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Long-term (1919–2019) rainfall trends and anomalies over the Meghalaya plateau, northeast India

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Abstract

This study examines long-term, century-scale (1919 to 2019) rainfall trends and anomalies across the Meghalaya plateau using district-level rainfall data from the Indian Meteorological Department and the Agriculture Department, Government of Meghalaya. Trends and magnitudes were measured with the help of non-parametric Mann-Kendall (classical and modified) tests, and Sen's slope estimator, which reveal a statistically insignificant increasing trend (+1.87 mm yr^{-1}) in annual rainfall over the century. Seasonal variation during pre-monsoon, monsoon, and winter seasons also shows a statistically insignificant increasing trend, except for the post-monsoon period, which has an insignificant decreasing trend. More recent decade of 1999-2009, however, demonstrates a statistically significant declining trend ($p < 0.05$; Sen's slope = –28.8 mm yr^{-1}). Rainfall Anomaly Index (RAI) and SPI-12 calculations indicate 55 (RAI) and 57 (SPI-12) dry years versus 46 and 44 wet years, respectively, with extreme dry conditions in 2013 (RAI = –4.31) and extreme wet conditions in 1974 (RAI = +6.83). Further, results suggest extreme variations in rainfall in recent years, with implications for rainfed agriculture practised by the tribal people here.

Keywords: *Rainfall anomaly, Meghalaya, Mann–Kendall test, Sen's slope, Rainfall Anomaly Index, SPI-12, monsoon variability, northeast India*

Introduction

In developing countries like India and Africa, the agricultural sector and the economy as a whole are strongly influenced by rainfall patterns and volumes. But in recent decades, rising sea surface temperature and surface air temperature, along with climate change, have altered the volume, frequency, and magnitude of rainfall, affecting many nations (Irannezhad *et al.*, 2021; Halder & Yaseen, 2024). Long-term rainfall trends and anomalies are necessary and important indicators for understanding climate variability and change over extended periods. Further, such an analysis will enable proper planning and management of water resources, as well as the prediction of drought and flood conditions.

In the present context, the application of the Mann-Kendall test and Sen's slope estimate for analysing rainfall trends and their magnitudes, along with the use of the Rainfall Anomaly Index (RAI) to detect and quantify rainfall anomalies are becoming significantly acceptable for investigating long-term variability in rainfall and are such variation is linked to climate change (Mohammed & Santhanakrishnan, 2021; Rao *et al.*, 2023).

The use of the Mann-Kendall test and Sen's slope by Madhusudhan *et al.* (2021) to investigate the rainfall trend and magnitude over the Mandya district of Karnataka from 1991 to 2020 revealed that the annual rainfall depicted an insignificant negative trend across the majority of the stations at a 95 percent confidence level, hence accepting the null hypothesis that there were no marked changes in the annual rainfall. The Sen's slope indicated both increasing and decreasing rainfall magnitudes, thus showing regional variation.

Likewise, Aryal *et al.* (2022) have used the Rainfall Anomaly Index (RAI) in their study, highlighting that Nepal had experienced 23 years of wet conditions, indicated by positive RAI values and 18 years of dry conditions, indicated by negative RAI values. The results also showed that the majority of the dry conditions occurred after 2005, while a continuous drought-like condition persisted from 2012 to 2015. This clearly indicates significant variation in climatic elements, and, according to the researchers, this is primarily driven by anthropogenic forces responsible for accelerated global warming and climate change.

Rao *et al.* (2023) used the Mann-Kendall test and Sen's slope estimator to study rainfall trends in Chintapalle and Visakhapatnam, Andhra Pradesh, from 1990 to 2020. They found the average annual rainfall decreased, though insignificantly, at 1.63 mm/year. The RAI also identified drought-like conditions of varying intensity.

A century-scale analysis of rainfall over the Meghalaya plateau is important as this region receives the highest rainfall in the world, and is dominated by tribal people who are almost entirely dependent on rainfed shifting/bun cultivation for their livelihoods. Studies (Gargol & Soja, 2015; Roy *et al.*, 2022; Nandi, 2024) suggest that due to limited rainfall stations and records, the majority of research on rainfall volume and trends has been focused on the plateau's southern and northern parts where data are more readily available. However, to understand climate change and its impact on the economy and people, long-term rainfall analyses across the plateau region are necessary. Also, long-term rainfall analysis is crucial because short-term analysis often results in contradictory or inconclusive trends. Hence, this long-term analysis is expected to establish a clear baseline for accurate climate change assessment, water resource management, agricultural planning, and disaster risk reduction.

