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Extreme Rainfall Trends and Hydrometeorological Disasters in Tropical Regions: Implications for Climate Resilience

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Abstract

Hydrometeorological disasters due to extreme weather events represent a significant threat to the security of life in Jambi Province. In order to develop effective strategies for mitigating this threat, it is essential to gain a comprehensive understanding of the underlying dynamics that give rise to such disasters. Despite the high frequency of these events, more research is needed on the complex relationship between trends in extreme indices and the frequency of hydrometeorological disasters in this region. This study addresses this gap by utilizing rainfall data from 2008 to 2020 from the Integrated Multi-satellite Retrievals for GPM (IMERG) and hydrometeorological disaster data from the National Disaster Management Agency (BNPB). A range of extreme rainfall indices, including PRCPTOT, R85P, R95P, R99P, CWD, CDD, R1mm, R10mm, R20mm, R50mm, RX1Day, RX5Day, and SDII, were subjected to careful analysis concerning hydrometeorological disasters, including floods, landslides, tornadoes, droughts, and forest fires. Notable results indicate a significant increasing trend ($p < 0.05$) for the CWD index, while decreasing trends are observed for R85P, R95P, R99P, R50mm, RX1Day, RX5Day, and SDII. PRCPTOT and R20mm show decreasing trends, and CDD shows an increasing trend, although it is not statistically significant ($p > 0.05$). Subsequently, there was a significant increase in landslides and tornadoes, while forest fires and floods showed an insignificant increase ($p > 0.05$). Drought exhibited a significant decreasing trend in Jambi. Correlation analysis revealed the complex relationship between extreme weather indices and hydrometeorological disasters. The positive correlations observed between most extreme rainfall indices and floods and landslides, except for CDD, indicate that extreme rainfall is the primary cause of these disasters in Jambi. The correlation is particularly pronounced in areas with mountainous topography, where landslides are more prevalent. The positive correlations observed between CDD and droughts and forest fires suggest that periods of reduced rainfall and increased drought contribute to these disasters. This correlation is more robust in districts with extensive peatlands. The results provide valuable insights into the vulnerability of Jambi Province to hydrometeorological disasters and highlight the importance of understanding regional variations in extreme weather events. These findings improve our understanding of the interactions between climate indices and disasters and provide the basis for informed risk reduction and adaptation strategies in changing climatic conditions.

Keywords:

Hydrometeorological Disasters;

Extreme Weather;

Climate Change;

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1- Introduction

The province of Jambi, located on the eastern coast of Sumatra with mountainous topography to the west (Figure 1), exhibits distinctive environmental characteristics. The region is characterized by high humidity, which facilitates the formation of convective clouds that can result in heavy rainfall and extreme weather conditions [1]. The diverse

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topography, particularly Bukit Barisan in the western part of Jambi province, also influences wind patterns and supports the formation of convective clouds that trigger heavy rainfall [2, 3]. The region is also susceptible to the influence of large rivers, such as the Batang Hari, which have the potential to affect rainfall patterns and the occurrence of extreme weather events [4].

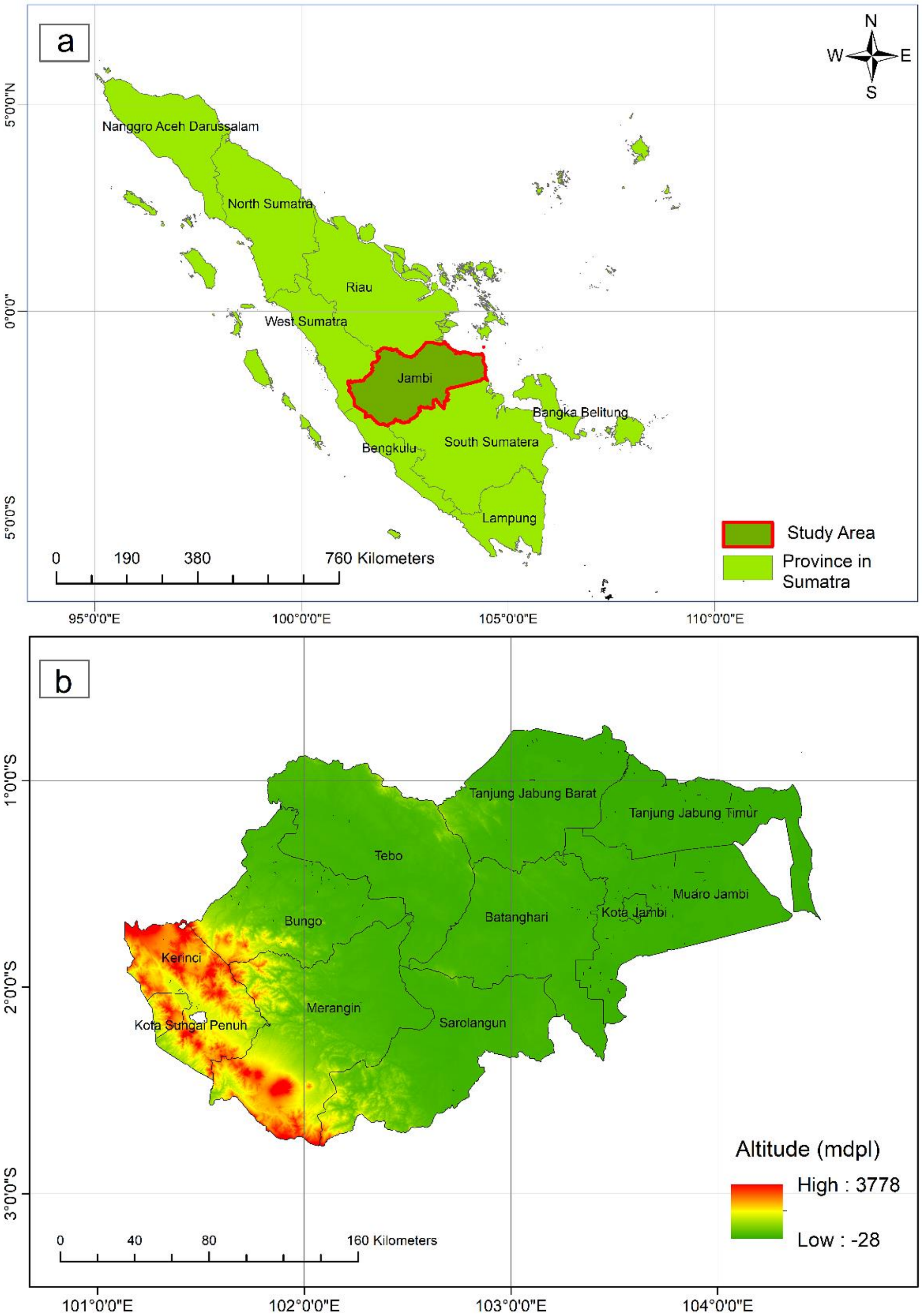

Figure 1. **(a) Location of Jambi province in Sumatra Island, and (b) Topography of Jambi province**

The Jambi Province has been subject to a number of hydrometeorological disasters, including floods, flash floods, tornadoes, and landslides. These disasters have the potential to endanger the safety of communities and infrastructure in the region. The National Disaster Management Agency (BNPB) has recorded 227 floods, 29 landslides, 73 tornadoes, 42 droughts, and 125 forest fires between 2008 and 2020. The impact of hydrometeorological disasters can be cascading, as evidenced by the 2018 event in which heavy rains caused flooding that submerged hundreds of homes [5]. Furthermore, extreme weather conditions, particularly during the dry season, can result in severe forest fires in Jambi [6].

