The comparison of rainfall intensity analysis methods in upstream area of Belik Watershed, Yogyakarta

N Munawaroh1, N N A Puspitasari2, M P Hadi1 and U Suarma1

1Department of Environmental Geography, Faculty of Geography, Universitas Gadjah Mada, Indonesia
2Undergraduate student, Faculty of Geography, Universitas Gadjah Mada, Yogyakarta, Indonesia

*Corresponding email: utiasuarma@ugm.ac.id

Abstract. Belik Watershed is one of a catchment which located in urbanized area of Yogyakarta. The upper stream part of this watershed have very important role as recharge area. However, vast land conversion occurrence in Sleman Regency threatened its function and cause several inundation case within the area. In other words, stream capacity unable to accommodate the surface runoff. This research intend to analyzed rainfall return period and compare rainfall intensity analysis methods to be implement in the research area. Furthermore, statistical analysis performed to carry out suitable method in the previous research aims. The comparison of rainfall intensity analysis in the short time series distance utilizes Talbot Method and Sherman Method. Rainfall data of short times series distance obtained from Automatic Water Rainfall (ARR). This research analyse 2, 5, 10, 25 and 50 years of return period. Calculations of the standard deviation and error square mean root peak-weight (PWRMSE) determine to choose which method has a better result. The design of rainfall intensity result shown in the Intensity-Duration-Frequency (IDF) graph. Based on the calculation, the most appropriate method is the Sherman Method with standard deviation and PWRMSE for each return period in chronological order of 2 years (-0.27) (Z 3.52); 5 years (-0.67) (Z 3.83); 10 years (0.3) (Z 5.39); 25 years (0.6) (Z 7.56); and 50 years (-1.0) (Z 9.72).

1. Introduction
Rainfall is part of natural phenomenon which difficult to controlled. Therefore, it is fundamental component in hydrological data analysis and planning [1]. The data presented spatially and temporally will be somewhat random [2]. However, rainfall data is one of the data sources that can be utilized for water building planning. Data management includes spatial pattern, temporal, and quantity analysis. Rainfall occurrence varies between regions due to physical factors such as the variety of topography [3]. The amount of rainfall which occurs in short time, for example one hour duration known as rainfall intensity [4]. Rainfall intensity has huge impact for water management purposes.

Belik Watershed is a catchment which located in Sleman Regency, Special Region of Yogyakarta. Vast occurrence of land use change in Belik Watershed for the past 10 years has increased the concern regarding environmental issue. The massive change from open land into built up area resulted in reduction of catchment area and increase the potential of surface runoff. High intensity rainfall could trigger inundation in certain area within Belik Watershed and flooded the residential area [5] (Figure 1).
Heavy rainfall occurrence on built up area could enlarge runoff number [6]. Runoff movement follow the gravitation from certain regions through the surface [7]. Based on the circumstance, rainfall intensity measurement in Belik Watershed is essential to determine rainfall design. Rainfall design construct the depth of rainfall in a specific area that used as a reference for designed a building [8].

2. Methodology

2.1 Study Area

This research located in Belik Watershed (0.88 km²), Sleman Regency, Special Region of Yogyakarta, Indonesia. Moreover, Belik Watershed situated in urbanized area. Geographically, the research area coordinate 110°22′43″-110°23′29.4″ E and 7°45′53.1″- 7°45′45.6″ S (Figure 2). Based on the geomorphologic conditions, research areas located at the volcanic plain (0%-2%) with geological formation Gunung Merapi Muda (Qmi). The material consists of tuff, volcanic ash, agglomerate breccia and molten lava [11]. This formation has the potential of good aquifer [12]. In addition, catchment area use to fulfil the water needs of community in the surrounding area [13]. Since many people interested to occupied land in this area, therefore land use dominated by settlements and buildings [14]. Rainfall intensity calculates by using rainfall data from year 2002-2011 from the Santan stations. This gauge station is the nearest to the study area location.
2.2 Methodology
This study uses primary data rainfall. Talbot and Sherman methods will be used to analyze rainfall intensity in this research. The reason behind method selection based on the rainfall data used is short-term rainfall data with a minute duration. Additionally, this method is an empirical method.

2.2.1 Rainfall Intensity Observation. Rainfall intensity defines as the momentum or water level in specific time unit (mm/hour). The value could be diverse based on assessed period of time. This distinctive value caused by duration or frequency. Rainfall intensity calculation as follow:

\[ I = \frac{R}{t} \]  

Where:

- \( I \) = rainfall intensity (mm/h)
- \( R \) = maximum hourly rainfall within a day (mm)
- \( t \) = rainfall duration (h) [2]

Rainfall design can be obtained by analyze its frequency based on certain return period. Partial series method conducted to cope with data availability limitation to set minimum value with particular consideration. Rainfall data used in this research is a short-term category data; hence it is calculate by Talbot and Sherman method. Both methods compare to obtain preeminent empirical formula in the study area. The formula written as follow:
2.2.2 Talbot Method.

\[ I = \frac{a + b}{t} \]  
\[ a = \frac{\sum (t_i I_i (t_i^2) - \sum (t_i) I_i (t_i))}{N \sum (t_i^2) - \sum (t_i) I_i (t_i)} \]  
\[ b = \frac{\sum (t_i I_i (t_i) - N \sum (t_i^2) I_i)}{N \sum (t_i^2) - \sum (t_i) I_i (t_i)} \]

Here in, \( I \) is rainfall intensity in (mm/h), \( t \) is time of rainfall in (minute), \( N \) is total rainfall data, \( a \) and \( b \) are Constanta which depend in time of rainfall [6].

