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Extreme Rainfall Analysis in the Bengawan Solo Watershed, Java

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ABSTRACT

As the largest watershed in Java Island, the Bengawan Solo watershed has experienced recurrent hydrometeorological hazards, leading to infrastructure damage, casualties, and environmental degradation. Research on extreme rainfall causing the hazards in the Bengawan Solo watershed is still limited. This study examines extreme rainfall events by analyzing daily rainfall data (1991-2020) from three observation stations namely Musuk, Tinap, and Lowayu, which represent the upstream, middle, and downstream of the Bengawan Solo watershed. The Extreme Value Theory (EVT) using the Block Maxima approach with a Generalized Extreme Value (GEV) method was used to determine the rainfall return period of 5, 10, 20, 30, and 50-year. We applied the Mann-Kendall test to assess the annual trends of extreme rainfall indices recommended by the Expert Team on Climate Change Detection and Indices (ETCCDI). The results found that the highest estimated annual maximum of daily rainfall was in Musuk station (226.7 mm), followed by Tinap station (159.3 mm) and Lowayu station (149.4 mm). While no significant trend was observed for Musuk, other stations showed a significant trend for the decrease of the daily rainfall intensity, the increase of the number of annual rainy days, the decrease of the annually maximum amount of five consecutive precipitation days, and the increase of the annually number of consecutive wet days. There is also an increase in the maximum amount of annual rainfall for one day (Rx1day) at Lowayu station, which indicates a higher risk of disaster due to high rainfall. Additionally, an increasing trend in the total annual rainfall (PRCPTOT) at Musuk, Tinap, and Lowayu stations suggests a greater potential for water storage to meet water needs in these areas.

KEYWORDS

climate index, generalized extreme value, hydrometeorological hazards, return period, watershed management

INTRODUCTION

According to the 2022 Intergovernmental Panel on Climate Change (IPCC) report, several regions in the world are predicted to experience changes in rainfall, which could result in floods and droughts, potentially resulting in disruption of ecosystems, availability of clean water, food production, and community economic activities, as well as infrastructure damage (Portner et al., 2022). Changes in rainfall impact local ecosystems and socio-economic activities (Chen et al., 2022; Lucas et al., 2021). Understanding the characteristics of rainfall, especially extreme rainfall, is needed to improve water resource management strategies (Muharomah and Setiawan, 2022; Venkata Rao et al., 2020). The impacts of extreme rainfall events vary depending on the level of community preparedness and the mitigation measures in place (Clarke et al., 2021; Titko et al., 2021). Therefore, it is crucial to take proactive measures of extreme rainfall to mitigate and adapt to the consequences of extreme rainfall events (Zhou 2023). Further, we can reduce the likelihood and severity of their impacts, protect lives and properties, and ensure the sustainability of our food supplies (Hemmati et al., 2022).

Bengawan Solo watershed faces several environmental challenges such as flood, drought, critical land, water pollution, erosion, sedimentation, and other social issues (Hannum et al., 2020; Taufik and Annisa, 2022). Several studies have explored changes in rainfall patterns in the Bengawan Solo watershed, including Auliyani and Wahyuningrum (2020), which reported an increased trend in rainfall for the upstream Bengawan Solo, and Trinugroho et al., (2022), which found the coastal regions of the Bengawan Solo Sub-Watershed experience a downward trend, which means that coastal regions will become drier than mountainous regions in the future.

Meanwhile, research on extreme rainfall in the downstream Bengawan Solo watershed was carried out by Mulyanti et al. (2020), who found a decreased extreme rainfall index and identified a link between extreme events and ENSO. It is crucial to understand and analyze extreme rainfall patterns in the Bengawan Solo Watershed to prevent disasters and other hydrological problems. Therefore, this research plays a vital role in addressing this problem and offers insights into rainfall patterns that can help in decision-making and planning for the future.

This research investigates extreme rainfall using Extreme Value Theory (EVT) method and analyzes the annual extreme rainfall trend based on the Mann-Kendall test. EVT provides a valuable framework for analyzing extreme events, allowing for more accurate risk assessment and better decision-making in situations where extreme values are of particular interest (Alves and Neves, 2016; Gilli and këllezi, 2006; Lemos et al., 2021).

EVT has been widely applied in various scientific disciplines, including earth sciences, structural engineering, finance, hydrology, and climatology (Alves and Neves, 2016; Towler et al., 2020). Also, our analysis follows the recommendations of the Expert Team on Climate Change Detection and Indices (ETCCDI). The insights provided by these research findings are invaluable in mitigating the risks associated with environmental and societal events caused by extreme rainfall occurrences.

RESEARCH METHODS

Study Area

The research focused on the Bengawan Solo watershed, which spans across the provinces of Central Java and East Java. It is geographically located at 110°18' E to 112°45' E and 6°49' E to 8°08' E (Figure 1). The watershed covers an area of 16.000 km^2, which is mainly divided into three sub-watersheds, namely the Bengawan Solo Hulu Sub-watershed, the Kali Madiun Sub-watershed, and the Bengawan Solo Hilir Sub-watershed.