Thus, the main objective of this research is to analyse rainfall trends and magnitudes on an annual, seasonal, and decadal scales and to examine annual rainfall anomalies from 1919 to 2019 over the Meghalaya plateau.

Study area

Meghalaya is located in the northeastern part of India, extending between 24°58'N and 26°07'N latitude and 89°48'E and 92°51'E longitude (Fig. 1). This plateau acts as a horst, separating the Brahmaputra Valley in the north from the Surma Valley in the south and west (Das *et al.*, 1971) and is mainly inhabited by tribal people, namely the Khynriam, Pnar, Bhoi, War, and the Garos, most of whom are engaged in agriculture as their source of livelihood. Meghalaya covers an area of 22,429 km^2 and is characterised by a subtropical monsoonal climate, with average rainfall ranging from 1,500 mm to 24,000 mm and average temperatures ranging

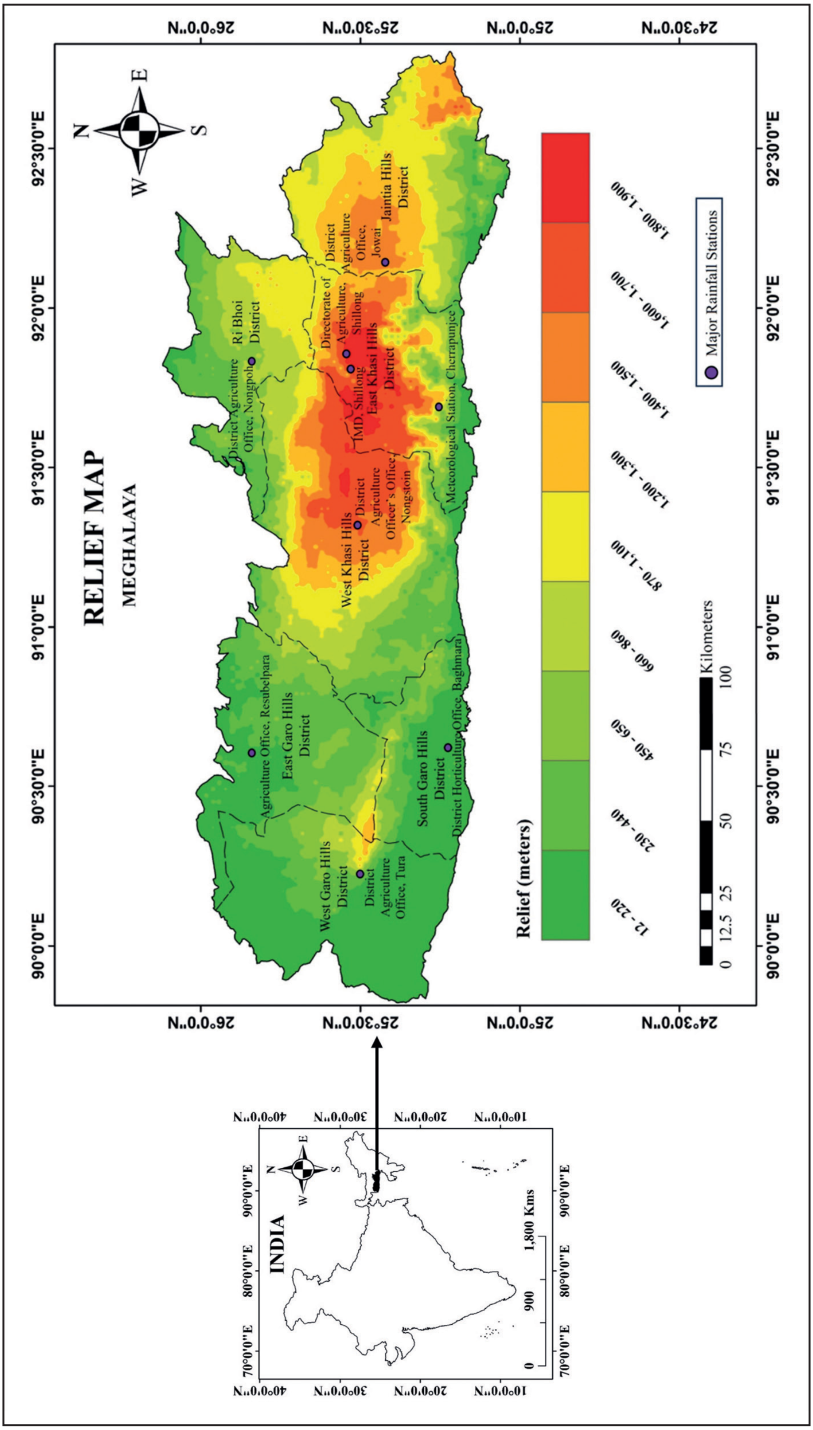

Fig. 1: Location of the study area

from 12°C to 33°C (Soja & Starkel, 2006; FSI, 2019).

The plateau is strongly influenced by the southwest monsoon winds, accounting for about 80 percent of the yearly rainfall, occurring between June and September. The distribution of rainfall is significantly influenced by the topography of this plateau, as the southern escarpment of the plateau rises from the Bangladesh plains; these winds strike the southern escarpment, bringing rain to the entire plateau region. As these winds move towards the central and northern part of the plateau, rainfall is drastically reduced, affecting the agricultural livelihood of the tribal people (Prokop, 2014).

Database and methodology

Firstly, for a long-term analysis of rainfall, monthly rainfall data for Meghalaya were collected from the 110-year (1901-2010) monthly rainfall data series for districts, states, and Met sub-divisions, and for all India from the Ministry of Earth and Science, India Meteorological Department, retrieved from https://imdpune.gov.in/ library/public/ e-book110.pdf (Indian Meteorological Department, n.d.-a).

Secondly, for the years 2012, 2013, 2014, 2015, 2017, 2018, and 2019, monthly rainfall data for Meghalaya were collected from the rainfall statistics of India, available at https:// hydro.imd.gov.in/ hydrometweb/ (Indian Meteorological Department, n.d.-b).

