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Analysis of trends and variability in frequency and intensity indices of precipitation over Myanmar during 1985-2020

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Abstract: In this study, an analysis of long-term extreme precipitation indices was conducted using daily observation data from 38 stations in Myanmar spanning from 1985 to 2020. Three frequency indices and six intensity indices of precipitation were analyzed using RClimDex software. The Mann-Kendall test, along with Sen's slope method, was employed to determine the trends and magnitude of extreme indices. The spatial distribution patterns varied across different physiographic regions, with 63% to 76% of the stations displaying increasing trends in various indices. The consecutive dry days showed increasing trends in the hilly regions, whereas the consecutive wet days exhibited decreasing trends in those areas. For the maximum 1-day precipitation, 45% of stations displayed increasing trends, with 5% of those being statistically significant. The Western Hilly Region exhibited rising trends in extremely wet days, whereas other regions have experienced mixed trends. These findings highlight the need for adaptive water resources engineering and management to address the localized changes of precipitation trends that affect floods and droughts in Myanmar.

Keywords: precipitation; RClimDex; extreme indices; rainfall

1. Introduction

Precipitation plays a vital role in understanding climate change, as it is a key indicator of the global water cycle [1]. Analyzing long-term trends in precipitation is essential for civil engineering, as infrastructure such as roads, bridges, reservoirs, and drainage systems must be designed to accommodate current and future climate conditions [2], [3]. The changing patterns of rainfall were found as the "signature" of climate change, noting that inadequate development in this area increases vulnerability to climate change impacts [4]. Myanmar, located in Southeast Asia, experiences a diverse monsoon climate, shaped by the Southwest Monsoon and tropical systems like cyclones from the Bay of Bengal. Precipitation in Myanmar varies significantly across regions, with most rainfall concentrated in the monsoon season from May to October [5]. Over the past few decades, Myanmar has seen substantial climate change [6], [7]. leading to alterations in the timing, intensity, and frequency of precipitation. The observed and anticipated changes in climate involve an overall rise in temperature, a progressive alteration in rainfall patterns, and a rise in frequency and intensity of severe climate conditions such as heat waves, droughts and floods [8], [9].

In the report of the Climate Risk Index 2025, Myanmar was ranked fourth among 183 countries most affected by extreme weather events during 1993-2022 [10]. The trends and variability of extreme climatic events, especially precipitation indices, have serious consequences for Myanmar, where a large portion of the population relies on agriculture. Prior research on precipitation in Myanmar has predominantly focused on analyzing long-term trends, variability, and the impacts of large-scale climatic phenomena such as the El Niño–Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) [3], [11]; however, it has not focused on extreme precipitation indices. While numerous researchers have examined the observed trends in extreme climatic indices at global and regional levels, Myanmar has not been adequately addressed in their studies. The observed trends and variability of seasonal and annual precipitation in Pakistan from 1960 to 2016 were examined in [12]. Their results identify significant trends in seasonal and annual precipitation patterns across Pakistan, highlighting regional variations and potential implications for water resource management and agricultural planning. A few numbers of research have been conducted to investigate the observed trends and rainfall extreme events on a regional scale, including Myanmar; however, only a few stations were employed in their studies. For instance, [13] analyzed data from six stations, while [14] opted for five stations in Myanmar to study the trends of extreme indices in temperature and precipitation in Southeast Asia, the South Pacific region, and the broader Indo-Pacific region. Their findings indicate a notable decrease in the frequency of rainy days across Myanmar, while total annual precipitation increased at multiple monitoring stations. Additionally, [15] studied daily rainfall indices over the Indochina Peninsula, including Myanmar, from 1960 to 2007. Their results reveal an increase in the number of heavy rainfall days ranging from 11 to 42 days, with a distribution of decreasing trends in the maximum 1-day and 5-day precipitation indices observed in a limited area of northern Myanmar. The use of uneven stations distribution and a lack of long-term observational data may contribute to the disparities in projected trends in these studies. While several comprehensive analyses of observed rainfall have been undertaken, there is still a notable gap in research specifically addressing extreme precipitation events in Myanmar. For instance, [16] examined trends and alterations in temperature and precipitation extreme indices in Myanmar by analyzing observed data from 35 stations during 1981-2015. Their findings reveal that rising trends in precipitation anomalies were not statistically significant over the 35-year period. Conversely, slight trends towards wetter conditions were observed, with the rate of 7.652 mm/year. Additional indicators of precipitation extremes, such as the annual total wet day precipitation, the numbers of heavy precipitation days, extremely wet days and consecutive wet days, align with these rising trends.

The assessment of precipitation extremes often relies on standardized climate indices. Despite advancements in understanding precipitation extremes in Myanmar, several challenges persist. One significant limitation is the scarcity of high-quality and long-term recorded data. Although Myanmar has a network of meteorological stations, many of these stations experience issue such as incomplete datasets or inadequate maintenance, which complicate the analysis of long-term precipitation trends. Closing these gaps would enhance the understanding of climate change impacts in Myanmar and provide valuable insights for informing policies on climate adaptation, disaster risk management, and sustainable development. With the overview of these findings, this study aims to investigate the trends and variations of extreme precipitation indices in Myanmar by employing the Mann–Kendall and Sen's slope tests. While previous studies have been conducted, they frequently depend on a restricted number of ground stations. In contrast, this study utilizes a dense network of recent precipitation data. Daily precipitation data collected from 38 stations were used to calculate the precipitation indices, following the methodologies outlined by the Expert Team on Climate Change Detection and Indices (ETCCDI) and processed using the RClimDex software.

The study of precipitation indices is essential for identifying and understanding trends in climate extremes. These indices are essential indicators of climate change and help in identifying vulnerable areas. They also support risk assessment and guide targeted adaptation strategies in sectors such as agriculture, water resource engineering and management, and public health. Moreover, climate indices are also essential for verifying climate models and enhancing the accuracy of future climate projections, thereby informing sustainable planning and policy decisions.

2. Material and methods

2.1 Study area and data collection

Myanmar is located approximately between latitudes 9° 32' N and 28° 31' N and longitudes 92° 10' E and 101° 11' E. The country shares borders with India and Bangladesh to the west, China to the north and Thailand and Laos PDR to the east. To the south, it is bordered by the Bay of Bengal and the Andaman Sea. Myanmar has around 60 rivers, most of which flow from the north to the south, and major rivers include the Ayeyarwady, Chindwin, Sittaung, and Thanlwin. Its coastline, approximately 1,470 km long, follows the continental shelf and features shallow bathymetry in the deltaic areas. The total area is about 676,577 km2 and has a population of approximately 52 million, with approximately 77% living in rural regions [16]. There are seven states and seven regions in Myanmar as the administrative aspect. Moreover, the country can be divided into eight physiographic regions based on physical characteristics and topography [8]. The physiographic regions are, namely, the Ayeyarwady Delta Region, Central Dry Zone Region, Eastern Hilly Region, Northern Hilly Region, Rakhine Coastal Region, Sittaung and Yangon Deltaic Region, Southern Coastal Region and Western Hilly Region and they are shown in Figure 1.