Data Source

Our research analyzed daily rainfall data from the Musuk, Tinap, and Lowayu stations, which were respectively located in the upstream, middle, and downstream of Bengawan Solo watershed (Table A1).

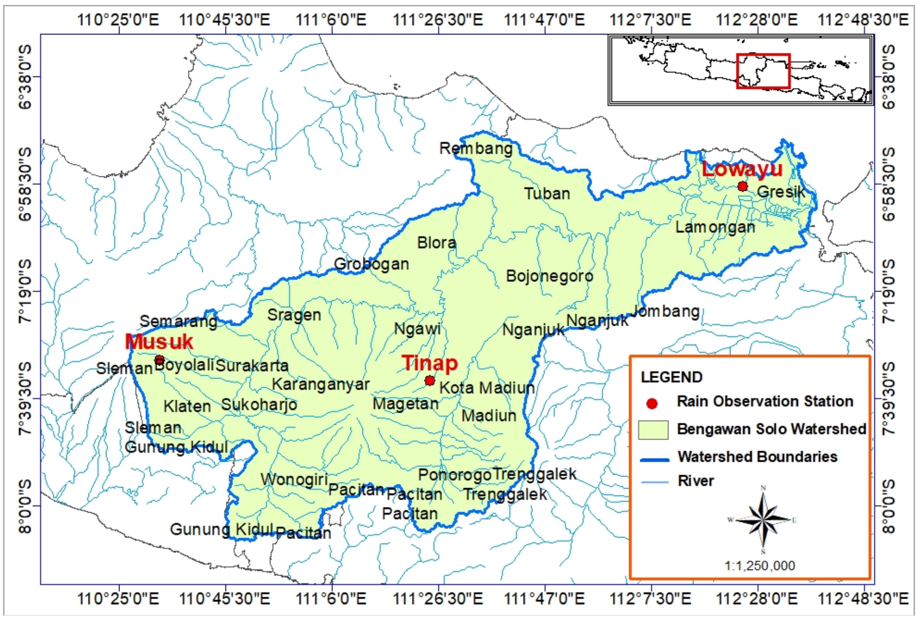

Figure 1. The study area of Bengawan Solo watershed.

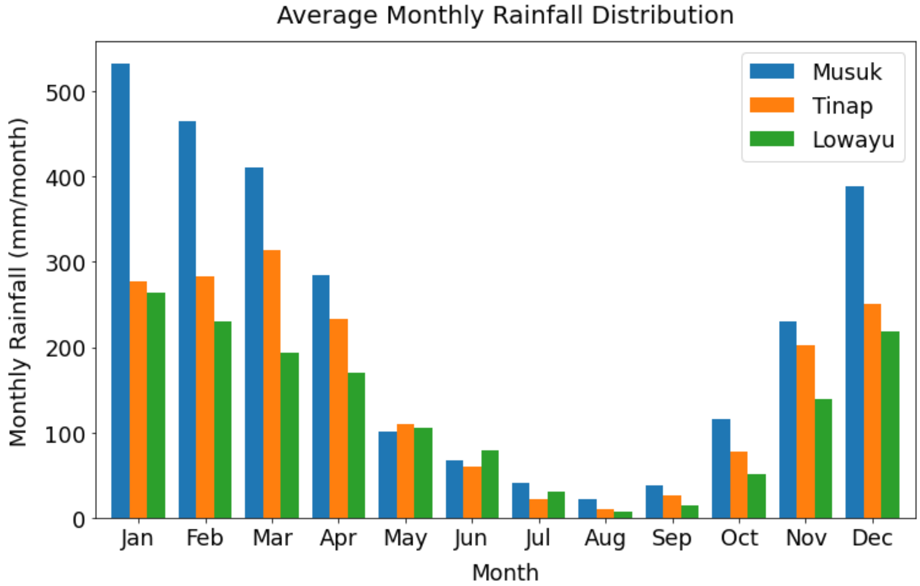

Figure 2. Monthly rainfall pattern in 1991-2020.

We used daily data spanning over three decades from 1991 to 2020, which were obtained from the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG). To process the data, we utilized tools such as Microsoft Excel and the Python programming language in Jupyter Notebook.

Data Preprocessing

Quality control data consisted of missing and duplicate data checks, tolerance tests, and homogeneity tests. The tolerance test used the upper and lower limits with 1% and 99.9% quantiles, respectively. Tolerance tests were carried out to detect outliers and differentiate them from extreme values (Walker et al., 2016). In this research, we used a variety of tests to ensure the homogeneity of the data series to avoid bias, erroneous trend detection, and incorrect interpretation of rainfall data sets (Fofana et al., 2022; Kocsis et al., 2020). These included the Standard Normal Homogeneity Test (SNHT) for one break, as well as the Pettitt Test and the Buishand Range Test. SNHT is effective in detecting breaks at the beginning and end of the data series, while Pettitt and Buishand Range tests are more sensitive in detecting breaks in the middle of the data series (Elzeiny et al., 2019; Wijngaard et al., 2003).

