Trend analysis of extreme precipitation indices in the southern part of Java

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Abstract. Global warming causes changing on climate system which driving extreme climate and metrological event. The occurrence of extreme event, such as extreme precipitation can lead to flooding and drought which can have an impact on agriculture production. To observe the extreme event, Expert Team for Climate Change Detection Indices (ETCCDI) developed 27 extreme indices which are 11 extreme precipitation indices and 16 extreme temperature indices. In this study, we analyze the trend of extreme precipitation indices to understand the changing of precipitation in Southern part of Java. Extreme precipitation indices were analyzed using Climpact2. Trend significance of extreme indices time series were calculated using non-parametric Mann-Kendall Test. Spatial distribution of the annual trend in each index illustrated using IDW interpolation. Most of significant trend in extreme precipitation indices occurred in North West station of study area. Negative significant trend only happened on consecutive wet days (CWD) index that means wet days was decrease. Positive significant trend happened in every index except consecutive dry days (CDD), Number of heavy precipitation days number of heavy precipitation days (R10mm), and PRCPTOT. Precipitation in study area occur with high intensity in short period.

1. Introduction

Currently, climate change is one of important thing to understand. Climate change is an event of changing patterns and intensity of climate elements as global warming impact [1]. It is known that the average of global warming during 1880-2012 was 0.85°C [2, 3]. This phenomenon increased the frequency of weather anomalies such as extreme weather. Extreme weather is a climatic phenomenon that is rarely occurs at specific places and times, such as cold wave, heat wave, heavy rain, and drought. These events are caused by climate variability defined as variations in mean or other statistical variation, as opposed to extreme rainfall defined by several thresholds [3, 4].

An increase in water vapor in the atmosphere can lead to an increase in temperature associated with extreme precipitation events [5]. Extreme precipitation event can have an impact on high runoff, flooding and erosion. Low precipitation can cause drought which damages agricultural production. The Climate Change Detection and Index Expert Team (ETCCDI) developed 27 extreme indices related to precipitation and temperature. Many studies use this index to analyze climate change and extreme meteorological events at the global or regional level [3, 6]. In this paper, we analyze trends in 12...
extreme precipitation indices at 7 weather stations in southern Java. This work aimed to describe which parts of the study area have a statistically significant trend in the extreme precipitation indices.

2. Methodology

2.1. Study area and meteorological data
The study area located in the Southern part of Java. Daily rainfall data for 32 years (1988-2019) from 7 weather stations were used (Figure 1). In this study, rainfall data collected from Balai Besar Wilayah Sungai Serayu Opak (BBWSsO). Annual average rainfall in this location was 1708 mm/year. Empty rainfall data were completed using US National Weather Service Method. The homogeneity rainfall data was tested using Rescaled Adjusted Partial Sum method [7].

![Weather Station Distribution Map](image)

**Figure 1.** Distribution of weather station in study area

2.2. Calculation of extreme precipitation indices

2.2.1. Software. Calculation of extreme precipitation indices was performed using ClimPACT2 version 1.2.8. ClimPACT2 Software was based on RClimDEX software developed by WMO CCI/WRCP/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI). This software is written in R language, thus, it requires base package of R. There were two steps to calculate the indices. The first step was load and check data then second step were calculating indices. Data that load to this software has some requirements which are (1) ASCII text file, (2) Columns as following sequences: Year, Month, Day, RR, TX, TN (NOTE: RR units = millimeters and Temperature units = degrees Celsius), (3) For data records, missing data must be coded as -99.9; data records must be in calendar date order [8].

2.2.2. Extreme precipitation indices. In this study, we calculated the 12 extreme precipitation indices which were recommended by ETCCDI and ET-SCI. Description of each index is showed at Table 1. After obtaining extreme precipitation indices, time series of each indices was plotted and subjected to statistical analysis to determine the presence or absence of the trends. Statistical significance was determined using Mann-Kendall test at p value ≤ 0.05 [3].

2.3. Spatial distribution
The spatial distribution of trends precipitation indices was illustrated using Inverse Distance Weighting (IDW) interpolation method. The IDW method is multivariate interpolation that involves the process of assigning a value to an unknown point by using weighting sum values from a set of known scattered points.
points [9]. This method is able to explain for a simple spatial dependence in interpolation of observation points and does not require an a priori investigations of spatial variability [10].

