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The Relationship between Extreme Precipitation Events in East Africa during the Short Rainy Season and Indian Ocean Sea Surface Temperature

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Abstract

The East African short rainy season (October-November-December) is one of the major flood seasons in the East African region. The amount of rainfall during the short rainy season is closely related to the lives of the people and the socio-economic development of the area. By using precipitation data and sea surface temperature data, this study reveals the spatial and temporal variation patterns of extreme precipitation during the East African short rainy season. Key findings include significant rainfall variability, with Tanzania experiencing the highest amounts in December due to the southward shift of the Intertropical Convergence Zone (ITCZ), while other regions receive less than 100 mm. Extreme rainfall events (90th percentiles) are evenly distributed, averaging 2 to 10 days annually. Historical data shows maximum seasonal rainfall often peaks at 15 mm, with frequent occurrences of daily rainfall exceeding 10 mm during OND. Additionally, a positive correlation (0.48) between OND precipitation extremes and Indian Ocean Dipole (IOD) anomalies is statistically significant. These findings highlight the climatic variability and potential trends in extreme rainfall events in East Africa, providing valuable insights for regional climate adaptation strategies.

Keywords

East Africa, Sea Surface Temperature (SST), Extreme Rainfall, Short Rains Season, Indian Ocean Dipole (IOD)

1. Introduction

In recent decades, the world has witnessed an increase in extreme rainfall events, such as floods. These intense rainfalls have significant adverse impacts on both human and natural systems (Myhre et al., 2019). It is widely recognized that global warming plays a crucial role in altering the characteristics of extreme weather events. Numerous studies have sought to identify changes in the frequency and intensity of these extreme events attributable to human activities or natural variability. Rainfall, often considered unpredictable, follows a probabilistic pattern in its occurrence, allowing for the assessment of its return periods corresponding to any given amount. Extreme rainfall involves an increase in the total mean precipitation at a location and more intense events occurring over short periods. Changes in the intensity of rainfall, coupled with changes in the intervals between events, can also lead to variations in overall totals (Ogega et al., 2020).

The year 2020 marked a notable period of extreme weather, with unprecedented heat waves, wildfires, and heavy rainfall leading to flooding and a record-breaking Atlantic hurricane season (LeComte, 2021, IPCC, 2021). Jakarta, Indonesia, recorded 377 mm of rain on January 1, 2020, breaking records dating back to 1866 and causing widespread flooding that displaced 30,000 people (Robinson et al., 2021). Often, extreme events occur when natural variability and long-term climate change align in the same direction.

Seasonal rainfall is crucial for the people living in Eastern Africa, in countries of Burundi, Kenya, Rwanda, Tanzania, and Uganda (Ogega et al., 2020). The number, duration, and timing of these rainfall seasons vary, primarily driven by the movement of the inter-tropical convergence zone (ITCZ) (Hafez, 2012). In 2019, East Africa experienced one of the wettest short rains (October-December) in recent decades, resulting in floods and landslides that adversely affected over 2.8 million people (Ogega et al., 2020).

Various indices characterize heavy precipitation events based on their severity. These include wet days (R1 ≥ 1 mm), heavy precipitation days (R10 ≥ 10 mm), very heavy precipitation days (R20 ≥ 20 mm), severe precipitation days (R50 ≥ 50 mm), very wet days (R95p, daily precipitation ≥ 95th percentile), extremely wet days (R99p, daily precipitation ≥ 99th percentile), annual total precipitation in wet days, and the simple daily intensity index (SDII), which measures mean precipitation on wet days. Previous studies, such as Ogega et al. (2020), evaluated the performance of 24 model runs from five Coordinated Regional Climate Downscaling Experiment (CORDEX) Regional Climate Models (RCMs) in simulating East Africa's precipitation patterns. These models projected precipitation changes for the period 2071-2099, based on the baseline period 1977-2005, under the representative concentration pathway (RCP) 8.5 scenario. The projections indicated a decrease in mean daily precipitation for MAM (March-May) and an increase for OND (October-December), along with an increase in consecutive dry days and a decrease in consecutive wet days. Additionally, there was a general increase in SDII and the width of the precipitation distribution right tail (99p-

90p), suggesting a higher likelihood of heavy and extreme precipitation events by the end of the 21st century. This indicates that global warming intensifies both the frequency and intensity of extreme precipitation events, which must be communicated effectively (Nicholson, 2017; Wainwright et al., 2019; Borhara et al., 2020).

The study also noted that in East Africa, including Tanzania, extreme precipitation events occurring once per decade may increase by about 10 times when considering both intensity and frequency. Changes in all aspects of heavy precipitation are vital for society, especially for constructing resilient infrastructure (Chang'a et al., 2017). This study explores the common causes and expected consequences of extreme rainfall in East Africa. Climatically, this region is primarily influenced by westerly winds in the central equatorial Indian Ocean that transport moisture away from East Africa, and trade winds that bring moisture to the region. Extreme positive Indian Ocean Dipole (IOD) (Saji et al., 1999) events trigger low-level easterly wind anomalies from the north-central Indian Ocean, weakening the westerly flow and leading to wetter conditions in East Africa and drier conditions in the central and eastern Indian Ocean (Saji & Yamagata, 2003a; 2003b). The IOD, a climate pattern affecting the Indian Ocean, significantly influences local weather, causing heavy rains or droughts in Africa and Australia, and associated sea-level changes can increase the threat of coastal flooding.

Another factor is the ITCZ, a zonal band of maximum precipitation resulting from surface meridional convergence and tropical atmospheric convection (Waliser & Gautier, 1993; Hafez, 2012). The ITCZ's position and behavior are shaped by the distribution of oceans and continents, with its position slightly north of the Equator over the eastern Pacific and Atlantic Oceans (Wang et al., 2022). Seasonal shifts in solar irradiance cause meridional convergence and local convection, defining wet and dry seasons in many tropical areas, including the monsoon regions of Asia, Australia, the Americas, and Africa (IPCC, 2014).