The procedure for carrying out the homogeneity test has been explained in detail by Wijngaard et al., (2003) and Elzeiny et al., (2019), and the homogeneity test results indicated homogeneity if the p-value is greater than alpha = 0.05. In this study, the monthly rainfall data for each rain post was considered homogeneous if the results of at least two homogeneity tests in that month were homogeneous. Tolerance tests and homogeneity tests were carried out in the Jupyter Notebook especially for the homogeneity tests, we employed pyHomogeneity package (Shourov et al., 2023).

Extreme Value Theory (EVT)

Extreme Value Theory (EVT) is a theoretical framework for studying extreme or extreme events, which do not occur very often but are large relative to most observations (Alves and Neves, 2016). This research used the EVT (Extreme Value Theory) method to identify extreme values. Specifically, using the Block Maxima (BM) approach with a GEV (Generalized Extreme Value) distribution (Farah and Azevedo, 2017). This involves selecting the maximum value from the yearly data to accurately identify extreme values. According to Gilli and këllezi, (2006), Block Maxima applies the Theorem of Fisher and Tippett, and Gnedenko, where the data is expected to have a Gumble, Frechet, or Weibull distribution. Jenkinson, (1955) combined these three standard distributions into one distribution known as the Generalized Extreme Value (GEV) distribution. As described by Omey et al. (2009), the GEV distribution is shown in Equation 1.

$$G(z) = \exp\left\{-\left(1+\xi\left(\frac{z-\mu}{\sigma}\right)\right)^{-1/\xi}\right\} \quad (1)$$

Defined on z such that $1+\xi(z-\mu)/\sigma > 0$ and has a location parameter (μ) with $-\infty < \mu < \infty$, a scale parameter (σ) with $\sigma > 0$ and a shape parameter (ξ) with $-\infty < \xi < \infty$. The GEV distribution can be divided into three types based on the shape parameter (ξ): Type 1 which has a Gumbel distribution if the value of $\xi = 0$, Type 2 which has a Frechet distribution if the value of $\xi > 0$, and Type 3 has a Weibull if the value of $\xi < 0$. The determination of the extreme values and GEV distribution.

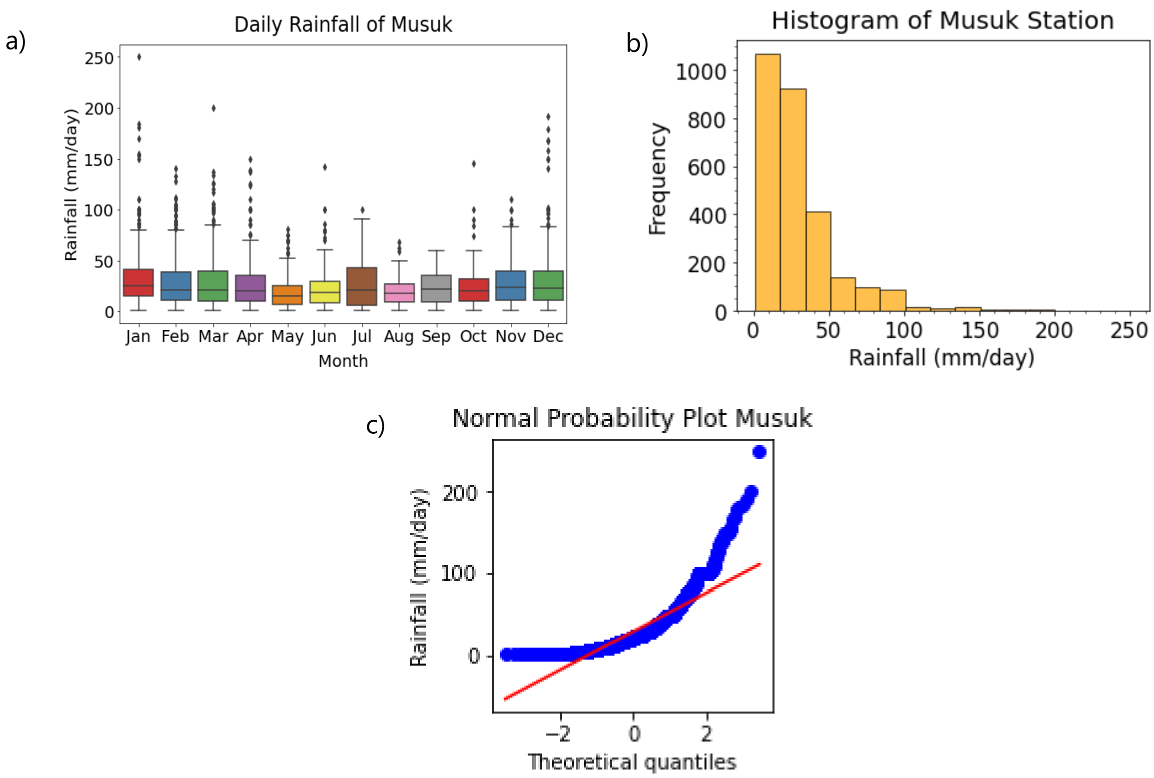

Figure 3. (a) Boxplot, (b) histogram, and (c) normal probability plot of daily rainfall data of Musuk station in 1991-2020.

distribution parameters was done using the Python library pyextremes in Jupyter Notebook (Bocharov, 2023).

