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Outlier Identification Techniques in Daily Rainfall Data

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Abstract: A quality test was conducted on daily rainfall data in the Sumatra region to select good data. The data used came from 19 observation stations belonging to the Meteorology, Climatology, and Geophysics Agency (BMKG) spread across the Aceh-Lampung provinces from early 1985 to late 2023. The quality test aims to ensure data reliability, consistency, and validity. Daily rainfall data often face issues such as missing data, unrealistic extreme values, and recording discrepancies, which can reduce the accuracy of climate analysis. The quality test examined data completeness and outliers using the interquartile range. The quality test results showed a data completeness level of 93%, thus declaring the data valid. Outliers were identified in small amounts (<1%) for very high rainfall intensity at the Minangkabau meteorological station in West Sumatra (470 mm/day), the Bengkulu climatological station (400 mm/day), the FL Tobing meteorological station in North Sumatra (430 mm/day), the Fatmawati Soekarno meteorological station in Bengkulu (390 mm/day), the West Sumatra climatological station (320 mm/day), the South Sumatra climatological station (230 mm/day), and the Radin Intan II meteorological station in Lampung (265 mm/day). These values were not removed from the analysis because they passed the data quality test and represented meteorologically realistic extreme rainfall events. The results of the evaluation of daily rainfall data in Sumatra during the study were representative and reliable enough to be used in further climatological analysis.

Keywords: Outliers; Quality; Rainfall; Reasonableness; Test

Introduction

Indonesia is an archipelago comprising thousands of islands with diverse geographic and climatological characteristics, one of which is Sumatra, one of the largest. Sumatra boasts a complex topography, dominated by the Bukit Barisan Mountains, which stretch north-south. It is flanked by lowlands and extensive coastlines to the east and west. Sumatra comprises ten provinces: Aceh, North Sumatra, West Sumatra, Riau, the Riau Islands, Jambi, Bengkulu, the Bangka Belitung Islands, South Sumatra, and Lampung.

Sumatra is a region with high levels of rainfall variability, both spatially and temporally (Marzuki et al., 2022). Climate variability in this region is influenced by a combination of global, regional, and local factors, including the El Niño–Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD), the Madden–Julian Oscillation (MJO), and sea surface temperature (SST) conditions in the waters surrounding Sumatra (Hermawan, 2010). The physiographic factors of the Bukit Barisan Mountains play a significant role in shaping the spatial distribution of rainfall. Areas with higher elevations tend to receive greater rainfall due to orographic uplift (Prasetyo et al., 2018). Indonesia generally experiences high rainfall during the December–February (DJF) period, which coincides with the west monsoon activity; the March–May (MAM) and

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September–November (SON) periods are transitional seasons; and June–August (JJA) is the dry season due to the dominance of the east monsoon (Zaini et al., 2023).

