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Observed trend of precipitation extreme in Kalimantan

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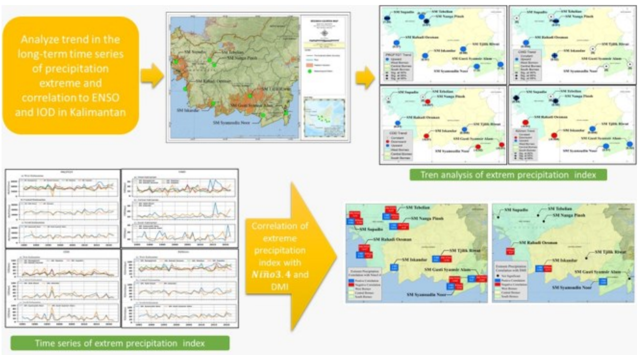
Graphical abstract



Abstract

It has been suggested that the global warming due to an increase in green house gas concentrations could lead to extreme climate events, such as precipitation extreme and droughts. This study is designed to analyze trend in the long-term time series of preciptation extreme in Kalimantan, focusing on observed data obtained from eight meteorological stations spanning from January 1985 to December 2022. Statistical analyses were employed to discern patterns and trends in extreme precipitation events. The findings reveal a discernible long-term trend characterized by fluctuations in precipitation extremes over the study period. The trend of total annual precipitation (PRCPTOT) has increased at all observation stations. Especially at SM. Nangapinoh and Supadio, the PRCPTOT trend increased significantly at the 99% and 90% levels. Meanwhile, the increase in consecutive wet days (CWD) trends only occurred at SM. Nangapinoh and Rahadi Oesman (West Kalimantan), and SM. Iskandar (South Kalimantan). A significant trend was found in SM. Nangapinoh (90%) and Iskandar (95%). In addition to experiencing an increase in the R20mm trend, there was a decrease in the trend. Significant trend increases at the 99% and 90% levels occurred in SM. Nangapinoh and Supadio. In addition, an increase in CDD trend occurred only in SM. Rahadi Oesman and Tjilik Riwut, although not significant. Meanwhile, the majority of extreme precipitation indices have a greater correlation with ENSO than the IOD.

Keywords: climate extreme; Kalimantan; Mann-Kendall test; precipitation extreme

1. Introduction

Precipitation extremes play a pivotal role in shaping the hydrological and ecological dynamics of regions worldwide, exerting significant impacts on water resources, agriculture, infrastructure, ecosystems, and soil erosions (Yang *et al.* 2016; Fei *et al.* 2021; Kastridis *et al.* 2024; Piacentini *et al.* 2018). Kalimantan, the Indonesian portion of the island of Borneo, is no exception to the influence of such extremes. Situated within the equatorial belt, Kalimantan experiences a tropical climate characterized by high precipitation variability, with precipitation patterns profoundly influencing the region's socioeconomic and environmental landscapes (Estiningtyas *et al.* 2024). Understanding the trends and patterns of precipitation extremes in Kalimantan is therefore crucial for effective water resource management, disaster preparedness, and sustainable development initiatives.

Over recent decades, increasing attention has been devoted to the study of climate variability and its implications for regions globally (IPCC 2023). In Kalimantan, where precipitation extremes can trigger floods, landslides, and other natural disasters, the need for comprehensive analyses of observed trends in extreme precipitation events is particularly pressing. Such analyses provide valuable insights into the changing climatic conditions and their potential consequences for the region's inhabitants and ecosystems. Despite the significance of understanding precipitation extremes, relatively few studies have focused explicitly on this topic in the context of Kalimantan. Existing research often lacks a comprehensive examination of long-term trends, instead focusing on short-term analyses or specific events.

Precipitation trend analysis in the West Kalimantan for the Kubu Raya and Menpawah districts was conducted from 2000-2019. The results show an increase of monthly maximum consecutive 5-day precipitation (RX5day), monthly maximum 1-day precipitation (RX1day), and number of days when precipiation above 50mm (R50mm). Meanwhile, the consecutive dry days (CDD) experienced a decreasing trend (Aditya *et al.* 2021). Another study in the South Kalimantan revealed an increasing in precipitation of about 25mm per year over a period of 2000 - 2020 (Sukmara *et al.* 2022). Recent study based on Integrated Multi-Satellite Retrievals for GPM (IMERG) version 6 data over a period of 2001 – 2020 shows an increasing trend in precipitation extreme indices in new capital city of Indonesia in the east Kalimantan (Marzuki *et al*. 2023). The precipitation frequency-based indices, namely R20mm and R50mm, indicate an increasing trend in the last 2 decades. Similarly, the R5Xday index also revealed an increasing trend. On the other hand, the total amount of precipitation, the RX1day as well as the SDII (annual total precipitation divided by the number of wet days in the year) has shown a decreasing trend over the last 2 decades.

It should be note that the spatio-temporal variability of precipitation in the Indonesian region is influenced by the local and regional air-sea interaction (Aldrian and Susanto 2023). On seasonal time scale, the monsoon system mostly drives the seasonal variation of precipitation over the Indonesian region (Mulsandi *et al.* 2024). Most of the Indonesian region experiences wet season during the northwest monsoon, while during the southeast monsoon Indonesia experiences a dry season. On interannual timescale, the Indo-Pacific climate modes, namely the El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD), modulate the precipitation over the Indonesian region (As-Syakur *et al.* 2013; Lestari *et al*; 2018; Kurniadi 2021). El Niño and/or positive IOD conditions often result in decreased precipitation and increased temperatures, creating dry and drought-prone conditions, particularly in the archipelago's forested regions. These dry conditions significantly elevate the risk of forest fires in Indonesia (Iskandar *et al.* 2022; Nurdiati *et al.* 2021), which are exacerbated by the accumulation of flammable biomass in peatlands and forests. The combination of reduced precipitation, higher temperatures, and prolonged dry spells during El Niño events creates ideal conditions for the ignition and spread of fires (Hooijer *et al.* 2006; Wooster *et al.* 2012). These fires not only pose a threat to human health and safety but also cause extensive damage to ecosystems, biodiversity, and the economy, with impacts ranging from loss of habitat for endangered species to disruptions in agriculture and tourism (Sarmiasih & Pratama 2019; Lohberger *et al.* 2017).