Maximum Likelihood Estimation (MLE)

The Maximum Likelihood Estimation (MLE) method is commonly used to estimate the parameter values of a Generalized Extreme Value (GEV) distribution (Ahmed et al., 2024). The basic idea behind MLE is to find the values of the model parameters that maximize the likelihood function, which measures how well the observed data fit the statistical model. Omey et al. (2009) explained the log-likelihood function as shown in Equation 2 – 3.

For GEV with ξ ≠ 0,

$$\ell(\mu,\sigma,\xi) = -m\ log\ \sigma - (1 + 1/\xi)\sum_{i=1}^{m} log\left(1 + \xi\frac{z_i-\mu}{\sigma}\right) - \sum_{i=1}^{m}\left(1 + \xi\frac{z_i-\mu}{\sigma}\right)^{-1/\xi} \quad (2)$$

For GEV with ξ = 0,

$$\ell(\mu,\sigma) = -m\log\sigma - \sum_{i=1}^{m}\left(\frac{z_i-\mu}{\sigma}\right) - \sum_{i=1}^{m} exp\left(-\frac{z_i-\mu}{\sigma}\right) \quad (3)$$

By maximizing the log-likelihood function, estimates of the parameters $\hat{\mu}$, $\hat{\sigma}$, and $\hat{\xi}$ are obtained. Optimization was carried out using numerical methods. Parameter estimation in this research uses the Python programming language.

Distribution Suitability Check

According to Omey et al. (2009), although it is not possible to check the validity of extrapolations based on the GEV model, an assessment can be made concerning the observed data. Checking the suitability of the distribution can be done using quantile plots and probability plots (Yue, 2016). If the distribution pattern of extreme values in the quantile plot and probability plot follows a straight line or linear, then the distribution is appropriate.

Return Period

The return period value commonly called return value is the maximum estimated value produced through calculations using estimated values of distribution parameters (Van Campenhout et al., 2020). According to Gilli and këllezi, (2006), the return level value is the maximum value that is expected to be exceeded once in a period of k with period p (Equation 4).

$$\hat{R}_p^k = \begin{cases} \hat{\mu} - \frac{\hat{\sigma}}{\hat{\xi}}\left[1 - \left\{-log\left(1-\frac{1}{k}\right)\right\}^{-\hat{\xi}}\right], & \hat{\xi} \neq 0 \\ \hat{\mu} - \hat{\sigma}log\left\{-log\left(1-\frac{1}{k}\right)\right\}, & \hat{\xi} = 0 \end{cases} \quad (4)$$