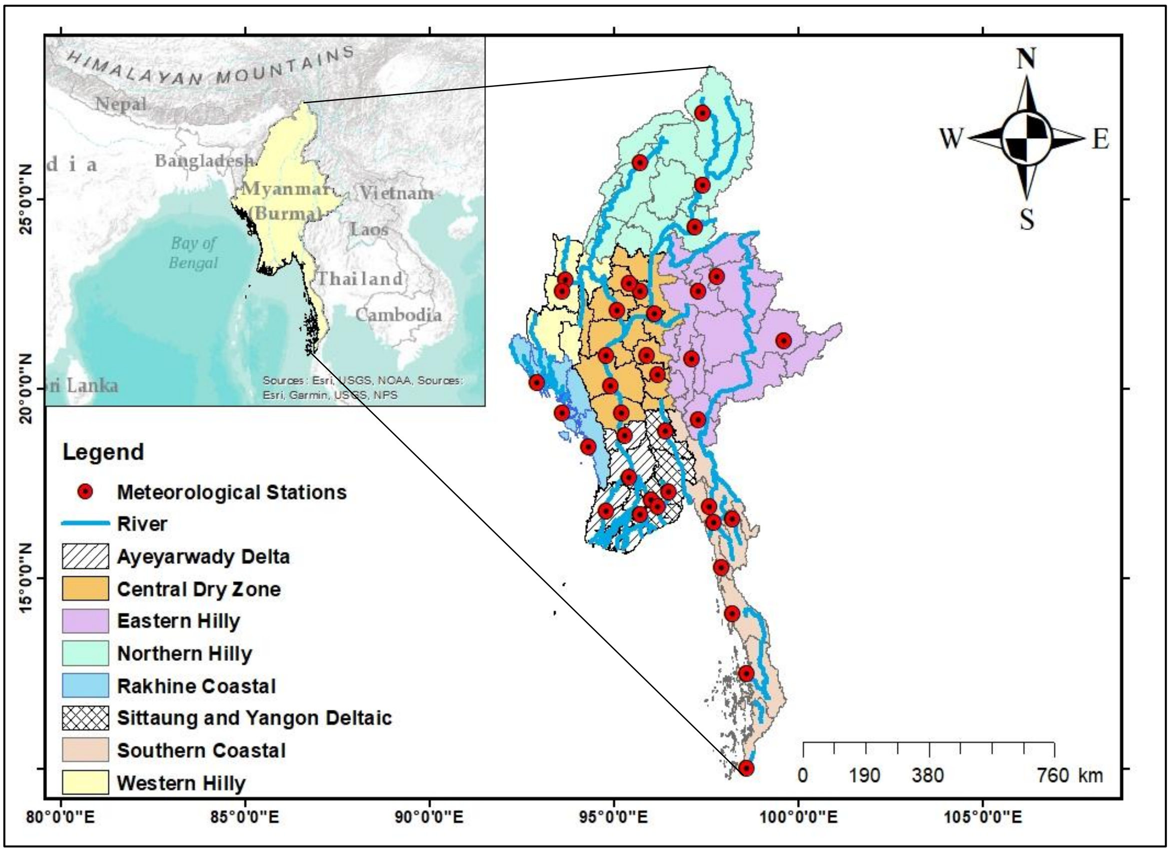

Figure 1. Location map of selected meteorological stations in Myanmar

This study examines the entire territory of Myanmar, encompassing all physiographic zones, though with data from a limited number of stations. The Department of Meteorology and Hydrology (DMH) manages data collection from 117 stations across the country [17]. Under the guidance of the World Meteorological Organization (WMO) in 1947, DMH initially managed eight meteorological stations and some part-time observatories. The number of stations increased to 25 by 1960 and then 77 by 1980. A few stations were installed later, and there are currently 117 stations in total [17]. For this

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study, daily precipitation records from 38 meteorological stations spanning 1985 to 2020 (36 years) were collected. Figure 1 shows the locations of the selected stations and the physiographic regions across Myanmar.

Table 1. Detailed information of the meteorological stations used in this study

Sr. No.	Region name	Station name	Station code	North Lat: (DD)	East Long: (DD)	Elev. (m)
1	Ayeyarwady Delta	Pyay	48,077	18.48	95.13	58
2	Ayeyarwady Delta	Hinthada	48,087	17.40	95.25	26
3	Ayeyarwady Delta	Pathein	48,094	16.46	94.46	9
4	Ayeyarwady Delta	Maubin	48,095	16.44	95.39	3
5	Central Dry Zone	Yayoo	48,032	22.75	95.42	107
6	Central Dry Zone	Shwebo	48,033	22.35	95.43	106
7	Central Dry Zone	Monywa	48,037	22.06	95.08	81
8	Central Dry Zone	Mandalay	48,042	21.59	96.06	74
9	Central Dry Zone	Chauk	48,052	20.54	94.50	82
10	Central Dry Zone	Meiktila	48,053	20.50	95.50	214
11	Central Dry Zone	Magway	48,065	20.07	94.55	52
12	Central Dry Zone	Yamethin	48,067	20.25	96.09	199
13	Central Dry Zone	Aunglan	-	19.40	95.20	54
14	Eastern Hilly	Lashio	48,035	22.56	97.45	747
15	Eastern Hilly	Hsipaw	48,040	22.36	97.18	436
16	Eastern Hilly	Taunggyi	48,057	20.47	97.03	1436
17	Eastern Hilly	Kengtung	48,060	21.18	99.37	827
18	Eastern Hilly	Loikaw	48,075	19.41	97.13	895
19	Northern Hilly	Putao	48,001	27.20	97.25	409
20	Northern Hilly	Hkamti	48,004	26.00	95.42	146
21	Northern Hilly	Myitkyina	48,008	25.22	97.24	145
22	Northern Hilly	Bhamo	48,019	24.16	97.12	111
23	Rakhine Coastal	Sittwe	48,062	20.08	92.53	4
24	Rakhine Coastal	Kyaukphyu	48,071	19.25	93.33	5
25	Rakhine Coastal	Thandwe	48,080	18.28	94.21	9
26	Sittaung and Yangon Deltaic	Taungoo	48,078	18.55	96.28	47
27	Sittaung and Yangon Deltaic	Hmawbi	48,092	17.06	96.04	27
28	Sittaung and Yangon Deltaic	Bago	48,093	17.20	96.30	15
29	Sittaung and Yangon Deltaic	Kaba-aye	48,097	16.46	96.10	20
30	Southern Coastal	Hpa-an	48,099	16.45	97.40	9
31	Southern Coastal	Mawlamyine	48,103	16.30	97.37	21
32	Southern Coastal	Kawkareik	48,104	16.38	98.15	17
33	Southern Coastal	Yay	48,107	15.15	97.52	3
34	Southern Coastal	Dawei	48,108	14.06	98.13	16
35	Southern Coastal	Myeik	48,110	12.26	98.36	36
36	Southern Coastal	Kawthong	48,112	9.58	98.35	46
37	Western Hilly	Hakha	48,030	22.39	93.37	1866
38	Western Hilly	Falam	48,031	22.55	93.41	1372

2.2 Extreme indices of precipitation

The first step of this study is preparing, or cleaning the collected data, a crucial process for statistical analysis, as climate variables and trends are highly sensitive to erroneous outliers from various sources. Raw data may contain special values, alphabets and words, wrong data types, missing values, not a number, unreasonable data and outliers. A quality control procedure was conducted by visualizing the data using graphs in MS Excel and performing additional quality checks with the RClimDex software (version 1.1).

Analyzing extreme climate indices requires carefully identifying and assessing different types of weather extremes. The Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI) has identified a core set of climate indices in which eleven indices for precipitation and sixteen indices for temperature in RClimDex. While most indices measure frequency, some assess intensity for both precipitation and temperature. Table 2 shows the selected precipitation indices based on their relevance to the region and its climatic characteristics.

Table 2. List of the selected extreme precipitation indices

ID	Name of index	Definition	Unit
CDD	Consecutive dry days	Maximum number of consecutive dry days (precipitation of <1 mm)	days
CWD	Consecutive wet days	Maximum number of consecutive wet days (precipitation of ≥1 mm)	days
Rtmm	Number of heavy precipitation days	Annual count of days when precipitation is ≥ t mm (t = threshold value)	days
PRCPTOT	Annual total wet day precipitation	Annual total from days ≥1-mm precipitation	mm
SDII	Simple daily intensity index	Ratio of annual total precipitation to the number of wet days (defined as PRCP>=1.0mm) in the year	mm/day
RX1day	Maximum 1-day precipitation amount	Annual maximum 1-day precipitation	mm
RX5day	Maximum 5-day precipitation amount	Annual maximum consecutive 5-day precipitation	mm
R95p	Very wet days	Annual total precipitation of days in >95th percentile	mm
R99p	Extremely wet days	Annual total precipitation of days in >99th percentile	mm

2.3 Trend detection

The trends in precipitation indices were analyzed using the Mann–Kendall test and Sen's slope methods. The Mann–Kendall test identifies significant monotonic trends—either increasing or decreasing—in time series data, while Sen's slope estimates the trend's magnitude using a linear model. Trend detection was performed with the MAKESENS template in Microsoft Excel [1], [18]. The non-parametric Mann–Kendall test is applied when the values in a time series, denoted as X_i, can reasonably be assumed to follow a specific model [18].

$$X_i = f(t_i) + \varepsilon_i \tag{1}$$

The null hypothesis (H_0) assumes no trend in the time series, while the alternative hypothesis (H_1) proposes either a decreasing or increasing trend. The statistical tests utilized include the S-statistic and the Z-statistic. For time series with fewer than 10 data points, the S-statistic is employed, while the Z-statistic is used for series with 10 or more data points. In the normal approximation method (Z test), the first step involves calculating the variance of (S) using the following formula.

