Variability and Trend of rainfall over Bandarban district

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Abstract

Bandarban, located in southeastern Bangladesh, is a mountainous district with complex topography that receives high amounts of rainfall due to the combined influence of the southwest monsoon from the Bay of Bengal and orographic uplift. This study investigates the long-term rainfall characteristics, variability, and trends in Bandarban using the Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS) dataset for 1981–2025. Results show a strongly seasonal rainfall regime, with the monsoon contributing 76.3% of the annual rainfall and an average annual rainfall of approximately 3,120 mm. Light rainfall events account for nearly 50% of all events, whereas heavy rainfall events (≥44 mm day^{-1}) comprise only 5.2% but pose significant risks of flash floods and landslides. Trend analysis indicates increasing rainfall during the monsoon and pre-monsoon seasons, although these trends are not statistically significant. In contrast, the Precipitation Concentration Index (PCI) exhibits a statistically significant increasing trend, indicating that rainfall is becoming more concentrated into fewer, more intense events. Despite this, near-normal rainfall conditions dominate approximately 70% of the study period, with extreme wet and dry years occurring infrequently. Comparison of 2001–2025 with the 1981–2000 baselines further reveal increases in mean rainfall and the frequency of extreme precipitation events, highlighting the growing influence of climate change on rainfall patterns in Bandarban.

Keywords: Rainfall, Monsson, PCI, Variability, Bangladesh***.***

1. Introduction

Rainfall is one of the most important climatic variables influencing the hydrological cycle, agricultural productivity, ecosystem sustainability, and socio-economic development. Variations in rainfall distribution, intensity, frequency, and duration directly affect water resources, food production, flood occurrence, drought conditions, and environmental stability. In recent decades, climate change has significantly altered rainfall characteristics across many regions of the world, resulting in increased hydro meteorological extremes and growing concerns regarding water security and disaster risk management (IPCC, 2023).

Bangladesh, located in the tropical monsoon region of South Asia. Bangladesh receives approximately 70-80% of its annual rainfall during the southwest monsoon season from June to September. The country's climate and economy are highly dependent on rainfall because agriculture, fisheries, and water resources are closely linked to seasonal precipitation patterns. However, changes in rainfall behavior have become increasingly evident in recent decades, with many regions experiencing shifts in rainfall intensity, timing, and variability. These changes have raised concerns regarding flood hazards, drought occurrence, crop production, and climate resilience (Shahid, 2010; Upal, 2020).

The southeastern part of Bangladesh, particularly the Chattogram Region, exhibits unique climatic and geographical characteristics. The region includes Chattogram, Cox's Bazar, Rangamati, Bandarban, and Khagrachhari districts and is characterized by complex topography consisting of coastal plains, hilly terrain, dense forests, and river networks. The Chattogram Hill Tracts (CHT), including Rangamati and Bandarban**,** receive some of the highest rainfall amounts in Bangladesh due to strong monsoonal influences from the Bay of Bengal and orographic lifting caused by the hill ranges. These factors contribute to substantial spatial and temporal variability in rainfall patterns across the region.

Rainfall variability in Bandarban has become an important research topic because of the increasing occurrence of climate-related hazards such as flash floods, landslides, soil erosion, riverbank instability, and waterlogging. The steep slopes, fragile geological formations, and intense monsoon precipitation make these districts particularly vulnerable to hydro-meteorological disasters. Heavy rainfall events frequently trigger landslides, resulting in significant loss of life, infrastructure damage, and environmental degradation. Studies conducted in the Chattogram Hill Tracts indicate that excessive rainfall is one of the primary triggering factors for landslide occurrence, especially in areas characterized by weak sedimentary rocks and deforested hill slopes.

Several studies have investigated rainfall variability and trends in Bangladesh. Shahid (2010) reported significant spatial variability in rainfall distribution across the country and highlighted the influence of climate change on rainfall patterns. Similarly, Upal (2020) analyzed rainfall data from 27 meteorological stations across Bangladesh and found that although many parts of the country exhibited declining annual and seasonal rainfall trends, southeastern Bangladesh showed increasing rainfall tendencies compared with other regions. This finding suggests that the Chattogram Region may be responding differently to changing climatic conditions due to its geographical location and topographic influences.

Recent research focusing specifically on southeastern Bangladesh has revealed notable changes in rainfall behavior. Rahman et al. (2025) analyzed annual maximum rainfall records from nine stations in the Chattogram Region during 1988–2023 using Mann–Kendall and Modified Mann–Kendall trend tests. Their study identified considerable spatial variability in rainfall trends, with several hilly stations showing decreasing annual maximum rainfall while some lowland stations exhibited increasing tendencies. The study emphasized that rainfall variability in the region is strongly associated with flood and landslide risks and highlighted the need for localized climate assessments.

The Chattogram Hill Tracts have experienced several devastating rainfall-induced disasters in recent years. Intense monsoon rainfall frequently causes flash floods and landslides in Rangamati and Bandarban. For example, severe monsoon rainfall events in southeastern Bangladesh have repeatedly triggered landslides and flooding, resulting in casualties, displacement, and infrastructure damage. Recent assessments indicate that heavy rainfall combined with unstable hill slopes significantly increases disaster vulnerability in these districts.

Fig. 6: Location of Bandarban district in Bangladesh

Climate model projections further indicate that rainfall extremes are likely to intensify across Bangladesh under future warming scenarios. Recent downscaling studies suggest that southeastern Bangladesh may experience substantial increases in extreme rainfall intensity during the twenty-first century. Projections indicate that the magnitude of extreme daily rainfall events could increase considerably by mid-century and late-century periods, thereby increasing the risks of flash floods, landslides, and water-related disasters in the Chattogram Hill Tracts.

Despite the growing number of studies on climate variability in Bangladesh, detailed investigations focusing specifically on long-term rainfall variability in Bandarban remain limited. Most existing studies have concentrated on national-scale rainfall trends or broader regional assessments without adequately addressing the unique climatic characteristics of the hilly southeastern region. Furthermore, comprehensive analyses integrating historical rainfall variability, extreme rainfall events, spatial distribution patterns, and future climate projections are still relatively scarce. Therefore, a detailed study of rainfall variability in Bandarban is necessary to improve understanding of regional hydro-climatic changes and support climate adaptation, disaster risk reduction, water resource management, and sustainable development planning. Attempt has therefore made to investigate the rainfall variability and its trend of Bandarban district.

The findings of such research would contribute significantly to understanding the impacts of climate change on rainfall dynamics in the Chattogram Hill Tracts and provide scientific evidence for policymakers, planners, and disaster management authorities in developing climate-resilient strategies for the region.

2. Methodology

2.1 Rainfall Data Processing

Daily precipitation data for the period 1981–2025 has been obtained from the Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS) dataset, which provides rainfall estimates at a spatial resolution of 0.05° (~5 km). CHIRPS combines satellite-based infrared precipitation estimates with in-situ rain gauge observations to produce a long-term, high-resolution rainfall dataset suitable for climatological, hydrological, and climate change studies, particularly in regions with sparse meteorological observations (Funk et al., 2015).

The analysis is conducted for Bandarban District (Fig:1), Bangladesh. The administrative boundary of Bandarban is extracted from the GADM Administrative Level-2 boundary dataset and used as the spatial mask for rainfall extraction. Prior to the analysis, the coordinate reference system (CRS) of the district boundary has been verified and matched with that of the CHIRPS raster data to ensure accurate spatial alignment and overlay. Daily CHIRPS rainfall data (netCDF form) files are processed using the terra package in R. Each raster layer represents the accumulated precipitation for one day. The Bandarban district polygon was overlaid on the CHIRPS grids, and precipitation values from all grid cells intersecting the district are extracted for each daily raster. The extracted pixel values are subsequently used to derive district-scale rainfall statistics representative of the entire study area. The sum of rainfall from all intersecting grid cells, representing the spatially accumulated rainfall over the district has been defined as the total rainfall (mm day^{-1}).