There has been a noticeable increase in rainfall intensity due to a warmer climate, a trend expected to continue, exacerbating flood risks. Developing flood-prone areas and the rising potential for damage are key factors in increasing flood risk. Warmer climates heighten the risk of river and flash flooding due to heavy rainfall and coastal flooding due to sea level rise. The impacts of climate-related extremes include ecosystem alterations, disruptions in food and water supply, infrastructure and settlement damage, and increased human morbidity and mortality, with significant consequences for mental health and well-being. In East Africa, the frequency of extreme events like floods, droughts, and landslides has risen, as evidenced by landslide occurrences in Uganda in July 2022 and northern Tanzania in December 2023. Rainfall accumulation exceeding 2000 mm per season has been observed in some areas (Makonyo & Zahor, 2023; Alupot et al., 2024), affecting approximately 2 million people and causing at least 1000 deaths due to extreme events linked to heavy precipitation. These statistics highlight the urgent need to understand and mitigate the impacts of extreme precipitation events in East

Africa, making this study essential for informing climate adaptation and resilience strategies.

The Indian Ocean Dipole plays a critical role in influencing precipitation in East Africa through various atmospheric and oceanic processes. During positive IOD events, where sea surface temperatures (SST) rise in the western Indian Ocean and fall in the eastern part, moisture transport and convergence over East Africa intensify, leading to increased rainfall (Saji et al., 1999). In contrast, negative IOD events often result in decreased rainfall due to diminished moisture flux. These SST variations induced by the IOD alter the Walker circulation, shifting convection patterns and impacting the distribution and intensity of precipitation (Yuan et al., 2008). Additionally, research indicates that changes in zonal wind anomalies and associated jet stream shifts are crucial in directing moisture-rich winds towards East Africa during positive IOD phases (Behera et al., 2005). Apart from the IOD, variations in SSTs, particularly in the Indian Ocean and adjacent regions, independently affect East African precipitation by influencing local and regional atmospheric dynamics, such as convection and moisture availability. Although many studies have discussed the variability of East African precipitation and its influencing factors, the understanding of extreme precipitation in East Africa is still insufficient. The main objective of this study is to investigate the relationship between extreme precipitation events in East Africa and sea surface temperatures (SST) in the Indian Ocean.

2. Data and Methods

2.1. Data

This study uses CPC data because the CPC Gauge-Based Analysis of Global Daily Precipitation (CPC-Global) from NOAA offers a unified and high-quality precipitation product by optimally combining data from 30,000 stations, including those from GTS, COOP, and other NMAs. This dataset ensures consistency and agreement across spatio-temporal scales, despite the historical decline in the number of operational gauges due to factors such as increasing operational costs, data release restrictions, and site abandonment (Strangeways, 2006). The CPC-Global product addresses timing discrepancies and multiday accumulations (Viney & Bates, 2004), making it a reliable source for accurate precipitation measurements and critical for precise climate analysis and comparison with other data sources. The data source can be downloaded through the following links
“https://psl.noaa.gov/data/gridded/data.cpc.globalprecip.html”,
“https://psl.noaa.gov/data/gridded/data.noaa.ersst.v5.html”.

