + 0.7797 \ln \left( -\ln \left( 1 - \frac{1}{T} \right) \right) \tag{4}
\]

where \(\bar{x}\) and \(S_X\) are the mean and standard deviation of the sample size, respectively; \(K(T)\) is the frequency factor as a function of the return period \(T\).

2.4. Mononobe Empirical Formula

Mononobe empirical formula expresses the conversion of annual maxima rainfall into a rainfall intensity for different durations, which is also widely utilized in hydrological applications. This formula will only be applied for the satellite-derived IDF. The equation is expressed as follows:

\[
R_t = \frac{R_T}{T} \left( \frac{t}{T} \right)^n t \tag{5}
\]

where \(R_T\) (mm) is the designated rainfall depth, \(R_t\) (mm/hour) is the cumulative rainfall depth for time \(t\), and \(T\) is the rainfall duration in hours, where as in general, the constant \(n\) is assumed to be 2/3.

2.5. Regression Formula

The regression formula suggested to be used in this study location is Talbot formula [9], which will be employed for all IDF construction. This suggestion was demonstrated by Fitriana and Yudianto in 2017 [10] by comparing it with other regression formulas, such as Sherman and Ishiguro. Talbot regression equation is expressed as follows:

\[
I_T = \frac{a}{t+b} \tag{6}
\]

\[
a = \frac{\left( \Sigma_{i=1}^{n} t_i \times t_i \right) \left( \Sigma_{i=1}^{n} x_i^2 \right) - \left( \Sigma_{i=1}^{n} x_i t_i \right) \left( \Sigma_{i=1}^{n} x_i^2 \right) \left( \Sigma_{i=1}^{n} t_i \right) + u \left( \Sigma_{i=1}^{n} x_i t_i \right)^2 - \left( \Sigma_{i=1}^{n} x_i^2 \right) \left( \Sigma_{i=1}^{n} t_i \right)}{N \Sigma_{i=1}^{n} t_i^3 - \left( \Sigma_{i=1}^{n} t_i \right)^2} \tag{7}
\]

\[
b = \frac{\left( \Sigma_{i=1}^{n} x_i t_i \right) \left( \Sigma_{i=1}^{n} x_i t_i \right) - \left( \Sigma_{i=1}^{n} x_i^2 t_i \right) \left( \Sigma_{i=1}^{n} t_i \right) + v \left( \Sigma_{i=1}^{n} x_i t_i \right)^2 - \left( \Sigma_{i=1}^{n} x_i^2 \right) \left( \Sigma_{i=1}^{n} t_i \right)}{N \Sigma_{i=1}^{n} t_i^2 - \left( \Sigma_{i=1}^{n} t_i \right)^2} \tag{8}
\]

where \(a\) and \(b\) are the regression formula parameters, \(I_t\) and \(t_i\) are the rainfall intensity (mm/hr) and duration in minutes, respectively.

2.6. Validation Measures

To evaluate the satellite-derived IDF curve’s reliability, validation measures are performed using Root Mean Square Error (RMSE) and Relative Error (RE). RMSE demonstrates the average deviation of two
different datasets, whereas RE shows the margin error compared to ground station data. Both equations are presented as follows:

\[
RMSE = \sqrt{\sum_{i=1}^{N} \frac{(\hat{X}_i - X_i)^2}{N}}
\] (9)

\[
RE = \frac{|\hat{X} - X|}{X}
\] (10)

where \(\hat{X}\) is the rainfall intensity yielded from satellite IDF curve, and \(X\) is the rainfall intensity yielded from ground station IDF curve.

3. Result and Discussion

3.1. Uncorrected Satellite Derived IDF

Figure 2 exemplifies the IDF curves derived from TRMM for different return periods than IDF derived from rainfall gauge. In general, the IDF curves derived from TRMM show an underestimation than the one from ground stations. It occurs because TRMM has trouble detecting heavy precipitation [11], and the derivation of the curve relies on the annual maxima.