To assess changes in rainfall characteristics between the baseline period (1981–2000) and the recent period (2001–2025), several rainfall indices were derived from the daily rainfall data. Daily rainfall refers to the total precipitation accumulated during a 24-hour period at a given location. In this study, daily rainfall amounts (P_d, mm day^{-1}) were obtained from the CHIRPS dataset and used as the primary variable for all subsequent analyses. Daily rainfall values (P_d, mm/day) were aggregated to monthly and annual totals. Monthly rainfall was calculated as:

$$P_m = \sum_{d=1}^{n} P_d \quad \text{………………. (1)}$$

where P_d is daily rainfall and n is the number of days in a month.

Annual rainfall (AR) was calculated as the sum of daily rainfall amounts within a calendar year:

$$AR = \sum_{d=1}^{N} P_d \quad \text{…………… (2)}$$

where P_d is the daily rainfall amount (mm) and N is the total number of days in a year. Annual rainfall represents the total precipitation received during a year and is expressed in millimeters (mm). Long-term trends in annual rainfall were evaluated using the non-parametric Mann–Kendall trend test and Sen's slope estimator.

2.1 Rainy-Day Frequency

Rainy-day frequency (RDF) was defined as the number of days within a year with measurable rainfall equal to or greater than 1 mm:

$$RDF = \sum_{d=1}^{N} I\,(P_d \geq 1) \quad \text{………… (3)}$$

where I is an indicator function that equals 1 when daily rainfall is at least 1 mm and 0 otherwise. This index provides a measure of rainfall occurrence and frequency.

2.2 Wet-Day Intensity

Wet-day intensity (WDI) represents the average rainfall amount on rainy days and was calculated as:

$$WDI = \frac{\sum_{d=1}^{N} P_d}{RDF} \quad \text{………………….. (4)}$$

Where, P_d is the daily rainfall amount on wet days (≥1 mm) and RDF is the annual number of wet days. This index is equivalent to the mean precipitation per wet day and is expressed in mm/day. It is conceptually similar to the Simple Daily Intensity Index (SDII) recommended by the Expert Team on Climate Change Detection and Indices.

2.3 Wet-Day Rainfall Distribution

Wet-day rainfall distribution describes the statistical distribution of rainfall amounts occurring on wet days (≥1 mm). For each climate period, descriptive statistics including the mean, median, standard deviation, minimum, maximum, 95th percentile (P95), and 99th percentile (P99) were calculated from all wet-day rainfall data. This analysis characterizes the variability and intensity spectrum of rainfall events and facilitates the assessment of changes in moderate and extreme precipitation.

2.4 Climate Period Comparison

To evaluate changes in rainfall characteristics, all indices were computed separately for two climate periods: 1981–2000 and 2001–2025. Differences between the periods were assessed using boxplots and non-parametric statistical tests. Summary statistics including the mean, median, standard deviation, minimum, maximum, P95, and P99 were calculated for each rainfall index to quantify changes in rainfall totals, frequency, intensity, and extremes.

2.5 Monthly Rainfall Climatology

The long-term monthly climatology was calculated using the arithmetic mean of monthly rainfall totals over the study period:

$$\overline{P_m} = \frac{1}{N}\sum_{i=1}^{N} P_{m,i} \quad \ldots\ldots\ldots\ldots\ldots (5)$$

where: $P_{m,i}$ is rainfall in month m in year i and N is the total number of years.
The standard deviation (SD) was also calculated to quantify interannual variability:

$$SD = \sqrt{\frac{\sum\left(P_{m,i}-\overline{P_m}\right)^2}{N-1}} \quad \ldots\ldots\ldots\ldots\ldots (6)$$

2.6 Annual Rainfall Trend Analysis

Long-term trends in annual rainfall were assessed using the non-parametric Mann–Kendall (MK) trend test (Mann, 1945; Kendall, 1975), which is widely used in hydro-climatological studies because it does not require data normality
The Mann–Kendall statistic is defined as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\left(x_j - x_i\right) \quad \ldots\ldots\ldots (7)$$

Where, $sgn\left(x_j - x_i\right) = \begin{cases} 1, & x_j > x_i \\ 0, & x_j = x_i \\ -1, & x_j < x_i \end{cases}$

The median of all pairwise slopes provides the overall trend magnitude. A positive value indicates an increasing trend, whereas a negative value indicates a decreasing trend.

Sen's Slope

The magnitude of trend was estimated using Sen's slope:

$$Q_i = \frac{x_j - x_i}{j-i} \quad \ldots\ldots\ldots\ldots\ldots (8)$$

The median of all Q_i values represents the trend magnitude.

2.7 Annual Rainfall Anomaly

Annual rainfall anomalies were calculated relative to the long-term mean annual rainfall:

$$A_i = P_i - \bar{P} \quad \ldots\ldots\ldots\ldots\ldots (9)$$

Where, A_i is annual rainfall anomaly, P_i is annual rainfall in year i, and $\bar{P}$ is the long-term mean annual rainfall. Positive anomalies indicate wetter-than-normal years, while negative anomalies indicate drier-than-normal years.

2.8 Precipitation Concentration Index (PCI)

The Precipitation Concentration Index (PCI) is a widely used statistical indicator developed by Oliver (1980) to quantify the temporal distribution and concentration of rainfall within a year. PCI provides information on rainfall seasonality and the degree to which annual precipitation is concentrated in a few months. It is particularly useful for assessing rainfall variability, drought susceptibility, flood potential, soil erosion risk, and climate change impacts on precipitation patterns. The Precipitation Concentration Index (PCI) was employed to assess the temporal concentration of rainfall within a year following Oliver (1980):

$$PCI = \frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} P_i\right)^2} \times 100 \quad \ldots\ldots\ldots\ldots\ldots (10)$$

Where, P_i = precipitation of month (mm) and $\sum P_i$= annual precipitation (mm). PCI values were interpreted according to Oliver (1980) as:

Sl	PCI	Interpretation
i.	<10	Uniform rainfall distribution
ii.	11–15	Moderate concentration
iii.	16–20	Irregular distribution
iv.	>20	Strong irregularity

Higher PCI values indicate rainfall concentrated in fewer months, while lower values indicate a more uniform annual distribution.

2.9 Standardized Precipitation Index (SPI)

Meteorological drought conditions were evaluated using the Standardized Precipitation Index (SPI), originally proposed by Thomas B. McKee and colleagues (McKee et al., 1993). SPI is recommended by the World Meteorological Organization as a standard drought monitoring indicator. Monthly precipitation totals were fitted to a Gamma probability distribution and subsequently transformed into a standard normal distribution:

$$SPI = \frac{X-\mu}{\sigma} \text{ .... (11)}$$

Where, X is precipitation, μ is mean precipitation, and σ is standard deviation.

SPI values were calculated at three accumulation periods:

- SPI-1, Represents short-term meteorological drought conditions at the monthly scale.
- SPI-3, Represents seasonal drought conditions and short-term water availability.
- SPI-12, Represents long-term hydrological and climatological drought conditions.

2.9.1 SPI Classification

Drought and wetness conditions were classified according to standard SPI categories.