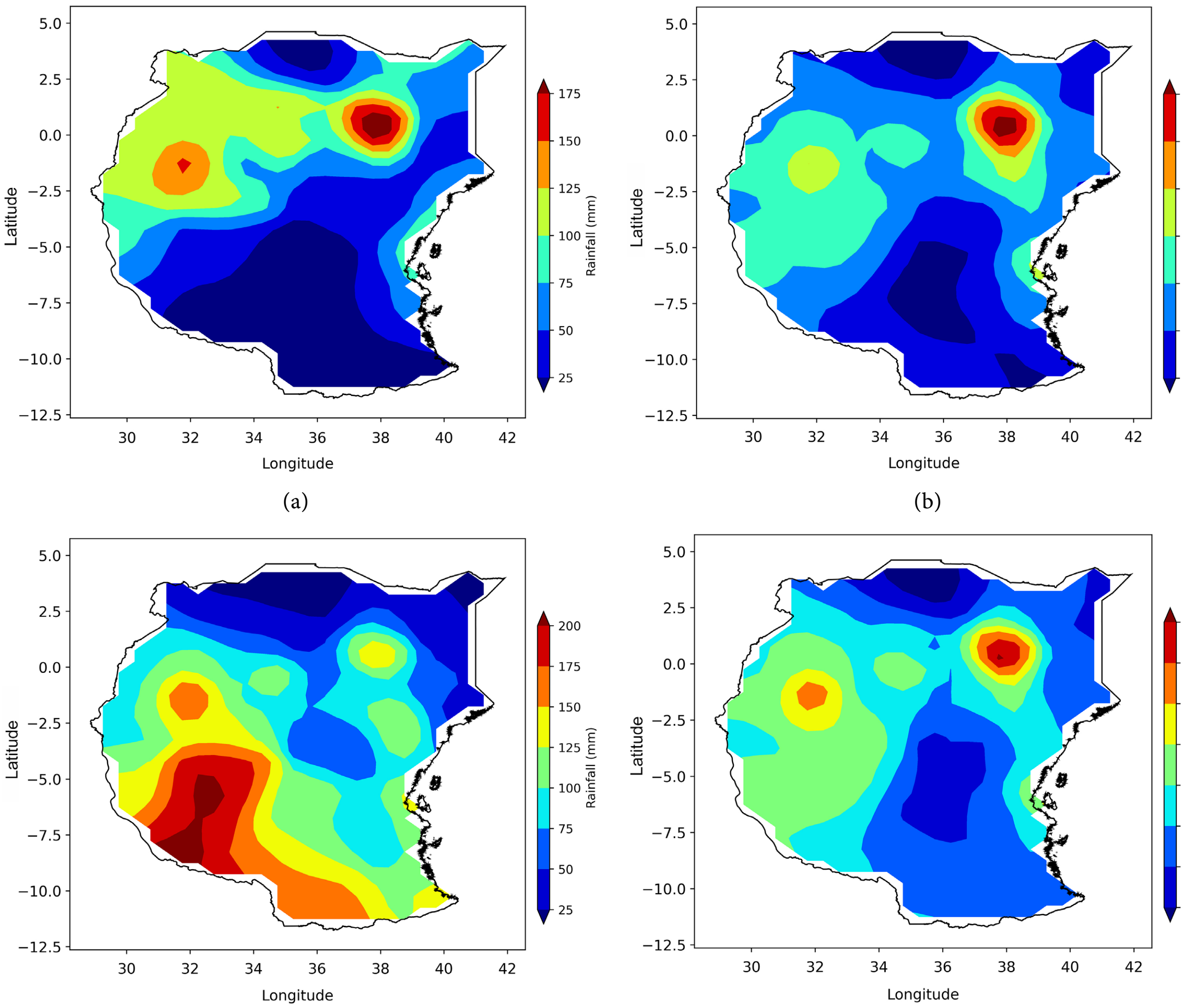
2.2. Methodology

This study utilizes a comprehensive methodology to analyze the variability and impacts of precipitation patterns in East Africa, focusing on extreme events and their correlation with climatic phenomena. The study area used in this study spans latitudes 12˚S to 5˚N and longitudes 29˚E to 43˚E, encompassing Burundi, Kenya, Rwanda, Tanzania, and Uganda. Key analyses include daily extreme frequency analysis to understand the frequency and distribution of extreme precipitation events (Nicholson, 2017), and a climatological study of rainfall patterns in East Africa to identify trends and seasonal variations (Williams & Funk, 2011). To analyze the trends in rainfall data, we employed the Sen's slope estimator and the Mann-Kendall test to assess the statistical significance and magnitude of the trends (Sen, 1968; Mann, 1945). The Sen's slope estimator, a non-parametric method, was used to determine the median rate of change in rainfall over the study period, providing a robust measure of trend magnitude that is less sensitive to outliers (Helsel & Hirsch, 2002). Concurrently, the Mann-Kendall test was applied to evaluate the statistical significance of the observed trends (Kendall, 1975). This non-parametric test assesses whether there is a monotonic upward or downward trend in the data series without assuming a specific distribution (Wilks, 2011). Additionally, a time series and correlation analysis of extreme events is performed to identify trends and their relationship with broader climatic patterns (Nicholson, 2015). The study also explores the correlation between anomalies in extreme precipitation frequency during the OND season and IOD anomalies over the period from 1979 to 2023, using correlation coefficients to quantify the relationship and assess statistical significance (Saji et al., 1999). The t-test was used to compare the means of rainfall data and IOD across different time periods to identify significant differences (Wilks, 2011). Robust statistical techniques such as boxplots, percent probability plots, and correlation analysis ensure accurate representation and interpretation of data. The analysis of climatic influences, such as the IOD and ITCZ, provides insights into the factors driving precipitation variability and extreme events in the region (Nicholson, 2017). By employing these methodologies, the study aims to provide a detailed understanding of precipitation dynamics in East Africa, contributing valuable insights for climate prediction, policy-making, and regional planning. The countries bordering this region include the Democratic Republic of Congo to the west, South Sudan to the north, Somalia to Northeast and Mozambique to the south.

3. Results

3.1. Rainfall Climatology in East Africa

The study of seasonal (OND) mean rainfall climatology in East Africa from 1979 to 2023 indicates an even rainfall distribution across the region. Areas around latitude 6˚ South to 4˚ North experience high rainfall availability which indicates favorable conditions for OND seasonal rainfall (**Figure 1(d)**). This heightened rainfall can be attributed primarily to the proximity to the ITCZ, which is driven by the movement of the sun. During the OND season, the sun crosses the equator and moves southward, causing the ITCZ to shift and bringing converging trade winds and moisture-laden air to this region. In contrast, other parts of East Africa receive less OND rainfall due to their distance from the equator, where the influence of the ITCZ diminishes as the sun position moves further away, resulting in less favorable conditions for significant rainfall. Narrowing the study to a country-specific analysis, monthly rainfall climatology plots indicate significant regional variations. Areas bordering Tanzania and Uganda, along with Central Kenya, experience substantial rainfall in October (Figure 1(a)), ranging between 100 mm and 175 mm, and even higher in November (Figure 1(b)), ranging between 120 mm and 280 mm. In December, most of Tanzania receives notably high rainfall, ranging from 100 mm to 200 mm (Figure 1(c)), with the Southwestern Highlands of Tanzania peaking with the highest amounts. In contrast, other countries in the region receive less than 100 mm during December. This variation is primarily due to the southward shift of the ITCZ, which brings increased moisture and rainfall to southern parts of East Africa while reducing rainfall in the northern regions.