Statistically, the Root Mean Square Error (RMSE) still reflects a notable deviation, ranges from 18-29 mm/hr. Having lower accuracy, the IDF curves derived from TRMM might cause a severe consequence on further engineering application. Therefore, to improve the derivation of IDF curves, further analysis of TRMM data correction would be necessary. Moreover, considering the mountainous regions of the studied location, the rainfall detection on the north, middle, and south part might cause an underperformance [12].

![Figure 2. IDF curves derived using uncorrected TRMM for different return periods (blue dot and line)](image-url)
3.2. Corrected Satellite Derived IDF

Having an inferior IDF result from the TRMM data, a correction should be performed to construct a better IDF. Studies on the correction towards satellite rainfall products have been demonstrated by many. One of the studies has recommended that further correction is critical to more reliability for higher precipitation rates [11]. Moreover, an evaluation using bias correction should also be considered before IDF development [1]. The correction is done by multiplying the daily rainfall data with the correction coefficient shown in Table 1 due to its simplicity. It is motivated by a study done in 2020 [13] in East Java; the TRMM 3B42 daily was grouped into five different ranges of rainfall classes. In addition to that, the study also concluded that the correction had statistically improved the use of TRMM data.

Table 1. Correction Coefficient For Five Different Daily Rainfall Classes [13]

| Daily Rainfall Range [mm] | Correction Coefficient |
|---------------------------|------------------------|
| ≤ 3                      | 0                      |
| 3 – 20                    | 0.8                    |
| 20 – 50                   | 1.1                    |
| 50 – 110                  | 1.2                    |
| ≥ 110                     | 1.3                    |

Figure 3. IDF curves derived using corrected TRMM for different return periods (blue dot and line)
Although the IDF curves have statistically improved by performing a correction, the difference estimation on rainfall intensity still appears on the shorter rainfall duration. It might happen due to the constant value for the Mononobe formula, as suggested by a study in 2017 [10]. The study modified the Mononobe formula in which a storm with a duration of fewer than 15 minutes has a larger constant. Besides that, TRMM 3B42 covers a larger area rather than a gauge. The comparison towards regional gauge leads to uncertainty issue, which is much more complicated. This idea was also proposed by Ombadi et al. [1]. Further investigation is necessary to take into account these shortcomings.

![Figure 4. Reduction of mean relative error of IDF derived from uncorrected TRMM data (red box) and from corrected TRMM data (blue hatch) for return periods 2, 5, 10, 25, 50 and 100 years](image)

3.3. Projection on the Satellite Derived IDF

By updating the corrected TRMM data into 2019, this study would also evaluate if any change is detected from the IDF curve. A study conducted in 2017 reveals an increment pattern of rainfall intensity in the Bandung Area over the past decade [14]. Figure 5 presents the IDF curves from satellite data year 1998-2019 for return periods 2, 5, 10, and 25-years. On the contrary, the result suggested no significant changes in the IDF curve from 2016 to 2019, which means that there is no meaningful change in precipitation pattern in Greater Bandung. There is a slight decrease in rainfall intensity throughout the duration for several return periods scenario.
4. Conclusions and Recommendations

4.1. Conclusions

This preliminary study aims to evaluate the performance of TRMM data in deriving IDF curves for different return period scenarios. It is found that low detection of heavy precipitation leads to underestimating rainfall intensity in the IDF curve. Therefore, it is necessary to improve the TRMM data before its utilization. The correction has confirmed a statistical improvement of IDF curves performance from TRMM data by reducing relative error and the RMSE value range. However, its application also needs to consider the variance of rainfall intensity, especially on the larger return period. Additionally, the result also shows that shorter duration storm shows a larger error than the more prolonged duration storm. The projection upon IDF Curves, by updating the TRMM data to 2019, is intended to detect any changing precipitation trend in Bandung Area. The result exhibits no significant trend detected for precipitation from 2016-2019 from the IDF curves. There is only a slight decrease in the intensity, especially in a shorter duration of the storm.

4.2. Recommendations

Recommendations to further improve this study are: (1) An assessment of the scaling uncertainties between the satellite spatial range and point gauge should also be taken into account. (2) A comprehensive study focusing on the difference between shorter and longer duration of the storm should be further investigated.

5. References

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