Sl No	SPI Value	Category
i.	≥ 2.0	Extremely Wet
ii.	1.5 to 1.99	Severely Wet
iii.	1.0 to 1.49	Moderately Wet
iv.	-0.99 to 0.99	Near Normal
v.	-1.0 to -1.49	Moderately Dry
vi.	-1.5 to -1.99	Severely Dry
vii.	≤ -2.0	Extremely Dry

2.9.2 SPI Heatmap Analysis

A heatmap of SPI-12 values was generated to visualize the temporal evolution of wet and dry conditions. Positive SPI values indicate wetter-than-normal conditions, whereas negative SPI values indicate drought conditions. The heatmap facilitates identification of prolonged drought episodes and wet periods over the study period.

3. Analysis

3.1 Variability of daily rainfall in Bandarban district

Based on the daily total amounts of rainfall over the district area of Bandarban, rainfall has been categorized as- no rain, light rain, moderate rain, moderately heavy rain, heavy rain, very heavy rain and extreme rain and these are defined for advantage as Cat-I, Cat-II, Cat-III, Cat-IV, Cat-V, Cat-VI and Cat-VII respectively. Analysis reveals that most dominating of about 50% of the total rainfall events are in Cat-I. About 12.5% rain events are heavy category and among these events Cat-V, Cat-VI and Cat-VII events are of 4.0%, 1.1% and 0.1% respectively. The relevant other information is given in Table 1. More detailed rainfall distribution of Bandarban district is given in the Fig. 2.

Table 1: Categorization of daily rainfall in Bandarban district

Category	Rainfall Scale (mm)	Number of rainfall events	Percentage (%)
No rain (Cat-I)	<1	8207	49.9
Light rain (Cat-II)	1-10	4524	27.5
Moderate rain (Cat-III)	11-22	1646	10.0
Moderately Heavy rain (Cat-IV)	23-43	1207	7.3
Heavy rain (Cat-V)	44-88	650	4.0
Very heavy rain (Cat-VI)	89-149	179	1.1
Extreme rain (Cat-VII)	>=150	23	0.1

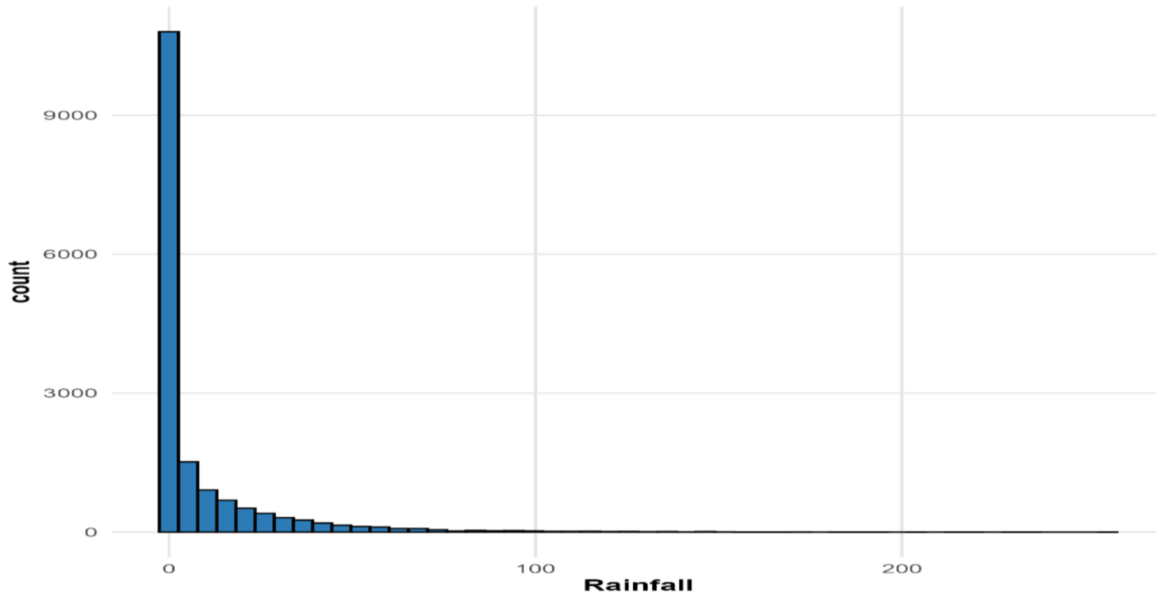

Fig. 2: Histogram of the daily rainfall of Bandarban district during 1981-2025.

3.2 Variability of Monthly rainfall

The amounts of monthly rainfall in Bandarban district are notable from April to October. It is higher in the monsoon months with the highest in July, followed by June and August. Rainfall in other months is lower and is the lowest in January (Fig. 3) As a follow up of this, the standard deviation (SD) is the highest in July, followed by August and June, but lowest in January. The coefficient of variations (CVs) is higher in winter (December, January and February) and pre-monsoon (March, April and May) and post-monsoon (October and November) months, and lower in the monsoon months (June, July, August and September). It is the lowest in June during the observed period of 1981-2025 (Table 2).