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t(t_p-1)(2t_p+5)\right] \tag{2}$$

Then, the value of Z statistic is computed by using S and VAR(S) as follows.

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}}, & if\ S > 0 \\ \frac{S+1}{\sqrt{VAR(S)}}, & if\ S < 0 \end{cases} \tag{3}$$

Additionally, when S = 0, the Z-value is also zero. The statistical significance of a trend is evaluated using the Z-value. A positive Z-value suggests an upward trend in the time series, while a negative Z-value indicates a downward trend. The null hypothesis (H_0) is rejected if the absolute Z-value exceeds $Z_{1-\alpha/2}$. Under such circumstances, the trend is deemed significant at the chosen significance level (α). For this analysis, trends were considered significant at a 95% confidence level (α=0.05). The Sen's slope method a non-parametric technique was used to assessment the degree of tendencies in the data at time series analysis [18]. The slope of "n" pairs of statistics can be first estimated by using the following equation:

$$\beta_i = median\left[\frac{x_j - x_k}{j-k}\right] \forall (k < j) \tag{4}$$

In this formula, x_j and x_k represent data values at times j and k, separately, and time j is after time k (k ≤ j). β_i is the Sen's slope estimator. A negative β_i value signifies a declining trend; a positive β_i value represents an increasing trend over time. If "n" is an even number, then the Sen's slope estimator is computed by using the following equation:

$$\beta_{med} = \frac{1}{2}\left(\beta_{[n/2]} + \beta_{[(n+2)/2]}\right) \tag{5}$$

If "n" is an odd number, then the Sen's slope estimator is calculated by using the below formula:

$$\beta_{med} = \beta_{[(n+1)/2]} \tag{6}$$

3. Results and discussion

3.1 Anaysis of collected precipitation data

Figure 2 illustrates the long-term annual precipitation in each physiographic region. The figure clearly shows that annual precipitation amounts vary across different regions. The highest amount of precipitation can be observed in the Rakhine Coastal Region (4975 mm), followed by the Southern Coastal Region (4688 mm), the Northern Hilly Region (3053 mm), the Sittaung and Yangon Deltaic (4688 mm), the Ayeyarwady Delta (2247 mm), the Western Hilly (1654 mm), the Eastern Hilly (1277 mm) and the Central Dry Zone (833 mm). Relatively high precipitation variations in the coastal regions are clearly visible. For instance, in Rakhine, there was an obvious increase in 1994 (6259 mm) and a decrease in 1989 (3654 mm). Similarly, in the Southern Coastal Region, there was an obvious increase in 1994 (5862 mm) and a decrease in 1998 (3269 mm).

According to the time series results over 36 years, the Central Dry Zone exhibited the lowest rainfall amount, and in 1998, the annual rainfall was only 566 mm. This finding suggests that although precipitation varied significantly over the hilly regions and coastal areas, the Central Dry Zone persistently received much less precipitation throughout time, indicating an obvious disparity in the climatic trend of the region. The exceptionally low precipitation in 1998 highlights the arid conditions prevalent in the Central Dry Zone.

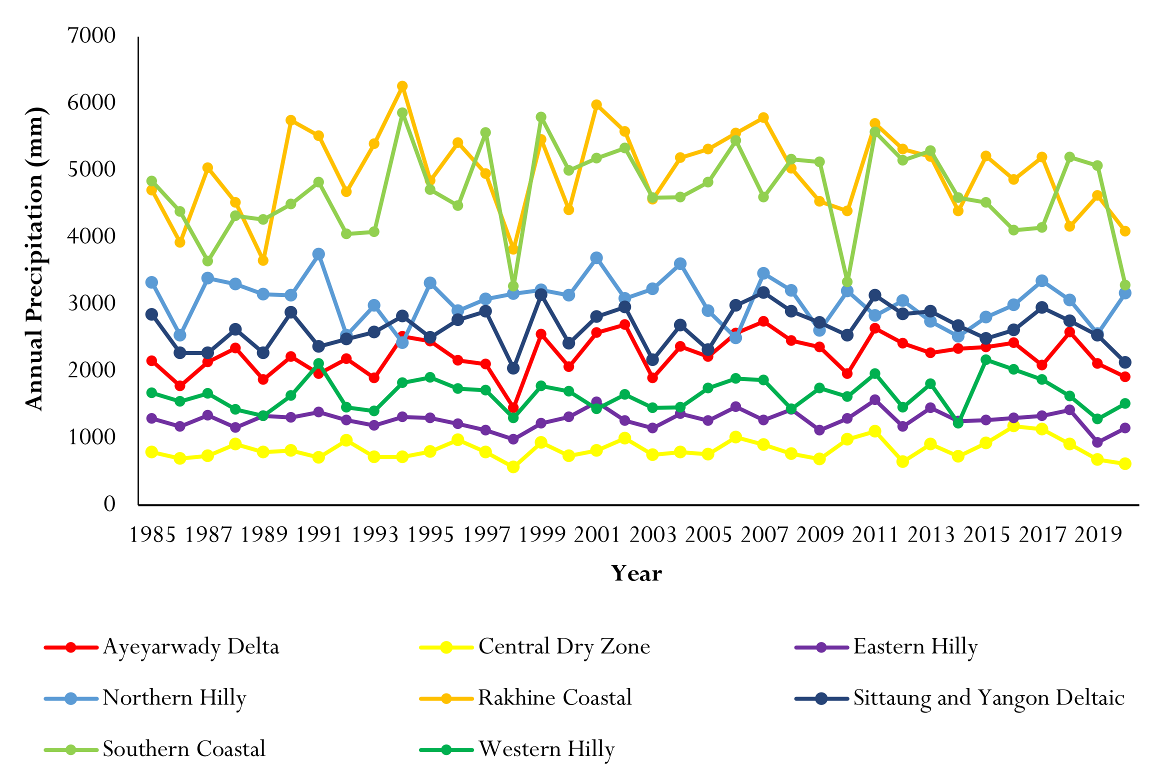
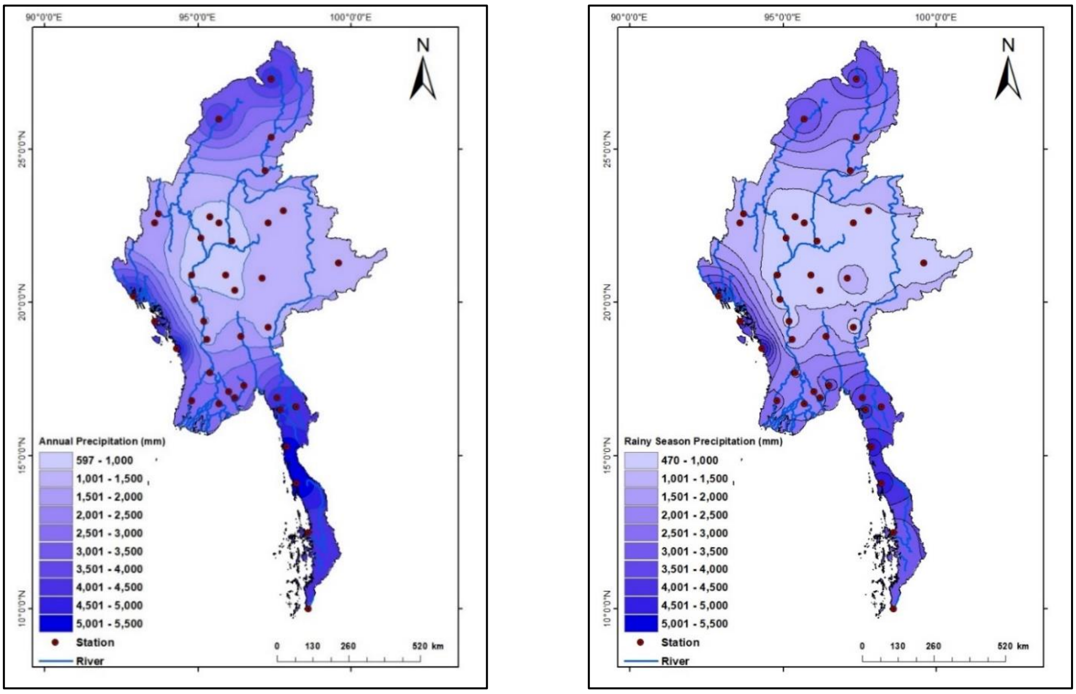