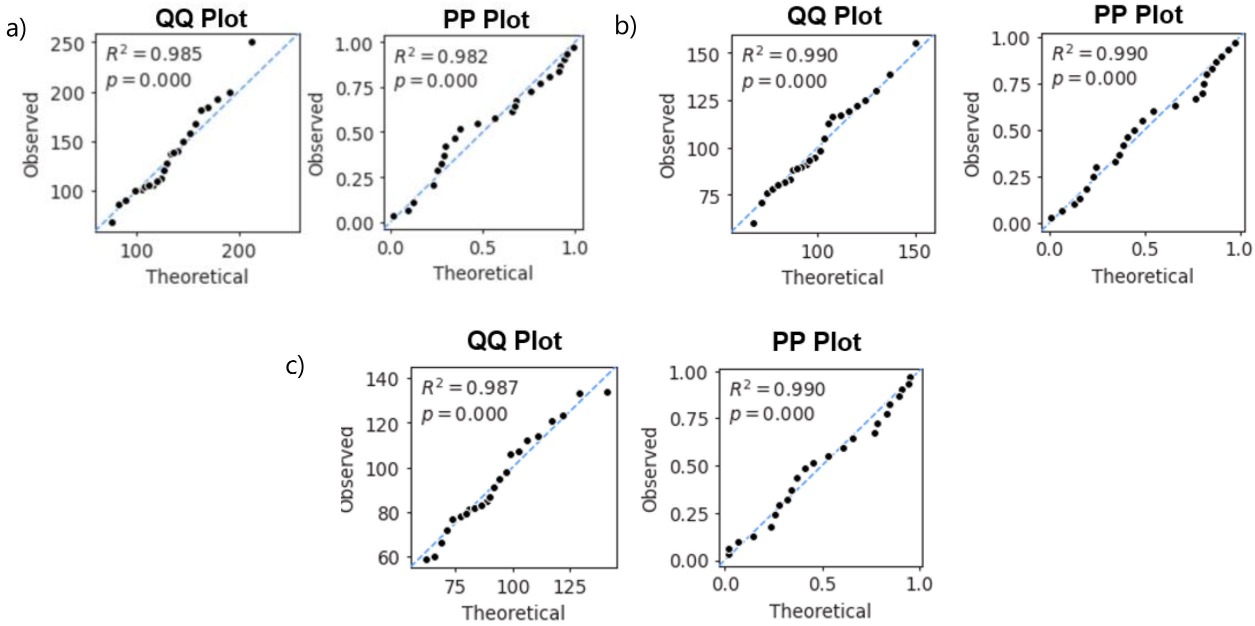

Figure 4. Quantile (QQ) plots and probability (PP) plots of the annual maxima of daily rainfall in (a) Musuk, (b) Tinap, and (c) Lowayu station 1991-2020.

Extreme Precipitation Indices

The extreme precipitation indices used in this study (Table A2) follow the recommendations of the Expert Team on Climate Change Detection and Indices (ETCCDI). The ETCCDI standard extreme precipitation index has been widely used to study climate variability throughout the world (Chen et al., 2022; Zou et al., 2021). The Mann-Kendall Test method used to determine the existence of extreme precipitation trends and analyze the magnitude of the trend value from Sen's slope calculation results (Venkata Rao et al., 2020; Zou et al., 2021). The extreme rainfall indices was calculated using Microsoft Excel. Then the value and significance of the trend of the extreme rainfall indices were determined using the Mann-Kendall Test and Sen's slope using the Python package pyMannKendall in Jupyter Notebook.

RESULTS AND DISCUSSION

Data quality control has involved several checks, such as missing data and duplicate data checks, tolerance tests, and data homogeneity tests. In the 1991–2020 period, the missing monthly rainfall data from the Musuk, Tinap, and Lowayu rain posts was 1.94%, 3.06%, and 1.39% of all monthly data. The average monthly rainfall was used to fill in the blank monthly rainfall data for each station so that monthly rainfall patterns could be described in the rainfall analysis stage. There was no duplicate data for the three stations based on the amount of monthly rainfall.

For the daily rainfall data tolerance test, the lower limit of rainfall from the Musuk, Tinap, and Lowayu rain posts was 0 mm, while the upper limit was 229 mm, 179 mm, and 170 mm, respectively. The monthly rainfall data at the Musuk, Tinap, and Lowayu Rain Posts were homogeneous (Table A3) because the results of at least two homogeneity tests in all months were homogeneous.

Rainfall Chracteristics

The characteristics of the Musuk, Tinap, and Lowayu stations were determined based on the descriptive statistics of daily rainfall and monthly rainfall patterns. The monthly rainfall pattern was monsoon type, with the highest monthly rainfall Between January and March (Figure 2). The rainy season period occurred in November–April, and the dry season period occurs in May–October.

The occurrence of heavy rainfall was determined by analyzing the boxplot, histogram, and normal probability plot of daily rainfall data. There were outliers in the boxplot that indicated extreme rainfall events at each station (Jiang et al., 2019). The histogram also indicated extreme values as shown in an elongated tail pattern (Figures 3a and 3b). Additionally, the normal probability plot indicated the extreme event (Figure 3c).

Valuation of Extreme

The Musuk station recorded the highest annual maxima of daily rainfall in 2009, which was 250 mm, at 8 January 2009 (Figure A1a). For Tinap and Lowayu stations, the annual maxima of daily rainfall were 155 mm (on 12 March 2016) and 134 mm (on 26 December 2007), respectively (check Figures A1b and A1c). The estimation parameters for the estimated GEV distribution are presented in Table 1. All stations