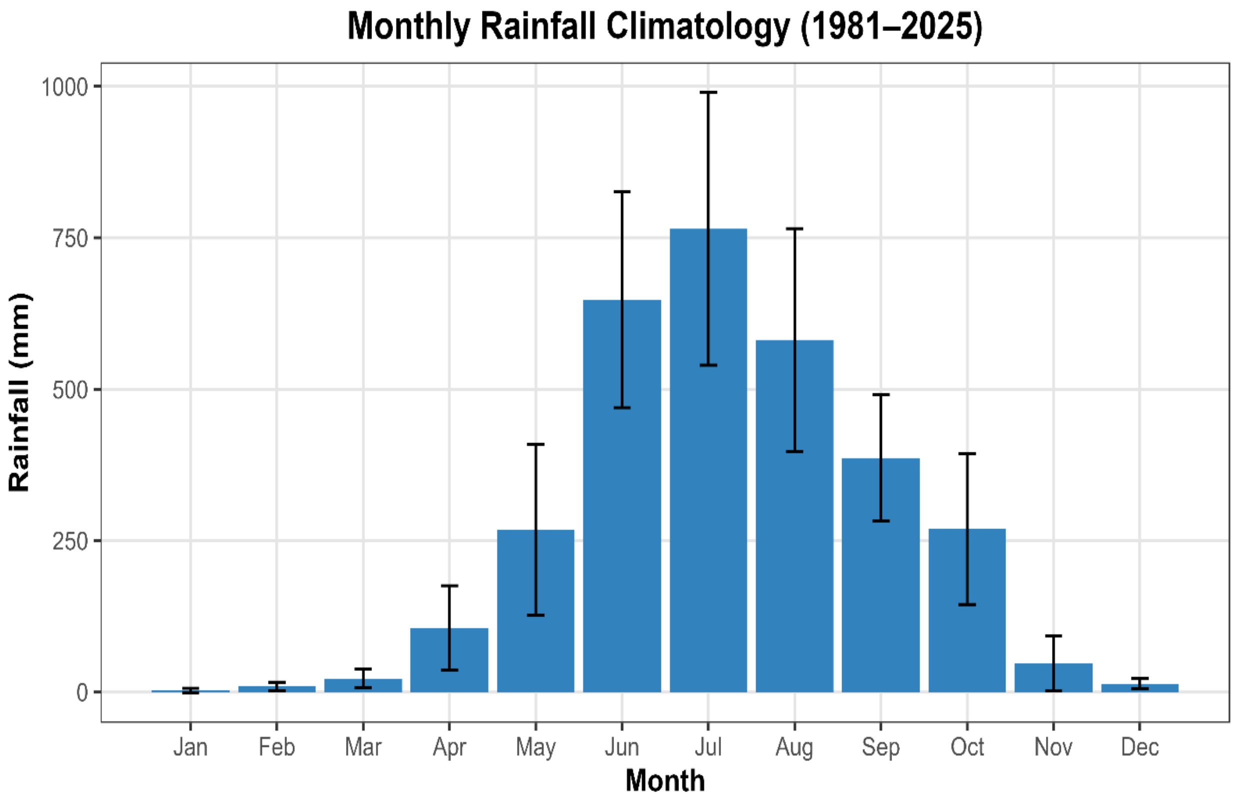

Fig. 3: Monthly distribution of rainfall in Bandarban district during 1981-2025

Table 2: Mean monthly rainfall, SD and CV of Bandarban district

Month	Mean Rainfall (mm)	Standard Deviation (SD) in mm	Coefficient of Variation (CV) mm
January	2.7	3.8	141
February	9.5	7	73.3
March	22.5	15.6	69.1
April	105.9	69.7	65.8
May	268.2	141.1	52.6
June	647.7	178.1	27.5
July	764.9	225.1	29.4
August	581.3	183.9	31.6
September	386.8	104.2	26.9
October	269.1	124.4	46.2
November	47.3	45.5	96.3
December	13.9	8.4	60.6

3.3 Variability of Seasonal rainfall

As an agricultural district seasonal amounts of rainfall, its distribution and variation is very important. Monsoon is the dominating season for rainfall is highly necessary for rice production but rainfall in other seasons is essential for growing vegetables and other crops in the districts. Analysis reveals that the dominating rainfall season is the monsoon, which has been embedded by two seasons with considerable rainfall amounts on pre-monsoon and post monsoon (Fig. 4). Average amounts of rainfall in monsoon, post-monsoon, pre-monsoon and winter seasons during the observed period are 2380.7, 316.4, 396.7 and 25.5 mm respectively (Table 3), which are respectively 76.3%, 10.1%, 12.7% and 0.8% of the annual average rainfall.

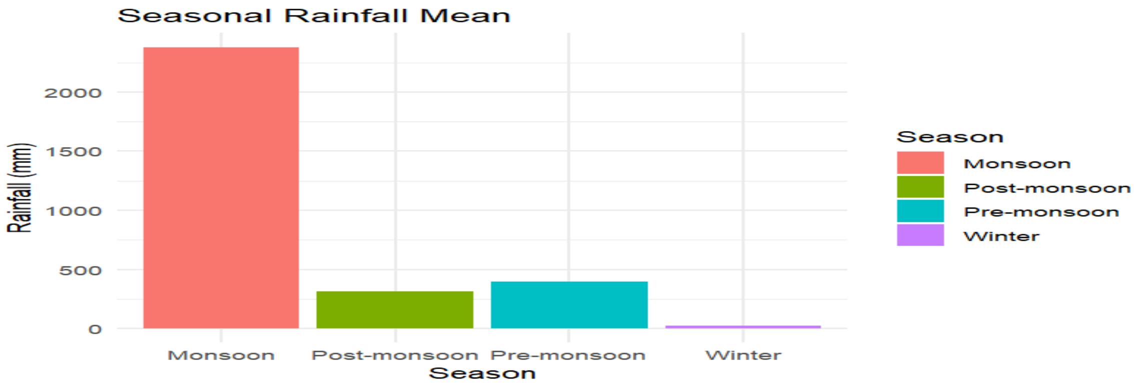

Fig. 4: Seasonal distribution of rainfall in Bandarban district

A rank-based correlation coefficient of Mann–Kendall test values are positive, i.e., increasing trends for both monsoon and post-monsoon seasons but negative for other two seasons (Table 3). P-vales for all of the seasons are greater than 0.05, is the indication of no significant trends in the seasons. Again, the rainfall trends for monsoon and post-monsoon seasons are positive with the magnitudes of 5.66 mm/year and 1.24 mm/year respectively. On the other hand, the trends of pre-monsoon and winter seasons are negative, with the magnitudes of -1.02 mm/year and 0.22 mm/year (Table 3 and Fig. 5).

Table 3: Mean seasonal rainfall, SD and CV, Mann Kendall Trends of Bandarban district

Season	Mean rainfall (mm)	Standard Deviation (SD)	Coefficient of Variation (CV)	Kendall's tau (MK tau)	p-value (MK-p)	Trends (Sen slope)
Monsoon	2380.7	336.7	14.1	0.15	0.14	5.66
Post-monsoon	316.4	138.3	43.7	0.07	0.5	1.24
Pre-monsoon	396.7	146.9	37	-0.04	0.72	-1.02
Winter	25.5	11.5	45.1	-0.17	0.11	-0.22
Annual	3119.8	391.0	12.5	0.15	0.14	7.92

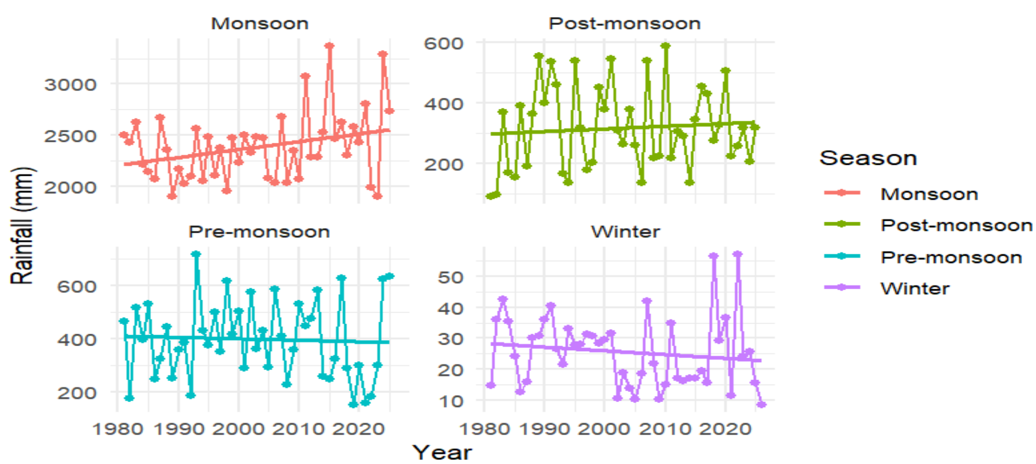

Fig. 5: Trends of rainfall in different seasons in Bandarban district

3.4 Variability of Annual rainfall

Annual amount of rainfall in Bandarban district is highly varying in nature (Fig. 6). The average rainfall in this district during the observed period is about 3120 mm. The STD of annual rainfall in this district is 391.0 mm and the CV is 12.5. Analysis reveals that the Kendall's tau (MK tau) value is positive and trend (Sen's Slope) is 7.92 mm and the p-value is 0.14 (Table 3).