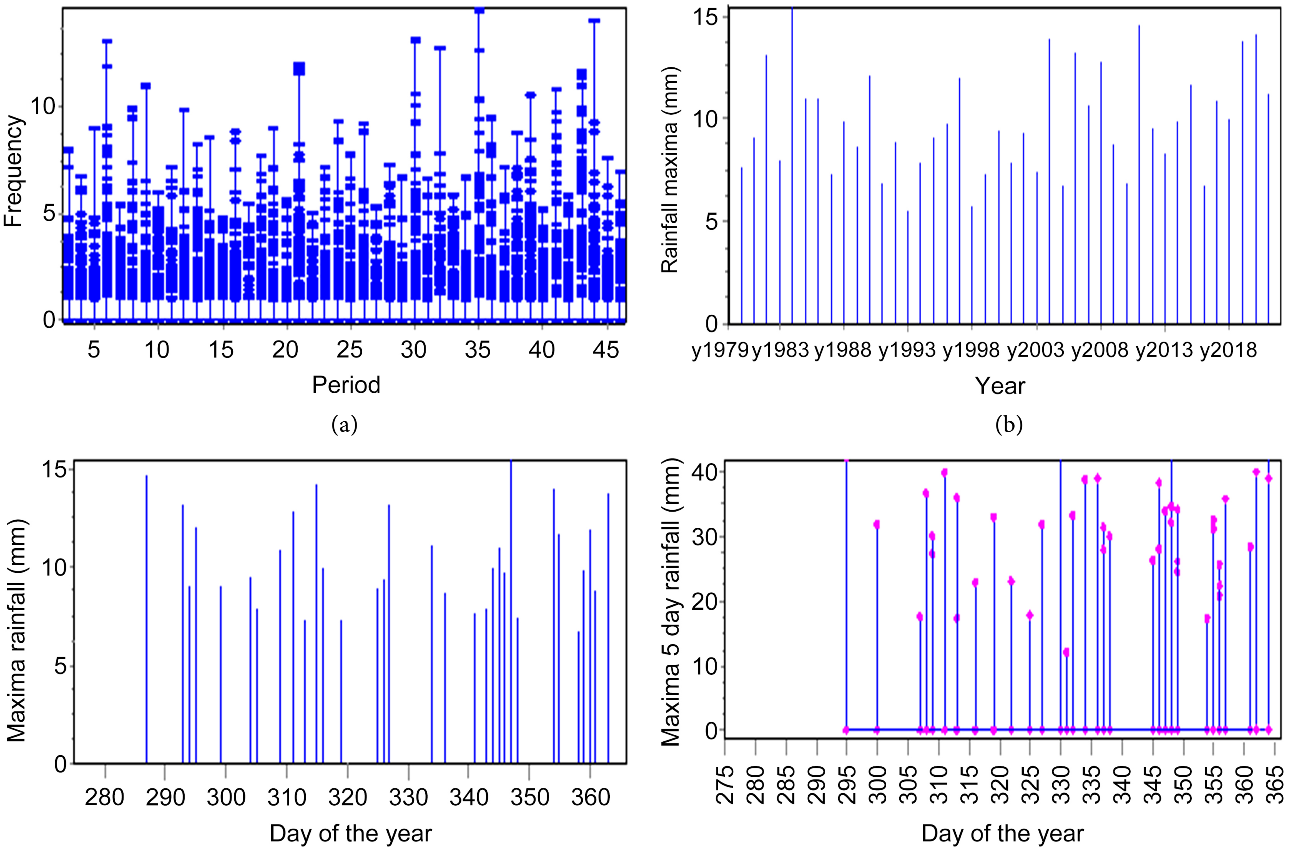


(a) (b) (c) (d)

Figure 1. East Africa's mean rainfall climatology for wet days (1979-2023) where (a) October, (b) November, (c) December, and (d) October to December (OND).

3.2. Daily and Seasonal Rainfall Analysis and Quality Control

Effective analysis of seasonal (OND) rainfall characteristics necessitates rigorous data quality control processes to ensure accuracy and reliability. These processes involve meticulous validation and correction of raw data, removing inconsistencies and errors that could skew results. Once quality control is ensured, daily boxplots (**Figure 2(a)**) reveal a balanced distribution of extreme frequency (90th percentiles), averaging between 2 to 10 days seasonally. Further, data plots show that maximum seasonal rainfall peaks (**Figure 2(b)**) were at 15 mm, with numerous years exhibiting extreme frequencies over 10 mm. Thoroughly inspected data (**Figure 2(c)** and **Figure 2(d)**) indicates that 5-day rainfall accumulations consistently exceed 12 mm, with some years reaching as high as 45 mm. Historical trends, assessed through a percent probability plot (**Figures 2(e)-(i)**) spanning 1979-2023, underscore the reliability of the data, showing a prevalent occurrence of daily rainfall exceeding 10 mm during OND. Quality-controlled data ensures confidence in findings where over half of the years experienced rainfall surpassing 50 mm, peaking at 120 mm with an 80% probability in October. In November, the median rainfall reaches 80 mm, while December often records over 100 mm. Thus, robust data quality control is essential for portraying accurate variability and intensity within the OND season.



(a) (b)

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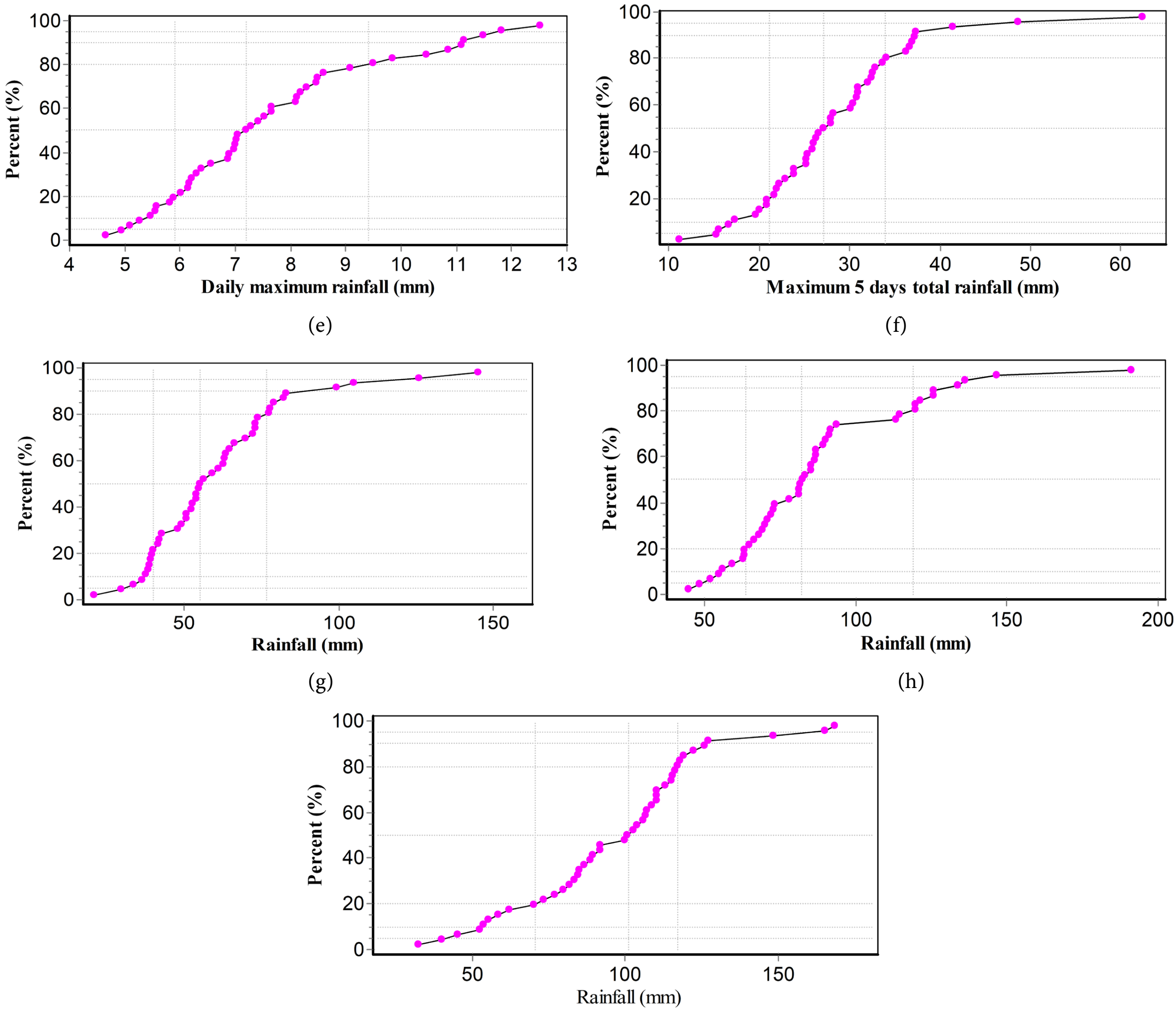


