Trends in Extreme Climate Indices in Cherrapunji for the period 1979 to 2020

Raju Kalita (kalita.raju.nehu@gmail.com)
North-Eastern Hill University https://orcid.org/0000-0002-3222-8689

Dipangkar Kalita
North-Eastern Hill University

Atul Saxena
North-Eastern Hill University

Research Article

Keywords: Cherrapunji for the period, Mann-Kendall, tropical nights

Posted Date: July 19th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-706445/v1

Trends in Extreme Climate Indices in Cherrapunji for the period 1979 to 2020

Raju Kalita[1*], Dipangkar Kalita[1], Atul Saxena[1]
[1]Department of Physics, North-Eastern Hill University, Shillong, India

Corresponding author: **Raju Kalita**, [*]Corresponding author's e-mail: **kalita.raju.nehu@gmail.com**

Abstract:

We have used Mann-Kendall trend test and Sen's slope estimator method to find out significant changes in extreme climate indices for daily temperature as well as precipitation over the period 1979 to 2020 in Cherrapunji. In the present study, a total of 24 precipitation and temperature based extreme climate indices were calculated using RClimDex v 1.9-3. Among 24 indices, 7 were derived from number of days above nn mm rainfall (Rnn) according to Indian Meteorological Department (IMD) convention and the rest were in accordance with the Expert Team on Climate Change Detection and Indices (ETCCDI). It was observed that, among all the indices, consecutive dry days (CDD), summer days (SU25) and very light rainfall (VLR) days increased significantly with 0.54, 1.58 and 0.14 days/year respectively, while only consecutive wet days (CWD) decreased significantly with 0.36 days/year. A slight negative trend was also observed in case of tropical nights (TR20) and among the other precipitation indices as well. Again, the indices associated with daily maximum temperature increased significantly with annual change of 0.06 to 0.07 ºC/year. And for indices associated with daily minimum temperature, almost no change or a slight negative change was observed, except a significant positive trend in February and significant negative trend in November for TNN only. The analysis reveals that some of the extreme climate indices which explains the climatic conditions of Cherrapunji has changed a lot over the period of 42 years and if this trend continues then Cherrapunji will be under threat when it comes to climate change.

Declarations:

Funding

This work was funded by Climate Change Programme of Department of Science and Technology, Government of India (project sanction no: DST/CCP/HICAB/SN-Meghalaya/177/2018(G)).

Conflicts of interest/Competing interests

There are no conflicts of interest.

Availability of data and material

Daily temperature and precipitation data of Cherrapunji are available at www.cherrapunjee.com/daily-weather-data/

Code availability

Not applicable.

Authors' contributions

Raju Kalita, Dipangkar Kalita and Atul Saxena has contributed equally to this paper.

Ethics approval

Not applicable.

Consent to participate

Not applicable.

Consent for publication

Not applicable.

Abstract:

We have used Mann-Kendall trend test and Sen's slope estimator method to find out significant changes in extreme climate indices for daily temperature as well as precipitation over the period 1979 to 2020 in Cherrapunji. In the present study, a total of 24 precipitation and temperature based extreme climate indices were calculated using RClimDex v 1.9-3. Among 24 indices, 7 were derived from number of days above nn mm rainfall (Rnn) according to Indian Meteorological Department (IMD) convention and the rest were in accordance with the Expert Team on Climate Change Detection and Indices (ETCCDI). It was observed that, among all the indices, consecutive dry days (CDD), summer days (SU25) and very light rainfall (VLR) days increased significantly with 0.54, 1.58 and 0.14 days/year respectively, while only consecutive wet days (CWD) decreased significantly with 0.36 days/year. A slight negative trend was also observed in case of tropical nights (TR20) and among the other precipitation indices as well. Again, the indices associated with daily maximum temperature increased significantly with annual change of 0.06 to 0.07 ºC/year. And for indices associated with daily minimum temperature, almost no change or a slight negative change was observed, except a significant positive trend in February and significant negative trend in November for TNN only. The analysis reveals that some of the extreme climate indices which explains the climatic conditions of Cherrapunji has changed a lot over the period of 42 years and if this trend continues then Cherrapunji will be under threat when it comes to climate change.