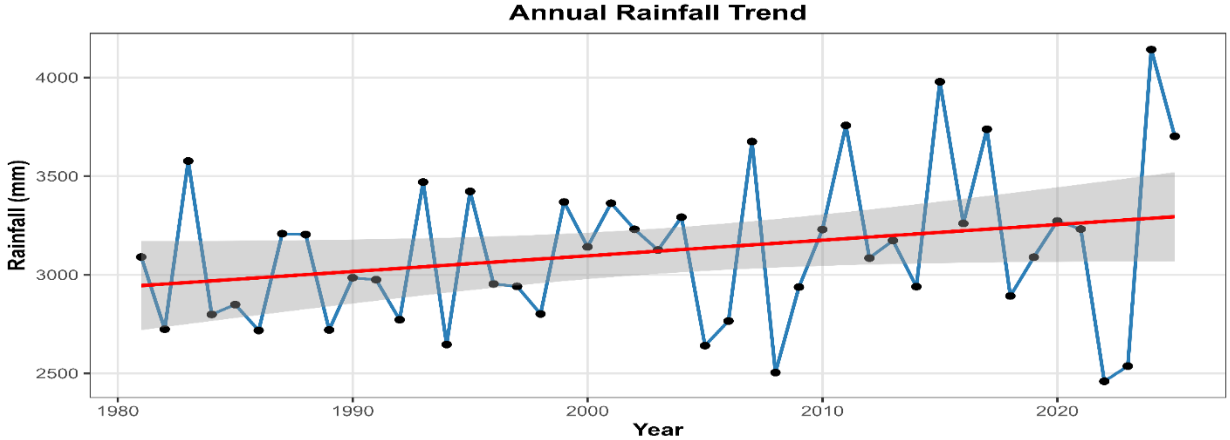

Fig. 6: Temporal variation of annual rainfall in Bandarban district

3.5 Deviation of rainfall in Bandarban district

In monsoon season maximum positive deviation (41.6%) is found in 2015 and minimum negative deviation (-20.3%) is found in 1989. During the observed period 9-seasons have positive deviation, but 31 seasons have negative deviation. Normal rainfalls are found in the remaining 31-seasons. In the recent years of 2024 the notable deviation was 38.3%. On the other hand, in the recent years of 2022 and 2023 the negative deviations of -16.6% and -20.3% were notable. Rainfall amounts were very high during the recent 20 years (Fig. 7).

In post-monsoon season the maximum positive deviation of rainfall (86.0%) is found in 2010 and minimum negative deviation (-71.6%) is found in 1981. During the observed period 17 seasons were with positive deviation and 25 seasons were with negative deviations. In the recent years of 2020 the deviation was 60.1% and in 2024 it was -34.7%. As a whole, rainfall deviations are high in this district (Fig. 8). In pre-monsoon season, the maximum positive deviation of 80.9% in 1993 and minimum deviation of -62.1% in 2019. During the observed period 17 seasons were above positive deviation and 27 seasons were with negative deviation. In the recent years of 2024 and 2025 deviations were 57.1% and 59.6%. On the other hand, the notable negative deviations in 2021 and 2022 were -59.9% and -53.9%. Negative deviations were dominating during the recent years in this district (Fig. 9).

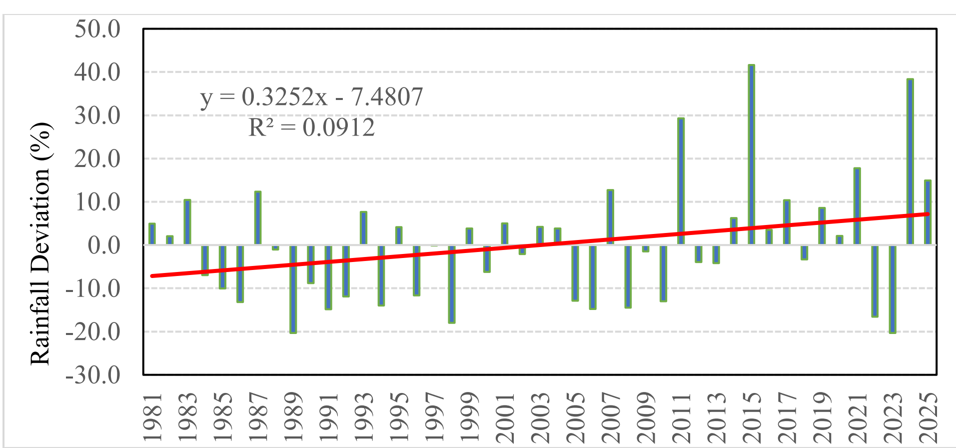

Fig. 7: Deviation of Monsoon Rainfall in Bandarban district during 1981-2025

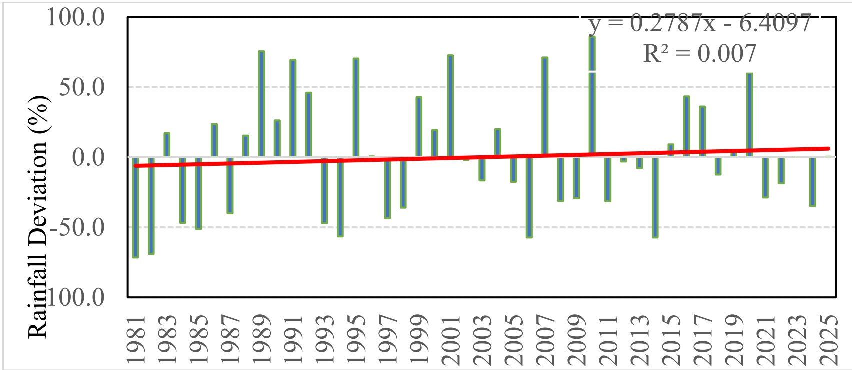

Fig. 8: Deviation of Post-monsoon Rainfall in Bandarban district during 1981-2025