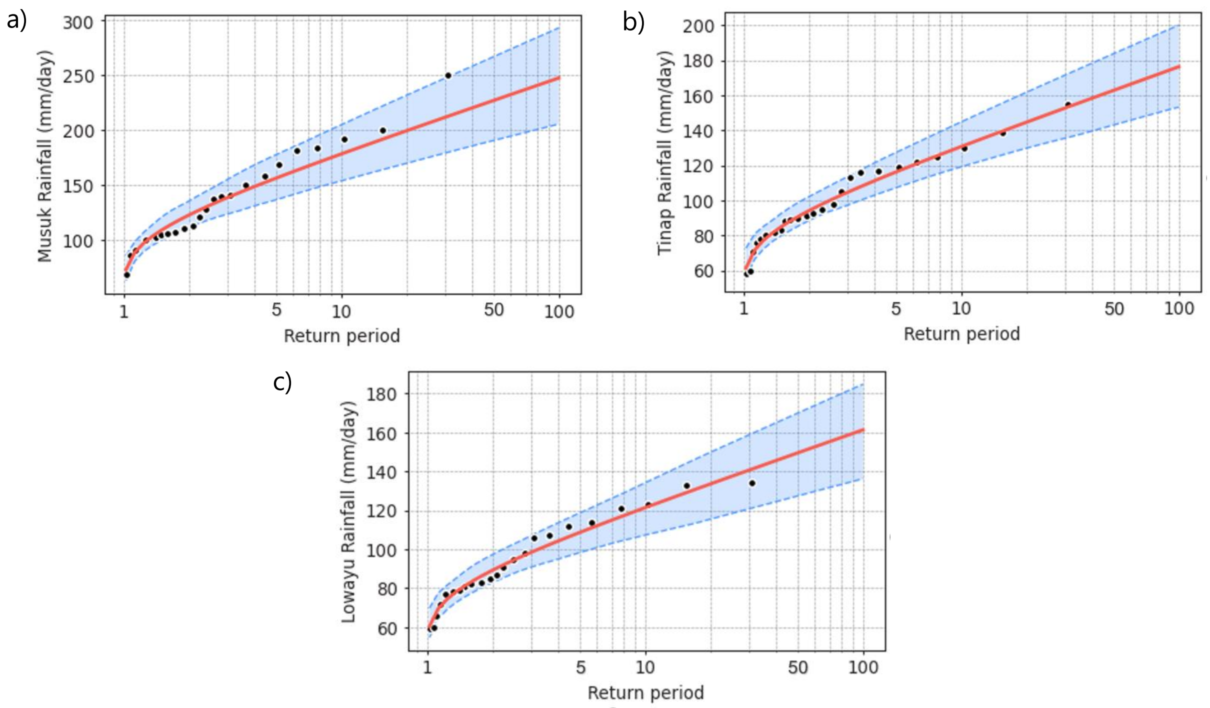

Figure 5. The return value plots of the annual maxima of daily rainfall 1991-2020 of (a) Musuk, (b) Tinap, and (c) Lowayu station. the shaded blue region represents a 95% confidence interval.

indicated have a Gumbel distribution as the shape parameter was 0. The Musuk station had the highest location and scale parameter values, which were 111.536 and 29.512, respectively. This indicated that Musuk station tends to have higher extreme values, and the diversity of extreme values was higher with values that are further from the average value than the Tinap and Lowayu stations.

Representation of extreme

The suitability of a distribution for a dataset depends on how well the distribution captures the underlying characteristics of the data (Joo et al., 2018). The annual maxima of daily rainfall data from the Musuk, Tinap, and Lowayu stations exhibited a strong GEV distribution, as revealed by the quantile plots and probability plots (Figure 4). The distribution was characterized by a high coefficient of determination (R^2) between observed rainfall and theoretical one.

The estimated parameter values of each GEV distribution were used to calculate the return period of the annual maximum rainfall. We calculated the maximum value that will probably occur within a period of 5-, 10-, 20-, 30-, and 50-years. Table A4 presents the return value with a 95% confidence interval. The Lowayu station, where represented the downstream Bengawan Solo watershed area, had the smallest return period value that consistent for all return period. The highest value of return period was observed at the Musuk station, which represented the Bengawan Solo Hulu watershed (Figure 5). For 5-yr return period was 155.8 mm/day, while for 50-yr period was 226.7 mm/day.

Based on historical data from 1991–2020, there were rainfall events that their values closed to the value of return period. For example, in case of Musuk statiun, the daily rainfall on 18 January 2002 was equal to the 5-yr return period. Daily rainfall on 30 December 2012 and 26 March 2012 was proportional to 10-yr and 20-yr return periods, respectively. For Tinap station, two events were closed to y- and 10-yr return period i.e. on 9 January 1998 (116 mm) and 28 February 28 2017 (130mm), respectively. Three events were identified for Lowayu station, which equal to 5-, 10-, and 20-yr return period.

Table 2 presents the values of annual trend for extreme rainfall indices at the Musuk, Tinap, and Lowayu stations. The trend for each indiex varies among station. For PRCPTOT, it showed an increase trend for all the stations, which was consistent with other findings (Trinugroho et al., 2022; Auliyani and Wahyuningrum 2020). The increased trend was laso observed in the number of annual rainy days with rainfall ≥ 1 mm per day (R1mm), and CWD.

Table 1. List of ETCCDI extreme precipitation indices.

Parameter	Musuk	Tinap	Lowayu
shape ξ	0.000	0.000	0.000
location μ	111.536	89.038	83.059
scale σ	29.512	18.018	17.007

Table 2. The value of trend in extreme precipitation indices based on Mann-Kendall test. The data is for 1991-2020.

Indices	Stations		
	Musuk	Tinap	Lowayu
PRCPTOT	16.000	1.792	7.591
SDII	-0.030	-0.272*	-0.208*
Rx1day	-0.500	-0.750	0.333
Rx5day	1.464	-1.190*	-0.462
R1mm	0.722	1.267*	1.235*
R20mm	0.250	0.000	-0.071
CDD	0.400	0.250	-0.500
CWD	0.000	0.111	0.083*
R95p	7.227	-8.000	4.824
R99p	1.000	-2.500	4.438
R95pTOT	0.242	-0.470	-0.073
R99pTOT	0.000	-0.093	0.174

*significant at $p < 0.05$

In contrast, a decreasing trend was observed for the daily precipitation intensity (SDII) ($p<0.05$, Table 2), which was similar to other study in the Bengawan Solo (Mulyanti et al. 2020) for different observation period (1979–2017). There are several indices that indicated no consistent trend throughout the watershed such as: Rx1day, Rx5day, R20mm, CDD, R95p, R99p, R95pTOT, and R99pTOT. A positive trend might be found on the upstream but a negative trend was observed in the downstream, and vice versa.