The Indian Meteorological Department used a specific daily gridded rainfall dataset (IMD4). Using the inverse distance-weighted (IDW) interpolation scheme by Shepard (1968), rain gauge station data were transformed onto a high-resolution (0.25 × 0.25) grid. After IDW interpolation, an area-weighted average was used to obtain state-level rainfall data for Meghalaya.

Finally, the missing years' data for 2011 and 2016 were obtained from the Department of Agriculture, Government of Meghalaya. For these years, rainfall in Meghalaya was estimated as follows: first, annual rainfall was recorded at two to four stations within each district under the District Agriculture Office and the Agriculture Department (Table 1). Next, the station means were then averaged within each district to obtain district-level annual means. Finally, the arithmetic mean rainfall of all districts was calculated to estimate the state's overall rainfall for those years.

Table 1: Districts and number of rainfall stations, Meghalaya.

Name of Districts	Number of rainfall stations	Period of record
East Khasi Hills	3	2006-2019
West Khasi Hills	3	2006-2019
Ri Bhoi	4	2006-2019
Jaintia Hills	1	2006-2019
East Garo Hills	2	2006-2019
South Garo Hills	2	2006-2019
West Garo Hills	2	2006-2019

Source: Directorate of Agriculture, Meghalaya
(https://megagriculture.gov.in/PUBLIC/download_dwd_documents.aspx)

Table 2: Rainfall Anomaly Index (RAI) and Standard Precipitation Index-12 (SPI-12) classification

RAI range	Class description	SPI range	Class description
≥ 3	Extremely wet	≥ 2	Extremely wet
2.00 to 2.99	Very wet	1.50 to 1.99	Severe wet
1.00 to 1.99	Moderately wet	1.00 to 1.49	Moderately wet
0.50 to 0.99	Slightly wet	0.00 to 0.99	Mildly wet
0.49 to - 0.49	Near normal	0 to – 0.99	Mild drought
- 0.50 to - 0.99	Slightly dry	-1.00 to -1.49	Moderately drought
-1.00 to -1.99	Moderately dry	-1.50 to -1.99	Severe drought
-2.00 to -2.99	Very dry	≤ -2	Extreme drought
≤ - 3	Extremely dry	-	-

Sources: Van Rooy, 1965; McKee et al, 1993; Topçu & Seçkin, 2016

Monthly rainfall data were analysed at annual, seasonal, and decadal scales. The Mann-Kendall test evaluated the null hypothesis (Ho) of no trend against the alternative hypothesis (Ha) of a significant trend in time series data. Seasonal rainfall trend was analysed by disaggregating the data into four seasons: pre-monsoon (March-May), monsoon (June to September), post-monsoon (October to November), and winter (December to February).