Figure 2. Long-term annual precipitation of eight regions in Myanmar during 1985- 2020

The precipitation distribution map identifies precipitation variations across Myanmar, highlighting with high and low precipitation levels. Figure 3 displays the spatial distribution patterns of average annual precipitation and rainy season precipitation (from mid-May to October) for the period 1985 to 2020. The spatial analysis of annual and seasonal (rainy season) precipitation was conducted using data from 38 rain gauge stations across Myanmar. Annual precipitation is categorized into ten classes, ranging from very low (597-1000 mm) to very high (5001-5500 mm). The spatial distribution map of annual precipitation indicates the pattern of rainfall events across the country. It shows very high precipitation along the coastal areas, particularly in the Rakhine Coastal and Southern Coastal Regions. Moreover, the northern part of the country, notably at Putato and Hkamti stations, experiences very high precipitation. In contrast, the Central Dry Zone Region exhibits comparatively lower precipitation, which is a drought-prone area of the country. Generally, the spatial distribution pattern of the rainy season precipitation map mirrors the pattern of annual precipitation map, but the Eastern Hilly Region also shows very low precipitation like the Central Dry Zone Region. The highest precipitation in the rainy season were recorded at Thandwe station (4923 mm) in the Rakhine Coastal Region, followed by Yay station (4692 mm) and Dawei station (4673 mm) in the Southern Coastal Region.



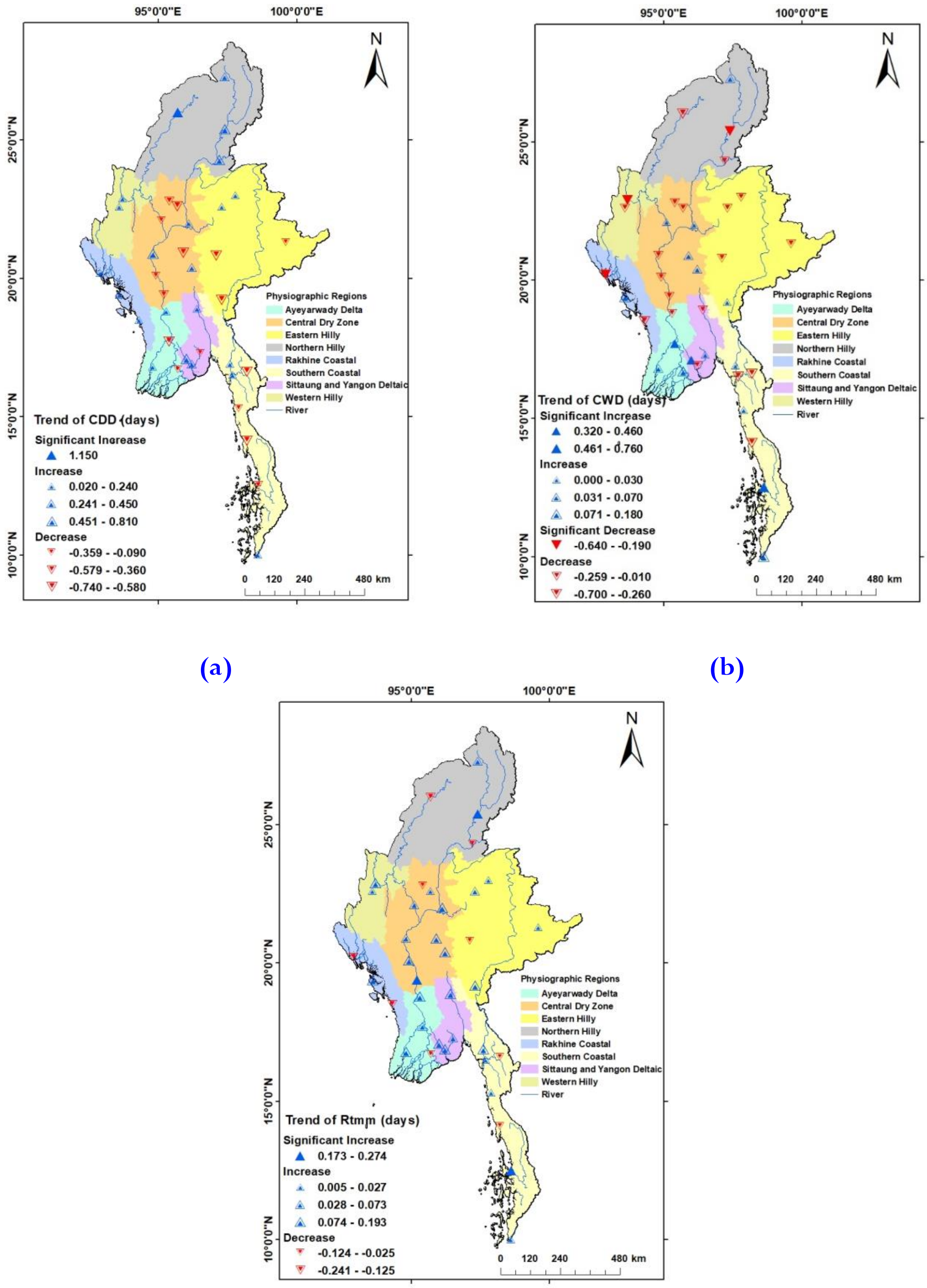
(a) **(b)**

Figure 3. Spatial distribution pattern of (a) annual precipitation and (b) rainy season (Mid-May to October) precipitation in Myanmar during 1985-2020

3.2 Trends and variability in frequency indices of precipitation

The climate extreme indices were calculated by using RClimDex software after finishing the data quality control process. The extreme indices of precipitation were classified into two major categories for easier comprehension. The consecutive dry days, consecutive wet days and the number of heavy precipitation days are all included in frequency indices. Figure 4 shows the trends in frequency indices of precipitation at 38 meteorological stations in Myanmar during the period 1985-2020. A significant increasing trend is indicated by a solid blue upward-pointing triangle; a non-significant increasing trend is shown by a small solid upward-pointing blue triangle enclosed within a larger hollow upward-pointing blue triangle outline. Conversely, a significant decreasing trend is represented by a solid red downward-pointing triangle, while a non-significant decreasing trend is denoted by a small solid downward-pointing red triangle enclosed within a larger hollow downward-pointing red triangle outline. The results of frequency indices of precipitation are presented in Table 3 for the selected meteorological stations, which are distributed across the physiographic regions covering the period from 1985 to 2020. To provide a comparative view, the results of intensity indices are also presented in the same table. The values highlighted in bold and shaded grey exhibit statistical significance at the 95% confidence level ($p<0.05$).

According to the results from Figure 4(a) and Table (3), the trends in consecutive dry days (CDD) exhibited mixed trends across Myanmar. All stations situated in the Northern Hilly Region were found to exhibit increasing trends. Among these stations, Hkamti station demonstrated a significant increasing trend of 1.15 days/year. Similarly, the trends of consecutive dry days in the Western Hilly and Rakhine Coastal Regions were also observed as an increasing trend with 0.155 to 0.212 days/year and 0.147 to 0.237 days/year, respectively. In the Sittaung and Yangon Deltaic Region, three out of four stations were found to exhibit increasing trends, with a range of 0.151 to 0.809 days/year. The consecutive dry days at Bago station decreased by 0.272 days/year. Lashio and Hsipaw stations, located in the Eastern Hilly Region, were detected as increasing trends, while other three stations, such as Taunggyi, Kengtung, and Loikaw, were decreasing trends. Similar to the Eastern Hilly Region, the observed trends of consecutive dry days in the Central Dry Zone, Ayeyarwady Delta and Southern Coastal Regions were also mixed trends. Among 38 stations, Hkamti station was identified as having a significant increasing trend, whereas no other stations showed a significant decreasing trend.