The Bengawan Solo watershed area plays a critical role in our ecosystem, and understanding the patterns of extreme rainfall in this region is crucial for the future. Our recent research has yielded valuable insights into the rainfall patterns and trends that have occurred within the Bengawan Solo watershed over the past thirty years. With this information, we can equip policymakers and decision-makers with the necessary tools to make informed decisions regarding water management and disaster preparedness in the region. By utilizing our findings, the region can effectively adapt and mitigate the effects of extreme weather events, ultimately minimizing losses incurred as a result.

This research offers a more in-depth analysis of extreme rainfall by examining data from three stations representing different parts of the watershed: upstream, middle, and downstream. While previous studies have focused on changes in annual or seasonal rainfall (Hernández Ayala and Méndez Tejeda, 2023), zeroes in on the crucial aspect of analyzing extreme rainfall across the entire Bengawan Solo watershed area. However, it is important to note that the results of this study do not compare with simulation models that consider anthropogenic influences and climate variability, both of which can impact extreme rainfall patterns (Mukherjee et al., 2018). Thus, it is imperative to continue this research by incorporating data from more observation stations or using downscaling data with bias correction to better represent the entire Bengawan Solo watershed area. By comparing the results with simulation models that consider anthropogenic influences and climate variability, we will gain a more accurate understanding of the extreme rainfall patterns in this region.

CONCLUSIONS

The annual maxima of daily rainfall from the Musuk, Tinap, and Lowayu stations, which are respectively located in the upstream, middle, and downstream of the Bengawan Solo watershed, have a GEV distribution. The estimated return value of annual maxima of daily rainfall for the 5, 10, 20, 30, and 50-year return periods from the three stations has increased over the years, with the highest return value for each period in the Musuk station due to the orographic influence. It is expected to be of concern to related parties considering that various flood and landslide disasters have occurred in the Bengawan Solo watershed when extreme rain is not as large as the estimated return value.

Significant trends occurred in the middle and downstream Bengawan Solo watershed for the decrease of the daily precipitation intensity (SDII) and the increase of the number of annual rainy days with precipitation ≥ 1 mm per day (R1mm), as well as for the decrease of the maximum amount of annual five consecutive precipitation days (Rx5day) in the middle Bengawan Solo watershed and the increase of the annual number of consecutive wet days with precipitation ≥ 1 mm per day (CWD).

There are also increases in the annual precipitation amount (PRCPTOT) in Bengawan Solo that impact the water storage potential to supply water demands in the Bengawan Solo watershed and the annual maximum amount of precipitation for one day (Rx1day) that could increase the risk of disaster due to high rainfall impacts in the downstream area of the Bengawan Solo watershed. These trends suggest a potential shift towards more intense rainfall events in the region, which could implicate water resource management and flood risk. Stakeholders need to consider these changing precipitation patterns when planning for sustainable water use and disaster preparedness in the Bengawan Solo watershed

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ANNEX

Table A1. Information of stations.

Station	Latitude	Longitude	Elevation (msl)	Village	Sub-district	District/City	Province	Missing Data (%)
Musuk	-7.539	110.546	704 m	Musuk	Musuk	Boyolali	Central Java	1.94
Tinap	-7.604	111.413	138 m	Sugiwaras	Maospati	Magetan	East Java	3.06
Lowayu	-6.986	112.419	20 m	Lowayu	Dukun	Gresik	East Java	1.39

Table A2. List of ETCCDI extreme precipitation indices.

Index	Indicator Name	Definition	Units
PRCPTOT	Annual total wet-day precipitation	Annual total precipitation in wet days (RR ≥ 1 mm)	mm
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days (RR ≥ 1mm) in the year	mm/day
RX1day	Max 1 day precipitation amount	Maximum of 1 day precipitation	mm
RX5day	Max 5 day precipitation amount	Maximum of consecutive 5 day precipitation	mm
R1mm	Number of precipitation days	Annual count of days when RR ≥ 1 mm	days
R20mm	Number of very heavy precipitation days	Annual count of days when RR ≥ 20 mm	days
CDD	Consecutive dry days	Maximum number of consecutive days with RR < 1 mm	days
CWD	Consecutive wet days	Maximum number of consecutive days with RR ≥ 1mm	days
R95p	Very wet days	Annual total precipitation when RR > 95th percentile	mm
R99p	Extremely wet days	Annual total precipitation when RR > 99th percentile	mm
R95pTOT	Contribution from very wet days	Fraction of precipitation amount due to very wet days	%
R99pTOT	Contribution from extremely wet days	Fraction of precipitation amount due to extremely wet days	%

Table A3. Homogeneity tests result of daily rainfall data in 1991-2020.

