Detection of Trend Behaviour of Extreme Rainfall Over Java Using Mann-Kendall

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Detection of Trend Behaviour of Extreme Rainfall Over Java Using Mann-Kendall

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Abstract. The purpose of this research is to detect the areas that are impacted by climate change in Java Indonesia by creating a model that analyzes the trend of extreme rainfall distribution for the last 42 years. Man Kendal test is used to analyze the rainfall trend behaviour that will determine the happening of climate change or not in that area. The result of this research gave information that several places in Java might be impacted by climate change. This result is crucial to use as an early warning of areas that are sensitive to natural disasters that are most likely caused by climate change like a flood.

1. Introduction

Floods are natural disasters that often occur in Indonesia. Based on a report from the National Disaster Management Agency (BNPB), which works as an Indonesian disaster organization, it is stated that of the 2220 natural disasters that occurred in early 2020 to September 2020, 606 natural disasters were floods. This means that floods have contributed 27.3% of the total natural disasters that occurred during that period. In addition, the number of floods has also continued to increase over the past nine years. During the year of 2011, 554 flood events were recorded. Meanwhile, in 2019, the number of floods has reached 1271 cases. This means that there has been an increase in cases of flooding by 129% during that time.

Floods have a significant impact on the condition of the infrastructure, economy, and social development of the affected areas [1]. The floods that occurred in early January 2020 in West Java have resulted in financial losses of at least 1 billion rupiahs. Besides, 11 people were killed, 12 were seriously injured and 517 were slightly injured.

A flood is defined as an overflow of water that submerges land that is usually dry [2]. Flood is part of a hydrometeorological disaster caused by meteorological parameters (rain intensity, humidity, temperature, etc.). Hydrometeorological disasters are sensitive to climatic conditions and their changes [3].

Climate change caused by increasing earth temperature makes the intensity of rainfall on earth even heavier [4]. Every 1^0 C temperature increase will gain the atmosphere carrying capacity by about 7% [5]. With the greater the capacity of the atmosphere, the rainfall intensity will be greater [6] and the value of extreme rainfall will increase which will increase the risk of flooding.

Intergovernmental Panel on Climate Change-IPCC says areas affected by climate change are more vulnerable to catastrophic flooding [7]. Detecting areas affected by climate change is an important step that must be taken. With this information, we can collect data on places that may have higher potential for the increasing number of disasters such as floods.

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In this study, we analyzed the behavior of rainfall trends to detect areas that may be impacted by climate change using daily rainfall data from the Climate Prediction Center (CPC) Unified Precipitation Project. Rainfall data were processed using annual maxima series before being analyzed using Mann Kendall to detect the behavior of rainfall trends in places in Java. Rstudio and ArcGIS are used to process all of our daily rainfall data. With this study, we obtain data from areas that might be affected by climate change and prone to flooding in Java.

2. Data and Study Location

2.1. Study location

We used Java as our study location. Java is an island located in Indonesia, Southeast Asia. This island consists of 6 provinces, 85 regencies and 34 cities. Geographically, it is located west of Bali, east of Sumatra, south of Kalimantan, and north of Christmas Island. Indonesia has a population of around 267.7 million, of which 141 million live on the island of Java. This makes Java the most populous island in Indonesia.

Java is also the island with the most floods in Indonesia. 588 flood events were recorded in Java, out of a total of 1271 flood events that occurred in Indonesia at the year of 2019. This makes Java Island the most strategic location for this research.