(e)

(f)

(g)

(h)

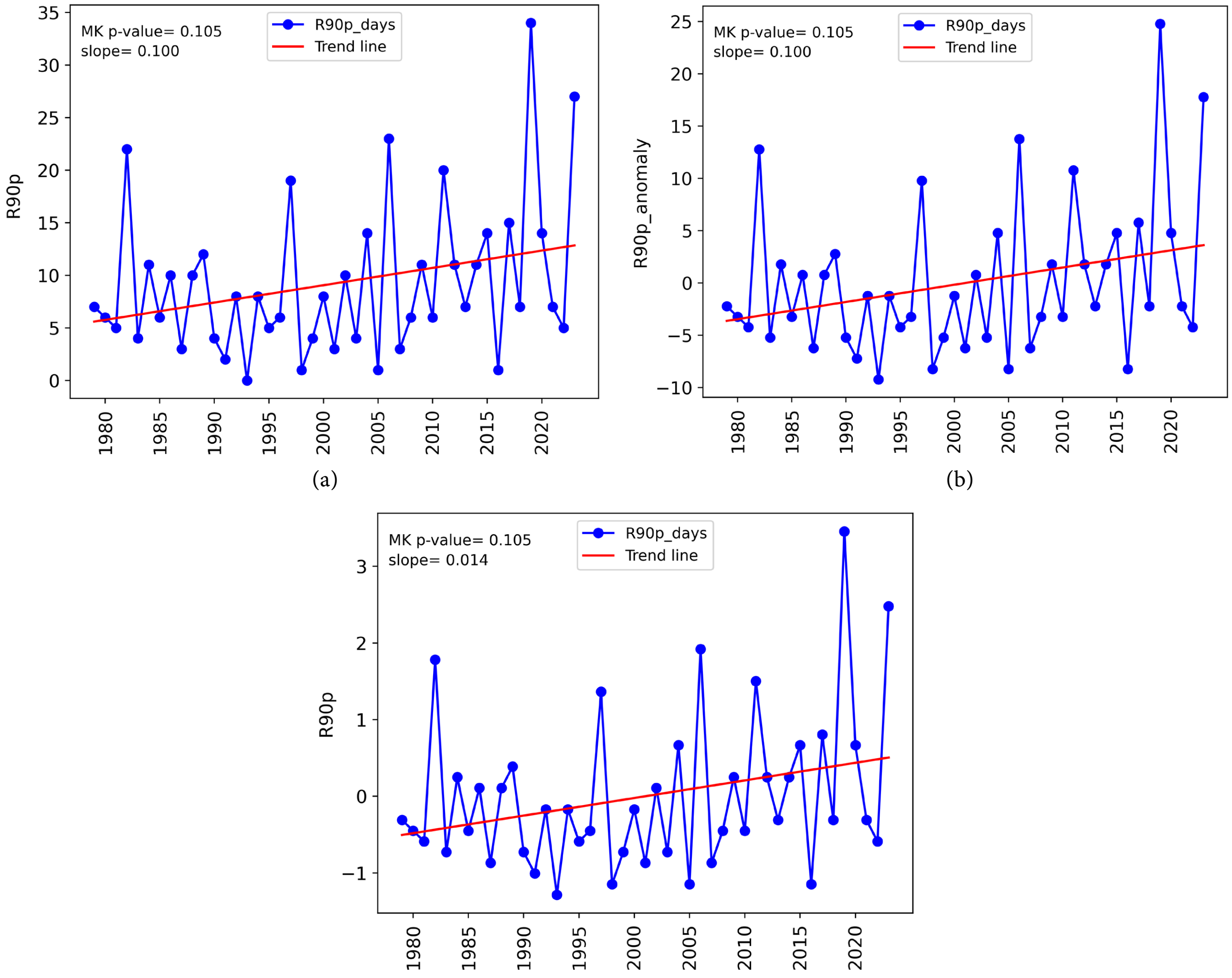
(i)

Figure 2. East Africa (a) Precipitation (>90%) for OND 1979-2023, (b) Precipitation daily Maxima for 1979-2023 by year, (c) Precipitation daily Maxima for 1979-2023by day number, (d) 5-day maximum precipitation against day of the year, (e) Percent probability plot 1979-2023, (f) Percent probability 5 days 1979-2023, (g) Percent probability for Oct 1979-2023, (h) Percent probability for Nov. 1979-2023 and (i) Percent probability for Dec. 1979-2023.