Given the significant impacts of hydrometeorological disasters, a comprehensive understanding of extreme weather patterns and hydrometeorological disasters in Jambi Province is essential. Extreme weather phenomena and hydrometeorological disasters have exhibited a global increase, as evidenced by studies indicating an increase in the frequency, duration, and magnitude of extreme hydrometeorological events, such as floods and droughts [7–10]. Furthermore, satellite data indicates an increase in the frequency, duration, and magnitude of extreme hydro-climatic events under conditions of global warming [11, 12]. Consequently, research into these trends is becoming increasingly important in order to gain an understanding of their impacts at the local level.

While numerous global studies have identified trends in hydrometeorological hazards and their relationship to extreme weather events, studies specific to Jambi Province remain scarce. Some studies have been conducted on rainfall trends in Sumatra in general, such as the study by Perdanawanti [13], which found positive trends in extreme indices such as the simple daily intensity index (SDII), the maximum 1-day rainfall (RX1day), and rainfall above the 99th percentile (R99p) during the period 1981-2010. Furthermore, research has indicated that the spatial patterns of intense rainfall in Southeast Asia and the South Pacific, including Jambi Province, are less consistent than those of extreme temperature trends [14]. This lack of spatial uniformity may contribute to the unpredictability of floods and shifts in seasonal rainfall observed in Jambi Province, particularly in regions undergoing rapid land use change [4]. Furthermore, the impact of land use change on environmental factors such as albedo and the Normalized Difference Vegetation Index (NDVI) in Jambi Province has the potential to influence rainfall patterns. However, this area has limited research [15].

This study aims to address the existing knowledge gap by investigating extreme weather trends and hydrometeorological disasters in Jambi Province. The study will investigate the trend and analyze the correlation between the extreme rainfall index and each type of hydrometeorological disaster to determine which index can be an excellent proxy to predict a particular disaster. This research is expected to contribute significantly to the understanding of mitigation and adaptation to extreme weather risks in Jambi Province.

2- Data and Method

The stages of the research conducted are presented in Figure 2. These include data collection, analysis, and the drawing of conclusions.

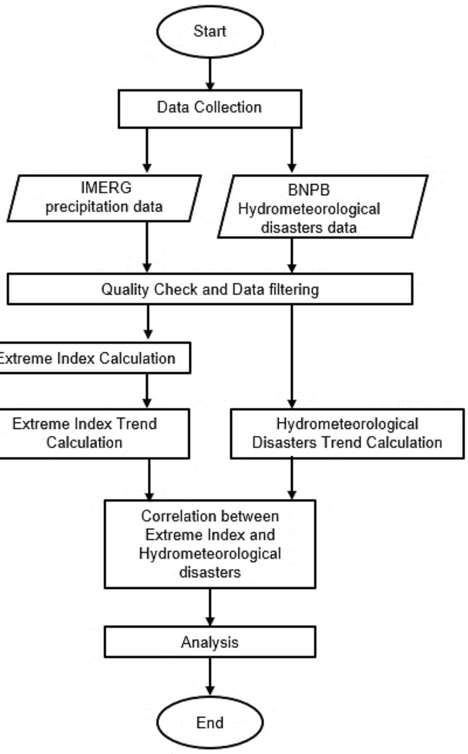

Figure 2. Research flow chart

2-1- Data

2-1-1- Precipitation Data

This study was conducted in Jambi Province, which is geographically located between 0.45°-2.45°N and 101.30°-104.30°E. The data source for this study is rainfall from IMERG satellite products for 13 years of observation (2008-2020). The data set utilized is limited to 2008, due to the availability of hydrometeorological disaster data from that year onwards. IMERG, which stands for Integrated Multi-satellite Retrievals for GPM, is a satellite rainfall product produced by NASA to estimate surface rainfall in various regions on Earth. IMERG was employed in this study due to its superior accuracy, enhanced capability to detect extreme events, higher spatiotemporal resolution, and superior performance in different regions compared to other rainfall datasets [16, 17].

The IMERG data set combines information from GPM satellites to provide real-time and finalized precipitation data in various formats. The spatial resolution of the IMERG data is 0.1° x 0.1° and the measurement interval is every 30 minutes. The high resolution of this data set enables the identification of more detailed rainfall patterns in a smaller area, rendering it suitable for extreme weather analysis in areas of Jambi Province that may exhibit high spatial variability. Furthermore, IMERG utilizes data from a range of meteorological satellites, including GPM and other satellites, in addition to surface weather information and ground rain observations. It provides global precipitation estimates with extensive coverage, even in areas that are challenging to access or where ground observations are lacking. The primary objective of IMERG is to provide accurate and comprehensive global precipitation estimates to support a variety of applications, including flood monitoring, water resources management, climate modeling, and scientific research [18]. Ramadhan et al. [19, 20] found that IMERG data can observe extreme rainfall variability in the Indonesian maritime continent based on the extreme rainfall index. Furthermore, they evaluated the capability of IMERG-F in Sumatra by demonstrating the correlation of IMERG-F data with five extreme indices. The aforementioned advantages render IMERG data a valuable resource for the study of extreme weather trends and hydrometeorological disasters in Jambi Province, as has been demonstrated in numerous previous studies [16, 21, 22].

2-1-2- Hydro-meteorological Disasters Data

The data on hydro-meteorological disasters in Jambi province for the period 2008-2020 were collected in spreadsheet format from the National Disaster Management Agency (BNPB) website [5]. BNPB is the agency responsible for disaster data management in Indonesia. The information contained in this data provides an in-depth understanding of the different types of natural disasters that commonly occur in Indonesia, including earthquakes, floods, landslides, tornadoes, droughts, tsunamis, forest fires, and volcanic eruptions.

The data provided by BNPB also includes details on the number of casualties, physical damage, and socio-economic impact caused by each disaster. In addition to the historical aspects, the BNPB provides information on disaster mitigation programs implemented by the government and other partners. These programs aim to reduce disaster risk in communities. This information includes disaster risk maps, emergency response plans, and disaster-related public education and awareness programs. The data provided by the BNPB is a historical record and a valuable source of information to support disaster mitigation and management efforts in Jambi Province.

2-2- Methods

The extreme weather index was initially calculated using the extreme rainfall index developed by the Expert Team on Climate Change Detection and Index (ETCCDI), as shown in Table 1. The index introduced by the ETCCDI can be categorized based on the intensity, duration, and frequency of extreme precipitation events [22]. Some indices used are PRCPTOT, R85p, R95p, R99P, and SDII, which measure intensity. The duration index includes both CWD and CDD. The frequency indices are R1mm, R10mm, R20mm, R50mm, Rx1day and RX5day. As the BNPB data is presented at the district level, the extreme rainfall index is calculated by averaging for each district in Jambi province.