2.2.3 Sherman Method.

\[ I = \frac{a}{t^b} \]  
\[ \log a = \frac{\sum (\log I_i) \sum (\log t_i)^2 - \sum (\log t_i) \sum (\log I_i \log t_i)}{N \sum (\log t_i^2) - \sum (\log t_i) \sum (\log t_i)} \]  
\[ \log b = \frac{\sum (\log I_i) \sum (\log t_i) - N \sum (\log t_i \log I_i)}{N \sum (\log t_i^2) - \sum (\log t_i) \sum (\log t_i)} \]

Here in, \( I \) is rainfall intensity in (mm/h), \( n \) is time of rainfall in (minute), \( N \) is total rainfall data, \( a \) and \( t \) are Constanta depend in time of rainfall [6].

2.2.4 Peak-Weight Root Mean Square Error Test (PWRMSE). This formula is used for approval in the complexity method. PWRMSE compare parameters and the difference in its result [15]. This test used to defines empirical characteristic of suitable rainfall intensity. PWRMSE test tend to shows higher \( Z \) value if the error value increase. Hence, the best possible way to define empirical formula through the lowest \( Z \) value available. The PWRMSE formula as follows:

\[ Z = \frac{1}{N} \left\{ \sum_{i=1}^{N} \left( I_i (I) - I_i (mean) \right)^2 \left( \frac{I_i (I) + I_i (mean)}{I_i (mean)} \right) \right\} \]

Here in, \( Z \) is value of PWRMSE, \( NI \) is amount of data the intensity of rain, \( I_i \) is rainfall intensity measurement result, \( I_i \) is rainfall intensity values, \( I_i (mean) \) is rainfall intensity average values intensity to observed.

2.2.5 Research Flow Charts. The steps of research consist of preparation, processing and data analysis, also descriptive analysis. The data analysis would be the basis of the output and recommendation of this research. The flowchart is shown below in (Figure 3).
3. Results and Discussion

3.1 Rainfall Intensity Observation and Return Period. The rainfall data were used for research is ARR of Santan Station for 10 years periods (2002-2011). Rainfall data analysis which under 20 years was using partial series with maximum limit as twice of total data series [16]. Previous research was using rainfall dataset within interval for 5 years to estimate return period up to 1000 years [17]. Return period were used are 2, 5, 10, 25, and 50 years. The estimating of return period does not influenced by the rainfall data were used [16]. The calculate result of the Log-Pearson III method is shown below (Table 1).

| Duration (Minute) | 60  | 120 | 180  | 240 |
|-------------------|-----|-----|------|-----|
| T (Yr)            |     |     |      |     |
| 2                 | 35.22 | 29.977 | 23.794 | 13.942 |
| 5                 | 56.66 | 37.495 | 35.285 | 20.502 |
| 10                | 71.28 | 40.089 | 42.804 | 24.361 |
| 25                | 89.79 | 41.844 | 52.102 | 28.688 |
| 50                | 103.47 | 47.611 | 57.721 | 27.911 |

The calculate result shown as Table 1 obtained from Formula (1) with scale (mm/h). The rainfall intensity is the primary element for calculating Talbot method and Sherman method.

Figure 3. Flow Chart of Research Methodology.
3.2 Determination of Rainfall Intensity Method. The Constanta resulted from calculation with Talbot and Sherman Methods for estimating rainfall intensity at Belik Watershed shown at Table 2. The Constanta is the primary formula for estimating as the formula (2) and (5). The result of the calculation of each method can be seen at (Table 3 and 4).

Table 2. Calculation of Constanta Talbot and Sherman Method.

| T (Yr) | Talbot | Sherman |
|--------|--------|---------|
|       | a      | b       | a      | n     |
| 2     | 4612.14| 49.63   | 458.97 | 0.60  |
| 5     | 6625.32| 48.89   | 840.99 | 0.65  |
| 10    | 7239.52| 35.40   | 1127.54| 0.68  |
| 25    | 7603.22| 17.61   | 1521.33| 0.70  |
| 50    | 7554.76| 5.11    | 2734.12| 0.81  |

Table 3. Calculation of Rainfall Intensity with Talbot Method.

| t (minute) | Return Period (Year) | Talbot |
|------------|----------------------|--------|
|            | 2                    | 5      | 10    | 25    | 50    |
| 60         | 42.07                | 60.84  | 75.89 | 97.97 | 116.03|
| 120        | 27.19                | 39.23  | 46.59 | 55.25 | 60.39 |
| 180        | 20.09                | 28.95  | 33.61 | 38.48 | 40.81 |
| 240        | 15.92                | 22.93  | 26.29 | 29.51 | 30.82 |