Introduction:

Change is the law of nature and hence the climate of the globe is also changing. But the anthropogenic activities have forced the climate to change at a faster rate (Alley et al. 2003). Evidences clearly shows that after the industrialization period, anthropogenic activities increased rapidly thereby enhancing greenhouse gas concentration in the atmosphere (Canadell et al. 2007; Falkowski et al. 2000). The increasing concentration of Greenhouse gas has affected the climate adversely resulting into 0.85 °C rise in global temperature during the period 1880-2012, as reported by Intergovernmental Panel on Climate Change's 5th Assessment Report (IPCC 2013). Now, the climate change has become one of the most relevant issue of the current century. Moreover, occurrences of extreme weather and climate events such as flash flood, severe drought, heat wave, changing pattern of precipitation etc has become some of the notable adverse effects of climate change. This has led diverse consequences on the livelihood of people, taking and risking their lives and causing severe economic damages (Walsh et al. 2020). Hence, it makes the study of climate extremes at spatial and temporal scale most relevant, as it provides a valuable information on how drastically climatic conditions can change over a period of time.

In order to assess such kind of changes, extraction of proper climate indices is important. The joint CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI) has recommended 27 core climate indices which are essential to define extreme climate at a particular location. Out of 27 indices, 16 are based on daily precipitation and 11 are based on daily temperature (both maximum and minimum) (Zhang and Yang 2004). These climate indices have been popularly used as a tool to detect and monitor the changes in extreme climate. Again, to assess and understand the affects of climate change, it is important to observe the trend in the time series of these meteorological variables, so as to adapt and mitigate its adverse impact (Mudelsee 2019). Trend analysis using various statistical tools, is an expressive way to extract a substantial pattern by which a future event can be predicted as well as the past can also be understood. Several studies have been carried out for climate impact analysis in search for a linkage of extreme events like flood, drought, cyclone etc using time series of different hydro-meteorological parameters like, temperature, precipitation, humidity, atmospheric pressure, wind speed, solar radiation, evaporation etc. Alexander et al. (2006) did a global study on observed changes in climate indices of daily temperature and precipitation and found significant warming tendency and wetter conditions throughout the 20th century. Similarly, Brown et al. (2010) found that the variability in the 27 indices from 1951 to 2002 in Northeastern USA was explained by the North Atlantic Oscillation, Pacific Decadal Oscillation, and Pacific–North American pattern. An extensive study by Zhang et al. (2005) on extreme climate indices of 75 stations from 15 countries in the Middle East region for the period 1950 – 2003 concluded significant increase in frequency of warm days, summer nights, while a significant decrease in the frequency of cold days, daily temperature range. Also, in the Central and South Asian region, a study on 116 meteorological stations for daily temperature and precipitation extremes for a period between 1961 to 2000 showed that 70% of the station's percentage of warm nights/days increased significantly, while percentage of cold nights/days decreased significantly (Klein et al. 2006).

In Indian context, several studies on climate extremes have been carried out using both ground-based station and rain gauge data in search for a trend and the variability among the parameters. Roy and Balling (2004) extracted

129 uniformly distributed rain fall stations out of 3838 stations, across the country, for a time period from 1910 to 2000 to study the variability in extreme precipitation events. They found most of the Deccan Plateau in the South and the Northwestern Himalayas in Kashmir showed increasing trend whereas decreasing trend were found in the Eastern part of the Gangetic Plain and parts of Uttaranchal (now known as Uttarakhand). While during the pre-monsoon (March-May) for the period of 1970 to 2005 across India as whole, the frequency of hot days and nights has increased and cold days and nights has decreased significantly (Kothawale et al. 2010). Though, studies have confirmed a trendless rainfall in the Northeastern region (NER) of India, but the rising trend in temperature is an adverse consequence of global warming (Jain and Kumar 2012; Jain et al. 2013). NER India receives highest rain fall across the country and its monsoon falls under Indian Summer Monsoon (ISM). Due to hilly terrain, large forest cover and unique geographical condition, the climate of this region has a significant impact on the livelihood of people and the biodiverse species (Das et al. 2009). Having the fact that NER India comprises of extreme climatic regions, but at a regional level there is very less extensive study on climate extremes.