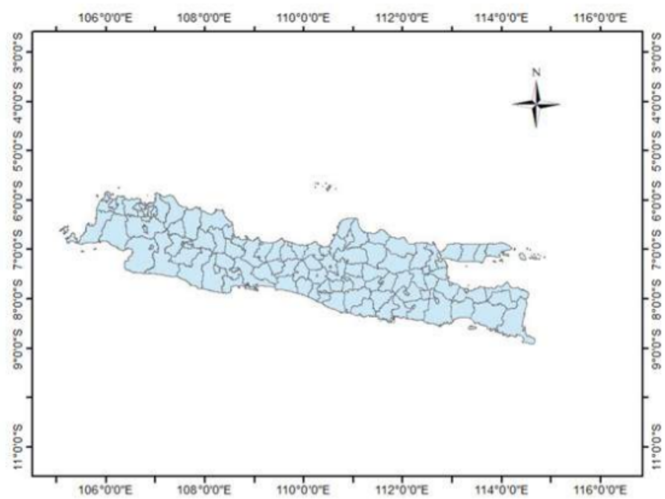

Figure 1. Java Island map

2.2. Data collection

The data we need in this study is daily precipitation data. We found that the daily precipitation or rainfall data based on ground-based measurements in our study location were of low quality with many values lost due to discontinuity observations and a few spatial coverages due to the limited number of rain gauge stations. Suroso and Bardossy (2018) have developed a model to fill in the missing rainfall data in several locations where rain gauge stations are located [8]. However, the model cannot be implemented at unsampled locations. Satellite-based rainfall data is an alternative to dealing with the lack of available data in the fields such as Tropical Rainfall Measurement Missions data [9][10][11]. However, the length of data is not long enough with only about 20 years of observations since the TRMM satellite was launched in 1997.

Daily precipitation data used in this study were collected from the Climate Prediction Center (CPC) Unified Precipitation Project. This daily precipitation data is recorded from 1 January 1979 to 9 October

2020 which provide us of 42 years of daily observation data. This type of data is in the form of a grid measuring $0{,}5^{0}$ x $0{,}5^{0}$ or equal to 55.5 kilometers by 55.5 kilometers. The data consists of 76 grids and is scattered throughout Java and available in NetCDF format. NetCDF (Common Data Form network) is an interface for array-oriented data access and a library that provides an interface implementation[12]. This data can be opened in ArcGIS Software, but the data must be converted into a Comma Separated Value (CSV) so that it can be further processed in Rstudio. To convert files, we use the help of ArcGIS and Rstudio software.

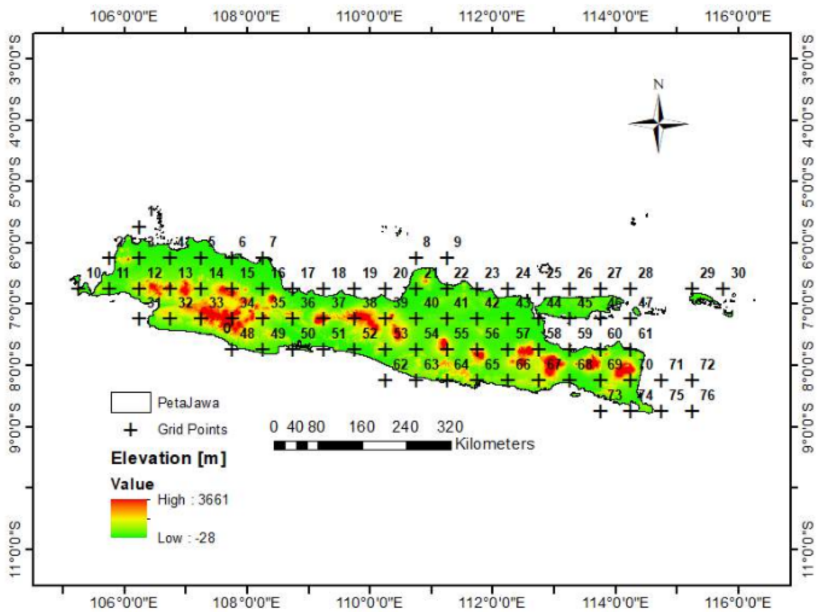

Figure 2. Grid Points location across Java

3. Method

We used an Annual Maximum Series (AMS) which includes only the highest values that appear in each year during the recording period. To detect trend behavior from rainfall data, the Mann Kendall test (Mann 1945; Kendall 1948) was used. And the last, to find the slope of the Mann Kendall test result we used Sen's slope method.

3.1. Extraction of Annual Maximum Series (AMS)

In the AMS extraction, we take the one with the highest value from about 365 daily rainfall data available per year. At the end we have 42 AMS data collected from 1979 to 2020 for one grid. This process was repeated for all 76 grids. To make the process faster and more efficient we used Rstudio.

3.2. Detection of Trends in Rainfall data

Trend analysis is carried out in order to know whether or not time series data consist of trending behavior namely increase, decrease, or the same with the time increase. Mann Kendall method is used to do trend analysis explained below.