Table 4. Calculation of Rainfall Intensity with Sherman Method.

| t (minute) | Return Period (Year) | Sherman |
|------------|----------------------|---------|
|            | 2                    | 5      | 10    | 25    | 50    |
| 60         | 39.21                | 58.97  | 71.04 | 85.17 | 100.72|
| 120        | 25.86                | 37.60  | 44.49 | 52.28 | 57.60 |
| 180        | 20.27                | 28.90  | 33.83 | 39.30 | 41.54 |
| 240        | 17.05                | 23.98  | 27.86 | 32.09 | 32.94 |

Statistic analysis used to calculate rainfall intensity which suitable with the condition and characteristic of Santan rain gauge station. The test was using peak-weight root mean square error (PWRMSE) and deviation between measured data with the prediction result. The suitable method for estimating rainfall intensity concludes with deviation average and the smallest PWRMSE [16]; [18]; [6] (see table 5, 6 and 7).
Table 5. Calculation of Talbot Method Deviation with Return Period of 2, 5, 10, 25, and 50 years.

| t minute | 2 years | 5 years | 10 years | 25 years | 50 years |
|----------|---------|---------|----------|----------|----------|
| 60       | 6.85    | 4.19    | 4.61     | 8.18     | 12.57    |
| 120      | -2.79   | 1.73    | 6.50     | 13.41    | 12.78    |
| 180      | -3.71   | -6.34   | -9.19    | -13.63   | -16.91   |
| 240      | 1.98    | 2.43    | 1.93     | 0.83     | 2.91     |
| Σ        | 2.33    | 2.01    | 3.84     | 8.79     | 11.34    |
| X        | 0.58    | 0.50    | 0.96     | 2.20     | 2.84     |

Table 6. Calculation of Sherman Method Deviation with Return Period of 2, 5, 10, 25, and 50 years.

| t minute | 2 years | 5 years | 10 years | 25 years | 50 years |
|----------|---------|---------|----------|----------|----------|
| 60       | 3.99    | 2.31    | -0.23    | -4.62    | -2.75    |
| 120      | -4.12   | 0.11    | 4.40     | 10.44    | 9.99     |
| 180      | -3.53   | -6.38   | -8.97    | -12.80   | -16.18   |
| 240      | -3.11   | 3.48    | 3.50     | 3.41     | 5.03     |
| Σ        | -0.6    | -0.5    | -1.3     | -3.6     | -3.9     |
| X        | -0.1    | -0.1    | -0.3     | -0.9     | -1.0     |

Table 7. Calculation of PWRMSE Talbot and Sherman Method.

| Return Period | Z Talbot | Z Sherman |
|---------------|----------|-----------|
| 2             | 4.477    | 3.763     |
| 5             | 4.141    | 3.729     |
| 10            | 5.994    | 5.165     |
| 25            | 10.430   | 8.623     |
| 50            | 12.775   | 9.717     |
| Σ             | 37.817   | 30.997    |
| X             | 7.563    | 6.199     |

The calculation result of deviation difference at table 5 and 6 shows that the method which suitable for calculating rainfall intensity is Sherman method’s. The deviation average Sherman method is (-2.3) meanwhile the total average of Talbot method is (5.41). The value proved by the result of calculation close to measured rainfall data (Xr).

The test of peak-weighted root means square error also illustrated that the smallest average comparison value is Sherman method’s calculation. It can be seen that PWRMSE value at every return period shows that the bigger return period for both methods. The condition happened because of ordinary rain characteristic, if the return period got bigger so did with the rainfall intensity, thus the error gets higher [16].
3.3 Rainfall Intensity Curve. Rainfall intensity can be represented by IDF curve. IDF curve Sherman method explained rainfall intensity and return period model in minute. The same explanation was also mention IDF curve a relation between the intensity of precipitation, the duration or the aggregation time of the rainfall in minute [10].

The minutes scale was used for knowing the rainfall intensity value variation is (mm/hour). The shape of IDF curve shows the same pattern for every return period. The longer rainfall duration, the smaller its rainfall intensity will be. Therefore, the bigger its return period, the bigger rainfall intensity value at the same rainfall duration [19].

IDF Curve (Figure 4) is the result of explanation of table 4 and the calculation was using formula (5). The IDF calculation result could be the basic at water management and water building design. Especially in this research could be the reference for designing water building at urban area to decrease the runoff.

4. Conclusion
Based on the calculation, the most appropriate method for rainfall intensity in Belik watershed is the Sherman Method with standard deviation and $PWRMSE$ for each return period in chronological order of 2 years (-0.27) (Z 3.52); 5 years (-0.67) (Z 3.83); 10 years (0.3) (Z 5.39); 25 years (0.6) (Z 7.56); and 50 years (-1.0) (Z 9.72). Rainfall intensity represents by IDF curve and useful tools in water resources management and design planning gproject in study area. The high rainfall intensity followed by inundation occurence need a better management plan in order to decrease the prevalence. Therefore, management plan such as flood control counter measure through artificial wells and drainage channel are essentially required.
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