(c)

Figure 4. Spatial distribution of trends in (a) consecutive dry days (b) consecutive wet days (c) number of heavy precipitation days during 1985-2020

The results from Figure 4(b) and Table (3) reveal that the trends of consecutive wet days (CWD) were mixed trends in all regions except the Western Hilly Region. The trends of consecutive wet days in the Western Hilly Region were detected as a decreasing trend in Hakha station and a significant decreasing trend at Falam station. The trends of consecutive wet days in the Eastern Hilly Region were identified as decreasing, apart from Loikaw station. The consecutive wet days at Loikaw station increased by 0.007 days/year in the observed period from 1985 to 2020. Similarly, the trends of consecutive wet days in the Northern Hilly Region were identified as decreasing, with the exception of Putao station. The consecutive wet days at Putao station increased by 0.051 days/year. Moreover, the consecutive wet days of the Rakhine Coastal Region were observed as decreasing trends, but the Kyaukphyu station was detected as an increasing trend with the rate of 0.116 days/year. Similar to the Rakhine Coastal Region, the observed trends of consecutive wet days in the Central Dry Zone, Ayeyarwady Delta, Sittaung and Yangon Deltaic and Southern Coastal Regions were also showing mixed trends. Among all stations, Hinthada, Hmawbi, and Myeik stations were detected as having significant increasing trends, with the highest increasing rate observed at Myeik station (0.775 days/year). Moreover, Myitkyina, Sittwe and Falam stations exhibited a significant decreasing trend, with the highest decreasing rate observed at Sittwe station (-0.638 days/year).

Figure 4(c) shows the trends in the number of heavy precipitation days (Rtmm) across the 38 stations in Myanmar from 1985 to 2020. The spatial distribution map indicates that the trend of heavy precipitation days in Myanmar exhibits mixed patterns. The threshold values of precipitation amount at the stations are different because their precipitation patterns and intensities are different from each other. The Western Hilly and Sittaung and Yangon Deltaic Regions were detected as increasing trends with rates ranging from 0.015 to 0.133 days/year and 0.067 to 0.14 days/year, respectively. Eight out of nine stations in the Central Dry Zone were detected as increasing trends, however, Yayoo station showed a downward trend with a rate of -0.027 days/year. Similarly, four out of five stations in the Eastern Hilly Region and three out of four stations in the Ayeyarwady Delta Region were also detected as increasing trends. The trends of the number of heavy precipitation days in the Northern Hilly Region, Rakhine Coastal Region and Southern Coastal Region were observed as mixed trends. Among 38 stations, Aunglan, Myitkyina and Myeik stations revealed significant increasing trends, with rates of 0.185, 0.173 and 0.274 days/year, respectively.

The analysis of trends in frequency indices of precipitation across Myanmar from 1985 to 2020 exhibits considerable regional and temporal variability in extreme patterns. These findings are consistent with regional patterns identified in earlier studies. Consecutive dry days typically demonstrated increasing trends in many regions, particularly in the Rakhine Coastal, Northern Hilly, and Western Hilly Regions. These results verify the findings of [15], [19], who reported significant increasing trends of the same index in the northern Myanmar. The rising trends in consecutive dry days highlight a trend towards a drier climate in those areas, implicating water resources, hydropower, and agriculture sectors. Yet, mixed trends were seen in the Eastern Hilly, Central Dry Zone, and Delta areas, where a few stations, such as Meiktila and Bago, indicated notable decreases. These mixed trends emphasize the necessity of localized adaptation strategies. Regarding consecutive wet days, the results show a prevalence of decreasing trends in 50% of stations, particularly in the Central Dry Zone, Northern, Western and Eastern Hilly Regions. These findings align with the results of [16]. The increasing trends in consecutive wet days in the Ayeyarwady Delta indicate a shift towards wetter conditions, which may cause landslides and floods. Moreover, the number of heavy precipitation days has been identified as showing a rising trend at several stations, aligning with the earlier study by [3], which reported similar trends in the variability of monsoon precipitation across Myanmar. Additionally, the trends of frequency indices are region-specific patterns, which emphasize the importance of regional analysis and continuous monitoring to mitigate the impacts of extreme events.

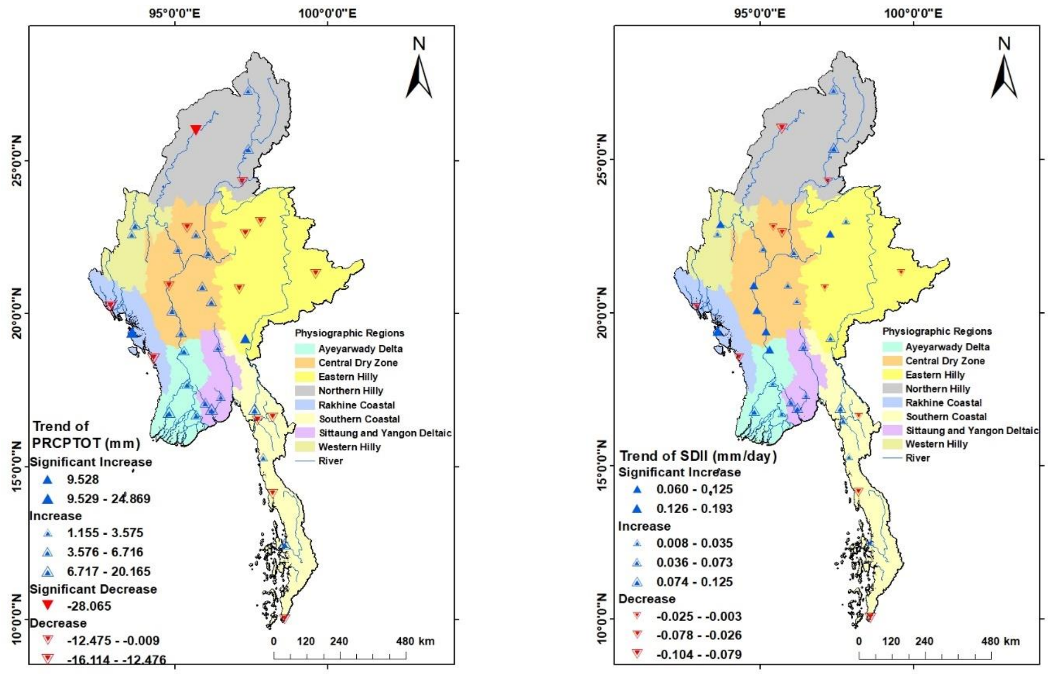
Table 3. Trend analysis results of extreme precipitation indices during 1985-2020 (Grey colour with bold indicates statistically significant at 95% confidence level)