Cherrapunji is among one such place with extreme climate conditions which received about 11,478±2,384 mm (1979-2020) of average annual rainfall, thereby called one of the wettest spot on earth (Jennings 1950). In the present study 17 climate indices as recommended by ETCCDI, has been extracted from times series of daily precipitation and temperature (both maximum and minimum) of meteorological station at Cherrapunji. 7 more precipitation indices have been introduced and extracted according to IMD convention with number of days with different amount of rainfall occurring in a year (Met Glossary). This study mainly focuses on (i) analysis of trend in ETCCDI recommended precipitation and temperature based indices (ii) analysis of trend in IMD conventional precipitation based indices.

Study Area:

1. Location and Orography

The study location falls under the Meghalaya Hills, which is a Northeastern state of India, located in-between the Brahmaputra Valley in the North and Bangladesh flood Plain in the south (Fig. 1). The Southern edge of Meghalaya plateau is steep and consists of several deep valleys that opens up towards Bangladesh on the South with steep cliffs on both sides. Cherrapunji is one small town on such a valley, at an altitude of about 4823 feet (1484 m) above mean sea level (MSL). It acts as a first orographic barrier for the humid southwest monsoon winds which proceeds from the Bay of Bengal. The warm rain clouds, moist air continuously thrusts on the cliff and cools rapidly as it reaches the altitude showering the vicinity of the town (Houze 2012). Thus, Cherrapunji becomes a unique station to study rainfall and other climatic parameters as it holds a record for highest single day rainfall in a 31-day calendar month (Guharthakurta 2007).

2. Climate

Cherrapunji locally known as Sohra, has a mild subtropical highland climate with influence of Indian Summer Monsoon (ISM) (Beck et al. 2018). The town has received about 11,478±2,384 mm (1979-2020) of average annual rainfall. In just eight months i.e., from March to October, Cherrapunji receives 98% of the annual rainfall. However, a little amount of rainfall or no rainfall is received from November to February. Almost 50 % of annual rainfall can be observed in just June and July month only. The Westerly wind which carries the moist and warm air over the Bay of Bengal is responsible for heavy monsoon in Cherrapunji (Murata et al. 2007; Murata et al. 2017). Study on $\delta^{18}O$ and δD stable isotope content of rainwater from Cherrapunj during the period 2007-2008 also confirms that the monsoon rainfall is predominantly due to the moisture extracted over the Bay of Bengal (Breitenbach et al. 2010). And the rain observed in the pre- and post-monsoons are mostly because of after effect of the cyclonic depressions in the Bay of Bengal. Due to excessive rainfall, the temperature is moderate throughout the year. However, the winter is dry and sometimes, minimum temperature reaches upto 0 °C or less. The average temperature fluctuates between 11.6 °C during January (winter) and 20.6 °C during August (summer) respectively (Prokop 2020).

3. Data set

The 42 years (1979-2020) of data on daily temperature (both maximum and minimum) and precipitation observed at Cherrapunji observatory were obtained from the website of Cherrapunjee Holiday Resort, located at Cherrapunji (Daily Weather Data). This website maintains the data collected from India Meteorological Observatory situated at Cherrapunji (Sohra) 91º44′ East Longitude and 25º15′ North Latitude and at 4267 feet (1313 m) above MSL and are publicly available. There was no missing record for minimum temperature, while almost 99% of data on daily precipitation and maximum temperature were complete. A quality control was performed to identify those missing values and were filled using Linear Regression Forecast method in excel sheet (Nadler and Kros 2007).