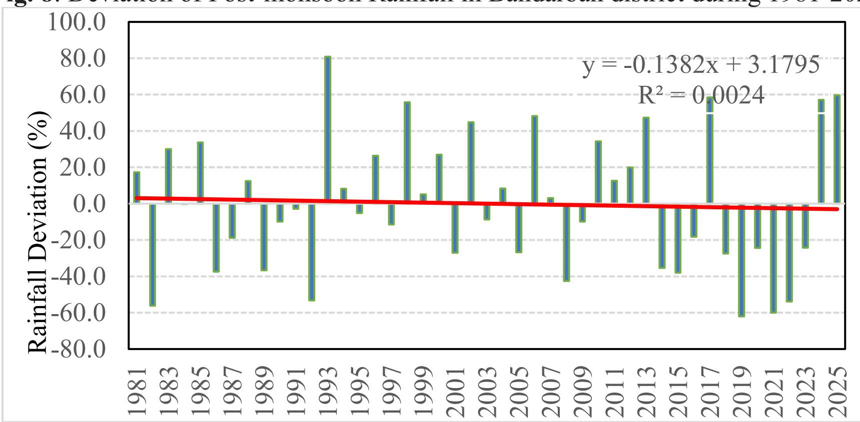

Fig. 9: Deviation of Pre-monsoon Rainfall in Bandarban district during 1981-2025

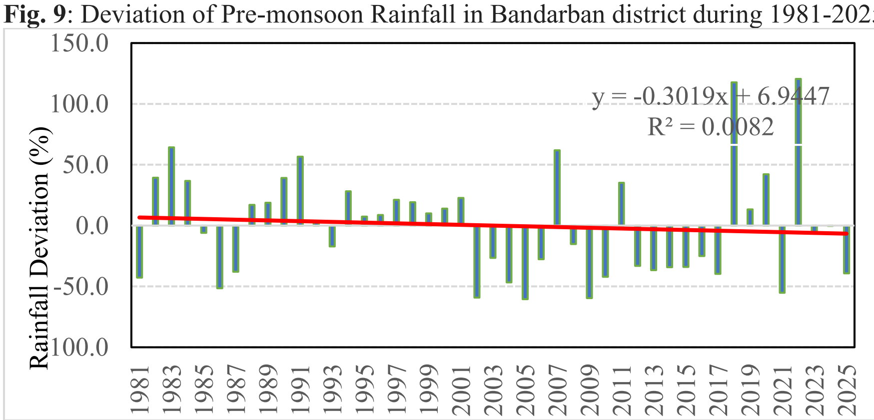

Fig. 10: Deviation of Winter Rainfall in Bandarban district during 1981-2025

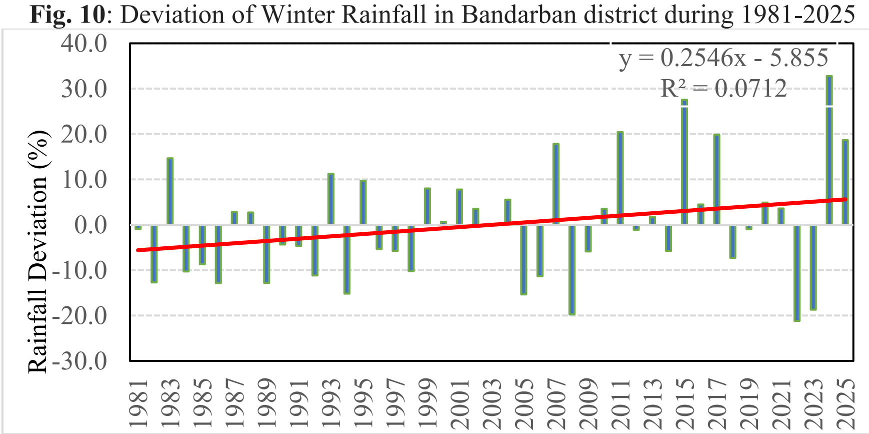

Fig. 11: Deviation of Annual Rainfall in Bandarban district during 1981-2025

In winter season, the maximum positive deviation of 120.6% in 2022 and lowest negative deviation of -60.6%. During the observed period 18 seasons were of positive deviation and 25 seasons were with negative deviation. In the recent years of 2018 the deviation was 117.8% and in 2025 it was of -39.2%. Highly rainfall deviations are quite frequent in the recent years in this district (Fig. 10). Annual rainfall of Bandarban district was highly variable in nature. During the observed period it was deviated as low as -21.2% (in 2022) and as maximum as 32.8% (in 2024). Within the observed period rainfall situation was with positive deviation in 8-years and it was negative deviation in 33 years. Highly frequent annual rainfall deviations are observed during the recent 20 years (Fig. 11), which is closely aligned with the monsoon rainfall pattern in this district.

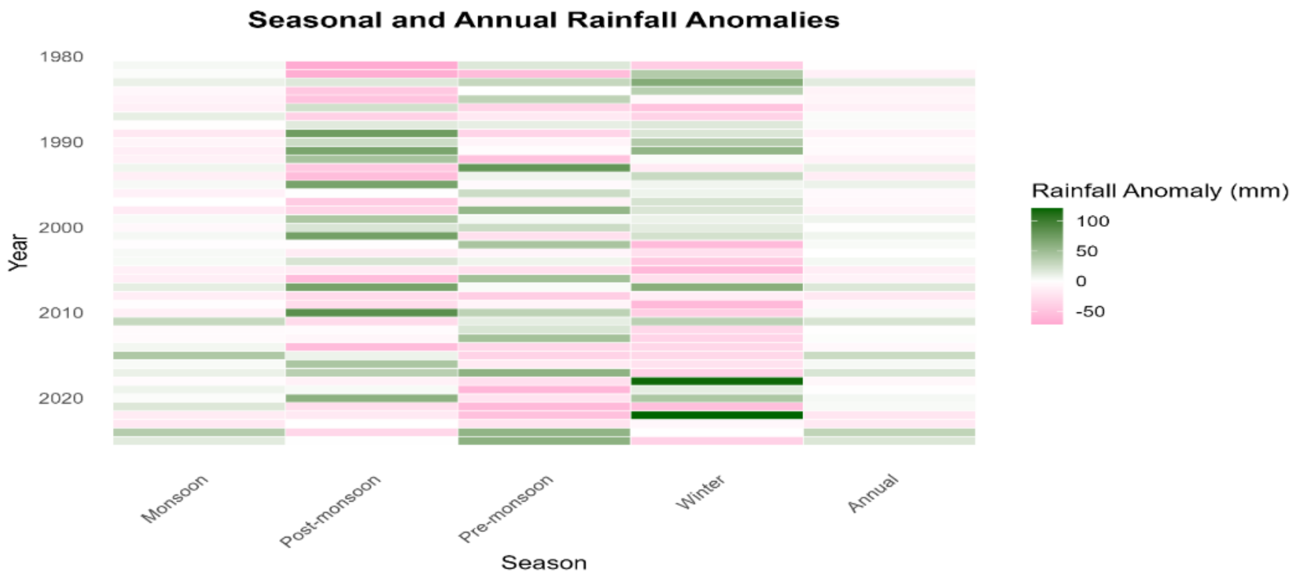

Fig. 12: Heat map displaying the deviation (%) of rainfall in Bandarban district during 1981-2025

A composite analysis of seasonal and annual rainfall deviations is depicted in the Fig. 11 and a brief summary of rainfall deviation is given in the Table 4. The number of excess rainfall instance in the monsoon, post-monsoon, pre-monsoon and winter seasons are 9, 17, 17 and 18 respectively but the number of deficit rainfall instances is 14, 20, 18 and 20. In the case of annual rainfall, the number normal rainfall is dominating, but the number of excess rainfall instances and deficit rainfall instances are in 8 years each.

Table 4: Summary of seasonal and annual rainfall in Bandarban during 1981-2025

Rainfall Status	Monsoon Season	Post-monsoon Season	Pre-monsoon Season	Winter Season	Annual
Maximum Deviation	41.6	86.0	80.9	120.6	32.8
Minimum Deviation	-20.3	-71.6	-62.1	-60.6	-21.2
Number of Excess Rainfall year	9	17	17	18	8
Number of Below Rainfall year	14	20	18	20	12
Number of Normal Rainfall year	22	8	10	7	25

3.6 Precipitation Concentration Index

Analysis of the Precipitation Concentration Index (PCI) on an annual basis reveals that rainfall over the Bandarban district is highly uneven. The distribution primarily falls into the irregular and strongly irregular categories, indicating increased susceptibility to localized floods during wet spells. According to Oliver's widely accepted Precipitation Concentration Index Classification, annual PCI values are divided into uniform (≤ 10), moderate (11–15), irregular (16–20), and strongly irregular (> 20) distributions. Over the observed period in Bandarban, the temporal distribution of rainfall deviates completely from uniform conditions. The magnitude of the annual PCI predominantly ranges between 16 and 20, signifying an irregular precipitation distribution. Historical analysis shows that rainfall is classified as irregularly distributed in 36 individual years during the observed timeframe. In several years, the PCI value exceeded 20, indicating a strongly irregular or high-concentration precipitation distribution.