Nevertheless, there is still a gap in the literature regarding the observed trends of precipitation extremes in Kalimantan over an extended period. Addressing this gap is essential for enhancing our understanding of the region's climate dynamics and improving the accuracy of future climate projections and risk assessments. Therefore, this study aims to bridge this gap by providing a systematic analysis of the observed trend of precipitation extremes in Kalimantan. Drawing upon observed meteorological datasets spanning multiple decades (1985 – 2022), this study employed statistical analysis to quantify changes in extreme precipitation events over time. By identifying trends and patterns in precipitation extremes, we seek to elucidate the underlying drivers and mechanisms driving these changes link to ENSO and/or IOD events. Additionally, we explore the potential implications of observed trends for forest fire management, and climate adaptation efforts in Kalimantan.

2. Materials and methods

2.1. Study area

Kalimantan is the third largest island in the world with, an area of 746,000 km^2 (Wooster *et al.* 2012). It is located at coordinates 7°N - 4.5°S, 108°E - 119°E, crossed by the equator. Borneo Island is mainly included in Indonesia's territory, partly in Malaysia and a small part in Brunei Darussalam. The Indonesian part is divided into five provinces: West, Central, East, North, and South Kalimantan (Yulianti & Hayasaka 2013). Almost the entire region is covered by tropical rainforests and peat. Forest types in Kalimantan include mangrove forests, peat swamps, freshwater swamp forests, mixed dipterocarp forests, montane forests, forests on limestone and ultrabasic soils (Area *et al.* 2007). The world's tallest dipterocarp forests are found in Borneo. These forests are vulnerable to drought and fire (E. Guhardja *et al*. 2000). The forest area in Kalimantan reaches 30% of the island area, which is about 24 million hectares, so Kalimantan has a lot of endemic fauna and flora.

Kalimantan is also the most biodiverse region in the world. Of the 15,000 plant species, 6,000 are endemic (Area *et al.* 2007). The fauna includes 268 species of mammals, 523 species of birds, 147 species of amphibians, 227 species of reptiles, and 738 species of freshwater fish (Widjaja 2014). Kalimantan is one of the world's places with orangutans, elephants, and rhinos living side by side. Besides being rich in flora and fauna, Kalimantan has 20 large rivers in the highland area. The forests in Kalimantan are inhabited by around 4 million Dayak tribes (the original occupants), divided into hundreds of different ethnic groups with their respective languages and cultures. Therefore, it is essential to protect the forest for the community and ensure water and food supply. In reality, Kalimantan has been transformed into agricultural land and plantations. These fragmented landscapes have been acquired through logging processes and human-caused burning events. If this process coincides with El Nino and positive IOD phenomena, then fires can spread to undisturbed forests and peatlands (Langner *et al.* 2007; Goldammer 2007; E. Guhardja *et al.* 2000). Therefore, this research was conducted in peat areas located in West, Central, and South Kalimantan, as shown in **Figure 1**.

2.2. Materials

This study uses precipitation data from the Meteorology, Climatology, and Geophysics Agency (BMKG) through the website at http://dataonline.bmkg.go.id. There are 14 stations in West Kalimantan, five in Central Kalimantan, and three in South Kalimantan. However, only eight stations from the three provinces have complete data for 38 years. The data used is from January 1985 to December 2022, recorded at stations as shown in **Table 1**.

2.3. Methods

Four indices from the Expert Team on Climate Change Detection and Indices (ETCCDI) were selected to characterize extreme precipitation. The indices are PRCPTOT (total annual precipitation), CDD (number of consecutive dry days), CWD (number of consecutive wet days), and R20mm (number of days with at least 20mm of precipitation) (Zhang *et al.* 2011).

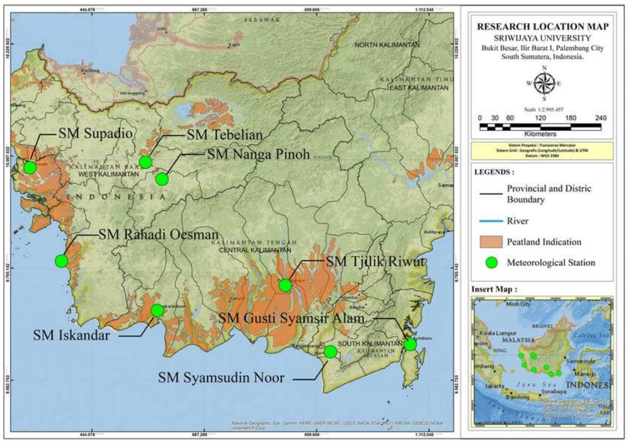


Figure 1. Research locations covering West Kalimantan, Central Kalimantan, and South Kalimantan-Peat areas are marked with brown color.

2.3.1. Man-Kendall Test

The Mann-Kendall test is a non-parametric test used to determine the data trend based on the relative ranking of a specific period (Mann 1945). This test does not have to fulfill the assumption of normality. The Mann-Kendall test can be calculated using the following equation (Kendall 1948):

$$S=\sum_{k=1}^{n-1}\sum_{j=k+1}^{n}\operatorname{sgn}\left(x_j-x_k\right), \tag{1}$$

$$\operatorname{sgn}\left(x_j-x_k\right)=\begin{cases}+1, if\left(x_j-x_k\right)>0\\ 0, if\left(x_j-x_k\right)=0\\ -1, if\left(x_j-x_k\right)<0\end{cases}$$

A positive S value indicates an increasing trend, but a negative S value indicates a decreasing trend. The variance of the S value can be calculated using the following equation:

$$Var(S)=\frac{n(n-1)(2n+5)}{18} \tag{2}$$

If n is greater than 8, S is statistically close to a normal distribution. Statistical tests are performed using the typical distribution approach, and the standard Z test statistic is calculated using the following equation:

$$Z=\begin{cases}\dfrac{S-1}{\sqrt{var(S)}}, if\ S>0,\\ 0, if\ S=0,\\ \dfrac{S+1}{\sqrt{var(S)}}, if\ S<0.\end{cases} \tag{3}$$

A positive Z value indicates an increasing trend, while a negative Z value indicates a decreasing trend.