3.2.1. Null hypothesis. Null hypothesis, H_o : There is no trend

3.2.2. Alternate hypothesis. Alternate hypothesis, H_a : There is a downward trend or an upward trend

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3.2.3. Mann Kendall. Mann Kendall (S) is described as :

$$\boldsymbol{S} = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \mathbf{sgn}(\mathbf{x_j} - \mathbf{x_i}), \tag{1}$$

where :

$$\mathbf{sgn}(\mathbf{x}) = \begin{cases} +\mathbf{1}, \mathbf{x} > \mathbf{0} \\ \mathbf{0}, \mathbf{x} = \mathbf{0} \\ -\mathbf{1}, \boldsymbol{x} < \mathbf{0} \end{cases} \tag{2}$$

x = time series data

N = number of time series data

3.2.4. Denominator. Denominator is described as :

$$D = \left[\frac{1}{2}N(N-1) - \frac{1}{2}\sum_{i=1}^{m} t_i\,(t_i - 1)\right]^{\frac{1}{2}} \left[\frac{1}{2}N(N-1)\right]^{\frac{1}{2}} \tag{3}$$

3.2.5. Tau Kendall statistic. Tau Kendall statistics is described as :

$$\tau = \frac{S}{D} \tag{4}$$

3.2.6. Variance of S. Variance of S is described as :

$$\sigma_S^2 = \frac{1}{18}\left[N(N-1)(2N+5) - \sum_{i=1}^{m} t_i\,(t_i - 1)(2t_i + 5)\right] \tag{5}$$

Where : m is the number of tied groups (same value) in the data set and ti is the number of data points in the i-th tied group

3.2.7. Test statistics. Test statistics described as :

$$Z = \begin{cases} \frac{(S-1)}{\sigma_s}, & if\ S > 0 \\ 0, & if\ S = 0 \\ \frac{(S+1)}{\sigma_s}, & if\ S < 0 \end{cases} \tag{6}$$

Where : σ_s is standard deviation and S is Mann Kendall test

3.2.8. Probability. Probability (P-value) is calculated based on Z value using standard normal distribution. $P - value = P(z > Z) = 1 - P(z < Z)$

3.2.9. Conclusion. Conclusion is explained as if P-value < significance level to reject Null hypothesis (alpha, used 10%), then Reject the Null hypothesis. Not only that, if Z > critical Z, then Reject the null hypothesis.

3.3. Sen's Slope Estimator

Sen's slope estimator (Sen 1968) used for estimation of the slope or rate of change To derive an estimate of the slope Q, the slopes of all data pairs are calculated

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$$Q_i = \frac{x_j - x_k}{j-k}, i = 1,2, \ldots .. N, j > k \quad (7)$$

If there are n values in the time series, we get as many as $N = n(n-1)/2$ slope estimates Qi. The Sen's estimator of slope is the median of these N values of Qi. The N values of slopes are ranked from the smallest to the largest and the Sen's estimator is the median of all slopes.

$$Q_{\text{med}} = \begin{cases} Q_{\left|\frac{N+1}{2}\right|} & \text{if } N \text{ is odd} \\ \frac{Q_{|N/2|} + Q_{|(N+2)/2|}}{2} & \text{if } N \text{ is even} \end{cases} \quad (8)$$

4. Results and Discussion

4.1. Trends in rainfall for the past 42 years in Java

Of the 76 grids that we analyzed using the Mann Kendall test, there were 13 grids that showed an upward trend. All of these 13 grids may be affected by climate change. The locations of the 13 grids are seen in the figure 2. While the results of the 13 grid analysis can be seen in tables 1 and figure 1.

Based on the test results, these 13 grids are located in 5 provinces and are divided into 12 cities. It can also be seen that these 13 grids are accumulated in 3 regions located on the west, center and east of the island of Java

Table 1. 13 grid points showing increase trend from Mann Kendall test

Grid Code	Province Location	Regency or City	Tau (=S/D)	Sl (2-sided p value)	S (MK test)	D (deno minator)	Var S
4	DKI Jakarta	DKI Jakarta	0,42393	7,99E-05	365	861,0001	8514,33
5	West Java	West Java	0,40534	0,00016	349	861,0001	8514,33
6	West Java	West Java	0,19861	0,06542	171	861,0001	8514,33
12	Banten	Banten	0,24739	0,02159	213	861,0001	8514,33
13	West Java	West Java	0,27294	0,01121	235	861,0001	8514,33
14	West Java	West Java	0,24739	0,02159	213	861,0001	8514,33
15	West Java	West Java	0,21022	0,05109	181	861,0001	8514,33
39	Middle Java	Middle Java	0,18002	0,09513	155	861,0001	8514,33
40	Middle Java	Middle Java	0,24506	0,02285	211	861,0001	8514,33
43	East Java	East Java	0,19396	0,07202	167	861,0001	8514,33
57	East Java	East Java	0,25203	0,01924	217	861,0001	8514,33
58	East Java	East Java	0,20325	0,05933	175	861,0001	8514,33
66	East Java	East Java	0,23810	0,02705	205	861,0001	8514,33