**Table 1.** Extreme precipitation indices recommended by ETCCDI

| Index  | Indicator Name                          | Definition                                                                 | Units   |
|--------|-----------------------------------------|---------------------------------------------------------------------------|---------|
| CDD    | Consecutive dry days                    | Number of maximum consecutive days with RR < 1 mm                          | Days    |
| CWD    | Consecutive wet days                    | Number of maximum consecutive days with RR > 1mm                          | Days    |
| R10mm  | Number of heavy precipitation days      | Number of days when RR ≥ 10 mm                                           | Days    |
| R20mm  | Number of very heavy precipitation days | Number of days when RR ≥ 20 mm                                           | Days    |
| RX1day | Max 1day precipitation amount           | Maximum of total RR in 1 day                                              | mm      |
| RX5day | Max 5day precipitation amount           | Maximum of total RR in 5 day                                              | mm      |
| PRCPTOT| Annual total wet-day precipitation      | Annual total RR in wet days (when RR ≥ 1 mm)                             | mm      |
| SDII   | Simple daily intensity index            | Annual Total RR divided by the number of wet days (when RR ≥ 1 mm)       | mm/day  |
| R95p   | Very wet days                           | Annual sum daily of RR > 95th percentile                                  | mm      |
| R99p   | Extremely wet days                     | Annual sum daily of RR > 99th percentile                                  | mm      |
| R95PTOT| Contribution from very wet days         | Fraction of total wet-day rainfall that comes from very wet days         | %       |
| R99PTOT| Contribution from extremely wet days    | Fraction of total wet-day rainfall that comes from extremely wet days     | %       |

3. **Results**

3.1. **Consecutive dry days (CDD) and consecutive wet days (CWD)**

Consecutive dry days (CDD) indicates the number of consecutive dry days where the rainfall is less than 1 mm per day at each station. All stations, except Nyemengan station, experienced a positive CDD trend (Table 2). However, this trend is not statistically significant. This positive trend shows that at every station, except for Nyemengan, the CDD has increased by 0.444 - 1.397 day/year. Consecutive wet days (CWD) indicates the number of consecutive wet days where the rainfall is more than 1 mm per day at each station. All stations, except Gedangan station, experienced negative CDD trend (Table 2). Statistically, the Kedung Keris and Nyemengan stations have a significant decline trend, amounting to -0.332 days/year and -0.272 days/year, respectively. Example of the CDD and CWD time series are shown in Figure 2.

![CDD and CWD time series example](image-url)
Table 2. Annual trend of extreme precipitation indices

| Indices     | Gedangan | Karangploso | Kedung Keris | Ngawen | Nyemengan | Pundong | Terong |
|-------------|-----------|-------------|--------------|--------|------------|---------|--------|
| CDD         | 0.824     | 0.444       | 1.005        | 1.397  | -0.302     | 0.636   | 0.823  |
| CWD         | 0.113     | -0.317      | -0.332*      | -0.197 | -0.272*    | -0.003  | -0.256 |
| R10mm       | 0.198     | 0.255       | 0.131        | -0.02  | 0.160      | 0.034   | 0.491  |
| R20mm       | 0.097     | 0.467*      | 0.297        | -0.144 | 0.360      | 0.009   | 0.71*  |
| RX1day      | -1.897    | 0.564       | 1.724        | 0.116  | 3.139*     | 1.151   | -0.162 |
| RX5day      | -1.429    | 2.538*      | 1.085        | -0.846 | 3.078*     | 1.604   | -3.535 |
| PRCPTOT     | 2.227     | 13.084      | 18.152       | -3.165 | 12.813     | 1.142   | 16.684 |
| SDII        | -0.132    | 0.389*      | 0.124        | -0.009 | 0.361*     | 0.08    | 0.245  |
| R95p        | -3.475    | 12.779*     | 16.302*      | -2.382 | 16.779*    | 0.761   | 9.545  |
| R99p        | -3.562    | 5.465*      | 6.08         | -2.069 | 7.891*     | 0.792   | -3.183 |
| R95pTOT     | -0.094    | 0.530*      | 0.614*       | -0.097 | 0.851*     | 0.011   | 0.24   |
| R99pTOT     | -0.097    | 0.244       | 0.261        | -0.166 | 0.437*     | 0.011   | -0.071 |