Years exhibiting strongly irregular rainfall include 1982, 1987, 1997, 2003, 2014, 2016, 2019, and 2021. The clustering of these extreme metrics in recent decades highlights a shift toward more erratic climate patterns in the region. Temporal distribution analysis demonstrates a statistically significant increasing trend in the annual PCI for the Bandarban district (Fig. 13). This upward trajectory suggests that the total annual rainfall is concentrating into fewer, more intense months rather than spreading evenly across the year. The Mann-Kendall test yields a positive Kendall's Tau (τ) value. This confirms a monotonic increasing trend in precipitation concentration over Bandarban district. The computed p-value falls below the standard significance threshold ($\alpha = 0.05$), meaning the null hypothesis of "no trend" is rejected. The observed rise in rainfall irregularity is statistically significant and driven by shifting climate dynamics rather than random natural variability. Sen's Slope estimator shows a positive annual rate of change, quantifying the steady, long-term increase in the index value per year

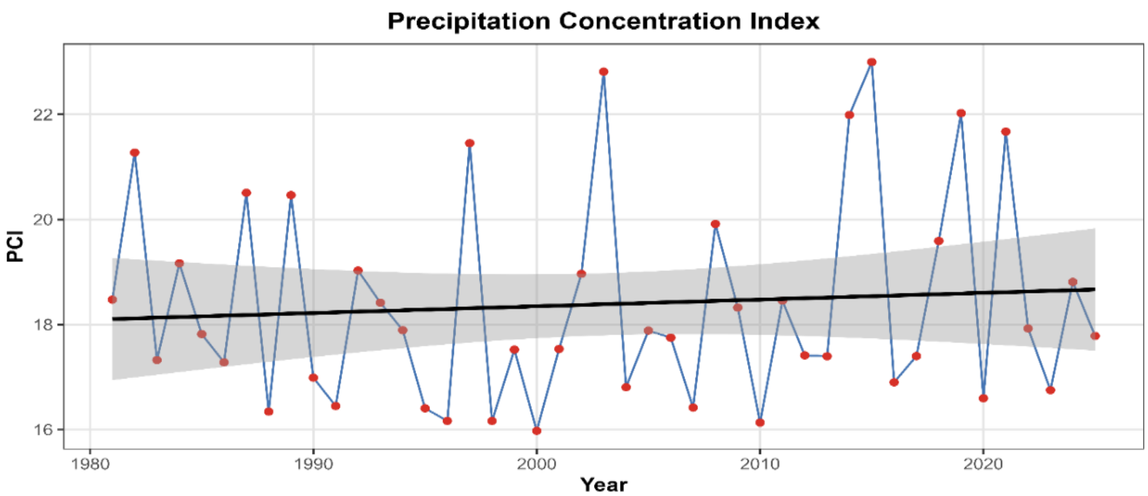

Fig. 13: Temporal variation of PCI over Bandarban district during 1981-2025

3.7 Standardized Precipitation Index

An analysis of the **Standardized Precipitation Index (SPI)** using rainfall data (1981–2025) reveals that conditions in the Bandarban district are predominantly 'Near Normal'. Severe dry and extreme conditions are statistically rare, indicating a very low risk of rainfall-related hazards. Short-term precipitation anomalies analyzed over a 3-month scale are dominated by the 'Near Normal' category, accounting for approximately (70%) of the observed period. Hazardous SPI occurrences are minimal, as follows: (i) **Extreme Wet:** ~ 2.6%, (ii) **Severe Wet:** ~ 2.2%, (iii) **Severe Dry:** ~ 5.2% and (iv) **Extreme Dry: ~1.3%.**

The long-term SPI for the region displays similar stability. The dominant category is also 'Near Normal', covering ~ 72% of the study timeframe. Significant wet and dry situations occur infrequently: (i) **Extreme Wet:** ~ 4.0%, (ii) **Severe Wet: ~ 4**.0%, (iii) **Severe Dry:** ~ 5.6% and (iv) **Extreme Dry:** ~ 0.0%.

The associated SPI heat map (Fig. 15) indicates that extreme or severe rainfall-related risks are negligible across the region. However, a closer temporal evaluation reveals that strictly "wet" situations have become less frequent in the Bandarban district in recent years.

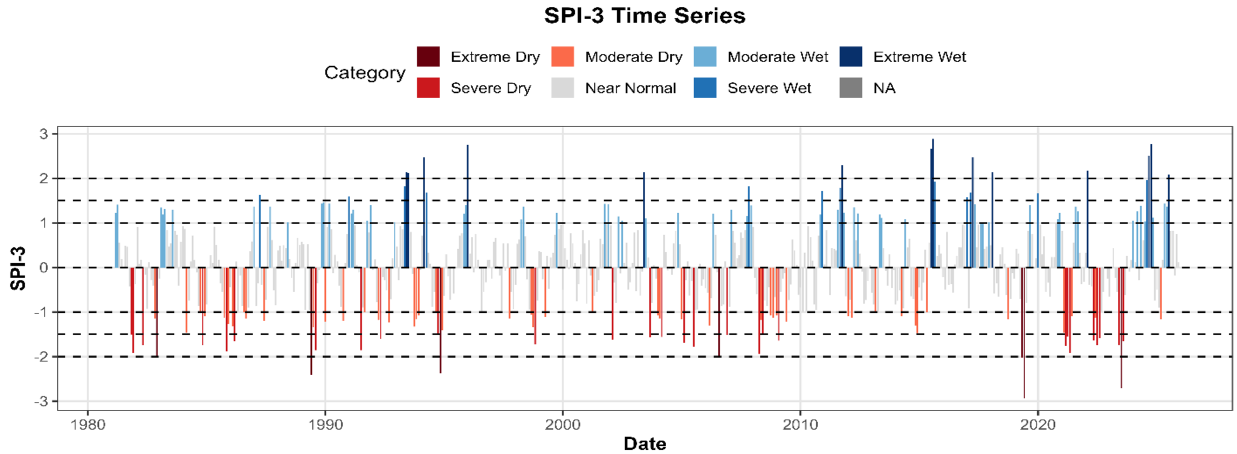

Fig. 14: Temporal variation of 3-month SPI over Bandarban district during 1981-2025