Another non-parametric method for trend analysis of the hydrological and hydrometeorological data sets is Sen's Slope estimate (1968), which measures the magnitude of the trend, the slope, and the intercept of the linear rate of change.

To account for serial correlation in long-term data, the Modified Mann-Kendall (MMK) test was then applied using the Yue and Wang (2004) variance-correction approach, based on lag-1 correlation. All calculations were conducted using R (version 4.2.1) and XLSTAT (version 2022.5.1).

Finally, monthly rainfall data were analysed to identify annual rainfall anomalies from 1919 to 2019 using the RAI (Van Rooy, 1965), as it enhances accountability, visibility, and requires less expertise. In this method, rainfall data are sorted from highest to lowest. The highest rainfall value gets the top rank, and the lowest gets the bottom rank. The averages of the ten highest and ten lowest rainfall values are then calculated for the study period. The positive and negative RAI indices are calculated using the average of ten extremes using the formula:

$RAI = 3 \times (P - \bar{P}) / (\bar{M} - \bar{P})$ for positive anomalies,

$RAI = -3 \times (P - \bar{P}) / (\bar{X} - \bar{P})$ for negative anomalies

P= yearly rainfall

$\bar{P}$ = yearly average rainfall for the time series under study (mm)

$\bar{M}$ = the average of the ten highest yearly rainfalls for the time series under study (mm)

$\bar{X}$ = the average of the ten lowest yearly rainfalls for the time series under study (mm)

The average of the ten most extreme positive and negative anomalies has been assigned random limit values of +3 and -3, respectively. The RAI classification has been utilised in this study to identify

Table 3: Annual, seasonal and decadal rainfall (1919 to 2019), Meghalaya plateau.

Annual rainfall trend (1919-2019)								
Time Series	Classical Mk test				Modified Mk test			
	Statistics (Z)	p value	Sen's slope (Q)	Tau	Statistics (Z)	p value	Sen's slope (Q)	Tau
1919-2019	0.64	0.52	1.87	4.35	0.6	0.54	1.87	0.04
Seasonal rainfall trend (1919-2019)								
Time Series	Classical Mk test				Modified Mk test			
	Statistics (Z)	p value	Sen's slope (Q)	Tau	Statistics (Z)	p value	Sen's slope (Q)	Tau
Pre-Monsoon	0.41	0.67	0.32	2.81	0.44	0.65	0.32	0.02
Monsoon	0.5	0.61	1.3	3.4	0.465	0.64	1.3	0.03
Post-Monsoon	-0.04	0.96	-0.04	-3.16	-0.04	0.97	-0.04	-0.003
Winter	0.3	0.75	0.02	2.09	0.32	0.74	0.02	0.02
Decadal rainfall trend (1919-2019)								
Time Series	Classical Mk test				Modified Mk test			
	Statistics (Z)	p value	Sen's slope (Q)	Tau	Statistics (Z)	p value	Sen's slope (Q)	Tau
1919 -1929	0.93	0.35	3.7	0.23	1.36	0.17	3.7	0.23
1929-1939	0.15	0.87	1.7	0.05	0.29	0.77	1.7	0.05
1939-1949	1.4	0.16	8.8	0.34	1.89	0.06	8.8	0.34
1949-1959	-0.62	0.53	-6.9	-0.16	-0.7	0.48	-6.9	-0.16
1959-1969	0.93	0.35	8.7	0.23	1.09	0.28	8.7	0.23
1969-1979	-0.46	0.64	-4.8	-0.12	-0.47	0.64	-4.8	-0.12
1979-1989	1.24	0.21	30.2	0.3	1.47	0.14	30.2	0.3
1989-1999	0.93	0.35	14.5	0.23	1.17	0.24	14.5	0.23
1999-2009	-2.17	0.02*	-28.8	-0.52	-2.56	0.01*	-28.8	-0.52
2009-2019	0.46	0.64	7.2	0.12	0.51	0.6	7.2	0.12

* Value is statistically significant at a 95% confidence level.
+ sign indicates an increasing trend, whereas – sign indicates a decreasing trend.