2.3.2. Sen's Slope Estimator

The slope of Sen provides information on how much the average extreme precipitation changes per year. This trend test is assumed to be linear and quantifies time-varying data. Sen's slope test is better than the linear regression test because the test is not affected by outliers and data errors (Sen 2013). The equation used is as follows:

$$Q_i=\frac{\left(x_j-x_i\right)}{j-i},\ i=1,2,3,\ldots N, \tag{4}$$

x_j and x_i data at time j and i respectively Where j>i. The N values of Qi are sorted from smallest to largest, then Sen's Slope uses the median Qi (Qmed) calculated by the equation below:

$$Q_{med}=\begin{cases}Q_{\left[\frac{N+1}{2}\right]},\ if\ N=odd,\\ \dfrac{Q_{\left[\frac{N}{2}\right]}+Q_{\left[\frac{N+2}{2}\right]}}{2}, if\ N=even.\end{cases} \tag{5}$$

The turning point of each extreme rainfall index trend can be determined using the Sequential Mann Kendall Test (SqMK). Detailed information about SqMK can be found at (Bisai *et al.* 2014; Stathi *et al.* 2023).

Table 1. Location of BMKG Stations used in the Study

No	Station Name	Province	Coordinates	
			Latitude	Longitude
1	SM. Rahadi Oesman	West Kalimantan	-1.80000	109.97000
2	SM. Nangapinoh	West Kalimantan	-0.42000	111.47000
3	SM. Supadio	West Kalimantan	-0.14206	109.45000
4	SM. Tebelian	West Kalimantan	0.06000	111.47000
5	SM. Tjilik Riwut	Central Kalimantan	-2.22000	113.95000
6	SM. Iskandar	Central Kalimantan	-2.73000	111.66000
7	SM. Syamsudin Noor	South Kalimantan	-3.44200	114.75400
8	SM. Gusti Syamsir Alam	South Kalimantan	-3.30000	116.17000

SM: meteorological station

2.4. Partial Correlation

Partial Correlation determines the influence of ENSO and IOD on the extreme rainfall index. This correlation corresponds to more than one bivariate relationship and is distinguished using subscripts. The coefficient of partial correlation is symbolized by r_{yxz}, where the variable to the right of the point is the control variable. So, r_{yxz} this means a partial correlation coefficient that measures the relationship between variables x and y while controlling for variable z. The equation used to calculate the partial correlation coefficient is (Healey 2012; Iskandar *et al.* 2013):

$$r_{yx.z} = \frac{r_{yx} - (r_{yz})(r_{xz})}{\sqrt{1-r^2_{yz}}\sqrt{1-r^2_{xz}}} \quad (6)$$

3. Results

3.1. Annual precipitation analysis

The spatial distribution of annual precipitation in West, Central, and South Kalimantan can be seen in **Figure 2.** The lowest annual precipitation total for West Kalimantan is in SM. Rahadi Oesman, which amounted to 2,041.3 mm/year, occurred in 2014. At the same time, the highest is in SM. Nangapinoh at 5,781.7 mm/year, which occurred in 2016. In the Central Kalimantan region, SM. Iskandar has the lowest total annual precipitation. Iskandar, which occurred in 1997, amounting to 1,702.3 mm/year. At the same time, the highest is in SM. Tjilik Riwut at 4,405.5 mm/year, which occurred in 2017. South Kalimantan has the lowest total annual precipitation in SM. Gusti Syamsir Alam at 1309 mm/year, which occurred in 1997. At the same time, the highest total annual precipitation is in SM. Gusti Syamsir Alam of 4780 mm/year, which occurred in 1988. The variation of Kalimantan's total annual precipitation ranges from 1300-5800 mm/year. The lowest total annual precipitation is in South Kalimantan, while the highest is in West Kalimantan. The high precipitation variability in Kalimantan indicates that Kalimantan is experiencing the impact of climate change.

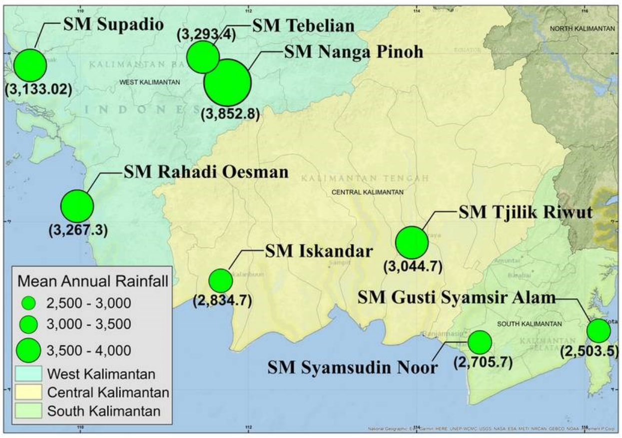


Figure 2. Total Annual Precipitation

3.2. Trend analysis of extreme precipitation index

Figure 3 shows the trend of PRCPTOT at the eight Meteorological Stations. It can be seen that the trend of PRCPTOT at eight stations has increased. A significant increase occurred at SM. Nangapinoh (3.67 mm/year) and SM. Supadio (1.27 mm/year) with significance levels of 99% and 90%, respectively. **Figure 4** shows that changes appearing in the PRCPTOT time series at Nangapinoh SM started in 2013, while SM Supadio started in 2007. The maximum trend occurred in SM. Nangpinoh, experienced an increase in PRCPTOT per year of 3.67mm. At the same time, the smallest trend increase occurred in SM. Rahadi Oesman by 0.07 mm/year. The increasing trend in eight stations shows that West, Central, and South Kalimantan tend to be in wet conditions.