Rainfall characteristics, including amount, intensity, duration, pattern, and frequency, require reliable observational data from rain gauge stations to produce accurate climatological analysis. Understanding extreme rainfall is crucial because this phenomenon has the potential to trigger various hydrometeorological disasters such as floods, landslides, erosion, drought, and forest fires, especially during the dry season (Kurniadi et al., 2021; Irfan et al., 2022; Akhsan et al., 2023). To ensure the reliability of the rainfall data used in the analysis, a quality check was performed on the data obtained from the Meteorology, Climatology, and Geophysics Agency (BMKG). This stage aims to identify errors that may occur during data collection, recording, and storage. These errors can be caused by human factors, such as data entry or formatting errors, or instrumental factors, such as clogged rain gauge funnels. Quality checks play a crucial role in ensuring the validity of data and climatological analysis results (Ośródka et al., 2022) and have proven effective in detecting various technical issues, such as clogged measuring instruments, abnormal humidity, and other meteorological data anomalies (Dandrifosse et al., 2024). Quality control activities are conducted to assess the completeness and reasonableness of daily rainfall data, ensuring that the data used in the analysis is truly representative (Hachem et al., 2024). This process also helps identify problematic data that does not meet eligibility criteria, which then determines whether to include or remove it from the calculation (Supari et al., 2017). Results from various quality control methods show good consistency and provide more accurate results than manual inspection (Cheng et al., 2024a). Quality control functions to detect anomalous data, values that fall far outside the data distribution. This process is a crucial tool in ensuring the quality of rainfall datasets (Villalobos-Herrera et al., 2022). Data visualization has also proven effective in helping identify and detect error patterns in rainfall data (Hunziker et al., 2017). Because rainfall measuring instruments can experience various sources of error, implementing quality control is necessary to ensure the reliability of the results (Yan et al., 2025). Outlier data quality testing is performed using a boxplot, which serves to identify and visualize data distribution and detect deviant values. Outlier data are values that deviate from the main distribution of the data and can represent valid extreme events. Identification of outlier data is done using a boxplot visualization technique. The standard boxplot is one of the most commonly used nonparametric analysis tools to detect outliers in a univariate data set (daily rainfall), because it is able to provide a clear visual depiction of the data distribution and the position of extreme values relative to the median and quartiles (Zhao & Yang, 2019; Ouyang et al., 2025). Boxplots are considered more effective in detecting extreme values based on the percentile approach, especially for the analysis of daily rainfall data with varying distributions (Wibawanty et al., 2025; Zhao & Yang, 2019).

An analysis of outlier daily rainfall data was conducted to identify whether these values were naturally occurring due to extreme meteorological events or due to errors in observation and data input. Previous studies have shown that boxplot-based outlier detection methods can significantly identify extreme rainfall events in various regions over the past two decades. The purpose of this study is to test the quality of rainfall data, including the identification of outlier values and extreme events in the Sumatra region using a four-stage mechanism, which is still relatively rare and has not been widely reported in the scientific literature. This procedure is considered more efficient and adaptive than classical methods and is very useful in climate studies related to daily rainfall variability and changes (Hael & Yuan, 2020).

Method

The data used in this study were obtained from the Meteorology, Climatology, and Geophysics Agency (BMKG), the official national climate data provider. Daily rainfall data from 19 BMKG stations across Sumatra were collected from early 1985 to late 2023. The spatial distribution of the data is shown in Figure 1. Research design and method should be clearly defined.

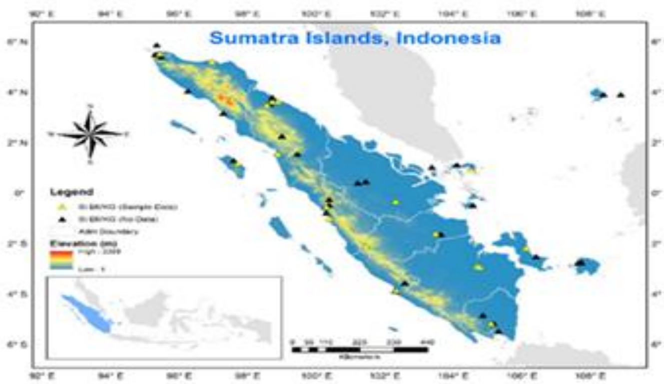


Figure 1. Distribution of BMKG stations in Sumatra

The quality testing process for daily rainfall data involves four main stages. The first stage assesses the completeness of daily rainfall data by calculating the overall proportion of missing data for the period 1985–2023. The second stage evaluates the completeness of the data on an annual basis to identify the distribution and consistency of missing data across the observation time series. The third stage involves analyzing outliers on a monthly scale. Daily rainfall data from January 1985 are compiled along with data from January 1986, 1987, and so on, covering the entire observation period for each month in different years. The fourth stage focuses on identifying outliers on an annual scale. For this purpose, daily rainfall data are aggregated and summarized by year from 1985–2023. This allows for an annual evaluation of extreme rainfall events. This method is used to assess the reasonableness of data for the same month and year, assuming that the same month and year tend to have a similar climatic background.