Source: Computed by the researcher

extreme rainfall conditions from 1919 to 2019. Finally, for a robust analysis, the Standard Precipitation Index-12 (SPI-12) has been computed using the two-parameter gamma distribution and the Standardised Precipitation-Evapotranspiration Index (SPEI) package in R Software version 4.2.1. The SPI-12 has been computed to measure meteorological drought, i.e., a period of dry or wet conditions (McKee *et al.*, 1993). Further, results from the SPI-12 have been compared to the RAI. The RAI and SPI-12 classification is shown in Table 2.

Results and discussion

Trend analysis of the annual, seasonal, and decadal rainfall from 1919 to 2019

The results (Table 3) of the test conducted through MK and MMK on annual rainfall, does indicate an increasing trend, though not significant at the 95 percent confidence level. This means the null hypothesis (Ho) is accepted and that there are no significant changes in annual rainfall from 1919 to 2019. The result agrees with the study by Kripalani and Kumar (2004), which reported that rainfall did not show a statistically significant trend from 1871 to 2001. Sen's slope estimate also suggests that the magnitude of annual rainfall is increasing at a rate of 1.87 mm/year during the past century.

Trends by seasons reveal an insignificant increase, except for the post-monsoon, which shows an insignificant decreasing trend at the 95 percent confidence level, thereby accepting the null hypothesis that no marked changes in seasonal rainfall over the plateau region are observed from 1919 to 2019. Further, the Sen's slope estimate indicates that rainfall during pre-monsoon, monsoon, and winter seasons is increasing, with the highest slope recorded during the monsoon, indicating an increase of 1.30 mm/year. On the contrary, the post-monsoon depicts a declining trend at -0.04 mm/year.

Although no marked changes in the annual and seasonal rainfall trends are seen in the period 1919 to 2019, variations in rainfall patterns and amounts are discernible over the plateau region due to the physiographic complexities, changes in Indian Ocean temperatures, land use/land cover changes, and emissions from anthropogenic sources (Prokop & Walanus, 2014; Kad & Ha, 2023). The seasonal variation in rainfall, although not statistically significant, is strongly influenced by the El Niño–Southern Oscillation (ENSO), which disrupts atmospheric circulation and alters the Indian summer monsoon, resulting in erratic rainfall behaviour. Long-term fluctuations also show a positive relationship between the Southern Oscillation Index (SOI) and monsoon and post-monsoon rainfall, since ENSO, reflected in the SOI, is a primary climate driver. A negative SOI is mainly observed during the La Niña phenomenon, resulting in a stronger monsoon. On the contrary, a positive SOI is observed during the El Niño phenomenon, resulting in a weaker monsoon and less rainfall (Gadgil *et al.*, 2019; Singh & Kumar, 2022; Tinmaker & Shareef, 2024).

The computed decadal rainfall data (1919 to 2019) reveal that only one decade (1999 to 2009) shows a statistically significant decreasing trend at the 95 percent confidence level, thereby accepting the alternative hypothesis (Ha) and indicating a monotonic trend. The other nine decades show both increasing and decreasing trends, but these are statistically insignificant at the 95 percent confidence level. Likewise, the Sen's slope estimate reveals that the decade of 1979 to 1989 saw the largest increase in rainfall magnitude, at 30.2 mm/year, and the decade of 1999 to 2009 recorded the largest decrease in rainfall, at -28.8 mm/year.

A significant declining decadal rainfall trend (1999- 2009) observed in the plateau has been reported as the driest decade characterised by rainfall deficiency and such conditions persist due to the global atmospheric phenomenon and variability of the North East India summer monsoon rainfall associated with the large-scale moisture convergence that plays a significant role in the internal coupled ocean-atmosphere

Table 4: Annual Rainfall Anomaly Index (RAI) and Standard Precipitation Index-12 (SPI-12), Meghalaya plateau (1919 to 2019).