Month	**Musuk**				**Tinap**				**Lowayu**			
	SNHT	**PT**	**BRT**	**Ket**	**SNHT**	**PT**	**BRT**	**Ket**	**SNHT**	**PT**	**BRT**	**Ket**
Jan	0.079	0.115	**0.031***	H_o	0.790	0.522	0.719	H_o	0.461	0.314	0.174	H_o
Feb	0.291	0.352	0.126	H_o	0.672	0.306	0.153	H_o	0.271	0.354	0.260	H_o
Mar	0.920	0.598	0.872	H_o	0.520	0.683	0.435	H_o	0.107	0.143	0.407	H_o
Apr	0.998	0.961	0.930	H_o	0.341	0.135	0.176	H_o	0.539	0.399	0.135	H_o
May	0.603	0.360	0.398	H_o	0.613	0.367	0.251	H_o	0.564	0.523	0.535	H_o
Jun	0.886	0.851	0.647	H_o	0.839	0.871	0.587	H_o	0.848	0.920	0.853	H_o
Jul	0.961	0.776	0.741	H_o	0.987	0.420	0.800	H_o	0.575	0.302	0.552	H_o
Aug	0.149	0.909	0.737	H_o	0.318	0.578	0.421	H_o	**0.000***	0.958	0.552	H_o
Sep	0.332	0.540	0.368	H_o	0.631	0.810	0.645	H_o	0.883	0.965	0.716	H_o
Oct	0.978	0.775	0.845	H_o	0.860	0.302	0.526	H_o	0.767	0.668	0.555	H_o
Nov	0.825	0.855	0.805	H_o	0.926	0.654	0.907	H_o	0.558	0.616	0.105	H_o
Dec	0.076	**0.023***	0.204	H_o	0.515	0.444	0.223	H_o	0.134	0.557	0.495	H_o

*Nonhomogeneous based on statistical test results

H_o : homogeneous

SNHT: Standard Normal Homogeneity Test

PT : Pettitt Test

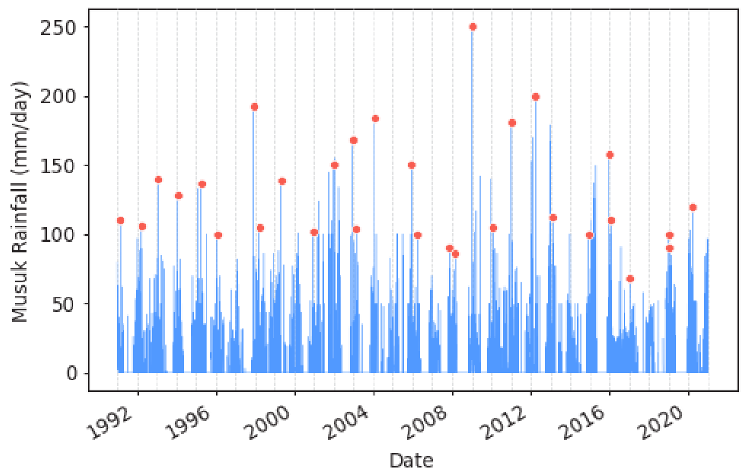
BRT : Buishand Range Test

Table A4. Return period values (mm/day) of the annual maximum rainfall 1991-2020.

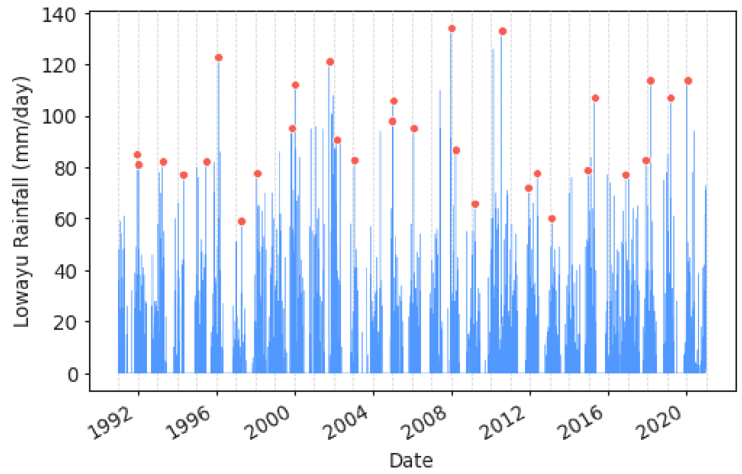
Return Periode (years)	**Musuk Upstream**	**Tinap**	**Lowayu Downstream**
5	155.8	116.1	108.6
10	177.9	129.6	121.3
20	199.2	142.6	133.6
30	211.4	150.0	140.6
50	226.7	159.3	149.4

Figure A1. Annual maxima (in the picture, remarked in red dots) of daily rainfall plots 1991-2020 of (a) Musuk, (b) Tinap, and (c) Lowayu station.

a)



b)



c)