Identification techniques refer to the methods used in data quality testing in the Rclimdex-QC (REF) software (Cheng et al., 2024). This method makes it easier to compare data distribution from month to month and year to year, and measure its reasonableness based on global climate conditions in the month and year studied. Boxplots use the field and the lower and upper quartiles (defined as the 25th and 75th percentiles (Junaidi, 2014; Adilah & Zarif, 2020). If the lower quartile is Q1 and the upper quartile is Q3, then the difference (Q3 - Q1) is called the interquartile range IQR. Outlier data are defined as (Q1 − 1.5 x IQR) and (Q3 − 1.5 x IQR).

Result and Discussion

The results of the first quality test which measures the percentage of completeness of daily rainfall data for 19 research stations can be displayed in Figure 2.

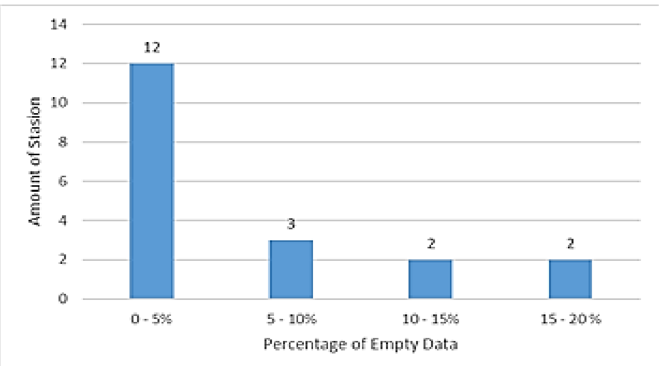


Figure 2. Daily rainfall data is empty

Based on Figure 2, the results of the quality test on the completeness of daily rainfall data show variations in the level of completeness between observation stations. Several stations recorded a relatively low percentage of empty data. The Deli Serdang geophysical station in North Sumatra showed the highest value of 18.70%, followed by the North Sumatra climatology station (10.14%), Radin Intan II meteorology station in Lampung (9.88%), West Sumatra climatology station (8.00%), Raja Haji Fisabilillah meteorology station (7.75%) in Riau Islands, and Minangkabau meteorology station in West Sumatra (5.34%). Most other stations had a percentage of empty data below 5%; the FL Tobing meteorological station in North Sumatra showed the best level of completeness with only 0.65% empty data. The distribution of data completeness shows that 12 stations had a percentage of empty data between 0–5%, three stations 5–10%, two stations 10–15%, and two stations 15–20%. This value indicates that the dataset has sufficient data completeness and can be used for climatological analysis (Subagyo Swarinoto, 2012; Estévez et al., 2022).

The results of the quality test analysis are then visualized in a diagram with a color gradient, as shown in Figure 3. The colors represent the level of completeness of the daily rainfall data, ranging from missing to complete. The red color at the bottom represents missing data with a percentage of 0%, while the green to yellow colors in the middle indicate complete data ranging from 30–85%. Meanwhile, the blue color at the top indicates fully complete daily rainfall data (100%). This visualization facilitates the assessment of data continuity between stations and between periods. In studies on improving the quality of time series data, heatmaps are created to visualize missing values or incomplete data in datasets after quality checks, visually clearly indicating complete (different colors) and missing (Salehy & Bailey, 2025). So that the distribution and quality of data suitable for use in long-term climatological analysis can be known (Jeong et al., 2025).