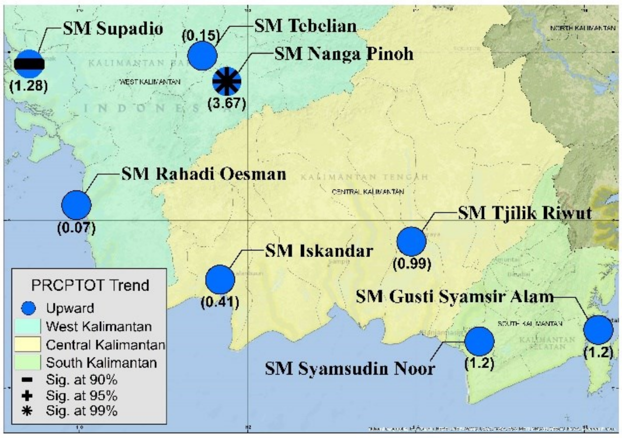


Figure 3. PRCPTOT Trends in West Kalimantan, Central Kalimantan and South Kalimantan

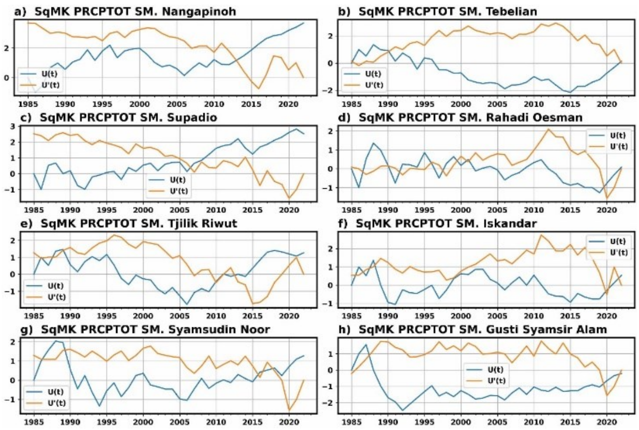


Figure 4. Graphical representation of the Mann–Kendall trend test of the PRCPTOT time series

The variation of PRCPTOT over 38 years in the three regions can be seen in **Figure 5**. The maximum PRCPTOT in West Kalimantan is found in SM. Nangapinoh of 5,781.7 mm which occurred in 2016 (**Figure 5a**). At the same time, the minimum PRCPTOT is found in SM. Rahadi Oesman of 2,041.33 mm, which occurred in 2014. For the Central Kalimantan region, the variation of PRCPTOT can be seen in **Figure 5(a)**. **Figure 5(b)** shows the maximum PRCPTOT value is found at SM. Tjilik Riwut amounts to 4,405.5 mm/year, which occurred in 2017. At the same time, the minimum PRCPTOT is found in SM. Iskandar of 1,702.3 mm/year, which occurred in 1997. Furthermore, South Kalimantan's annual precipitation variation (PRCPTOT) can be seen in **Figure 5(c)**. The maximum PRCPTOT is found in SM. Gusti Syamsir Alam of 4,780 mm/year, which occurred in 1988. Then, for the minimum PRCPTOT found in SM. Gusti Syamsir Alam amounted to 1,309 mm/year in 1997.

The magnitude of PRCPTOT is related to the CWD index. This means that when PRCPTOT is high, then during one year, the CWD value is also potentially high. **Figure 6** shows the trend of CWD at eight stations. Two stations in West Kalimantan experienced increasing trends, namely SM. Rahadi Oesman (0.006) and SM. Nangapinoh (0.01). One station was in Central Kalimantan, while the other five stations experienced no change. The resulting trend of 0 can be seen from **Figure 6**. A significant increase occurred in SM. Nangapinoh and SM. Iskandar has significance levels of 90% and 95%, respectively. **Figure 7** shows the changes in the CWD time series in SM. Nangapinoh began in 1999, while for SM Iskandar, the changes that appeared in the CWD time series started in 2003.

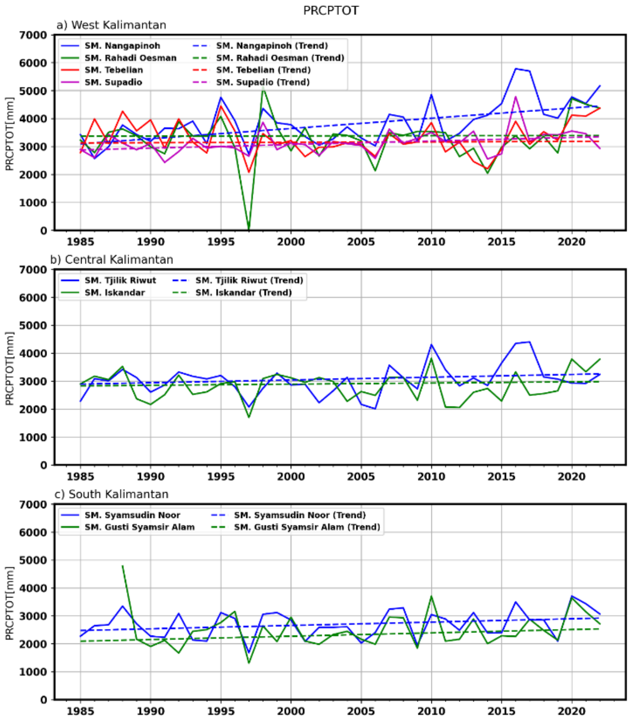


Figure 5. Time series of total precipitation from January 1985 to December 2022 observed at a) West Kalimanta, b) Central Kalimantan, c) South Kalimantan