RAI Range	Classification	No of years	Years	SPI -12 Range	Classification	No of years	Years
≥ 3	Extremely wet	2	1974, 2011	≥ 2	Extremely wet	2	1974, 1975
2.00 to 2.99	Very wet	7	1954, 1979, 1984, 1988, 1998, 1999, 2000	1.50 to 1.99	Severe wet	3	1999, 2000, 2011
1.00 to 1.99	Moderately wet	8	1948, 1951, 1956, 1966, 1970, 1973, 1987, 1995	1.00 to 1.49	Moderately wet	5	1954, 1955, 1956, 1985, 1988
0.50 to 0.99	Slightly wet	10	1938, 1952, 1955, 1964, 1986, 1991, 1993, 2004, 2007, 2016	0.00 to 0.99	Mildly wet	34	1932, 1941, 1949, 1951, 1952, 1953, 1957, 1964, 1965, 1966, 1967, 1969, 1970, 1971, 1973, 1979, 1980, 1984, 1986, 1987, 1989, 1990, 1991, 1992, 1993, 1995, 1996, 1998, 2001, 2002, 2005, 2012, 2016, 2017
0.49 to - 0.49	Near normal	25	1921, 1924, 1931, 1932, 1934, 1936, 1941, 1943, 1946, 1949, 1953, 1958, 1960, 1963, 1965, 1968, 1969, 1971, 1975, 1977, 1985, 1989, 2001, 2002, 2017.	0 to – 0.99	Mild drought	48	1919, 1920, 1921, 1922, 1923, 1924, 1925, 1926, 1927, 1928, 1929, 1930, 1931, 1933, 1934, 1935, 1936, 1937, 1938, 1939, 1940, 1942, 1943, 1944, 1945, 1946, 1947, 1948, 1950, 1958, 1959, 1960, 1961, 1963, 1968, 1972, 1976, 1977, 1978, 1983, 1994, 1997, 2003, 2004, 2007, 2008, 2015, 2018
- 0.50 to - 0.99	Slightly dry	12	1926, 1927, 1928, 1929, 1935, 1940, 1942, 1945, 1990, 1996, 1997, 2015	-1.00 to -1.49	Moderately drought	7	1962, 1981, 1982, 2006, 2009, 2010, 2019
-1.00 to -1.99	Moderately dry	22	1919, 1920, 1922, 1930, 1933, 1937, 1939, 1944, 1950, 1957, 1959, 1962, 1967, 1972, 1982, 1983, 1992, 1994, 2003, 2005, 2014, 2019	-1.50 to -1.99	Severe drought	2	2013, 2014
-2.00 to -2.99	Very dry	11	1923, 1925, 1947, 1976, 1978, 1980, 1981, 2008, 2009, 2010, 2012	≤ -2	Extreme drought	0	0
≤ - 3	Extremely dry	4	1961, 2006, 2013, 2018	-	-	-	-

Source: Computed by the researcher

dynamics affecting the annual, seasonal and decadal rainfall (Choudhury *et al.*, 2019).

An insignificant declining decadal rainfall trend from the current findings correlates with the findings of Rajeevan *et al.* (2008) that notes an insignificant declining rainfall trend in India in 1940s to the 1960s, characterised by less severe extreme rainfall events primarily due to the cooling phase of SST prevailing over the equatorial Pacific and Indian oceans (IPCC, 2007). Similarly, an insignificant increasing decadal rainfall trend is due to the SST warming, which makes the positive Indian Ocean Dipole (IOD) stand out. This causes airflow to converge over the Bay of Bengal and the Indian region, leading to increased rainfall (Ashok *et al.*, 2001; Rajeevan *et al.*, 2008; Kumar *et al.*, 2024) in the northeastern states of India, including Meghalaya.

Rainfall anomalies from 1919 to 2019

The region recorded negative RAI values for 55 years and positive RAI values for 46 years, indicating dry or drought-like conditions and wet or rainy conditions of varying intensity, respectively. On the contrary, the SPI-12 result shows that the plateau region experienced negative SPI-12 values for 57 years and positive values for 44 years, indicating drought and wet conditions of varying intensity, respectively. RAI result also corresponds to the SPI-12 result, as depicted in Table 4.