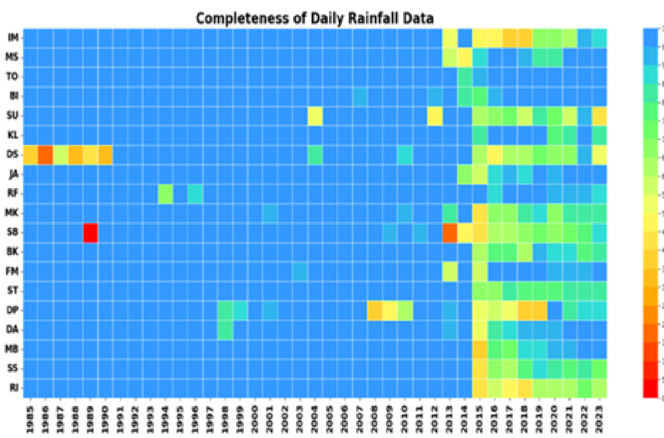
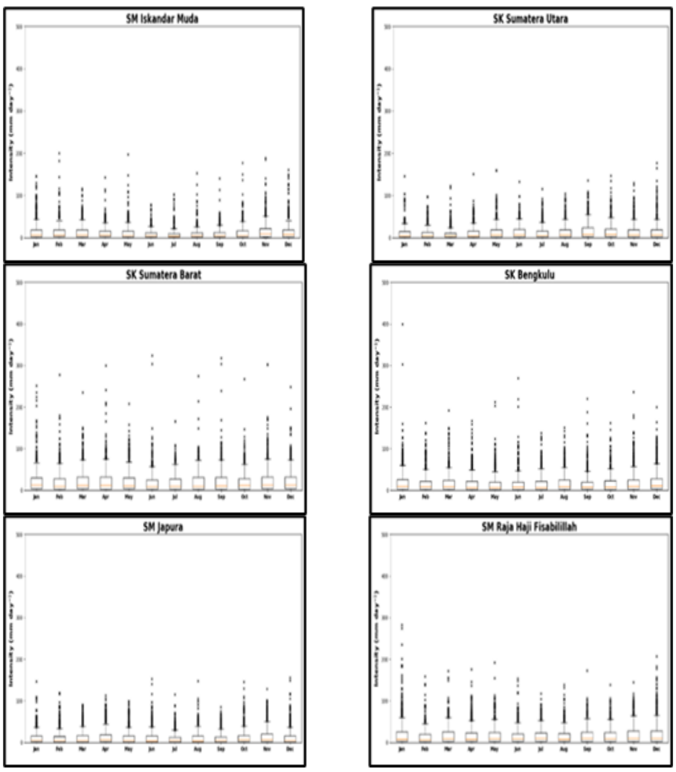


Figure 3. Percentage of completeness of daily rainfall data

Based on the analysis results in Figure 3, the average completeness of daily rainfall data at observation stations shows a high level of completeness. The percentage of completeness approaching 100% is indicated by the dominance of the color blue with an average of 82%. The Iskandar Muda Aceh meteorological station in the 2015–2021 period had an average data completeness above 61%, the Malikusaleh Aceh meteorological station (2013–2014) and the Deli Serdang North Sumatra meteorological station (1985–1990 and 2015–2021) showed a data completeness level ranging from 50–80%. The North Sumatra meteorological station (2015–2021) had an average data completeness above 75%. The Minangkabau West Sumatra meteorological station (2013–2023) ranged from 40–80%. The West Sumatra climatology station (2014–2022) had data completeness of 50–85%, and total data gaps in 1989 (0%). The Bengkulu climatology station (2015–2018) had an average completeness of above 69%. The Sultan Thaha and Depati Parbo meteorological stations in Jambi (2015–2023) showed an average completeness of above 72%. The S.M. Badaruddin II meteorological station in South Sumatra, the South Sumatra climatology station, and the Radin Intan II station in Lampung (2015–2023) had data completeness around 73%. The average completeness of daily rainfall data across all stations reached 93%. This demonstrates excellent data consistency for long-term climatological analysis (Contractor et al., 2020; Le, 2020; Anguler., 2003). This guideline document is used as a standard reference for the analysis of extreme rainfall events in climatological studies (Tank, 2009).

The results of the detection of outliers in monthly daily rainfall are then classified as follows.