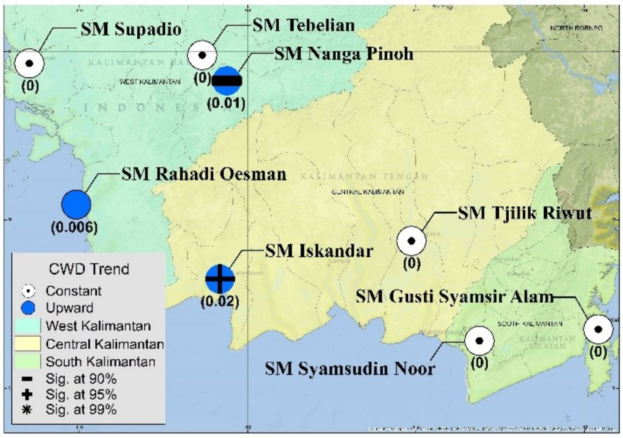


Figure 6. CWD Trends in West Kalimantan, Central Kalimantan, and South Kalimantan

The variation of CWD over 38 years in West, Central, and South Kalimantan ranges from 6-36 days, as seen in **Figure 8**. The maximum CWD in West Kalimantan is found in SM. Nangapinoh for 34 days, which occurred in 2014 and 2016 (**Figure 8a**). Furthermore, in Central Kalimantan, the maximum CWD is found in SM. Tjilik Riwut for 36 days in 2016 (**Figure 8b**). In South Kalimantan, the maximum CWD value is found in SM. Syamsudin Noor, with the longest rainy day occurred for 30 days in 2021 (**Figure 8c**). The observations show that the longest rainy season during the 38 years of observation occurred in Central Kalimantan, precisely in the city of Palangkaraya (SM. Iskandar).

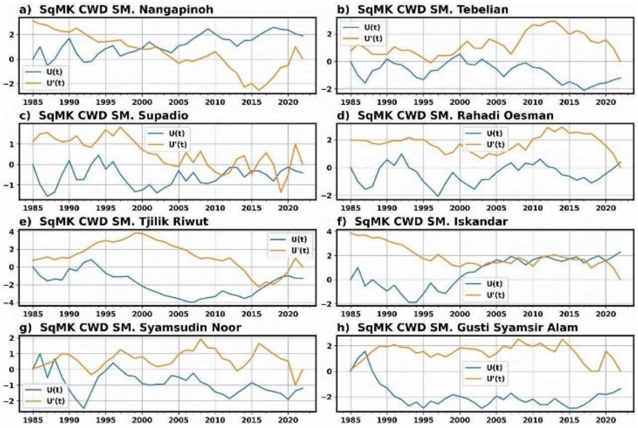


Figure 7. Graphical representation of the Mann–Kendall trend test of the CWD time series

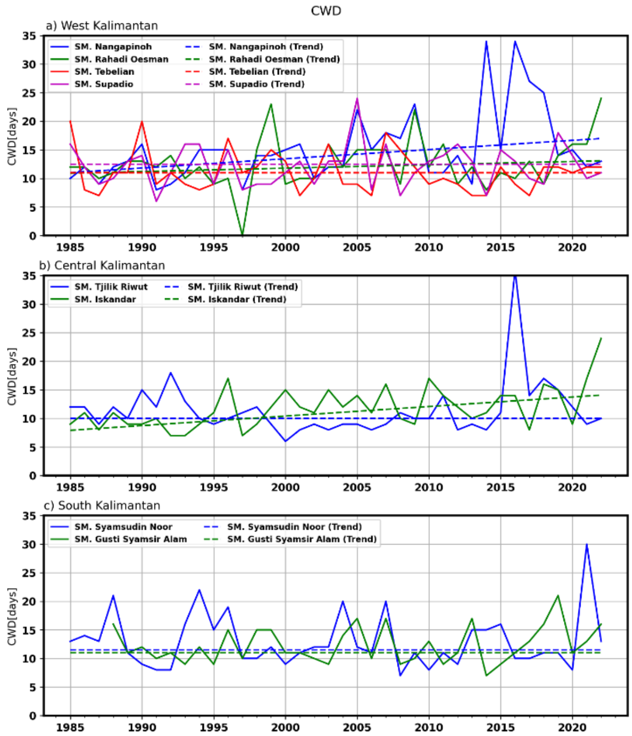


Figure 8. Time series of observed at CWD on a) West Kalimantan, b) Central Kalimantan, c) South Kalimantan

Figure 9 shows the trend value of CDD at eight observation stations. It can be seen that some stations have increased, but some have decreased. The increase in the CDD trend occurred in SM. Rahadi Oesman (West Kalimantan) and Tjilik Riwut (Central Kalimantan). Meanwhile, the downward trend in CDD occurred in SM. Iskandar (Central Kalimantan), SM. Syamsudin Noor and SM. Gusti Syamsir Alam (South Kalimantan). The largest increase in consecutive dry days (CDD) occurred in SM. Rahadi Oesman (West Kalimantan) by 0.01 days/year. At the same time, the minimum CDD trend is found in SM. Syamsudin Noor (South Kalimantan) by 0.02 days/year (**Figure 10**).

The maximum CDD value in West Kalimantan is found in SM. Rahadi Oesman for 53 days, which occurred in 1994 (**Figure 11a**). Furthermore, the maximum CDD value in Central Kalimantan was found in SM. Iskandar for 79 days occurred in 1997 (**Figure 11b**). In South Kalimantan, the maximum CDD value was found in SM. Gusti Syamsir Alam for 88 days, which occurred in 1997 (**Figure 11c**). Six of the eight observation stations showed that the longest number of days without rain occurred in 1997, where South Kalimantan experienced the longest days without rain compared to West Kalimantan, and Central Kalimantan (**Figure 12**).