Table 1. Extreme precipitation index from ETCCDI

Index	Indicator
PRCPTOT (mm)	The total amount of rainfall during a specific time period
R85P (mm)	The number of days with rainfall above the 85th percentile of the rainfall distribution
R95P (mm)	The number of days with rainfall above the 95th percentile of the rainfall distribution
R99P (mm)	The number of days with rainfall above the 99th percentile of the rainfall distribution
CDD (day)	Maximum number of consecutive days with less than a certain threshold of precipitation
CWD (day)	Maximum number of consecutive days with precipitation above a certain threshold
R1mm (day)	The number of days with rainfall equal to or exceeding 1mm
R10mm (day)	The number of days with rainfall equal to or exceeding 10mm
R20mm (day)	The number of days with rainfall equal to or exceeding 20mm
R50mm (day)	The number of days with rainfall equal to or exceeding 50mm
Rx1day (mm)	The maximum amount of rainfall in a single day
Rx5day (mm)	The maximum amount of rainfall over a period of five consecutive days
SDII (mm/day)	The average daily intensity of rainfall during a specific time period

The subsequent step is to calculate the trend of extreme weather and hydrometeorological disaster data using Sen's slope method [23]. This method employs differences between pairs of observations in order to minimize the effect of extremes that may be present in the time series of data. This approach enables Sen's Slope Method to provide more stable and consistent estimates of trend changes, even in the presence of significant data points. Furthermore, the method is non-parametric, which means that it does not require assumptions about the shape of the data distribution or population parameters. The formula for Sen's slope can be formulated as follows (Equation 1):

$$Q_i = \frac{x_j - x_k}{j - k} \quad \text{where} \quad j > k \tag{1}$$

x_j and x_k the value for time j and k (where $j>k$). If there are n values of x_j in the time series, there will be a total of $N = n(n-1)/2$ slope estimates (Q_i). The Sen slope estimator is the median of these NQ_i values. The NQ_i values are arranged in ascending order, and the Sen estimator is obtained using Equation 2 and 3. If Q is positive, it indicates an increasing trend; conversely, if it is negative, it suggests a decreasing trend:

$$Q = Q\left[\frac{(N+1)}{2}\right], \text{ if } N \text{ is odd} \tag{2}$$

$$Q = \frac{1}{2}\left(Q\frac{N}{2} + Q\left[\left(\frac{N+2}{2}\right)\right]\right), \text{ If } N \text{ is even} \tag{3}$$

A non-parametric statistical method, the Kendall-tau correlation, is employed to assess the correlation between extreme weather indices and hydrometeorological disasters. This correlation is used to determine the extent to which two ordered random variables exhibit a monotonic relationship. One of the primary advantages of the Kendall-tau correlation is that it does not depend on assumptions about the normal distribution of the data [24]. Consequently, the Kendall tau correlation is more suitable when the normality assumption is not met. The formula for the Kendall-Tau correlation can be expressed as follows (Equation 4):

$$\tau = \frac{C - D}{\frac{1}{2}n(n-1)} \tag{4}$$

The Kendall-tau correlation results can be interpreted by looking at the τ value. If the τ value is positive, it indicates a positive correlation between the extreme weather index and the hydrometeorological disaster being analyzed. Conversely, a negative τ indicates a negative correlation between the extreme weather index and the hydrometeorological disaster analyzed. On the other hand, a value of τ equal to zero indicates no significant correlation between the extreme weather index and the hydrometeorological disaster analyzed.

In addition, a p-value is used to provide a basis for recognizing a significant relationship between the extreme weather index and hydrometeorological disasters. A low p-value (less than α, the predetermined significance level) indicates that the observed results are unlikely to have occurred by chance. In this study, we used $\alpha = 0.05$. Conversely, a high p-value indicates that the observed results could have occurred by chance and that there is no strong evidence to reject the null hypothesis that there is no correlation between the two variables. Therefore, the interpretation of the p-value is essential in assessing the statistical significance of the Kendall-tau correlation results.

3- Results

3-1- Trends in Extreme Weather and Hydrometeorological Disasters

Figure 3 shows the trend of extreme weather indices in Jambi province during the 2008-2020. Various indices such as R85P (Figure 3b), R95P (Figure 3c), R99P (Figure 3d), R20mm (Figure 3i), R50mm (Figure 3j), Rx1day (Figure 3k), Rx5day (Figure 3l) and SDII (Figure 3m) show a decreasing trend in Jambi Province. This decrease indicates a decrease in the intensity of very heavy rainfall in the region during the last 13 years (2008-2020). On the other hand, the CWD index (Figure 3f) shows a significant increasing trend in Jambi Province with a p-value of less than 0.05. This indicates an increase in the duration and frequency of rainfall in some areas of Jambi. In other words, rainfall events are occurring more frequently and lasting longer, but with lower intensity. The increasing trend in CDD also reflects the increasing number of consecutive dry days in some areas of Jambi, although the increase is not significant (p-value > 0.05).

The results of this study are consistent with some previous studies, such as the findings of Shahid [25], who found an increasing trend in the CWD index, and the findings of Wilis and Nugroho [26], who found a decreasing trend in R50mm. This study is also consistent with the findings of Zaki et al. [27], who found a decreasing trend in R95P and Rx5day. The decrease in the Rx1day and SDII indices is also consistent with the research of Marzuki et al. [21]. These results provide empirical support for changes in extreme weather events in Jambi Province over time. The results of this study are consistent with some previous studies, such as the findings of Shahid [25], who found an increasing trend in the CWD index, and the findings of Wilis & Nugroho [26], who found a decreasing trend in R50mm. This study is also consistent with the findings of Zaki et al. [27], who found a decreasing trend in R95P and Rx5day. The decrease in the Rx1day and SDII indices is also consistent with the research of Marzuki et al. [21]. These results provide empirical support for changes in extreme weather events in Jambi Province over time.

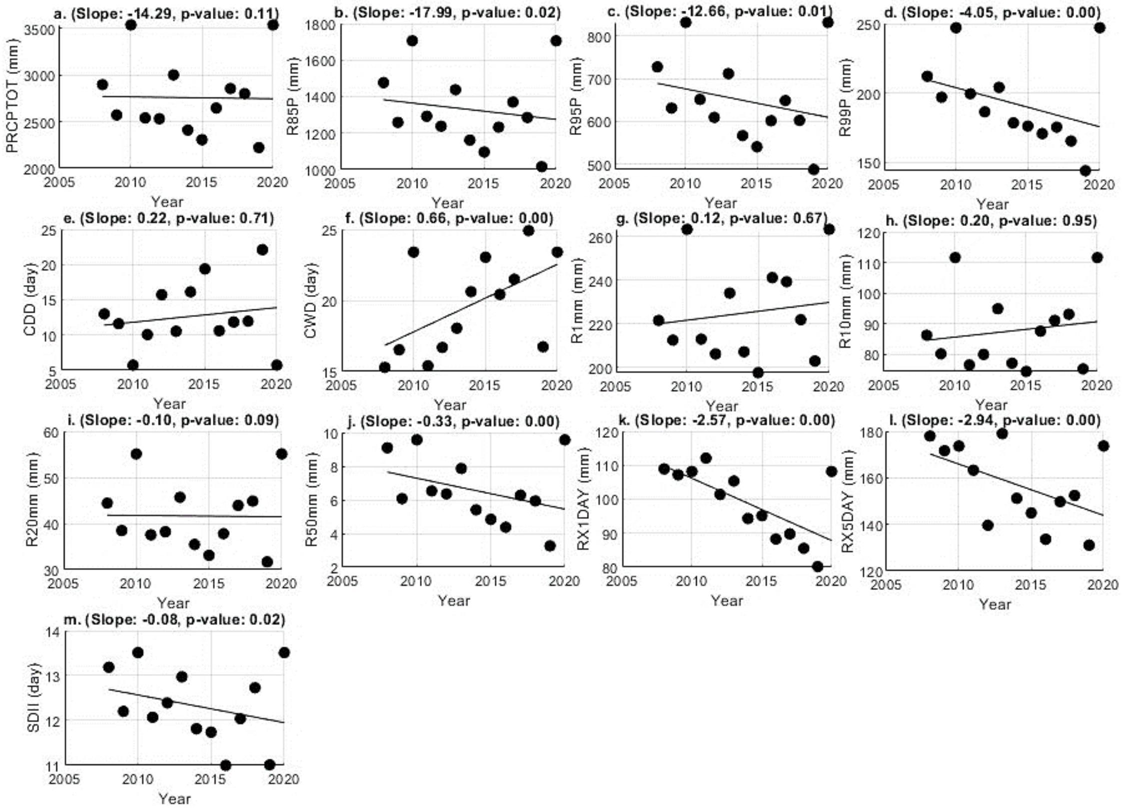

Figure 3. **Trend of extreme weather indices in the Jambi Province during 2008-2020**