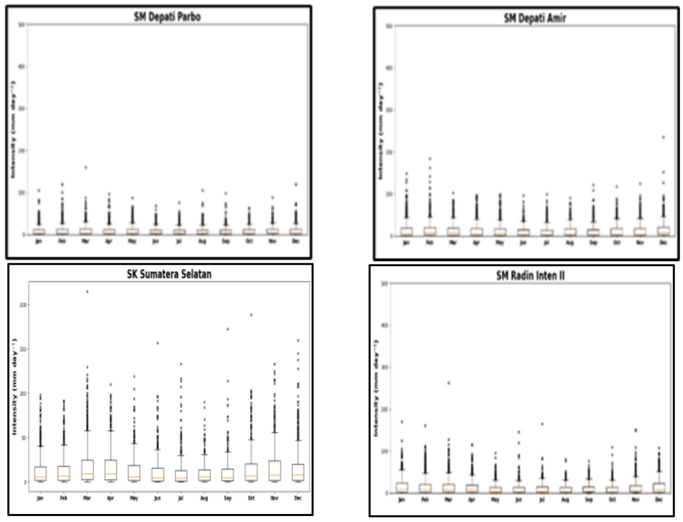


Figure 4. Boxplot of daily rainfall in months

Figure 4 clearly shows the outliers in monthly daily rainfall data from the BMKG over 39 years. Understanding the frequency patterns of extreme seasonal rainfall events and their trends is crucial (Fauzi et al., 2014). The following outliers show daily rainfall with an intensity above 200 mm/day. Daily rainfall exceeding 200 mm/day is categorized as very extreme.

Outlier data analysis using boxplots is shown in Figure 4. The number of abnormal data is quite small, <1%. At the FL Tobing meteorological station in North Sumatra, Minangkabau in West Sumatra, Fatmawati Sokarno in Bengkulu, the West Sumatra climatology station, and Bengkulu, there are outliers in the very extreme category. In the month of JJA, the very high daily rainfall is an outlier because in those months in Sumatra there is low daily rainfall and a dry season (Aldrian & Dwi Susanto, 2003; Ariska et al., 2023).

Analysis of daily rainfall data shows a number of outliers at several observation stations in the Sumatra region. At the FL Tobing meteorological station in North Sumatra, three outliers were recorded with rainfall intensity ranging from 300–430 mm/day. At the Minangkabau meteorological station in West Sumatra, and at the West Sumatra climatology station, there were seven outliers with rainfall intensity of 300–470 mm/day. February reached 470 mm/day, the highest value among all observed stations. At the West Sumatra climatology station, there were six outliers with rainfall intensity of 300–320 mm/day. At the Fatmawati Soekarno meteorological station and the Bengkulu climatology station, there were two outliers each with rainfall intensity of 300–400 mm/day. At the R.H. Fisabilillah meteorological station in the Riau Islands, there was an outlier with rainfall intensity above 250 mm/day in January. This value is still considered reasonable because it corresponds to the rainy season.

Table 1. Extreme daily rainfall with intensity >200 (mm/day)

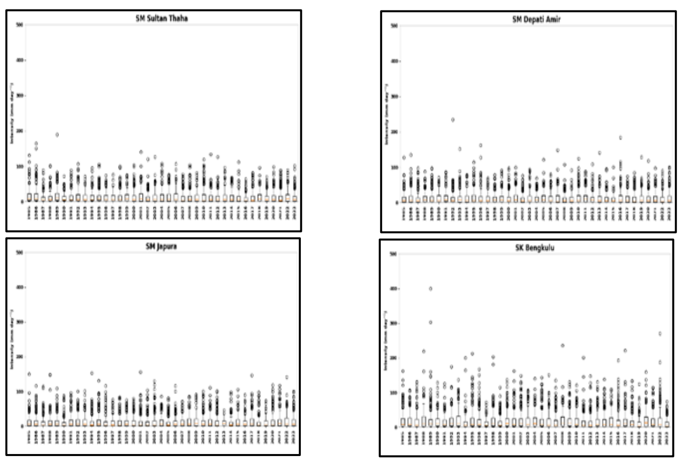
Station	Intensity	Month	Amount
Meteorology Malikussaleh Aceh	230	November	1
FL Tobing Meteorology North Sumatra	430	July	1
	300	October	1
	330	December	1
Binaka Meteorology North Sumatra	210	January	1
Geophysics Deli Serdang North Sumatra	220	February	1
	240	October	1
Meteorology RH Fisabilillah Riau Islands	275.290	January	1
Minangkabau Meteorology West Sumatra	470	February	1
	370	March	1
	380	April	1
	390	June	1
	300	July	1
	275	August	1
	310	September	1
	400	November	1
West Sumatra Climatology	300	April	1
	300.320	June	2
	275	August	1
	300.310	September	2
	300	November	1
Bengkulu Climatology	300.400	January	1
	205.215	May	2
	205.230.280	June	3
	240.290	September	2
	260	November	1
Meteorology of Fatmawati Sokarno Bengkulu	300.390	January	2
	230	January	1
	270	June	1
	240 dan 260	September	2
Meteorology Depati Amir of The Babel Islands	250	December	1
South Sumatra Climatology	230	March	1
Meteorology Radin Inten II Lampung	265	March	1