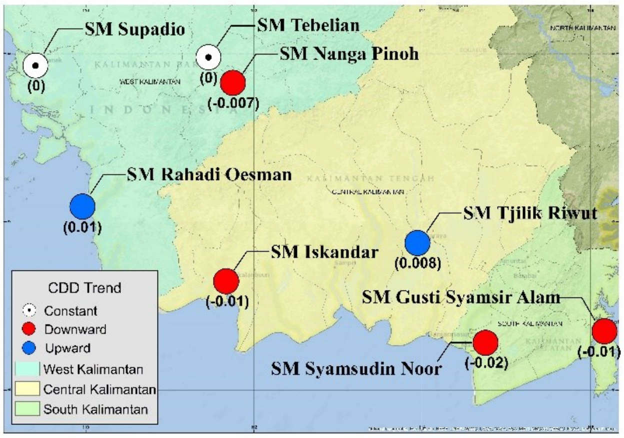


Figure 9. CDD Trend in West Kalimantan, Central Kalimantan, and South Kalimantan

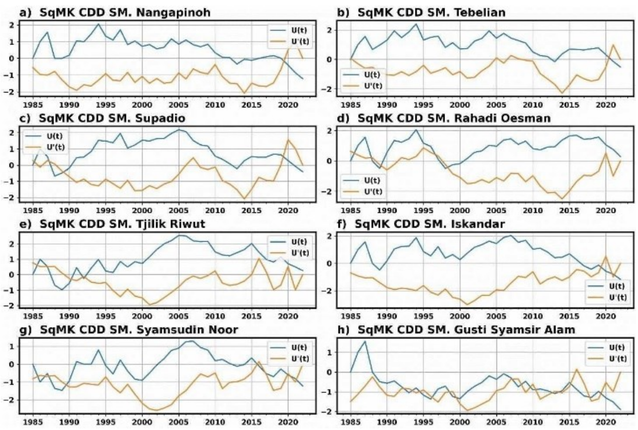


Figure 10. Graphical representation of the Mann–Kendall trend test of the CDD time series

The R20mm index indicates the number of days with precipitation ≥ 20mm per day. The maximum value of this index indicates an area's tendency towards wet conditionsThe R20mm trend has increased at six stations: SM. Supadio, SM. Nangapinoh, SM. Tjilik Riwut, and SM. Syamsudin Noor, and SM. Gusti Syamsir Alam. a significant increase occurred at SM. Supadio and Nangapinoh had significance levels of 95% and 99% respectively. **Figure 13** shows the changes that appear in the R20mm time series at SM. Supadio starting from 2005 while SM. Nangapinoh the changes appear from 2009. The stations that experienced a decrease in the R20mm trend were SM. Rahadi Oesman and SM. Iskandar.

SM. Nangapinoh (West Kalimantan) obtained the maximum R20mm increasing trend with a significance level of 99%. SM. Rahadi Oesman (West Kalimantan) experienced a decrease in the number of days with precipitation intensity ≥ 20mm by 0.01 days per year. Furthermore, the variation of R20mm value in each region can be seen in **Figure 14**.

The maximum R20mm value in West Kalimantan occurred in SM. Nangapinoh in 2016, where 94 days of rain occurred with an intensity ≥ 20mm. Furthermore, in Central Kalimantan, the maximum R20mm value occurred in SM. Tjilik Riwut for 80 days in 2010. For South Kalimantan, the maximum R20mm occurred in SM. Gusti Syamsir Alam for 84 days in 1988. Of the three regions, the longest rainy days with heavy intensity occurred in West Kalimantan, precisely the Malawi district, which occurred for 94 days in 2016.

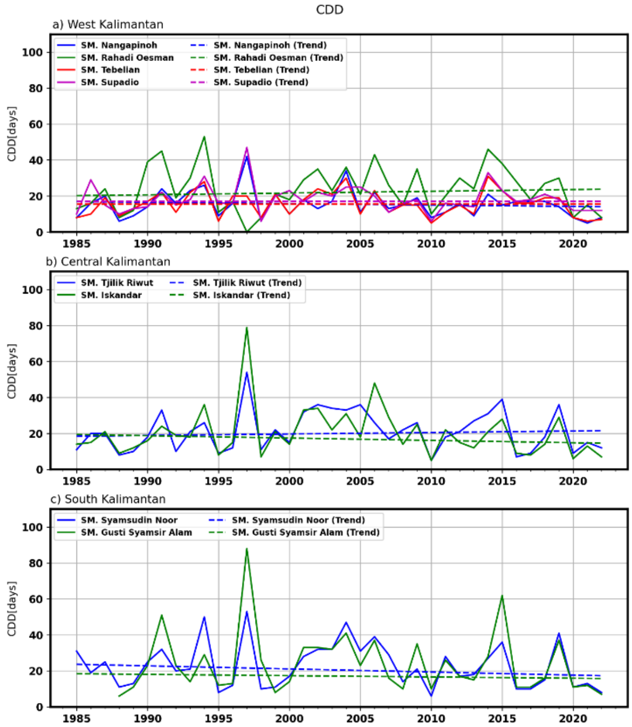


Figure 11. Time series of CDD observed at a) West kalimantan, b) Central Kalimantan, c) South Kalimantan

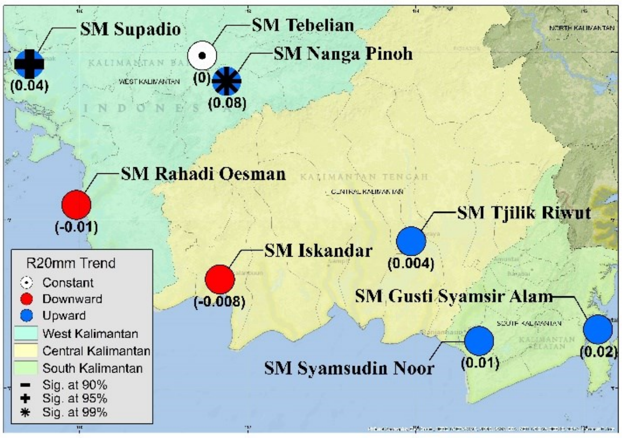


Figure 12. R20mm Trends in West Kalimantan, Central Kalimantan, and South Kalimantan