Figure 4 shows the trends of hydrometeorological disasters in Jambi Province from 2008 to 2020. In general, floods, landslides, tornadoes, and forest fires show an increasing trend, while droughts show a decreasing trend. However, the observed increase in flood and wildfire trends is not statistically significant (p-value > 0.05). The increasing trend in floods is consistent with previous studies [28, 29]. It is mainly observed in areas adjacent to rivers, where flooding occurs when river flows exceed normal capacity.

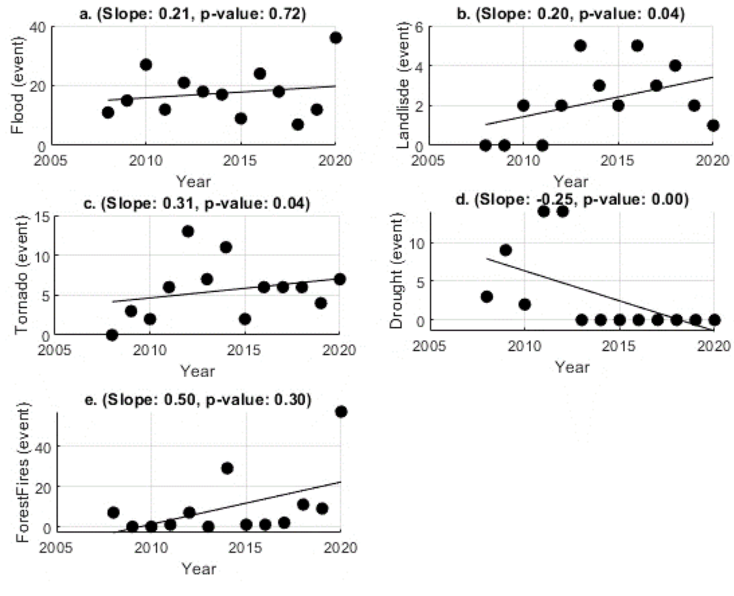

Figure 4. **Trend of hydrometeorological disasters in the Jambi Province during 2008-2020**

The increase in landslides is also consistent with the findings of Petley et al. [30], who attribute the increase to changes in precipitation patterns due to climate change. Increased rainfall intensity and shifts in precipitation patterns increase landslide risk by increasing soil saturation, compromising slope stability, and amplifying surface runoff. The increasing trend of tornado disasters in the Jambi region is consistent with the observations of Gensini and Brooks [31]. Variations in airflow patterns, humidity, and temperature gradients in the atmosphere promote conditions conducive to tornado formation. In addition, diverse topography, including mountains, valleys, and plains, influences airflow and the interaction between air masses. In contrast, the decreasing trend in drought disasters is consistent with the findings of Ferijal et al. [32], indicating a reduction in the number of consecutive dry days during the rainy season. While droughts are caused by a variety of factors, rainfall variability remains central to their development. However, the increase in forest and land fires in Jambi contradicts the findings of Riyanto et al. [33], who reported a decreasing trend of forest fires in Indonesia. Research by Fitriany et al. [34] highlights that forest fires are influenced by rainfall patterns and land and soil management practices, often associated with human activities such as illegal agricultural practices using slash-and-burn techniques.

3-2- Correlation between Extreme Weather Events and Hydrometeorological Disasters

Figure 5 shows the relationship between the extreme weather index and flood events in Jambi province. Most areas in Jambi show a positive correlation between extreme weather indices and flood events. The PRCPTOT (Figure 5-a), R85P (Figure 5-b), R95P (Figure 5-c), R99P (Figure 5-d), CWD (Figure 5-f), R10mm (Figure 5-h), R20mm (Figure 5-i) and SDII (Figure 5-m) indices show a significant positive correlation ($p < 0.05$) with flood events in several areas in Jambi. This positive correlation was observed in the areas of Muaro Jambi, Jambi City, Batang Hari, Sarolangun, Merangin and Tebo. An increase in the intensity, duration and frequency of rainfall may increase the risk of flooding in some of these areas. Meanwhile, the SDII index (Figure 5m) and CDD (Figure 5-e) show a significant negative correlation with flood events in Batang Hari, Muaro Jambi, Jambi City and East Tanjung Jabung. These results are consistent with previous studies that identified Jambi as a high rainfall area prone to flooding [35, 36].

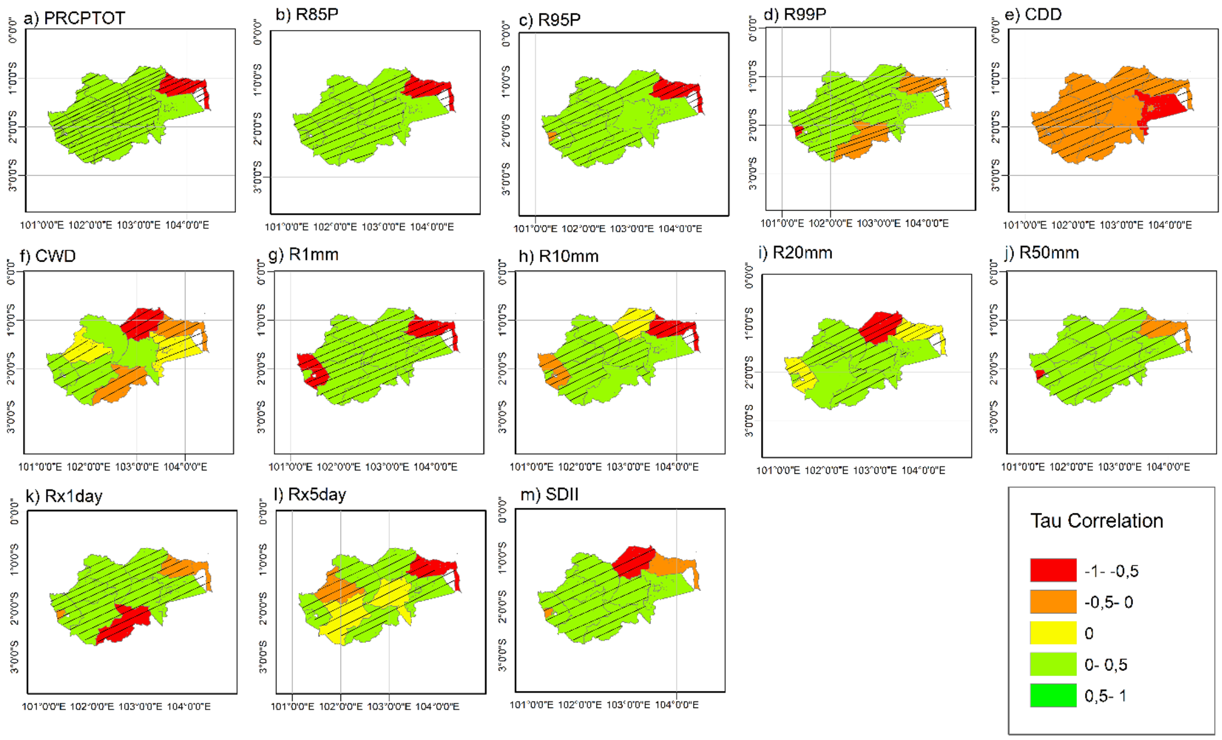

Figure 5. Correlation of extreme weather index with flood disasters in the Province of Jambi. The shaded area indicates that the correlation is not significant ($p > 0.05$)