Region	Station	Frequency indices			Intensity indices					
		CDD (days)	CWD (days)	Rtmm (days)	PRCPTOT (mm)	SDII (mm/day)	RX1day (mm)	RX5day (mm)	R95p (mm)	R99p (mm)
Ayeyarwady Delta	Pyay	0.046	-0.112	0.118	6.273	**0.125**	**1.262**	1.580	**6.31**	4.157
	Hinthada	-0.701	**0.321**	0.047	6.716	0.008	0.461	1.228	2.937	1.057
	Pathein	0.150	0.073	0.109	12.729	0.094	0.182	0.397	6.936	-0.087
	Maubin	-0.236	0.177	-0.056	4.903	0.008	1.035	1.703	0.388	3.026
Central Dry Zone	Yayoo	-0.505	-0.012	-0.027	-2.528	-0.003	-0.413	-0.195	-1.173	-1.278
	Shwebo	-0.657	-0.006	0.025	1.155	-0.026	-0.574	0.187	-1.52	-1.546
	Monywa	-0.135	0.002	0.073	2.251	0.009	-0.059	0.026	-0.332	-0.064
	Mandalay	0.163	0.032	0.124	3.973	0.073	0.714	1.308	1.202	2.541
	Chauk	0.680	-0.015	0.062	-0.041	**0.076**	-0.259	-0.505	0.984	0.964
	Meiktila	-0.743	0.036	0.142	5.518	0.024	-0.500	0.004	1.871	-0.311
	Magway	-0.196	-0.014	0.162	6.402	**0.090**	0.309	1.550	1.932	1.195
	Yamethin	0.416	0.072	0.193	4.687	0.025	-0.496	0.739	-0.934	-0.861
	Aunglan	-0.363	-0.048	**0.185**	5.318	**0.115**	**0.854**	**1.602**	**5.292**	**2.244**
Eastern Hilly	Lashio	0.065	-0.056	0.019	-1.006	0.019	-0.723	-1.076	0.755	0.027
	Hsipaw	0.184	-0.007	0.064	-0.009	**0.060**	-0.393	-0.648	-0.745	-0.301
	Taunggyi	-0.729	-0.152	-0.053	-4.627	-0.006	-0.452	-0.766	-4.438	-2.595
	Kengtung	-0.230	-0.005	0.027	-1.926	-0.005	-0.013	-0.342	0.124	-1.172
	Loikaw	-0.587	0.007	0.121	**9.528**	0.062	0.369	0.474	3.952	2.450
Northern Hilly	Putao	0.326	0.051	0.068	1.969	0.040	-0.213	-0.418	6.274	-0.453
	Hkamti	**1.150**	-0.309	-0.241	**-28.07**	-0.104	-2.371	-4.281	**-18.15**	**-11.64**
	Myitkyina	0.771	**-0.192**	**0.173**	6.496	0.106	0.535	-0.803	**9.807**	0.101
	Bhamo	0.586	-0.078	-0.025	-5.868	-0.009	-0.248	0.296	-3.255	-1.504
Rakhine Coastal	Sittwe	0.237	**-0.638**	-0.150	-12.48	-0.003	-0.553	0.219	4.120	-1.138
	Kyaukphyu	0.154	0.116	0.162	**24.87**	**0.193**	1.853	**4.292**	**16.814**	5.942
	Thandwe	0.147	-0.357	-0.125	-16.11	-0.042	-0.052	-1.906	-3.419	1.380
Sittaung and Yangon Deltaic	Taungoo	0.151	-0.160	0.102	1.273	0.052	-0.612	0.573	0.994	-3.228
	Hmawbi	0.809	**0.461**	0.122	5.203	0.038	0.678	0.730	4.118	1.274
	Bago	-0.272	0.021	0.067	3.575	0.033	-0.138	0.006	4.136	1.441
	Kaba-aye	0.45	-0.112	0.140	11.249	0.097	0.828	1.585	9.89	3.954
Southern Coastal	Hpa-an	0.187	0.020	0.129	14.649	0.125	1.070	2.673	6.941	4.311
	Mawlamyine	0.090	-0.290	0.018	-1.290	0.052	-0.306	0.238	0.564	-1.646
	Yay	-0.091	0.016	0.005	2.217	0.035	0.610	0.859	7.756	4.081
	Dawei	-0.712	-0.260	-0.077	-0.951	-0.039	-0.877	-1.744	0.587	-3.338
	Myeik	-0.371	**0.755**	**0.274**	20.165	0.030	0.245	-0.89	2.241	0.783
	Kawthong	0.019	0.178	0.024	-0.593	-0.079	-1.809	-3.243	-12.34	-7.673
	Kawkareik	-0.584	-0.699	-0.069	-5.502	-0.017	-0.012	2.158	6.101	-3.111
Western Hilly	Hakha	0.155	-0.052	0.015	1.934	0.012	0.026	1.044	3.583	1.001
	Falam	0.212	**-0.236**	0.133	4.266	**0.084**	0.625	1.544	**6.923**	2.314

3.3 Trends and variability in intensity indices of precipitation

The intensity indices of extreme precipitation comprise the annual total wet day precipitation (PRCPTOT), simple daily intensity index (SDII), maximum 1-day precipitation (RX1day), maximum 5-day precipitation (RX5day), very wet days precipitation (R95p) and extremely wet days precipitation (R99p).

Figure 5(a) presents the trends in annual total wet day precipitation (PRCPTOT) across the physiographic regions. The results from Figure 5(a) and Table (3) indicate that 24 stations exhibited increasing trends, although the remaining stations showed decreasing trends. Regional analysis revealed that all stations in the Ayeyarwady Delta, Sittaung and Yangon Deltaic and Western Hilly Regions were observed as positive trends. Moreover, seven out of nine stations in the Central Dry Zone exhibited increasing trends. In the Rakhine Coastal Region, the trend of annual total precipitation at Kyaukphyu station was significantly increased, with the highest rate at 24.87 mm/year, but the other two stations, Sittwe and Thandwe, were observed at -12.48 and -16.11 mm/year. In the Eastern Hilly Region, the trend of annual total precipitation at Loikaw station was significantly increased at the rate of 9.528 mm/year, while other stations such as Lashio, Hsipaw, Taunggyi and Kengtung stations experienced -1.006, -0.009, -4.627 and -1.926 mm/year, respectively. The trends of annual total precipitation in the Northern Hilly and Southern Coastal Regions exhibited mixed trends. Overall, 24 out of 38 stations (63%) displayed increasing trends, while 14 stations (37%) experienced decreasing trends. Hkamti station was identified as having a significant increasing trend with a rate of -28.07 mm/year.



(a) **(b)**

Figure 5. Spatial distribution of trends in (a) annual total wet day precipitation (b) simple daily intensity index during 1985-2020

Figure 5(b) illustrates the trends of the simple daily intensity index (SDII) in each region. The simple daily intensity index in the Ayeyarwady Delta, Western Hilly, and Sittaung and Yangon Deltaic Regions exhibited increasing trends, whereas other regions showed mixed trends. The trends of the simple daily intensity index were found to be increasing at 27 out of 38 stations, whereas the remaining stations displayed decreasing trends. Among the stations with positive trends, Aunglan, Chauk, Magway, Pyay, Hsipaw, Kyaukphyu and Falam stations recorded significant increases from 1985 to 2020. The highest positive trend was observed at Kyaukphyu station (0.193 mm/year). Conversely, the highest decreasing trend was observed at Hkamti station (-0.103 mm/year).

The results from Figures 6(a) and 6(b) highlight that the trends in maximum 1-day precipitation (RX1day) and maximum 5-day precipitation (RX5day) over Myanmar are closely aligned to each other. The trends in RX1day at 17 stations displayed increasing trends, whereas the remaining stations showed decreasing trends. Among the stations with positive trends, Pyay and Aunglan stations displayed significant increasing trends. Stations located in the Western Hilly Region and Ayeyarwady Delta

Region were observed to have an increasing trend of 0.026 to 0.625 mm/year and 0.182 to 1.262 mm/year, respectively. The trends of RX1day in the Central Dry Zone, Eastern Hilly, Northern Hilly, Rakhine Coastal, Sittaung and Yangon Deltaic, and Southern Coastal Regions were observed as mixed trends. However, many stations in these regions experienced declining trends, with values ranging from -0.012 to -2.371 mm/year.