3.3. Correlation between extreme precipitation index and ENSO phenomenon

Correlation analysis was conducted to determine the influence of ENSO events (Niño 3.4 index) on the extreme precipitation index. The results of the correlation analysis of extreme precipitation with the Niño 3.4 index in the Kalimantan region show positive and negative values. Niño 3.4 correlation with PRCPTOT, R20mm, and CWD showed negative values. At the same time, the correlation is positive for CDD and Niño 3.4 index. The largest ENSO influence on PRCPTOT occurs in South Kalimantan (SM. Syamsudin Noor). This is shown based on the Niño 3.4-PRCPTOT index correlation value of -0.56 with a significance level of 99%. In addition, there are two stations with significant correlations of -0.38 (SM. Nangapinoh) and -0.42 (SM. Iskandar) at the 99% significance level in West Kalimantan and Central Kalimantan. As well as five other stations in West Kalimantan, Central Kalimantan, and South Kalimantan (SM. Rahadi Oesman, SM. Tebelian, SM. Supadio, SM. Tjilik Riwut, and SM. Gusti Syamsir Alam) were also significantly correlated at the 95%-98% significance level. This significant correlation is in line with the results of previous research, which states that precipitation in Kalimantan has a significant correlation with ENSO (Lestari, dkk. 2018), with the peak of ENSO events between September-November (Chang, *et al.* 2003).

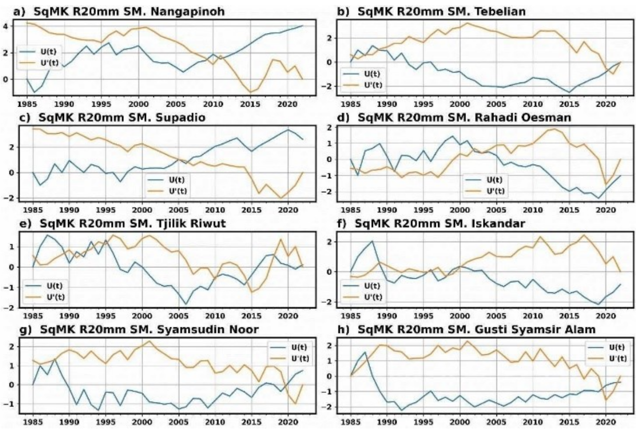


Figure 13. Graphical representation of the Mann–Kendall trend test of the R20mm time series

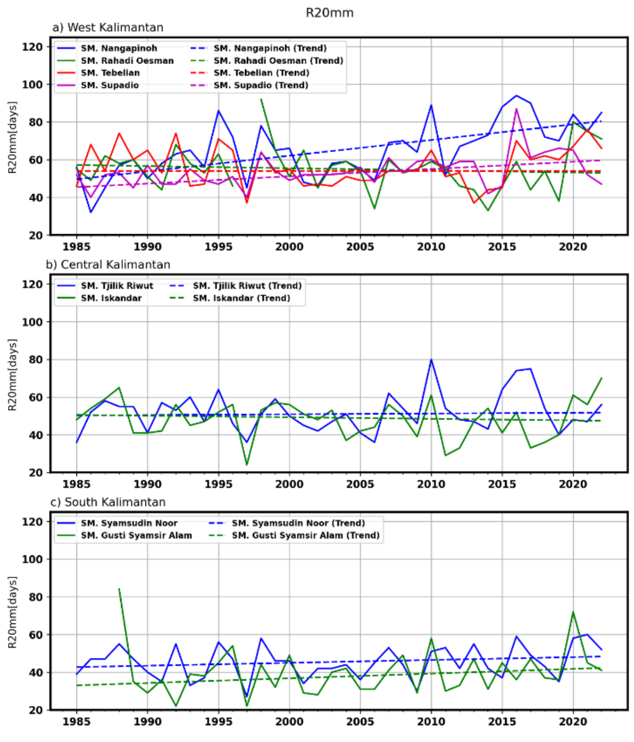


Figure 14. Time series of R20mm observed in a) West Kalimantan, b) Central Kalimantan, c) South Kalimantan

The CDD index significantly correlated with ENSO events at the 99% significance at all observation stations (West Kalimantan, Central Kalimantan, and South Kalimantan). For R20mm, six out of eight stations obtained a significant correlation ranging from 90% to 99% significance level. ENSO events have a significant correlation with the extreme precipitation index during the SON season for West, Central, and South Kalimantan.Meanwhile, the CWD index is not significantly correlated across all observation stations.

3.4. Correlation of extreme precipitation index with IOD phenomenon

The correlation analysis of the extreme precipitation index with DMI was conducted to determine the magnitude of DMI's influence on each extreme precipitation index. In general, the correlation results show the influence of DMI on extreme precipitation in West Kalimantan, Central Kalimantan, and South Kalimantan. This is shown based on the correlation value of DMI on the extreme precipitation index. The DMI-CDD correlation is positive (0.03-0.43) at all observation stations. However, a significant DMI-CDD correlation was only observed at SM. Iskandar (Central Kalimantan) and SM. Syamsudin Noor (South Kalimantan) had 98% and 99% significance levels, respectively. Furthermore, for the PRCPTOT index, only SM. Rahadi Oesman (West Kalimantan) obtained a significant correlation of -0.28 at the 90% level. Furthermore, the R20mm index only has two stations that obtain a significant correlation, namely SM. Rahadi Oesman (West Kalimantan) and SM. Iskandar (Central Kalimantan) has a significance level of 95%. Compared to ENSO, IOD has less influence on the extreme precipitation index, as indicated by the small number of stations that obtained a significant correlation. Meanwhile, CWD did not obtain a significant correlation with DMI for all observation stations.