As with floods, most areas in Jambi Province are positively correlated with landslides. Several extreme weather indices, such as PRCPTOT (Figure 6-a), R95P (Figure 6-c), R99P (Figure 6-d), CWD (Figure 6-f), R1mm (Figure 6-g), R10mm (Figure 6-h), R20mm (Figure 6-i), Rx1day (Figure 6-k), and Rx5day (Figure 6-l), showed significant positive correlations with landslide occurrence ($p < 0.05$). Significant positive correlations were observed in Tebo, Batang Hari, Muaro Jambi, Jambi City, Kerinci, Merangin, and Sarolangun, which correspond to the flood disaster sites (Figure 5). On the other hand, CDD (Figure 6-e) shows a negative correlation with landslides and is observed in all districts. Negative correlations were also observed for R85P (Figure 6-b), R99P (Figure 6-d), as well as Rx1day (Figure 6-k), Rx5day (Figure 6-l), and SDII (Figure 6-m) indices in some areas of Jambi province. However, they did not reach significance ($p < 0.05$). This study is also consistent with the findings in Nepal by Muñoz-Torrero Manchado et al. [37], who showed a strong correlation between the number of annual shallow landslides and accumulated monsoon rainfall. In addition, anthropogenic factors such as land use change also amplify the influence of the monsoon season on slope stability.

In the case of tornadoes, only the CWD index (Figure 7-f), which refers to the duration or number of consecutive rainy days, shows a significant positive correlation. A significant positive correlation is found in the East Tanjung Jabung region. The indices PRCPTOT (Figure 7-a), R85P (Figure 7-b), 95P (Figure 7-c), R99P (Figure 7-d), CDD (Figure 7e), R1mm (Figure 7-g), R10mm (Figure 7-h), R20mm (Figure 7-i), R50mm (Figure 7-j), Rx1day (Figure 7-k), Rx5day (Figure 7-l) and SDII (Figure 7m) were also positively correlated with tornado disasters in some areas of Jambi. However, they were not statistically significant ($p > 0.05$). In some areas, tornado disasters are also significantly negatively correlated with several indices such as PRCPTOT (Figure 7-a), R85P (Figure 7-b), R1mm (Figure 7-g), R10mm (Figure 7-h), R20mm (Figure 7-i), R50mm (Figure 7-j), Rx1day (Figure 7-k), Rx5day (Figure 7-l), and SDII (Figure 7-m). Research by Mateo et al. [38] also showed a high correlation between CWD and tornado outbreaks. Prolonged, high-intensity rainfall can create unstable atmospheric conditions and trigger wind convergence at the surface. When warm, moist air meets cold, dry air, significant pressure gradients can develop and trigger the formation of tornadoes.

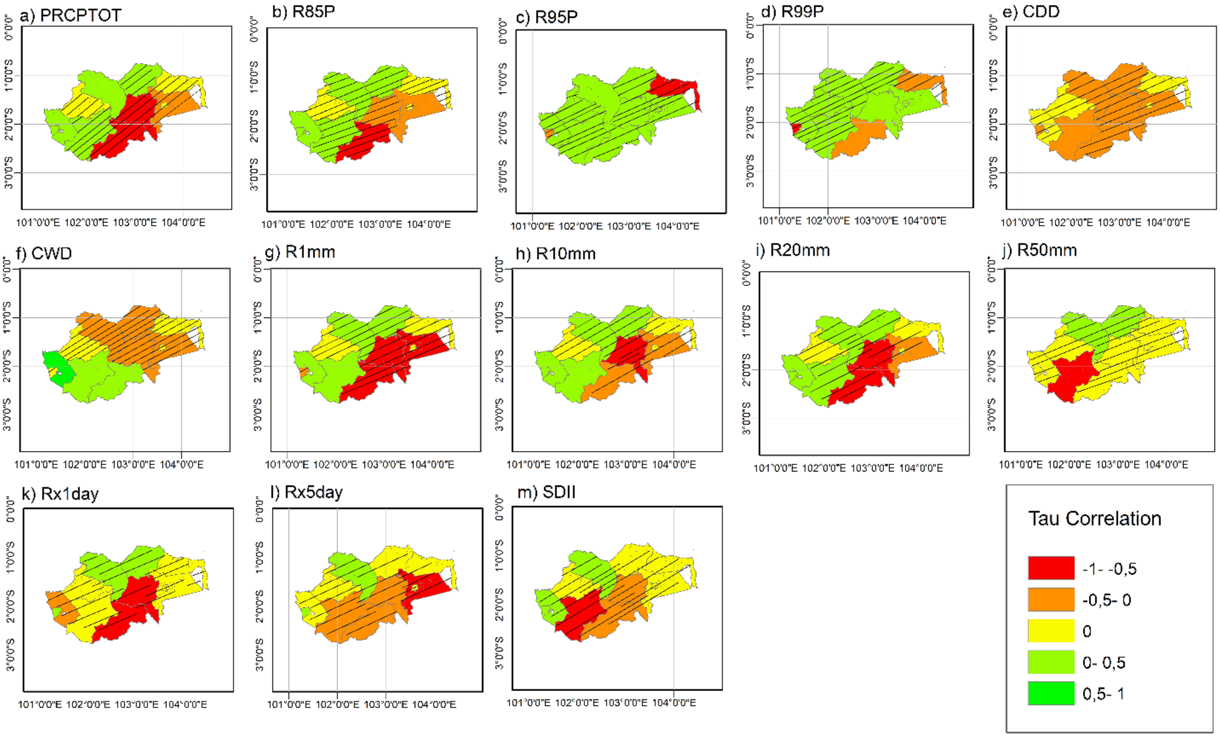

Figure 6. Correlation of extreme weather index with landslides in the Province of Jambi. The shaded area indicates that the correlation is not significant ($p > 0.05$)