Based on Table 1, the FL Tobing meteorological station in North Sumatra, the Minangkabau meteorological station in West Sumatra, and the West Sumatra climatology station show daily rainfall intensity exceeding 300 mm/day in June and July.

This type of extreme rainfall event is generally analyzed in the climatology literature as part of the characteristics of extreme rainfall intensity. It demonstrates high rainfall intensity variations influenced by regional climate variability (Pariyar et al., 2022). This value is considered climatologically abnormal because the JJA period is generally the dry season in Indonesia. However, because parts of Sumatra straddle the equator, high rainfall during the JJA period is a normal climatological condition due to the dominance of convective processes in the equatorial region. High rainfall in Sumatra is also related to strong tropical atmospheric dynamics, such as equatorial convection and global atmospheric disturbances (Baranowski et al., 2020). Daily rainfall data at the Minangkabau meteorological station in West Sumatra and the West Sumatra climatology station, with an intensity above 250 mm/day, is considered normal, as March, October, and December are the rainy season. Strengthening the convergence of sea breezes and valley winds causes rainfall in mountainous areas to exceed normal levels (Qian et al., 2010; Chang et al., 2005).

In March, October, and December, Sumatra generally experiences the rainy season, with variations in rainfall intensity ranging from low to high. Outliers recorded during this period are largely climatologically normal. One outlier, with an intensity of 200-265 mm/day, was observed in the meteorological regions of Bangka Belitung, Jambi, South Sumatra, and Lampung, representing extreme conditions in eastern Sumatra. According to the BMKG classification, daily rainfall with an intensity above 150 mm/day is categorized as extreme rainfall.

The distribution of data and the presence of outlier values are visualized in the boxplot shown in Figure 5, which provides an overview of the distribution, range of values, and potential anomalies in the daily rainfall data at each station.