4. Discussion and conslusion

Analysis of extreme precipitation trends in the West, Central, and South Kalimantan regions from 1985-2022 shows positive and negative trends. The positive trend of PRCPTOT at eight observation stations shows that for 38 years, the Kalimantan region has tended to be in wet conditions.This result has also shown by As-syakur *et al.* (2013). The largest and most significant trend increase occurred in SM. Nangapinoh (West Kalimantan). This PRCPTOT trend is correlated to ENSO by (-0.38) with a significance level of 99%. This aligns with the results of previous research conducted by Nguyen-Thanh *et al.* (2023) from 1979 to 2019. The maximum PRCPTOT in West Kalimantan occurred in 2016 at 5781.7 mm/year. This is because in that year, there was a negative IOD phenomenon (Fannia *et al.* 2021). In addition to PRCPTOT, the average total annual precipitation for West Kalimantan is also greater than that of Central and South Kalimantan. This indicates that West Kalimantan tends to be wetter than Central and South Kalimantan. Among the three regions, South Kalimantan is the region with the lowest average total annual precipitation. This result is also shown by the research of Sukmara *et al.* (2022) and Supari *et al.* (2016). Furthermore, in Central Kalimantan, the correlation between PRCPTOT and ENSO is -0.42 (SM. Iskandar) and -0.39 (SM. Iskandar) significant at the 99% and 98% levels. South Kalimantan, the correlation between PRCPTOT and ENSO is at SM. Syamsudin Noor and SM. Syamsir Gusti Alam was -0.565 and -0.612, respectively, with a significance level of 99% and 98%.

Compared to PRCPTOT, the increasing trend of CWD is less, ranging from 0.006-0.02 days per year. This is because ENSO and IOD have a low correlation ($r \leq 0.24$) with CWD in West Kalimantan, Central Kalimantan, and South Kalimantan. For 38 years, only three stations had an increase in the trend of CWD, while the rest did not change. Research conducted by Ramadhan *et al.* (2022) in the East Kalimantan region also showed an increase in CWD during 2001-2020. An increase in the trend of CWD occurred at SM. Iskandar (Central Kalimantan), SM. Nangapinoh and Rahadi Oesman (West Kalimantan). In 2014 and 2016, West Kalimantan experienced the longest rainy days (CWD) of 34 days, especially in SM. Nangapinoh. The maximum CWD in 2016 was caused by the negative IOD phenomenon during JJA and SO (Fannia *et al.* 2021). The same results also occurred in Central Kalimantan. This region had 36 consecutive rainy days in 2016, precisely in SM. Tjilik Riwut. Meanwhile, in South Kalimantan, the maximum CWD (30 days) in 2021 occurred in SM. Syamsudin Noor. The event is the impact of the LaNiña phenomenon (Novianti *et al.* 2023).

This is not the case with the CWD index. CDD showed increasing and decreasing trends in West, Central, and South Kalimantan but no significant trends as shown by Supari *et al.* (2016). SM. Rahadi Oesman (West Kalimantan) and Tjilik Riwut (Central Kalimantan) obtained increasing trends, SM. Nangapinoh (West Kalimantan), SM Syamsudin Noor and SM. Gusti Syamsir Alam (South Kalimantan) had a decreasing trend and SM. Tebelian and Supadio had no change in trend. A significant correlation between CDD and ENSO occurred at all observation stations (West Kalimantan, Central Kalimantan, and South Kalimantan) with a significance level of 99%. The results showed that the maximum CDD in the West Kalimantan region was in SM. Rahadi Oesman for 53 days precisely in 1994. This long dry season was caused by the positive IOD phenomenon (Lestari *et al.* 2018). Meanwhile, the dry season in Central Kalimantan is longer than in West Kalimantan. In 1997, there were 79 consecutive days without rain in SM. Iskandar. This event was caused by the El Nin˜o phenomenon and positive IOD in 1997 (Lestari *et al.* 2018). The same thing happened in South Kalimantan for 88 days in 1997, especially in SM. Gusti Syamsir Alam. In line with the research results by Lestari *et al.* (2019), the frequency of extreme precipitation strongly correlates with ENSO and IOD in the dry season. Increasing and decreasing trends in CDD were also experienced in central and east central Asia from 1981 to 2005 (Rai *et al.* 2024).

Compared to PRCPTOT, CDD, and CWD, the R20mm trends in West, Central, and South Kalimantan show more varied values. The trends obtained are increasing, decreasing, and constant. Five of the eight stations tended to be wet during the 38 years of observation. This result has also shown by Supari *et al.* (2016). The West Kalimantan region, especially SM. Nangapinoh and Supadio showed significant increasing trends at 99% and 95%. SM. Rahadi Oesman showed a decreasing trend and SM. Tebelian had no change. Meanwhile, in the Central Kalimantan region, an increasing trend was seen in SM. Tjilik Riwut. SM. South Kalimantan that obtained an increase in trend were SM. Syamsudin Noor and Gusti Syamsir Alam. The maximum R20mm (94 days) occurred in the West Kalimantan region in SM. Nangapinoh in 2016. This is because 2016, there was a negative IOD (Fannia *et al.* 2021). Central Kalimantan region experienced heavy rains for 80 days in 2010, especially SM. Tjilik Riwut. 2010, it coincided with the La Niña phenomenon La Niña phenomenon (Lestari *et al.* 2018). Study Patle & Libang (2014) stated that the increasing trend of precipitation has an impact on flooding. The increasing trend of R20mm that occurred in West Kalimantan was also experienced by the central Asian region during 1981-2005 (Rai *et al.* 2024).

Extreme precipitation trends in the West, Central, and South Kalimantan regions have increased over 38 years. PRCPTOT trends have increased at all observation stations. A significant increase in PRCPTOT trends occurred at SM. Nangapinoh and SM. Supadio precisely in the West Kalimantan region. Meanwhile, CWD also significantly increased at two stations, namely SM. Nangapinoh (West Kalimantan) and SM. Iskandar (Central Kalimantan) have significance levels of 90% and 95%. The number of rainy days with intensity ≥ 20mm significantly increased at SM. Nangapinoh and Supadio have significance levels of 99% and 95%. In addition, most of the extreme precipitation indices are significantly correlated with ENSO. The same research results were also shown in the Central Java region with observation time from 1990-2019 (Firmansyah *et al.* 2022), North Sumatra in the period 1981-2010 (Irwandi *et al.* 2018).

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