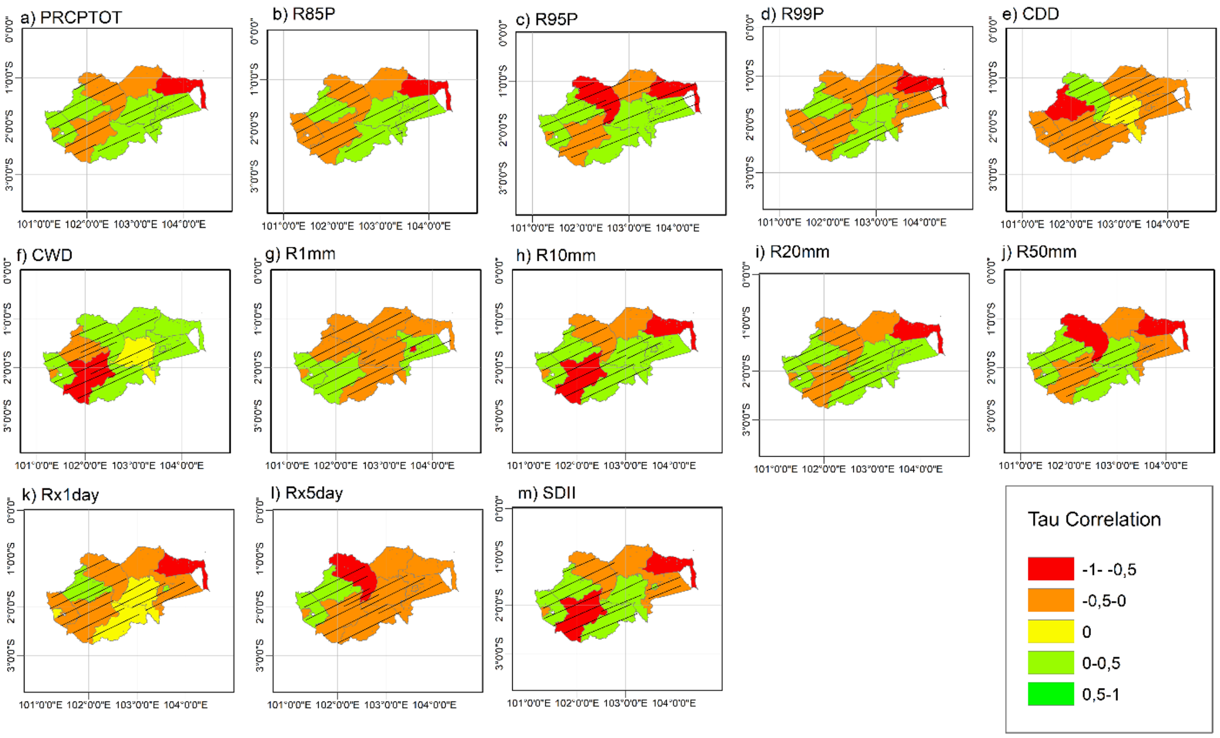

Figure 7. Correlation of extreme weather index with tornadoes in the Province of Jambi. The shaded area indicates that the correlation is not significant ($p > 0.05$)

Figure 8 shows the correlation of extreme weather indices with drought disasters in Jambi province. The CDD index (Figure 8-e) is significantly correlated positively with drought in Tebo, Bungo, Merangin, Muaro Jambi, and East Tanjung Jabung. This is certainly typical of the relationship between extreme weather and drought [39, 40]. When rainfall is reduced, drought occurs. Therefore, indices such as PRCPTOT (Figure 8-a), R85P (Figure 8-b), R95P (Figure 8-c), CDD (Figure 8-e), R10mm (Figure 8-h), and R20mm (Figure 8-i) show a significant negative correlation with drought. Drought in Jambi, Indonesia, may be caused by land use change and deforestation [41] due to the expansion of oil palm plantations. This has increased vulnerability to drought, as evidenced by reduced carbon sequestration during an intense El Niño event in 2015, which affected all vegetation in Jambi province vegetation [42]. In addition, the impact of the 2015 fires, which covered oil palm plantations in Jambi with haze, further exacerbated drought conditions [43]. Furthermore, hydrological drought in Jambi has been linked to fire vulnerability in the humid tropics, indicating complex socio-natural production, risks, and inequalities in the province [4]. In addition, the severity of the dry season in Indonesia is influenced by the Australian monsoon and local cloud formation, which is controlled by the sea surface temperature (SST) around Indonesia [44]. Furthermore, the El Niño phenomenon, as observed in 2015, has been shown to significantly affect rainfall patterns in Jambi and other regions [45].

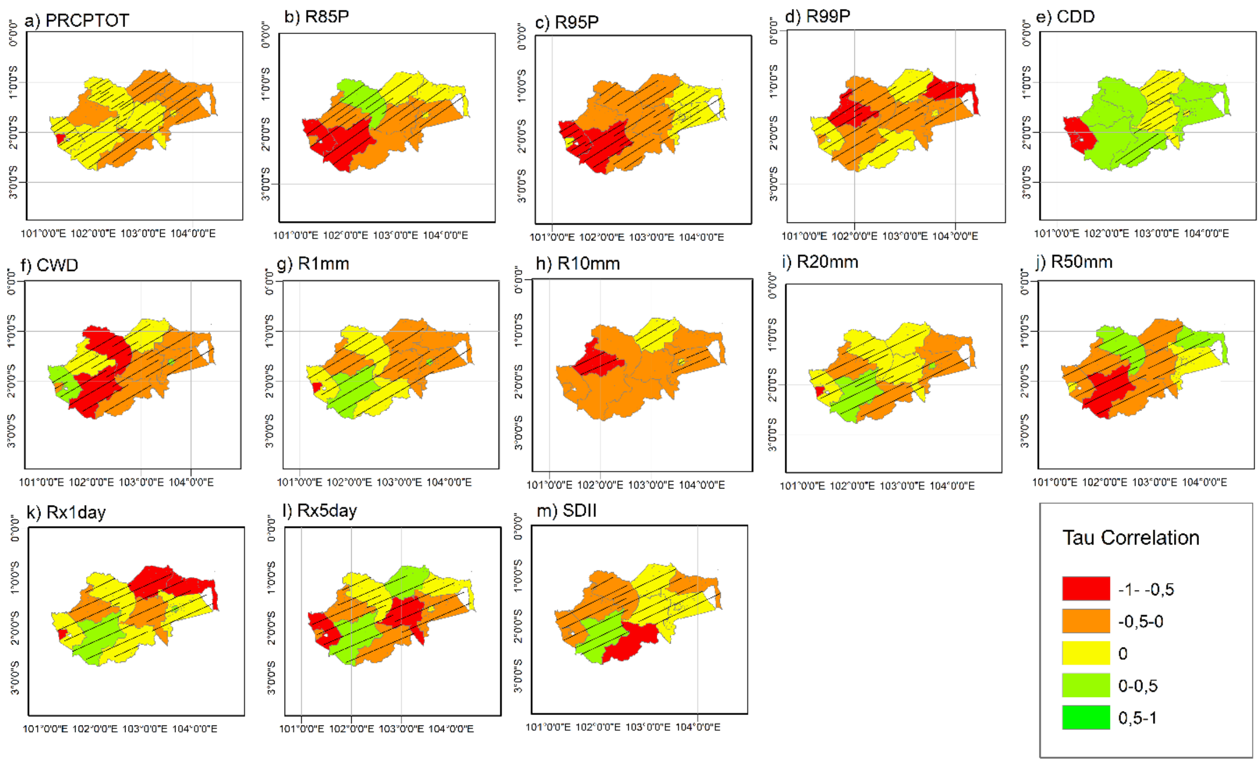

Figure 8. Correlation of extreme weather index with drought in the Province of Jambi. The shaded area indicates that the correlation is not significant ($p > 0.05$)

Figure 9 shows the correlation of extreme weather indices with forest and land fire disasters in Jambi province. The CDD index (Figure 9-e) is significantly positively correlated with forest and land fires in some areas of Jambi, as is the case for drought (Figure 8). Some indices such as PRCPTOT (Figure 9-a), R85P (Figure 9-b), R95P (Figure 9-c), R99P (Figure 9-d), CWD (Figure 9-f), R10mm (Figure 9-h), R20mm (Figure 9-i), R50mm (Figure 9-j) and Rx1day (Figure 9-k) are significantly negatively correlated with forest and land fires. In contrast, the other indices show insignificant negative correlations throughout Jambi. Thus, low rainfall or periods of drought may increase the risk of forest fires. During drought, vegetation and organic matter in the forest become drier and more susceptible to fire. However, forest fires in Jambi are complex and are caused by both natural and human factors. Natural factors include predisposing conditions such as climate, altitude and suitability for certain tree crops [46]. In addition, the El Niño effect has been identified as a natural disturbance causing deforestation and peat swamp forest fires in Jambi province [47]. Human-related causes of forest fires in Jambi include land clearing for agricultural purposes, such as dry farmland and rice fields, and industrial activities, such as timber harvesting and conversion of secondary forests to plantations [48]. In addition, land allocation for specific land uses has been identified as a human-related factor contributing to fire occurrence in Jambi province [46]. Despite these complexities, we can still see that CCD is strongly correlated with flood events in Jambi.