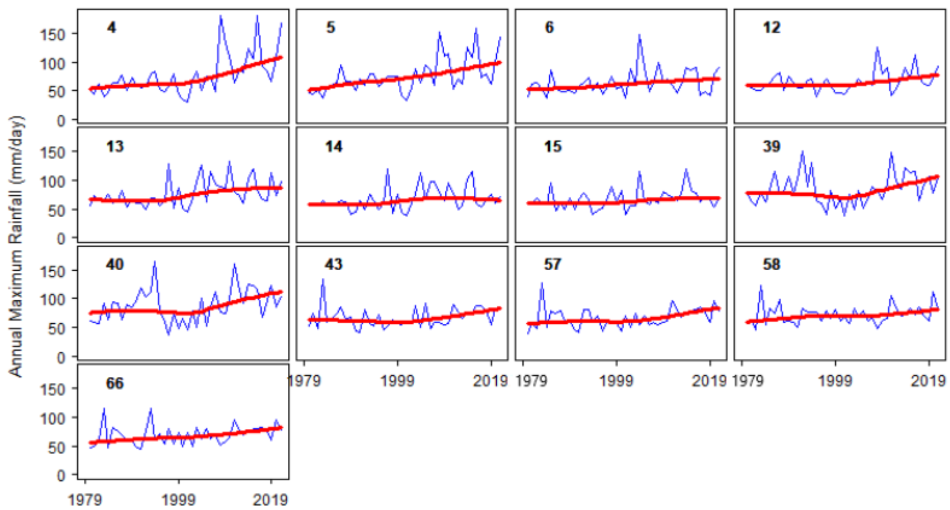

Figure 3. Rainfall Annual Maximum time series of the 13 grid points

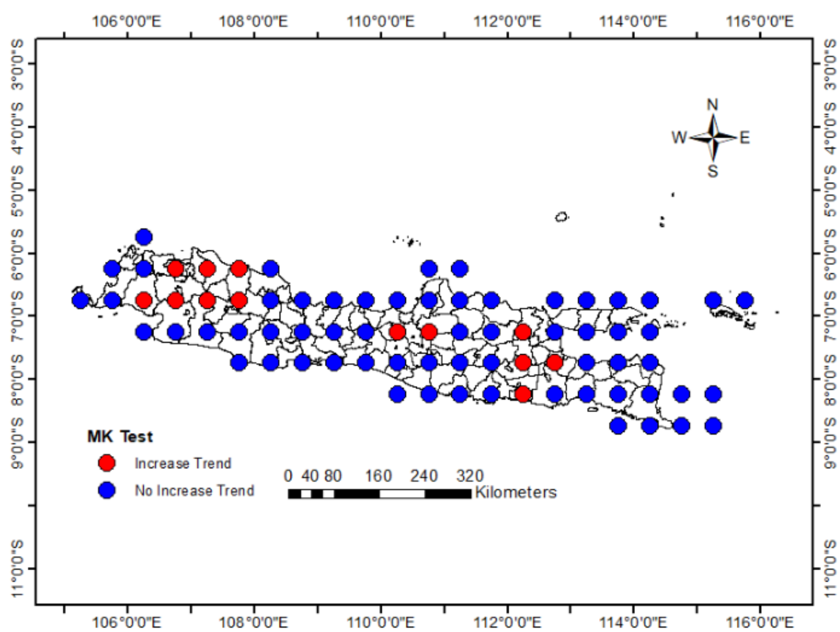

Figure 3. Increase and no increase trend grid points location across Java

4.2. Sen's Slope Estimator and Annual Maximum Series Result .

The result of Sen's Slope Estimator and Annual Maximum Series can be seen in table 2. From the results of the Annual Maximum Series Rainfall per year, we find that the largest maximum rainfall value is 171.0408 mm which occurs in Jakarta, DKI Jakarta province. The rain occurred in 2007 which caused a number of flood disasters to occur that year. Not only that, Jakarta also has the highest slope trend value with a value of 1.293329 which means it is possible for Jakarta to experience an increase in the maximum value of rain in the future. The increase in the maximum rain value that occurs in Jakarta is also likely to be faster than the 11 other cities experiencing an increasing trend.