The RAI result reveals that the Meghalaya plateau over a period of 100 years (1919-2019) has experienced 11 years of very dry conditions, 4 years of extremely dry conditions, 7 years of very wet conditions, and 2 years of extremely wet conditions. Likewise, the SPI-12 result shows that the plateau experienced 2 years of extremely wet conditions, 3 years of severe conditions, and 2 years of severe drought; however, no extreme drought was recorded (Table 4).

It is found that the period from 1925 to 1930, 1980 to 1983, and 2012 to 2015 (Fig. 2) experienced the longest drought-like conditions. According to Van Rooy's (1965) RAI classification, 2013 recorded the highest negative RAI value of -4.31, indicating extremely dry conditions, and this result corresponds to the result of the SPI-12, as the year 2013 experienced severe drought conditions in the plateau (Table 4). Similarly, according to the RAI results, long periods of wetness were recorded in 1954 to 1957, 1986 to 1988, and 1998 to 2000. Further, the years 1974 and 2011 recorded the highest positive RAI values of 6.83 and 5.1, respectively, indicating a period of extreme wet conditions, and this result corresponds with the result of the SPI-12, as the years 1974 and 2011 were a period of extremely wet and severe wet conditions as depicted in Table 4.

The drier years in Meghalaya can be attributed to alterations in the global atmospheric circulation caused by the El Niño phenomenon, which contributes to the warming of the SST in the eastern tropical Pacific Ocean. The warming of the SST in the eastern tropical Pacific Ocean weakens the southeast trade winds, which drift towards the Intertropical Convergence Zone over India (Tinmaker & Shareef, 2024). These southeast trade winds are the driving force behind the weakening of the summer monsoon, leading to lower than average rainfall and rainfall deficits in the plateau region, contributing to drier conditions. On the other hand, the La Niña phenomenon is the opposite of El Niño, which is responsible for heavy torrential rainfall contributing to the wet conditions.

Additionally, the study suggests that the IOD positive and negative phases also play