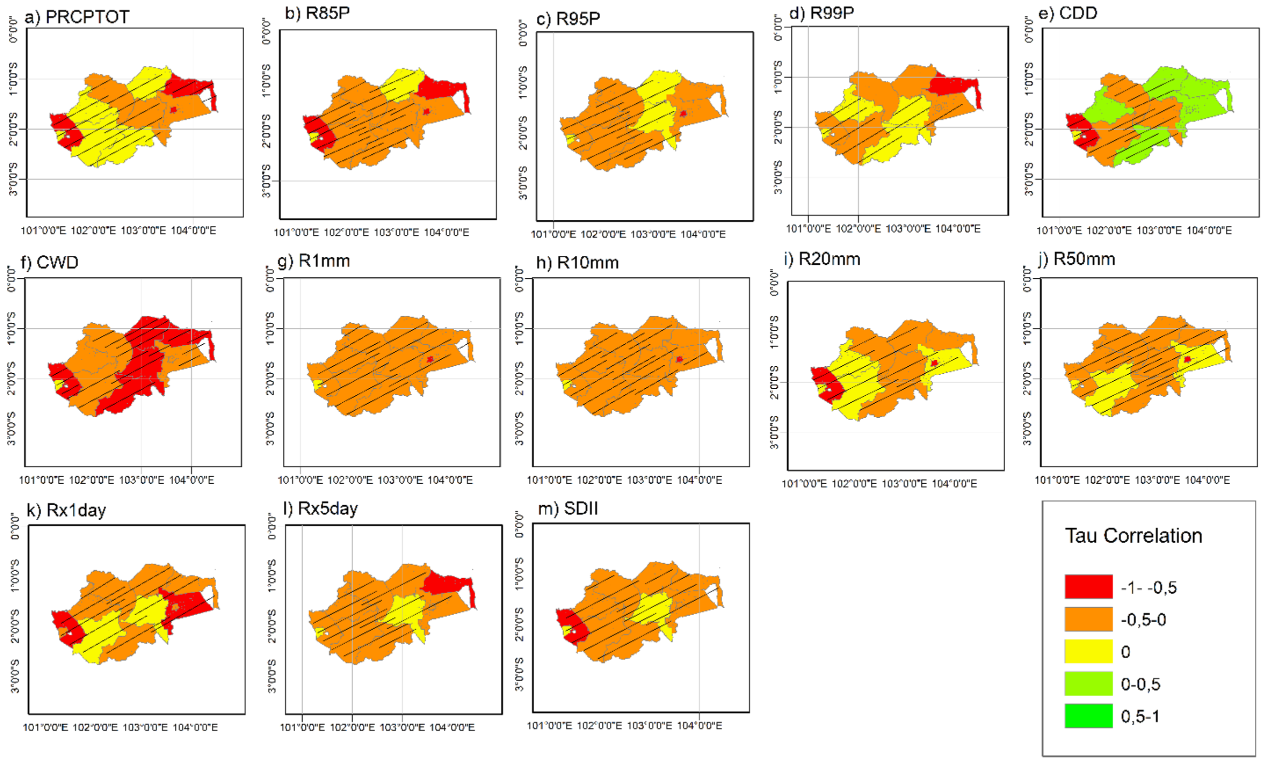

Figure 9. Correlation of extreme weather index with forest and land fire in the Province of Jambi. The shaded area indicates that the correlation is not significant (p > 0.05)

4- Discussion

From the preceding description, it is evident that there is considerable variation in the relationship between extreme weather events and hydrometeorological disasters. To illustrate this distribution of these relationships in greater detail, Table 2 presents the number of counties exhibiting negative and positive correlations between extreme weather events and hydrometeorological disasters. The data in the table are divided according to their statistical significance ($p<0.05$) and ($p>0.05$). Of all disasters, the relationship between extreme weather events and hydrometeorological disasters is most evident for droughts and forest fires. In most districts, the CDD index positively correlates with these two disasters, while the other indices correlate negatively. The positive correlation between the CDD index and fire and drought is due to the effect of high CDD on increasing fire hazard and occurrence. It has been demonstrated that there is a consistent relationship between drought, fire hazard indices and the impact of drought on fire have been shown continuously across different geographical locations and time scales [49–51]. In addition to drought, forest fires in Jambi are also highly dependent on the condition of peatlands. The districts of Tanjung Jabung and Muaro Jambi have large areas of peatland and thus experienced the most severe forest fires in 2019 [52]. This is also evident from the significant correlation between CDD and forest fires in these regions (Figure 9e). In contrast, Kerinci, Merangin and Sungai Penuh City exhibit a negative relationship between CDD. This is attributed to their mountainous topography, limited accessibility and high humidity [46].

Overall, flooding is positively correlated with all extreme rainfall indices, with the exception of CDD, which is negatively correlated. Therefore, high rainfall intensity and long duration tend to trigger flooding in Jambi, while dry days characterized by high CDD rarely cause flooding. The relationship between the frequency, intensity, and duration of extreme rainfall and flooding has been observed in various countries. For instance, Guhathakurta et al. [53] examined the impact of climate change on extreme rainfall events and flood risk in India, with a particular focus on the frequency of rainy days, rainy days with high rainfall, and extreme rainfall in a single day. Similarly, Tazen et al. [54] investigated the relationship between extreme rainfall events and flooding trends in Ouagadougou, Burkina Faso, emphasizing the calculation of rainfall indices related to frequency, intensity, and duration. Furthermore, Wu et al. (2018) emphasized the need for a combined event framework to assess flood risk in coastal and estuarine areas, considering the dependency between storm surge and extreme rainfall. The interdependence between extreme rainfall and storm surge significantly affects the risk of coastal flooding. This is also corroborated by the findings of Zheng et al. (2014), which highlighted the necessity of considering the interdependence between extreme rainfall and storm surge in estimating coastal flood risk. Consequently, the phenomenon of flooding in coastal areas is more intricate and influenced by a multitude of factors, including a combination of natural phenomena such as sea level rise, storm surges caused by tropical cyclones, heavy rainfall, river discharge, and land subsidence [55, 56]. Consequently, the relationship between extreme weather events and flooding may not always be positively correlated, as evidenced by the case of Tanjung Jabung Timur District, Jambi (Figure 4). Although the relationship between extreme rainfall indices and flood risk is complex and sensitive to a number of factors, including climate change, geographical factors, and storm surge dependence, flood events in Jambi can be explained by extreme rainfall indices.

Table 2. Summary of the number of districts where the correlation between the extreme precipitation index and hydrometeorological disasters is positive and negative. Correlation values equal to 0 are not included. A p-value of <0.05 indicates a significant correlation, otherwise an insignificant correlation.