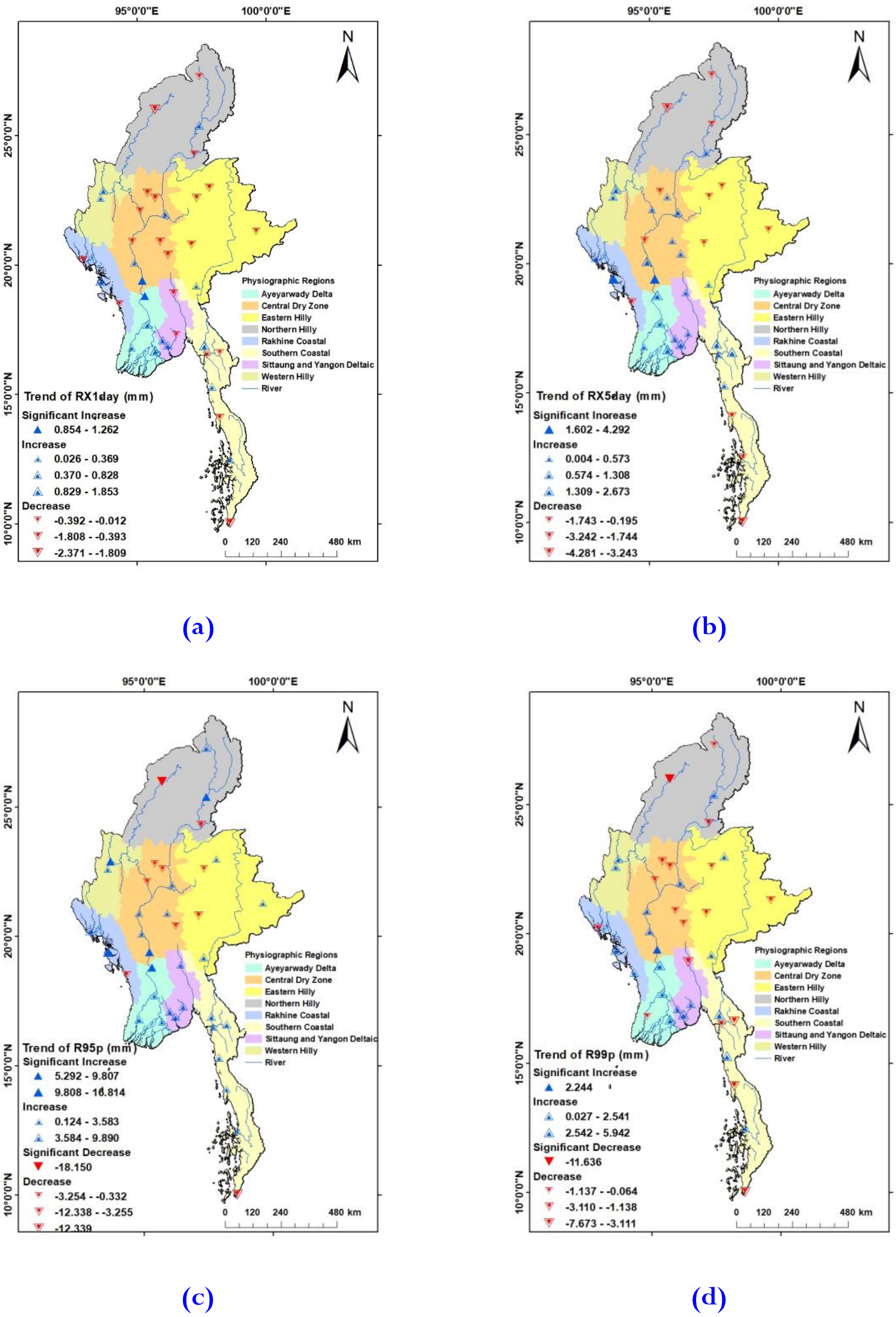


Figure 6. Spatial distribution of trends in (a) maximum 1-day precipitation (b) maximum 5-day precipitation (c) very wet days precipitation (d) extremely wet days precipitation during 1985-2020

In the maximum 5-day precipitation, 25 out of 38 stations indicated increasing trends, whereas the remaining stations exhibited decreasing trends. Among the stations with positive trends, Aunglan and Kyaukphyu stations were observed to have a significant increasing trend of 1.602 and 4.292 mm/year, respectively. Among the stations with negative trends, there was no station showed significant decrease trend. All stations located in the Ayeyarwady Delta Region, Sittaung and Yangon Deltaic Region, as well as the Western Hilly Region, were noted to exhibit increasing trends. Seven out of nine stations in the Central Dry Zone Region were increasing trends, although the rates of maximum 5-day precipitation of Chauk and Yayoo stations were -0.505 and -0.195 mm/year. The trends of stations in the Rakhine Coastal Region are different from each other. The maximum 5-day precipitation of Sittwe station experienced an increase, Kyaukphyu station experienced a significant increase, whereas Thandwe station exhibited a decreasing trend. Four out of five stations in the Eastern Hilly Region, three out of four stations in the Northern Hilly Region and three out of seven stations in the Southern Coastal Region were observed as having decreasing trends, whereas the remaining stations exhibited increasing trends. Among the studied stations, the most significant decreasing rate was recorded at Hkamti station (-4.281 mm/year).

Figures 6(c) and 6(d) illustrate that the trends of very wet days precipitation (R95p) and extremely wet days precipitation (R99p) across Myanmar are closely aligned to each other. The trends in R95p at 28 stations were observed to be rising, while the remaining 10 stations showed declining trends. Among the stations with positive trends, Myitkyina, Falam, Aunglan, Pyay and Kyaukphyu stations exhibited significant increases. The most pronounced increasing trend can be observed at Kyaukphyu station with a rate of 16.814 mm/year. In contrast, Hkamti station experienced a significant decreasing trend, out of ten stations with decreasing trends. Regional analysis revealed that the Ayeyarwady Delta, Sittaung and Yangon Deltaic, and Western Hilly Regions experienced increasing trends in R95p, indicating an overall increase in precipitation extremes in those regions. Moreover, five out of nine stations in the Central Dry Zone Region, three out of five stations in the Eastern Hilly Region, two out of four stations in the Northern Hilly Region, two out of three stations in the Rakhine Coastal Region and six out of seven stations in the Southern Coastal Region were observed as upward trends. However, the remaining stations in those regions indicated downward patterns, with values ranging from -0.322 to -18.15 mm/year. The trends of extremely wet days precipitation (R99p) at 20 out of 38 stations exhibited increasing trends, whereas the remaining stations showed downward patterns. Among the stations exhibiting positive trends, Aunglan station was found to have a significant increase trend of 2.244 mm/year. Hkamti station was the only one among the stations with declining trends to exhibit a significant decreasing trend. All regions, apart from the Western Hilly, displayed mixed trends in the index of extremely wet days precipitation. These findings highlight the variability in extreme events of precipitation across the physiographic regions in Myanmar.

The identified regional variability in the trends of intensity indices of precipitation across the country corresponds with findings from previous studies. In the index of annual total wet day precipitation, the upward trends in the Ayeyarwady Delta, Sittaung and Yangon Deltaic, and Western Hilly Regions align with the results of [3], which noted substantial rises in monsoon precipitation from 2000 to 2020. The observed rising trends in PRCPTOT across the physiographic regions implicate civil engineering works. This is significantly relevant in the design of bridges, dams, and reservoirs, as well as in the environmental and flood risk assessment. The observed increasing trends in the simple daily intensity index in the Ayeyarwady Delta, Sittaung and Yangon Deltaic, and Southern Coastal Regions are consistent with findings from a study by [15], which noted positive trends, particularly in the southern areas. These localized changes in SDII may impact water resources engineering and management and warrant further study to review the climatic factors in those areas. Additionally, the observed trends in R95p and R99p across Myanmar correspond with findings of previous studies, notably a comprehensive analysis by [16], which examined precipitation extremes from 1981 to 2015. Their study reported increasing trends in both R95p and R99p, with significant increases in the southern regions, consistent with the observations in the Ayeyarwady Delta and coastal areas.

The results of extreme precipitation indices indicated increasing trends in both intensity and frequency indices at numerous stations throughout the whole country from 1985 to 2020. Almost 63% to 76% of the stations exhibited increasing trends in the number of very heavy precipitation days, maximum consecutive 5-day precipitation amount, very wet days, annual total precipitation and simple daily intensity index. In the hilly regions, there were increasing trends in consecutive dry days, whereas consecutive wet days showed decreasing trends in those areas. These findings are consistent with the results reported by [16]. However, the observation of increasing trends stands in contrasts to the findings of [13], who reported no significant trends across Myanmar during the period from 1961 to 1998. This discrepancy may arise from their analysis being based on data from only six stations over a shorter period, potentially limiting the representation of regional variability in a large area. Furthermore, this underscores the significance of using updated data from a network of dense stations and emphasizing the necessity of regional analysis. The results of extreme precipitation indices from this study may contribute to the development of regional climate models by providing empirical data on precipitation trends, which is particularly crucial for regions like Myanmar, where climate data are limited and the most vulnerable area.

4. Conclusion

This study provides a comprehensive assessment of the trends and variability in extreme precipitation indices over Myanmar during 1985 to 2020 using observed daily precipitation data. The main findings in this work are as follows:

(a) The spatial distribution maps of annual and seasonal precipitation indicate relatively high precipitation in the coastal regions, whereas the Central Dry Zone consistently received much less precipitation throughout time.

(b) The frequency indices, such as consecutive dry days and consecutive wet days, were found to be mixed trends across the country. The trends in heavy precipitation days further highlight the growing variability in precipitation extremes. These findings highlight the increasing intensity of precipitation patterns across the country.

(c) The analysis of trends in intensity indices of precipitation across Myanmar reveals significant spatial and temporal variability in extreme events. The annual total wet day precipitation typically demonstrated increasing trends in many regions, particularly in the Ayeyarwady Delta, Sittaung and Yangon Deltaic, and Western Hilly Regions. The results of the daily intensity index in each physiographic region exhibit a compelling description of varying precipitation patterns. The trends in RX1day, RX5day, R95p, and R99p were found to be increasing at 45%, 66%, 74%, and 53% of the selected stations in this work, respectively. These findings indicate that Myanmar experienced significant changes in precipitation extremes from 1985 and 2020.