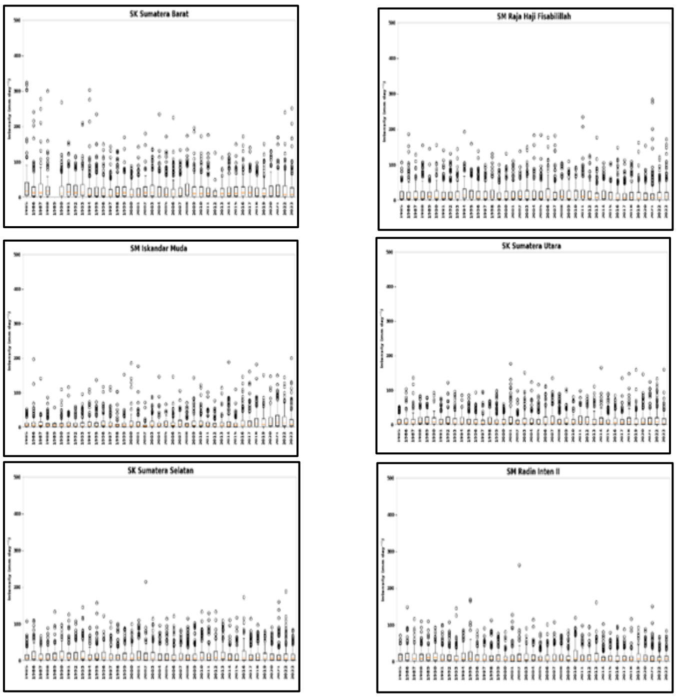


Figure 5. Boxplots of daily rainfall within a year

Based on Figure 5, the visualization results show that the distribution of daily rainfall at observation stations has different variations and outlier data during the annual observation period. The Iskandar Muda Aceh meteorological station recorded four outlier data in 2000 and 2023 with an intensity approaching and exceeding 200 mm/day. Daily rainfall exceeding 150 mm/day is classified as extreme rainfall in most tropical regions and is generally associated with the presence of medium-scale convective systems, orographic lifting, and atmospheric circulation conditions (Westra et al., 2014). The Malikussaleh Aceh meteorological station showed one outlier data above 200 mm/day in 2000. The Kualanamu North Sumatra meteorological station, there was one outlier data intensity of 150–200 mm/day in 1999 and two data in 2001. The Deli Serdang North Sumatra meteorological station recorded two outlier data above 200 mm/day in 2007 and four data intensity of 150–200 mm/day in 2015. The Japura Riau meteorological station recorded six outlier data with intensity of 140–160 mm/day in 1985, 1988, 1994, 2001, 2017, and 2022. The R.H. Fisabilillah Riau Islands shows two outlier data intensity of 200–250 mm/day in 2011 and two data above 250 mm/day in 2021. Minangkabau meteorological station of West Sumatra has two outlier data with intensity of 200–400 mm/day in 1986, two data of 200–300 mm/day in 1998, one data of 300 mm/day in 2001, one data of 300–400 mm/day in 2005, one data above 400 mm/day in 2012, and two data of 300–400 mm/day in 2015. The outlier pattern shows extreme rainfall intensity >200 mm/day consistent organized convective system is a dominant factor in tropical extreme rainfall events. Humid atmospheric structure and large-scale circulation support increase the occurrence of extreme intensity (An et al., 2023). In western Sumatra, this high average outlier data is significantly influenced by, among other factors, the IOD and the Asian winter monsoon (Nur'utami & Hidayat, 2016; Kasih et al., 2007).

Daily rainfall boxplots show that almost all observation stations in Sumatra have outlier data during the annual observation period. In northern Sumatra, the largest number of outliers was identified at the FL Tobing meteorological station in North Sumatra, with a daily rainfall intensity between 200–400 mm/day, with one event exceeding 400 mm/day. In central Sumatra, the most outlier data occurred at the Minangkabau meteorological station, Fatmawati Soekarno Bengkulu, the West Sumatra climatology station, and Bengkulu, with an average intensity of 200–400 mm/day and events exceeding 400 mm/day, particularly at the Minangkabau and Fatmawati Soekarno Bengkulu meteorological stations. The central region of Sumatra, influenced by the Bukit Barisan Mountains, experiences more frequent extreme rainfall events due to orographically enhanced convection (Zehri et al., 2025; Marpaung et al., 2012). Stations in central Sumatra show the highest frequency and intensity of outliers compared to other regions. In southern Sumatra, relatively fewer outliers are recorded, with an average intensity ranging from 200–265 mm/day. This indicates significant spatial variation in the distribution of extreme rainfall intensity. Central Sumatra experiences more frequent and intense extreme rainfall events than the northern or southern regions. Observations and simulations indicate that tropical atmospheric conditions, which are very humid and have strong convective organization, tend to produce higher daily extreme rainfall intensities (Bao et al., 2024).