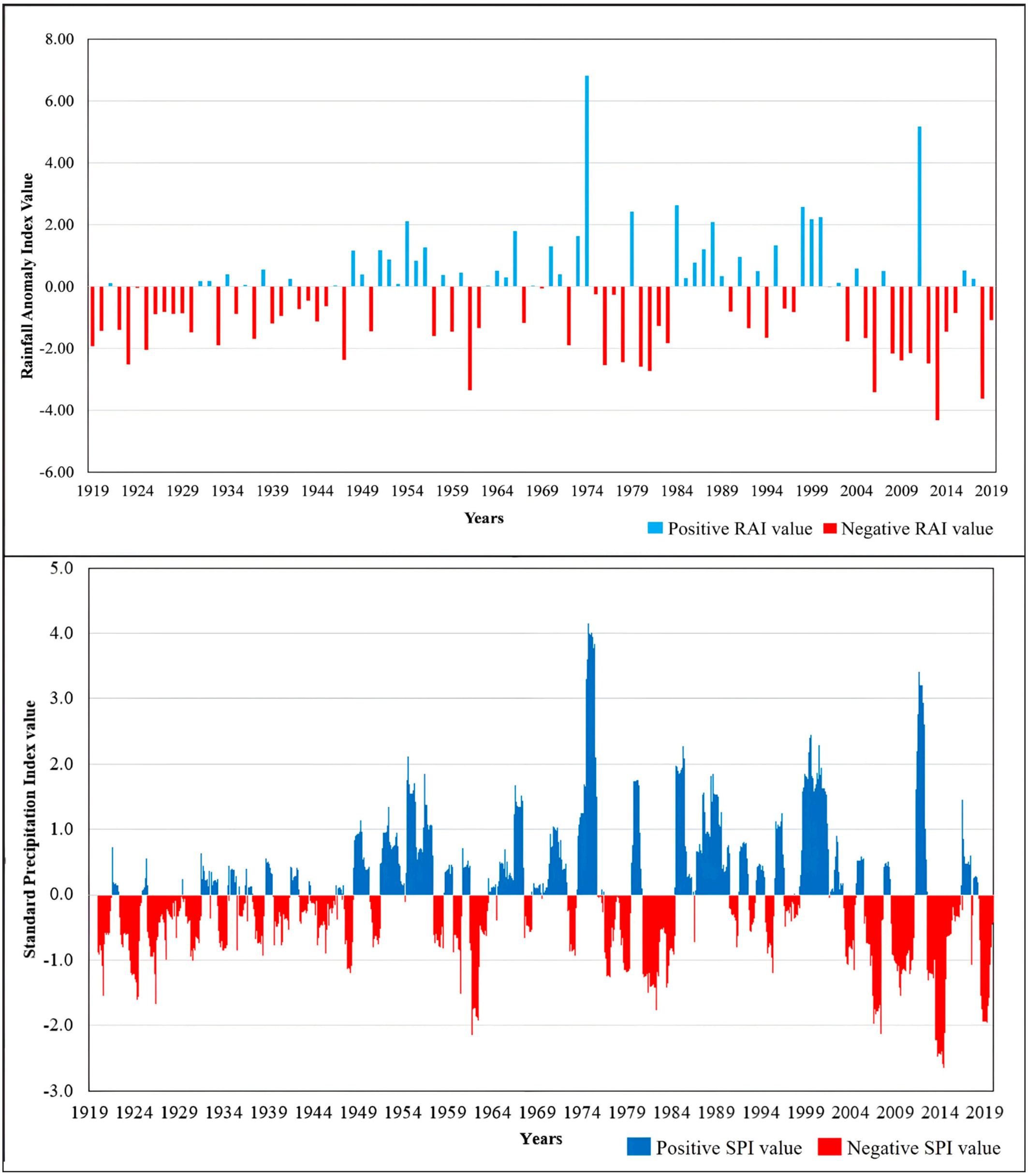

Fig. 2: Wet and dry periods, Meghalaya plateau (1919 to 2019)

a significant role during the commencement, peak, and retreating phases of the monsoon. The positive phase is characterised by an increase in SST in the western Indian Ocean and a decrease in SST in the eastern Indian Ocean. On the contrary, the negative phase is just the opposite of the positive phase. Further, Sarkar *et al.* (2021) suggest that the positive IOD phase and the warming SST in the western part of the Indian Ocean during

March to May result in a decline in monsoonal rainfall over northeast India. Consequently, the behaviour of the positive and negative IOD phases affects the three phases of the Indian monsoon, resulting in variability in annual rainfall in the plateau region.

Though the Meghalaya plateau is known to be among the wettest places on earth, there however has been significant changes in the distribution and pattern of rainfall during the past two decades. The RAI and SPI-12 result, as depicted in Table 4, reveals that the past two decades i.e., from 2006 onwards the plateau has experienced many dry/ drought conditions ranging from moderate to extremely dry/drought conditions and the current finding correlates with Ray *et al.* (2013) suggesting that drought of various intensities, from mild to moderate, has been recorded from 2004 to 2007 in Meghalaya. Apart for global factors, various studies reveal that regional factors such land use/ land cover changes, deforestation, rapid industrialisation, urbanisation and other developmental activities are responsible for changing the boundary layer heating rates, the cloud microphysics, magnitude, and intensity of regional rainfall extremes leading to floods or droughts (Schmid & Niyogi, 2017; Niyogi *et al.*, 2018; Seth *et al.*, 2019; Dubey *et al.*, 2022).

Conclusion

The long-term analysis of annual and seasonal rainfall over 100 years reveals an insignificant increasing trend with increasing magnitudes. The results show that variations in annual and seasonal rainfall are evident. Interestingly, only the decade of 1999-2009 shows a significant decreasing trend. The RAI results also revealed that Meghalaya has experienced more dry years than wet years in the past century, and the plateau has experienced two years of extreme wet conditions and four years of extreme dry conditions (drought), most of which occurred between the years 2006 and 2018. Consequently, the study highlights that rainfall variability is primarily influenced by the global atmospheric circulation, global warming, alterations in land use/land cover, together with the physiographic complexities that influence rainfall distribution, patterns, and intensity at a regional level.

As already mentioned, the plateau is dominantly inhabited by the tribal communities, who are still dependent on the monsoon rains for their agricultural practices. Hence, long-term changes in annual and seasonal rainfall, especially during the monsoon season, will affect the available water resources, adversely impacting agricultural productivity.

While no significant century-scale monotonic trend is detected, the marked increase in frequency and intensity of dry episodes since 2000 in one of the wettest places on Earth represents a new climatic risk for rainfed tribal agriculture.

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Competing interest

The corresponding author declares that they have no conflict of interest.

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