(d) Among 38 stations, Hkamti and Kyaukphyu have been identified as indicative stations. Hkamti station, located in the Northern Hilly Region, was noted to have the highest increasing trend in consecutive dry days, although the highest decreasing trends were observed in the annual total wet day precipitation, very wet days precipitation, extremely wet days precipitation and simple daily intensity index (SDII). Furthermore, Kyaukphyu station, situated in the Rakhine Coastal Region, was detected as having the highest increasing trends in the maximum 5-day precipitation, annual total precipitation amount, very wet days precipitation and simple daily intensity index.

The key findings from this study provide useful information to the policymakers in developing the adaptation and mitigation measures of extreme climatic events in Myanmar. Additionally, this study underscores the significance of regional analysis in extreme precipitation indices for civil engineering applications, such as the design of bridges, dams and reservoirs. Compared to other studies [13], [14], [15], [19], this study uses a denser network of station data. This dense network provides information on how the climate is changing across the country. Although this study does not address the consequences of the observed trends, it provides areas that are highly vulnerable. For instance, the coastal region of Myanmar is experiencing high precipitation. This indicates that the regions are highly vulnerable to floods in addition to sea level rise. It is therefore recommended that future research should place greater emphasize on analyzing the impacts of extreme precipitation events.

Author's declaration

Author contribution

Min Khaing: Conceptualization, methodology, calculation and analysis, visualization, manuscript writing, reviewing and editing. **Win Win Zin**: Conceptualization, methodology, project management, supervision, reviewing and editing. **Zin Mar Lar Tin San**: Conceptualization, methodology, formal analysis, reviewing and editing. **Soe Thiha** and **Manish Shrestha**: Reviewing and editing.

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Data availability

Data supporting the findings will be made available upon reasonable request to the corresponding author.

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Conflict of interest

The authors declare no conflict of interest in this research and publication.

Ethical clearance

This study did not involve human subjects; therefore, approval from the ethics committee was not required.

AI statements

The grammatical structure of this article was reviewed using ChatGPT, and the authors subsequently verified the accuracy and correctness of the sentences concerning the topic and data of this study, and ensure that no AI-generated sentences are included in this article. The language use in this article have been verified by an expert in the English language.

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References

[1] S. Subba, Y. Ma, and W. Ma, "Spatial and Temporal Analysis of Precipitation Extremities of Eastern Nepal in the Last Two Decades (1997–2016)," *Journal of Geophysical Research: Atmospheres*, vol. 124, no. 14, pp. 7523–7539, Jul. 2019, https://doi.org/10.1029/2019JD030639

[2] I. Bouizrou, M. Aqnouy, and A. Bouadila, "Spatio-temporal analysis of trends and variability in precipitation across Morocco: Comparative analysis of recent and old non-parametric methods," *Journal of African Earth Sciences*, vol. 196, p. 104691, Dec. 2022, https://doi.org/10.1016/j.jafrearsci.2022.104691

[3] Z. M. M. Sein *et al.*, "Recent variability of sub-seasonal monsoon precipitation and its potential drivers in Myanmar using in-situ observation during 1981–2020," *International Journal of Climatology*, vol. 42, no. 6, pp. 3341–3359, May 2022, https://doi.org/10.1002/joc.7419

[4] M. H. I. Dore, "Climate change and changes in global precipitation patterns: What do we know?," *Environ Int*, vol. 31, no. 8, pp. 1167–1181, Oct. 2005, https://doi.org/10.1016/j.envint.2005.03.004

[5] W. Win Zin and M. Rutten, "Long-term Changes in Annual Precipitation and Monsoon Seasonal Characteristics in Myanmar," *Hydrology: Current Research*, vol. 08, no. 02, 2017, https://doi.org/10.4172/2157-7587.1000271

[6] R. Horton *et al.*, "Assessing Climate Risk in Myanmar," New York, 2016. [Online]. Available: https://unhabitat.org/sites/default/files/2019/10/assessing-climate-risk-in-myanmar_technical-report.pdf

[7] M. Shrestha, S. Shrestha, and A. Datta, "Assessment of Climate Change Impact on Water Diversion from the Bago River to the Moeyingyi Wetland, Myanmar," *Curr Sci*, vol. 112, no. 02, p. 377, Jan. 2017, https://doi.org/10.18520/cs/v112/i02/377-384

[8] The Republic of the Union of Myanmar, *Myanmar Climate Change Strategy (2018 – 2030)*. 2019. [Online]. Available: https://myanmar.un.org/sites/default/files/2019-11/MyanmarClimateChangeStrategy_2019.pdf

[9] U. Ghimire, T. Piman, M. Shrestha, A. Aryal, and C. Krittasudthacheewa, "Assessment of Climate Change Impacts on the Water, Food, and Energy Sectors in Sittaung River Basin, Myanmar," *Water (Basel)*, vol. 14, no. 21, p. 3434, Oct. 2022, https://doi.org/10.3390/w14213434

[10] L. Adil, D. Eckstein, V. Kunzel, and L. Schafer, "Climate Risk Index 2025: Who suffers most from extreme weather events?," Bonn, 2025. [Online]. Available: https://www.germanwatch.org/sites/default/files/2025-02/Climate%20Risk%20Index%202025.pdf

[11] Z. M. Mie Sein, I. Ullah, F. Saleem, X. Zhi, S. Syed, and K. Azam, "Interdecadal Variability in Myanmar Rainfall in the Monsoon Season (May–October) Using Eigen Methods," *Water (Basel)*, vol. 13, no. 5, p. 729, Mar. 2021, https://doi.org/10.3390/w13050729

[12] A. Hussain *et al.*, "Observed trends and variability of seasonal and annual precipitation in Pakistan during 1960–2016," *International Journal of Climatology*, vol. 42, no. 16, pp. 8313–8332, Dec. 2022, https://doi.org/10.1002/joc.7709

[13] M. J. Manton *et al.*, "Trends in extreme daily rainfall and temperature in Southeast Asia and the South Pacific: 1961–1998," *International Journal of Climatology*, vol. 21, no. 3, pp. 269–284, Mar. 2001, https://doi.org/10.1002/joc.610

[14] J. Caesar *et al.*, "Changes in temperature and precipitation extremes over the Indo-Pacific region from 1971 to 2005," *International Journal of Climatology*, vol. 31, no. 6, pp. 791–801, May 2011, https://doi.org/10.1002/joc.2118

[15] M. Yazid and U. Humphries, "Regional Observed Trends in Daily Rainfall Indices of Extremes over the Indochina Peninsula from 1960 to 2007," *Climate*, vol. 3, no. 1, pp. 168–192, Feb. 2015, https://doi.org/10.3390/cli3010168

[16] K. K. Sein, A. Chidthaisong, and K. L. Oo, "Observed Trends and Changes in Temperature and Precipitation Extreme Indices over Myanmar," *Atmosphere (Basel)*, vol. 9, no. 12, p. 477, Dec. 2018, https://doi.org/10.3390/atmos9120477

[17] L. L. Aung *et al.*, "Myanmar Climate Report," 2017. [Online]. Available: https://www.burmalibrary.org/sites/burmalibrary.org/files/obl/2017-09-14-Myanmar-Climate-Report-en-red.pdf

[18] T. Salmi, A. Maatta, P. Anttila, T. Ruoho-Airola, and T. Amnell, "Detecting Trends of Annual Values of Atmospheric Pollutants by the Mann-Kendall Test and Sen's Slope Estimates—The Excel Template Application MAKESENS," Helsinki, 2002.

[19] T. Soe and K. M. Ma, "The geography of the Chindwin River Basin ," in *ChindwinFuturesNatural resources, livelihoods, institutions andclimate change in Myanmar's Chindwin River Basin*, Selangor: Strategic Information and Research Development Centre, 2021. [Online]. Available: https://www.sei.org/wp-content/uploads/2021/09/chindwin-futures-e-book-small-size-for-download-sept-2021.pdf

Nomenclature

Meanings of symbols used in the equations and other symbols presented in the article are as follows.

$f(t)$	Simultaneous monotonic trend with the function of time
ε_i	Residuals with the assumption of same distribution with zero mean
q	Number of tied groups
t_p	Number of data values in the p^{th} group
β	The Sen's slope estimator