At the Sultan Thaha Jambi meteorological station, one outlier data was recorded above 175 mm/day in 1988 and the Depati Parbo Jambi meteorological station showed one data above 200 mm/day in 1992. The Depati Amir Bangka Belitung meteorological station had one outlier data above 160 mm/day in 2010. The South Sumatra climatology station, there were three outlier data with an intensity of 150–230 mm/day in 2002. The Radin Intan II Lampung meteorological station found one outlier data with an intensity of 265 mm/day in 2002. Showing the existence of spatial and temporal variations in daily rainfall outliers between stations that reflect the heterogeneity of meteorological conditions in Sumatra. This is in line with research from (Ariska et al., 2024) rainfall in Sumatra is clearly depicted spatially and temporally in the years of El Niño/La Niña and positive/negative IOD. Rainfall in Sumatra has been identified as the region most influenced by IOD dynamics (Cai et al., 2013; Khaldun et al., 2018; Xu et al., 2020).

The average daily rainfall intensity in the southern part of Sumatra is relatively low, as indicated by the number of outliers above 200 mm/day. This condition indicates that extreme rainfall events in the region are rare compared to the northern and western parts of Sumatra, which have higher rainfall intensity. Rainfall events in Sumatra are influenced by the MJO phenomenon (Muhammad et al., 2020; Fadholi et al., 2013). According to (Ariska et al., 2022), extreme rainfall can result from a combination of climate and topographic factors. Spatial analysis of the relationship between the ENSO-IOD phase and extreme rainfall intensity differs regionally, in Sumatra (Hanifa & Wiratmo, 2024; Pakpahan et al., 2023; Mardiansyah et al., 2018). Extreme rainfall events in the Sumatra region are related to dynamics characterized by the presence of a strong-weak MJO, which then modulates trends in the intensity and frequency of extreme rainfall (Zehri et al., 2025; Lestari et al., 2019). The West Coast of Sumatra demonstrates a relationship between ENSO/IOD and extreme rainfall events. The Asian winter monsoon and the Australian summer monsoon influence extreme rainfall in Sumatra (Chen et al., 2025). It should be noted that data identified as outliers does not necessarily indicate poor or incorrect data. This study focuses on identifying data completeness and the presence of outliers, while determining the validity of outliers requires comparison with automated data from surrounding stations outside the scope of the study.

Conclusion

Daily rainfall data in Sumatra for the period 1985–2023 shows a fairly good level of data completeness, averaging 93%. The analysis shows that the Minangkabau meteorological station in West Sumatra and the West Sumatra climatology station had the highest number of outliers compared to other stations, indicating significant variation in extreme rainfall. The highest daily rainfall was recorded at the Minangkabau meteorological station in West Sumatra at 470 mm/day, and at the FL Tobing meteorological station in North Sumatra at 430 mm/day. Furthermore, a value of 400 mm/day was recorded at the Bengkulu climatology station and 390 mm/day at the Fatmawati Soekarno meteorological station in Bengkulu. Low extreme rainfall outliers were recorded at the Lampung meteorological station (265 mm/day) and at the South Sumatra climatology station (230 mm/day).

The proportion of outlier (extreme) rainfall events in Sumatra during the observation period was relatively low (<1%) of the total data. Extreme events generally occur in the months of DJF, MAM, and SON, which coincide with the rainy season and transitional season, in accordance with regional climatological conditions. The extreme rainfall events that occur in the month of JJA are classified as anomalous, because this period is the dry season in most parts of Indonesia (Aldrian & Dwi Susanto, 2003; As-syakur et al., 2014). The intensity of daily rainfall around the equator is higher than in the northern and southern regions of Sumatra due to the strong influence of local convection mechanisms and equatorial waves. The pattern of extreme rainfall events in Sumatra is dominated by short-duration events of one to two days per year, which exhibit typical characteristics of tropical convective rainfall.

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Author Contributions
Sudirman: Conceptualization, methodology, software, formal analysis, writing the first draft, and visualization.
Muhammd Irfan: Supervision, writing the review, and editing.
Supari: Supervision, methodology, writing reviews, and editing.
Hamdi Akhsan: Supervision, writing reviews, and editing.
Baba Musta: Supervision, writing reviews, and editing.
Nurul Adzkiya: Supervision, writing reviews, and editing.

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Conflicts of Interest
The authors declare no conflict of interest.

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