Four cities in West Java have an increasing slope trend ranging from 0.3-1.2 with maximum daily rainfall value from 119-157 mm. Please note that Bekasi city has the highest maximum daily rainfall and slope trend value. Two cities in Central Java have maximum daily rainfall values ranging from 150-165 mm. While in East Java, the maximum rain value does not exceed 134mm

.**Table 2.** Sein Slope estimator and maximum daily rainfall

Grid Code	Province Location	Regency or City	Maximum Daily Rainfall	Sen's Slope
4	DKI Jakarta	Jakarta	181,0408	1,293329
5	West Java	Bekasi	157,7979	1,25651
6	West Java	Subang	147,443	0,459487
12	Banten	Lebak	125,8213	0,409422
13	West Java	Sukabumi	133,6871	0,658161
14	West Java	Cianjur	119,0244	0,433659
15	West Java	Subang	119,9088	0,347181
39	Middle Java	Temanggung	150,4212	0,538636
40	Middle Java	Boyolali	165,6986	0,879215
43	East Java	Lamongan	133,6154	0,379314
57	East Java	Kediri	127,5932	0,529736
58	East Java	Pasuruan	123,4994	0,301528
66	East Java	Blitar	114,5412	0,442341

5. Conclusion

Based on the results of the Mann Kendall extreme rainfall test that we have done, of the 76 grids we tested in Java, there are 13 grids that experience an increasing trend in rainfall. The 13 grids are most likely affected by climate change which may experience upward changes in the maximum rainfall values that occur from time to time. We also find that these 13 grids accumulate into 3 areas. This result can be investigated further in other new research because the analysis of extreme rainfall that occurs simultaneously in several locations is interesting to study, such as the research of Suroso and Bardossy [13] in Singapore and Germany that there is a pattern of extreme rainfall that occurs in a clustered way.

From the seins slope test and the annual maximum series, it is found that Jakarta is the city with the highest slope trend and rainfall values, making it the most sensitive city to flooding caused by heavy rains.

This study provides informations of areas in Java that experienced upward trends of rainfall for a period of 42 years along with its maximum rainfall and slope value. It is expected that these results will give encouragement to conduct the same study on islands or other areas to evaluate rainfall trends and extreme rainfall values using different methods.

6. Reference

[1] Gasper R, Blohm A, & Ruth M 2011 *Social and economic impacts of climate change on the urban environment* **3(3)** Basel, Switzerland, MDPI 150-157.

[2] Rosyidie A 2013 *Banjir: fakta dan dampaknya, serta pengaruh dari perubahan guna lahan. Journal of Regional and City Planning* **24(3)** 241-249.

[3] Gupta A K, Nair S S, & Sehgal V K 2009 *Hydro-meteorological disasters and climate change: conceptual issues and data needs for integrating adaptation into environment-development framework* Earth Science India **2** 117-132.
[4] Hao Z, AghaKouchak A & Phillips T J 2013 *Changes in concurrent monthly precipitation and temperature extremes* **8** IOP 7.
[5] Trenberth K E 2011 *Changes in precipitation with climate change* **47** Climate Research 123.
[6] Kunkel K E, et al 2013 *Probable maximum precipitation and climate change* **40** Geophys Res Lett 1402–1408.
[7] Murray V, & Ebi K L 2012 *IPCC special report on managing the risks of extreme events and disasters to advance climate change adaptation* **10** IEEE 76-82.
[8] Suroso & Bárdossy A 2018. *Multisite daily precipitation simulation in Singapore.* MATEC Web of Conferences (Vol**. 195**, p. 05007). EDP Sciences.
[9] Jati, M.I.B, Suroso, and Santoso P B. 2019 *Prediction of flood areas using the logistic regression method (case study of the provinces Banten, DKI Jakarta, and West Java)* **1367** IOP Publishing p. 012087.
[10] Pratidina G, Suroso , P B Santoso 2019 *Detection of satellite data-based flood-prone areas using logistic regression in the central part of Java Island* **1367** IOP Publishing p. 012086.
[11] Umiati T, Suroso, Ardiansyah 2019 *Spatial analysis and monitoring of drought using Standardized Precipitation Index in East Java* **1367** IOP Publishing p. 012088.
[12] Rew R & Davis G 1990 *NetCDF: an interface for scientific data access* **10(4)** IEEE computer graphics and applications 76-82.
[13] Suroso & Bárdossy A 2018 *Investigation of asymmetric spatial dependence of precipitation using empirical bivariate copulas* **565** Journal of Hydrology 685-697.

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