Index	Number of districts for each disaster with positive and negative correlations									
	Flood (+.-)		Landslides (+.-)		Tornado (+.-)		Drought (+.-)		Forest Fire (+.-)	
	P < 0.05	P >0.05	P < 0.05	P >0.05	P < 0.05	P >0.05	P < 0.05	P >0.05	P < 0.05	P >0.05
PRCPTOT	2. 0	8. 1	3. 0	3. 3	0. 2	6. 3	0. 2	0. 3	0. 2	0. 4
R85P	2. 0	8. 1	2. 0	4. 3	0. 2	5. 4	0. 2	1. 5	0. 3	0. 6
R95P	3. 0	6. 2	1. 0	8. 2	1. 0	5. 5	0. 1	0. 6	0. 3	0. 5
R99P	2. 0	6. 3	3. 1	5. 2	1. 0	3. 7	0. 0	0. 7	0. 4	0. 3
CDD	0. 2	0. 9	0. 1	0. 6	0. 1	1. 8	5. 2	1. 0	4. 0	2. 4
CWD	2. 0	3. 3	3. 0	0. 4	2. 0	5. 3	0. 0	2. 7	0. 2	0. 8
R1mm	0. 0	9. 2	2. 0	2. 4	0. 2	3. 6	0. 2	2. 4	0. 1	0. 9
R10mm	3. 0	5. 2	3. 0	2. 3	0. 3	6. 2	0. 7	0. 2	0. 2	0. 8
R20mm	2. 0	6. 1	2. 0	3. 3	0. 2	6. 3	0. 2	2. 3	0. 2	0. 5
R50mm	0. 0	9. 2	0. 1	2. 0	0. 4	4. 3	0. 0	2. 6	0. 1	0. 7
Rx1day	0. 0	8. 3	1. 0	2. 3	0. 2	2. 4	0. 1	2. 4	0. 1	0. 8
Rx5day	0. 0	7. 2	1. 0	1. 3	0. 4	2. 5	0. 0	2. 6	0. 1	0. 8
SDII	2. 0	6. 2	1. 0	2. 3	0. 2	5. 4	0. 1	1. 5	0. 0	0. 9

Similarly, landslides are positively correlated with all extreme rainfall indices, with the exception of CDD, which is negatively correlated in Jambi. Therefore, high rainfall intensity and duration tend to trigger landslides in the region, whereas landslides are rare during dry periods with high CDD. This finding is consistent with studies in different geographical locations. Studies have demonstrated a power-law relationship between soil erosion by landslides and rainfall intensity, with scale exponents ranging from 2.94 to 5.03 [57]. Furthermore, the probability of landslide occurrence is related to extreme rainfall, suggesting that extreme rainfall is an important triggering factor for landslides [58]. This is supported by the observation that extreme rainfall facilitates landslides, rockfalls, and slope failures in some areas [59]. Furthermore, the infiltration of extreme rainfall concentrations has been identified as a contributing factor to the formation of saturated zones that can lead to landslides. In addition to rainfall, topography also has a significant influence on landslides, with steep terrains being more prone to landslides than gentle slopes [60, 61]. Consequently, the positive correlation between rainfall and landslides is more pronounced in areas with mountainous topography, including Kerinci District, Sungai Penuh City, Bungo District, and Merangin District (Figure 6).

The relationship between the extreme weather index and tornadoes is very complex due to the interaction of various meteorological factors, so the relationship between the extreme rainfall index and tornadoes varies significantly across districts in Jambi (see Table 1, Figure 7). Tornadoes are influenced by several variables, such as the relative helicity of the storm, the energy helicity index, and the severe weather threat index, which contribute to the occurrence of tornadoes [62]. Furthermore, while the impact of climate change on extreme events is well documented, the relationship between extreme weather factors and tornado frequency or intensity does not show a clear trend, suggesting the complexity of the relationship [63]. Furthermore, an investigation of the relationship between tornadoes and large-scale recurrent weather patterns in the United States highlighted the complex nature of tornado occurrence and its dependence on the broader weather regime [64]. In addition, the Madden-Julian Oscillation (MJO) was shown to have a significant impact on extreme precipitation, demonstrating the influence of large-scale climate phenomena on extreme weather events [65]. These findings suggest that the relationship between extreme weather indices and tornadoes is complex due to the multifaceted nature of tornado formation and the influence of multiple meteorological factors, including large-scale atmospheric circulation patterns, climate change, and the broader weather regime.

Although conclusions regarding the relationship between the extreme rainfall index and hydrometeorological disasters in Jambi Province have been described previously, some relationships were insignificant ($p > 0.05$) due to the limited number of hydrometeorological disasters in each district. An insignificant correlation coefficient ($p>0.05$) indicates that there is no statistically significant relationship between the variables studied [66]. This means that the variables are not reliably related and that any apparent relationship between them is likely due to chance [67]. Therefore, it is recommended that future research continue this study with a larger amount of data and a longer time period.

5- Conclusion

A comprehensive analysis of extreme weather indices and hydrometeorological disasters in Jambi Province from 2008 to 2020 reveals a nuanced relationship between these factors. The observed decreasing trends observed in various extreme weather indices, including R85P, R95P, R99P, R20mm, R50mm, Rx1day, Rx5day, and SDII, suggest a reduction in the intensity of heavy rainfall events over the period studied. However, the CWD index shows a significant upward trend, indicating an increase in the duration and frequency of rainfall events, albeit at a lower intensity. The results are consistent with previous studies and provide empirical support for increasing and decreasing trends in extreme weather events. In particular, the correlation analysis highlights the complex relationship between extreme weather indices and hydrometeorological disasters. Positive correlations between most extreme rainfall indices, except CDD, and floods and landslides underscore that extreme rainfall is the leading cause of floods and landslides in Jambi. Conversely, positive correlations between CDD and droughts and forest fires imply that periods of reduced rainfall and increased drought contribute to these disasters. The results provide valuable insights into the vulnerability of Jambi province to hydrometeorological disasters and highlight the importance of understanding regional variations in extreme weather events. The findings of the study enhance our comprehension of the interrelationships between climate indices and disasters, thereby furnishing a foundation for informed risk reduction and adaptation strategies in the context of evolving climatic conditions. While this research illuminates the observed trends and correlations, it also acknowledges the necessity for further investigation with a larger dataset and a longer time frame to reinforce the statistical significance of the observed relationships. Future studies should consider the multifaceted nature of meteorological factors influencing disasters and aim to include additional variables for a more comprehensive understanding of the evolving climate-disaster dynamics in Jambi Province.

6- Declarations

6-1- Author Contributions

Conceptualization, M.M.; methodology, M.M. and E.Y.; software, E.Y., R.R., and H.Y.; validation, E.Y., R.R., M.M., and H.Y.; formal analysis, M.M. and E.Y.; investigation, E.Y., R.R., and H.Y.; resources, M.M.; data curation, E.Y.; writing—original draft preparation, E.Y. and M.M.; writing—review and editing, C.H., P.R., and M.V.; visualization, E.Y., R.R., and H.Y.; supervision, M.M. and M.V.; project administration, H.Y.; funding acquisition, M.M. All authors have read and agreed to the published version of the manuscript.

6-2- Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6-3- Funding and Acknowledgements

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6-4- Institutional Review Board Statement

Not applicable.

6-5- Informed Consent Statement

Not applicable.

6-6- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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