3.3. Extreme Events Time Series and Correlation Analysis

The data and methodology for generating area average precipitation time series for the period of 1979 to 2023 in East Africa involved several key steps. Initially, precipitation data was loaded from a NetCDF file using x-array, followed by the calculation of the average area for daily rainfall over East Africa within specific longitude and latitude ranges (Lon: 29˚E to 43˚E, and Lat: 12˚S to 5˚N) using CDO. Subsequently, the data underwent preprocessing to compute rainfall amounts specifically for wet days (defined as rainfall greater than 1 mm), and the 90th percentile of wet rainfall amount was calculated for each period to identify extreme events. These extreme precipitation events were then grouped by season

(OND) to obtain the count of extreme events for each season of the year. Finally, statistical analysis was performed, including the Mann-Kendall trend test to assess the trend in extreme precipitation events over time and the calculation of Sen's slope to quantify the magnitude of the trend. This comprehensive methodology provides a robust framework for analyzing and understanding the patterns and trends of extreme precipitation events in East Africa over the specified time period. The analysis of extreme frequency events using the 90th percentile threshold reveals significant patterns over the period of 1979 to 2023.



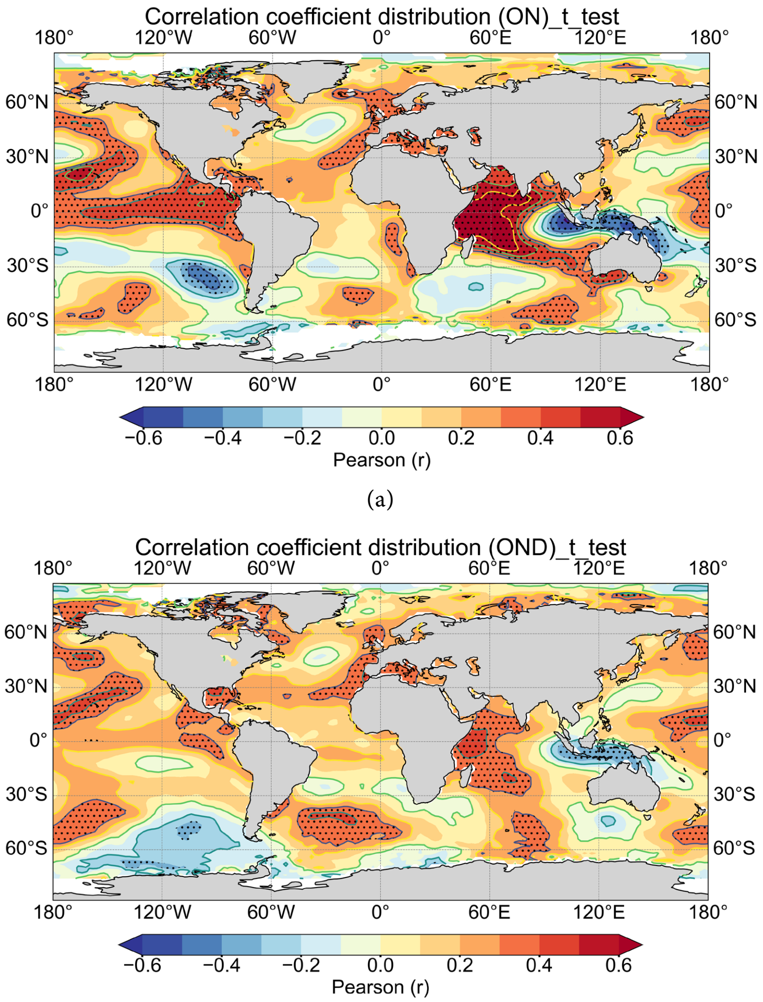
(a) (b)

(c)

Figure 3. East Africa area average time series for 90th percentiles for: (a) Extreme frequency trend OND, (b) Extreme frequency trend departures OND, and (c) Extreme frequency trend standardized anomaly OND.

In the time series plot for OND (Figure 3(a)), the maximum frequency reaches 34 events, with only two years experiencing no frequency events throughout the entire period. The slope of the trend line is calculated at 0.100, with a Mann-Kendall p-value of 0.105, indicating a potential trend though not statistically significant. Sixteen years lie above the trend line, suggesting an increasing trend in extreme frequency events. The departure plot (**Figure 3(b)**) illustrates a maximum departure of 23 and a minimum of −9, with 13 years exhibiting positive departures. The Mann-Kendall p-value is again 0.105, with a slope of 0.100. Moreover, the standardized time series anomaly plot (**Figure 3(c)**) highlights extreme values, with six years above 1 index on the positive side and five years below −1 index on the negative side. The Mann-Kendall p-value remains at 0.105, indicating consistency across analyses, while the slope is calculated at 0.014. These findings underscore the temporal variability and potential trends in extreme frequency events, providing valuable insights into the climatic dynamics of the region over the specified period.