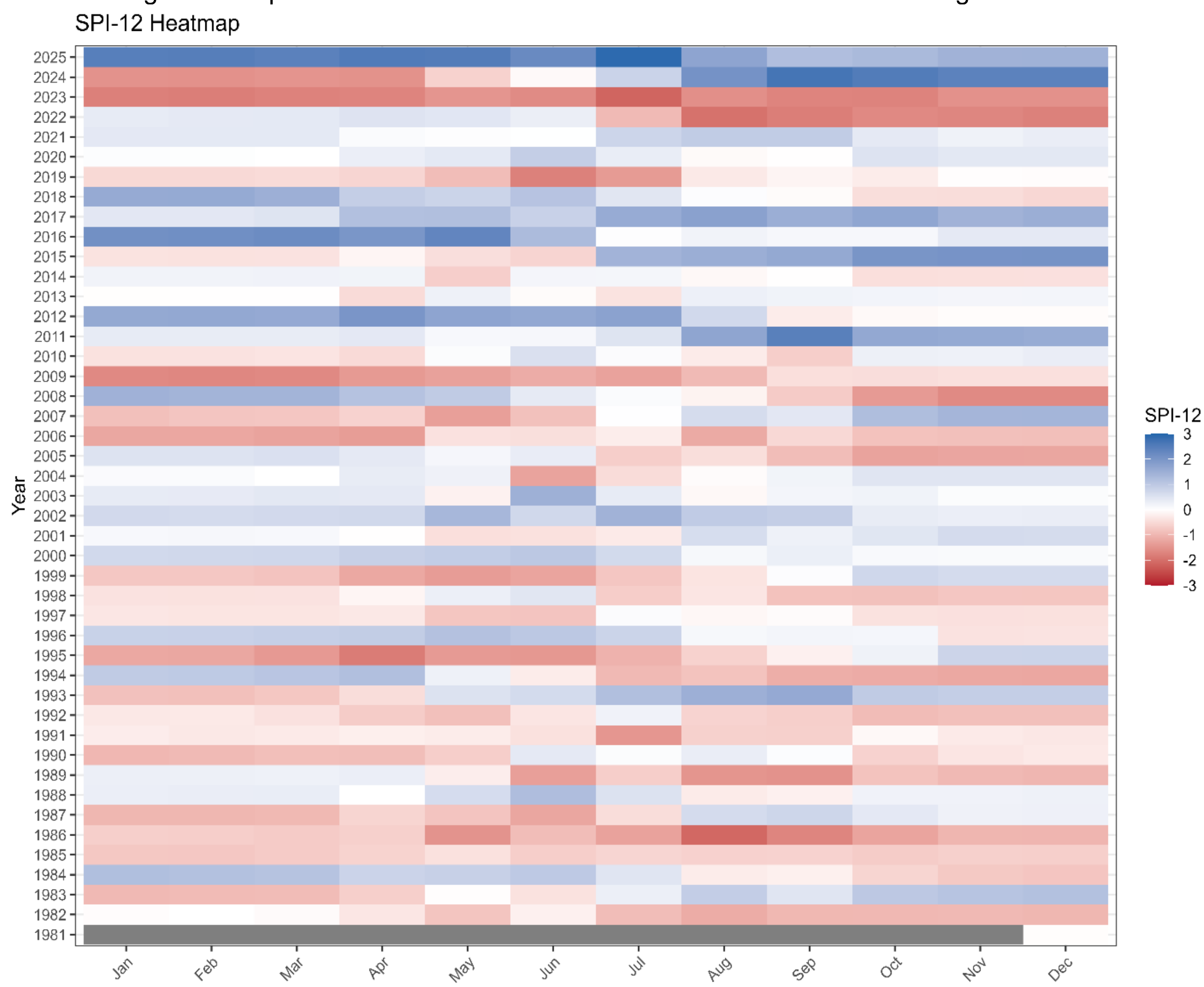

Fig. 15: Temporal variation of 12-month SPI over Bandarban district during 1981-2025

3.8 Changing behviour of rainfall

To assess the impact of climate change on precipitation, we compared rainfall distributions between two distinct periods (1981–2000 and 2001–2025) using box plots (Fig. 15). The analysis reveals that the 25th percentile, median, and 75th percentile of rainfall amounts have increased, alongside a rise in extreme precipitation events. This upward shift confirms a significant alteration in rainfall patterns during the 2001–2025 period compared to the historical 1981–2000 baseline (Table 5)

Table 5: Comparison of daily and annual rainfall conditions in two different climate periods

Conditions	Daily Rainfall (mm)		Annual Rainfall (mm)	
	1981-2000	2001-2025	1981-2000	2001-2025
Maximum	235.8	256.1	3577.1	4142.5
75th percentile	7.3	8.4	3207.4	3519.3
Median	0.0	0.1	2964.2	3229.8
25th Percentile	0.0	0.0	2778.5	2915.0
Minimum	0.0	0.0	2646.5	2459.6

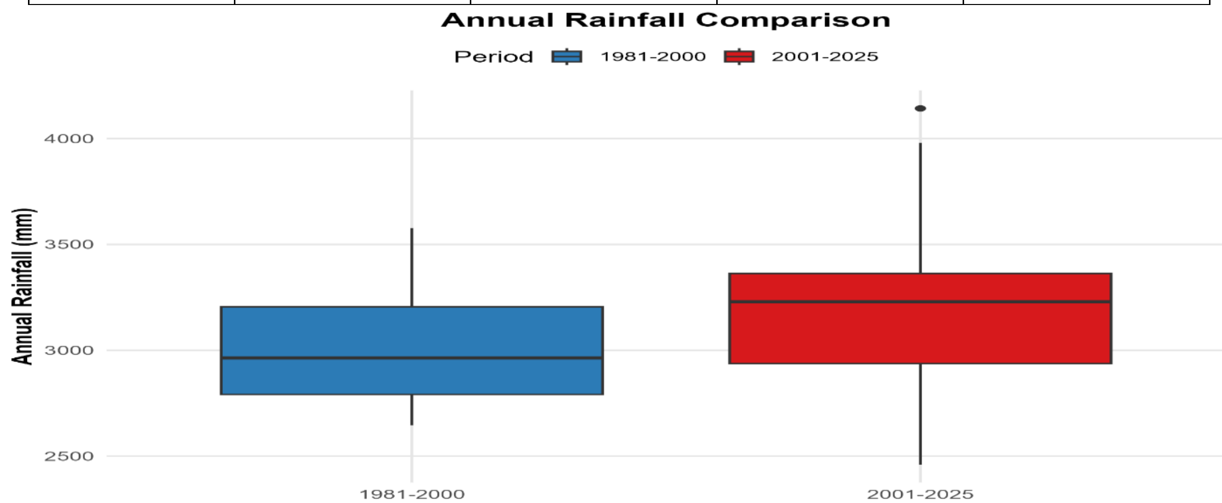

Fig. 16: Box plots of annual rainfall during 1981-2000 and 2001-2025

4. Conclusion

The rainfall in Bandarban exhibits extreme seasonal variation, while light rain (Cat-I) dominates about 50% of events. The district relies on significant monsoon precipitation for its robust agricultural cycles. Rainfall variance (coefficient of variation) is highest during winter and the transitional seasons. Rainfall events with 'Category V' are rare and above make up about 5.2% of total events, which can pose risks of localized flooding or landslides in the hilly district.

Bandarban district experiences a highly variable rainfall climate, with an average annual rainfall of approximately 3,120 mm. The monsoon season dominates the year's precipitation, while the pre-monsoon and post-monsoon periods also provide substantial rainfall. The district receives 76.3% rainfall in monsoon season, 12.7% in pre-monsoon season, 10.1% in post-monsoon season and 0.8% in winter season of annual total.

Both monsoon and pre-monsoon seasons exhibit positive rainfall trends with rate of 5.66 mm/year and 1.24 mm/year respectively. But both pre-monsoon and winter season show decreasing trends by -1.02 mm/year and -0.22 mm/year respectively. Mann–Kendall and p-value tests indicate that these seasonal trends are not statistically significant. Overall, the districts total annual rainfall fluctuates noticeably, with a standard deviation (STD) of 391 mm and a coefficient of variation (CV) of 12.5.

Rainfall in the Bandarban district is becoming increasingly erratic, with total annual rainfall concentrating into fewer, more intense months. Statistical testing confirms a steady upward trajectory in rainfall irregularity, pointing to climate change as the driver rather than natural variability. Based on Oliver's PCI Classification, Bandarban's rainfall distribution primarily falls into the irregular (16-20) to strongly irregular (>20) categories. Over the observed timeframe, 36 years experienced irregularly distributed rainfall. Strongly irregular precipitation was concentrated in recent decades, specifically in 1982, 1987, 1997, 2003, 2014, 2016, 2019, and 2021. The Mann-Kendall test estimates a statistically significant positive trend (α = 0.05), validating that the region is persistently shifting toward higher rainfall concentration.

Based on historical rainfall data (1981–2025), Bandarban district's precipitation conditions are highly stable and predominantly "Near Normal", resulting in a very low risk of rainfall-related hazards. Normal conditions cover approximately 70% of the timeframe, with extreme wet approximately 2.6%, severe wet approximately 2.2%, severe dry approximately 5.2%, and extreme dry approximately 1.3% occurrences remaining minimal. Normal rainfall conditions similarly dominate approximately 72% of the historical period, showing extremely low frequencies of significant dry or wet events. Despite the overall statistical stability, temporal analysis indicates a slight, recent decline in the frequency of strictly wet situations.

Climate change has significantly shifted rainfall patterns. Comparing the 2001–2025 period to the 1981–2000 baseline shows notable increases in average rainfall with the 25^{th}, 50^{th}, and 75^{th} percentiles all rising alongside a surge in extreme precipitation events.

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