*significant at p <0.05

3.2. Number of heavy and very heavy precipitation
Number of heavy precipitation (R10mm) index did show significant trend, although all stations, except Ngawen station, have positive trend indices. Number of very heavy precipitation (R20mm) index showed significant trend at Nyemengan Terong station that distributed at north middle of study area. Time series example of this index is showed at Figure 3. All of station have positive trend, except Ngawen station that have negative trend (Table 2). Positive trend indicates that number of day with precipitation >= 20 mm tended to increase over years.

Figure 3. Annual time series example for R10mm and R20mm at Karangploso station

3.3. Maximum 1-day and 5-day precipitation
Maximum 1-day precipitation (RX1day) index showed statistically significant trend (p <= 0.05) only at Nyemengan station and its value during 1988-2019 was 3.139 mm/year (Table 2). Nyemengan station is located at northern west of study area (Figure 5). Positive trend indicates that at this area the annual maximum 1-day precipitation was increasing. The stations which have a negative trend, although not significant, are Terong station which is located in the middle of the study area and Gedangan station which is located in the south east of the study area. Trend of RX5day index showed statistically significant at Nyemengan and Karangploso station, amounting 3.078 mm/year and 2.538 mm/year, respectively. Both of station located at the north west of study area. The positive trend indicates that the maximum 5-day precipitation was increasing at that area. Time series example of both indices are showed at Figure 4.
Figure 4. Annual time series example for RX1day and RX5day at Nyemengan station

Figure 5. Spatial distribution of trend indices in study area
3.4. PRCPTOT and SDII

The PRCPTOT index trend showed statistically not significant at all station at study area (Table 2). All stations, excluding Ngawen station, have positive trend with value 1.142-13.084 mm/year. Time series of this index is shown at Figure 6. SDII trend showed statistically significant at Karangploso and Nyemengan station that located at north west of study area (Figure 5) with the value of the trend 0.361 mm/day.year and 0.289 mm/day.year, respectively. This significant positive trend indicates that the daily intensity of precipitation at Nyemenagan and Karangploso was increasing every year. Figure 6 showed example time series of SDII index at Nyemengan station.

![Figure 6](image6.png)

**Figure 6.** Annual time series example for PRCPTOT and SDII at Nyemengan station

3.5. Number of very wet days (R95p) and extremely wet days (R99p)

Number of very wet days (R95p) index had statistically significant trend at three weather station that distributed at north west and middle of study area (Figure 5), namely Nyemengan, Kedung Keris, and Karangploso stations with the value 16.779, 16.302, and 12.779 mm/year, respectively. Number of extremely wet days (R99p) index is the amount of precipitation when the rainfall is more than 99th percentile of the data. This index trend showed statistically significant at Nyemengan and Karangploso station. Time series of both indices is presented in Figure 7.

![Figure 7](image7.png)

**Figure 7.** Annual time series example for R95p and R99p at Karangploso station

3.6. R95pTOT and R99pTOT

Contribution from very wet days (R95pTOT) index showed statistically significant trend at Nyemengan, Kedung Keris and Karangploso stations with the value 0.851 %/year, 0.614 %/year, 0.53 %/year, respectively. These stations are located at northern west and middle east of study area (Figure 5). R99pTOT index showed statistically significant trend only at Nyemengan station with the value of the trend 0.437%/year. This station is located at northern of the study area. Both time series indices are shown in Figure 8.
4. Conclusion
In this study, we have investigated the trend of extreme precipitation indices in southern part of Java, Indonesia. Most of significant trend in extreme precipitation indices occurred in north west station of study area. Negative trends which were statistically significant only happened on consecutive wet days indices at Nyemengan and Kedung Keris station indicating that wet days was decreasing. Positive significant trend happened in every index, except consecutive dry days, number of heavy precipitation days (R10mm), and annual total wet-day precipitation (PRCPTOT). From this phenomenon, water used in agricultural production should be more efficient so that it can be used continuously.

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