3.4. Correlation between Extreme Precipitation Events and Sea Surface Temperature



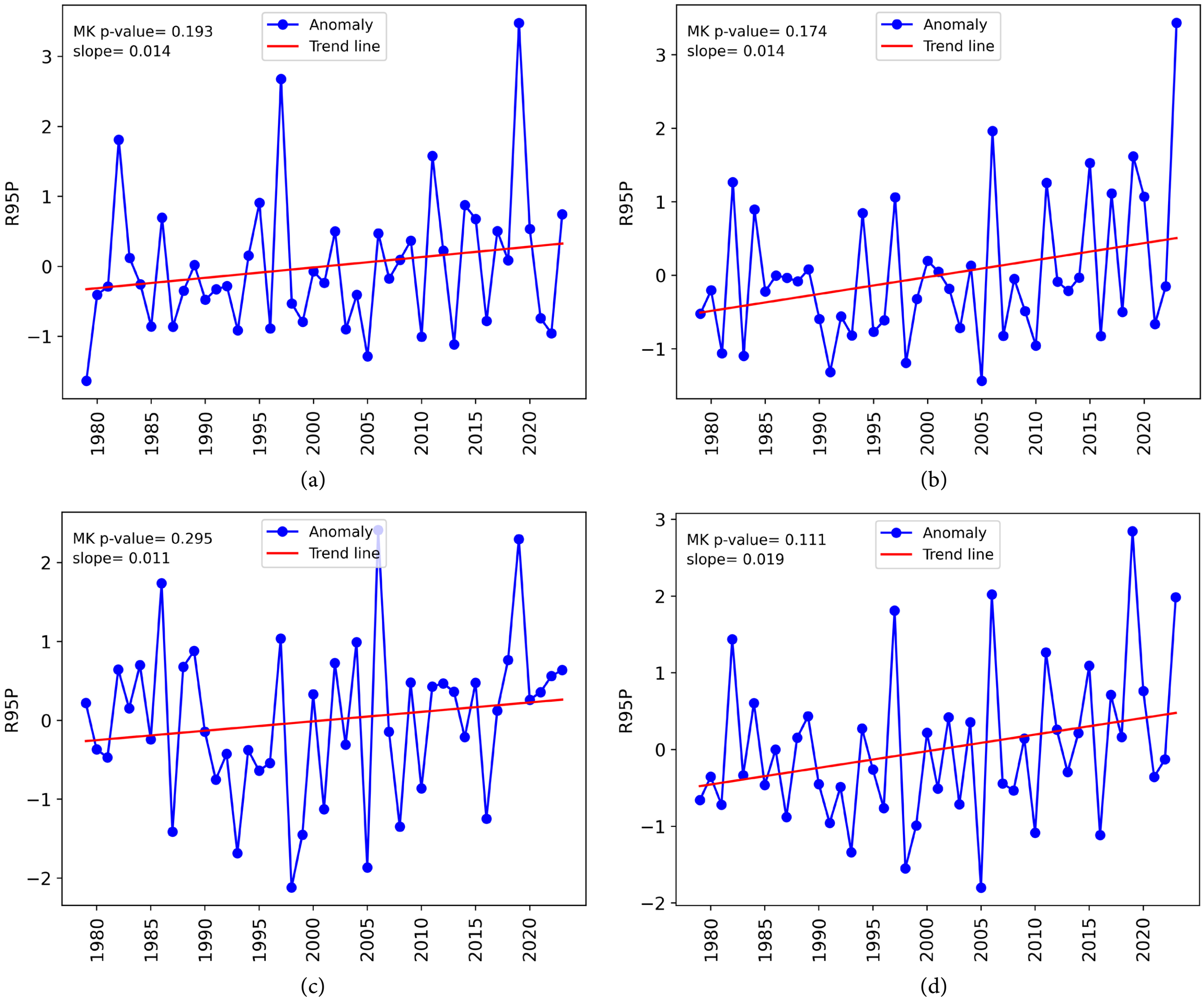
(a)

(b)

Figure 4. Spatial distribution of the correlation coefficients between the time series of the 90% threshold extreme precipitation days during the short rain season (OND) in East Africa and contemporaneous global SST anomalies for the period of 1979 to 2023, (a) October to December (OND) Precipitation vs October to November (ON) SST and (b) both for OND.

The spatial distribution of correlation coefficients between the time series of extreme precipitation events exceeding the 90th percentile during East Africa's short rain season OND and contemporaneous global SST anomalies has been investigated for the period spanning 1979 to 2023. To commence this analysis, extensive data preparation was undertaken, involving the acquisition and extraction of OND precipitation data across East Africa and October to November (ON) SST anomalies globally. Quality control procedures were rigorously applied to ensure the reliability and consistency of the datasets, mitigating potential biases or errors. Subsequently, correlation analysis was conducted between the OND precipitation and both OND/ON SST anomalies, utilizing robust statistical methods to quantify the relationship between these variables. To validate the significance of these correlations, a student t-test was applied to the spatial distribution of correlation coefficients between extreme precipitation events exceeding the 90th percentile during the OND season and contemporaneous global SST anomalies for the period spanning 1979 to 2023. The t-test results confirmed that the areas showing significant positive and negative correlations were indeed statistically significant. The resulting correlation coefficients were then spatially mapped to illustrate the geographical distribution of their strength and directionality. Through this comprehensive approach to data handling and analysis, insights into the complex interplay between East African precipitation extremes and global SST anomalies during the short rain season have been elucidated, providing valuable understanding for climate research and regional forecasting efforts. The study indicates that, the positive correlations between extreme precipitation events in Eastern Africa and sea surface temperatures (SST) were observed in several key regions. Firstly, over the Indian Ocean adjacent to Eastern Africa, indicative of a potential influence of SST in this area on extreme precipitation events (**Figure 4(a)**, **Figure 4(b)**) for OND and ON seasons. Secondly, in the South Atlantic Ocean southeast of South America, highlighting a linkage between SST in this region and extreme precipitation in Eastern Africa. Thirdly, positive correlation coefficients were identified in the Pacific Ocean region between longitudes 180W to 160W, suggesting a possible influence of Pacific Ocean temperatures on extreme precipitation in Eastern Africa. Conversely, negative correlations were noted in specific regions. Strong negative correlations were observed over the northern regions of the Australian Ocean, implying a cooling effect on extreme precipitation events in Eastern Africa. Negative correlations were also evident in the Southern Ocean southwest and south of South America, suggesting a potential cooling influence on extreme precipitation in Eastern Africa. These findings clarify the complex relationship between SST patterns and extreme precipitation occurrences in Eastern Africa, providing valuable insights for future climate research and regional forecasting efforts. The t-test results confirmed that the areas showing significant positive and negative correlations were indeed statistically significant. The resulting correlation coefficients were then spatially mapped to illustrate the geographical distribution of their strength and directionality. Through this comprehensive approach to data handling and analysis, insights into the complex interplay between East African precipitation extremes and global SST anomalies during the short rain season have been elucidated, providing valuable understanding for climate research and regional forecasting efforts.

3.5. Analysis of Extreme Precipitation Events for 95 Percentiles



(a) (b) (c) (d)

Figure 5. East Africa area rainfall average time series for 95th percentiles for: (a) October, (b) November, (c) December and (d) OND.

To comprehensively understand the patterns and trends in extreme rainfall events in East Africa, a further analysis was conducted using the 95th percentile threshold for the period from 1979 to 2023. This high threshold helps to isolate the most intense precipitation events, providing a clearer picture of extreme weather occurrences and their variability over time. This section provides detail findings from this analysis, highlighting significant trends and anomalies in extreme rainfall frequencies across different months and OND season. The analysis of extreme rainfall frequency events using the 95th percentile threshold from 1979 to 2023 reveals notable trends. In October (**Figure 5(a)**), the time series plot shows a trend slope of 0.014 with a Mann-Kendall p-value of 0.193, indicating a potential but not statistically significant trend, with 17 years above the trend line, suggesting an increase in extreme events. For November (**Figure 5(b)**), 15 years lie above the trend line and 24 years below, with a p-value of 0.174 and a slope of 0.014. The December (**Figure 5(c)**) standardized anomaly plot highlights 4 years with extreme positive values and 8 years with extreme negative values, with a p-value of 0.295 and a slope of 0.011, indicating a significant increase in extreme events. The seasonal plot (**Figure 5(d)**) shows a Mann-Kendall p-value of 0.168 and a slope of 0.018, with 7 years above the +1 index, 5 years below the −1 index, 17 years above the trend line, and 23 years below. These findings underscore the temporal variability and potential trends in extreme rainfall frequency events, providing valuable insights into the region's climatic dynamics.

3.6. Correlation between OND Precipitation Extremes and IOD Anomalies (1979-2023)

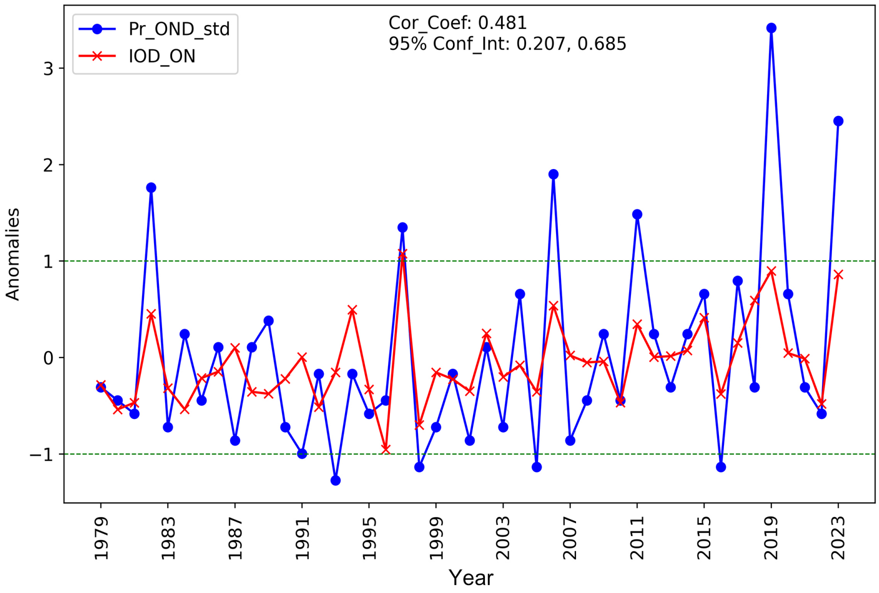


Figure 6. Correlation coefficient between rainfall extreme frequency events (OND) and IOD (ON) in East Africa 1979-2023.

Understanding the intricate relationship between precipitation patterns and climatic phenomena is essential for unraveling the dynamics of regional climate systems. In this context, the correlation between extreme precipitation frequency during the OND season and Indian Ocean Dipole (IOD) anomalies emerges as a pivotal area of investigation. The IOD, characterized by the difference in sea surface temperatures between the western and eastern Indian Ocean, exerts a profound influence on weather patterns across East Africa, particularly during the short rain season. Exploring the correlation between OND precipitation extremes and IOD anomalies from 1979 to 2023 provides valuable insights into the interplay between these climatic drivers and their implications for regional precipitation variability in East Africa. The correlation coefficient between precipitation extreme frequency (OND) and IOD anomalies (**Figure 6**) for the period of 1979-2023 in East Africa is 0.48. This indicates a moderate positive linear relationship between the two variables. Additionally, the 95% confidence interval for the correlation coefficient is between 0.21 and 0.68. Since the interval does not include zero, the correlation is statistically significant at the 95% confidence level, suggesting that changes in IOD anomalies are associated with changes in precipitation extreme frequency during the specified period.

4. Conclusion

In conclusion, this comprehensive study of seasonal (OND) rainfall characteristics in East Africa from 1979 to 2023 highlights significant regional and temporal variability in precipitation patterns. Rigorous data quality control processes ensured the accuracy and reliability of the findings, which revealed balanced distributions of extreme rainfall events, with notable peaks in 5-day accumulations and daily maximum rainfall during the OND season. The analysis underscores the critical role of the ITCZ, driven by the seasonal movements, in influencing rainfall distribution across the region. Country-specific analysis further clarifies that, areas bordering Tanzania and Uganda, as well as Central Kenya, receive substantial rainfall in October and November, while December sees heightened rainfall primarily in Tanzania, particularly in the Southwestern Highlands, due to the southward shift of the ITCZ. The study also identifies significant correlations between East African precipitation extremes and global sea surface temperature anomalies, particularly in the Indian Ocean, South Atlantic Ocean, and Pacific Ocean, as well as notable negative correlations in the Australian and Southern Oceans. These findings provide valuable insights into the climatic dynamics of East Africa, emphasizing the influence of global SST patterns on regional precipitation extremes. This knowledge is crucial for improving climate forecasting and water resource management in the region, ultimately aiding in better preparation for and mitigation of the impacts of extreme weather events. Among the limitation for this study was the use of single data sources and focusing exclusively on the SST and IOD limits the influence of other climate factors like ENSO and local atmospheric dynamics. Also, the data resolution may not accurately capture localized or short-term events, and the statistical methods might not fully address non-linear relationships or seasonal and interannual variations. Future research should include diverse datasets, examine other climate indicators, use higher-resolution data, and employ advanced statistical and modeling techniques. Furthermore, mechanistic studies and analyses incorporating multiple variables, such as atmospheric pressure and wind patterns, are recommended to gain a more comprehensive understanding of the factors influencing extreme precipitation in the region.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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