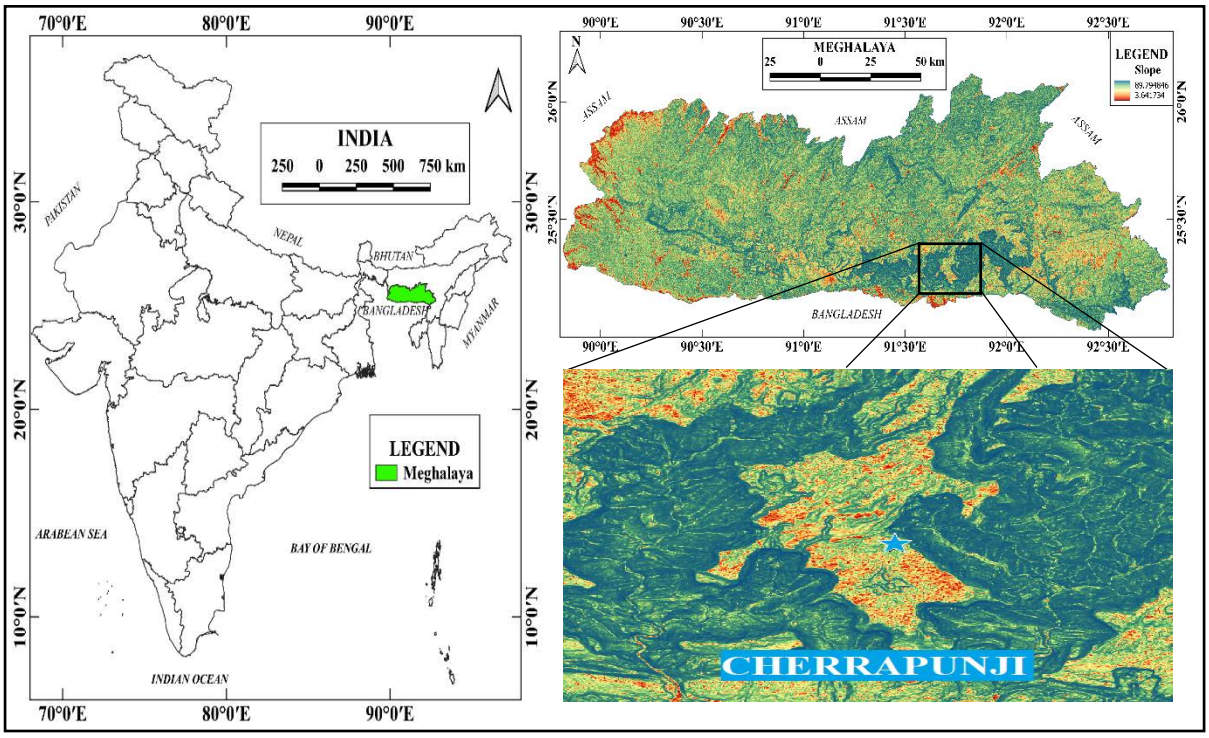

Fig. 1 Location of Cherrapunji in the study area.

Methodology:

1. RClimDex:

RClimDex is designed to provide a user-friendly interface to compute indices of climate extremes. It computes all 27 core indices recommended by the CCl/CLIVAR Expert Team for Climate Change Detection Monitoring and Indices (ETCCDI) as well as some other temperature and precipitation indices with user defined thresholds (Zhang et al. 2011). This version of RClimDex has been developed under R2.15.2 and it depends on the R library of climdex.pcic (Version 1.1-6) and PCICt (Version 0.5-4) for computing the 27 core indices as well as the R library of Tcl/Tk (Version 2.15.2) for the graphical user inter-face (Zhang and Yang 2004). The main objective of constructing climate extreme indices is to use for climate change monitoring and detection studies. The RClimDex also ensures a simple data quality control procedure in order to remove the outliers and identifying the missing data, before calculating the indices. Three steps involved in the entire process are: 1. The installation of R and setting up the user environment, 2. Quality control of daily climate data, 3. Calculation of the 27 core indices.

The current study involves the analysis of only 17 precipitation and temperature based indices (Tables 1 and 2) as recommended by ETCCDI and 7 precipitation based indices (Table 3) according to IMD convention. As RClimDex is designed to be applied anywhere in the world, thus it is important to choose the set of indices that best describes the local conditions of each study (Santos et al. 2017). Thus, a total of 24 indices were selected for this study due to the fact that the study location is in extreme climatic conditions with heavy rainfall and moderate monsoon temperature.

Table 1. List of ETCCDI precipitation based climatic extreme indices with definitions used in this study.

ID	*Indicator name*	*Definitions*	*Units*
CDD	Consecutive dry days	Maximum number of consecutive days with RR<1mm	Days
CWD	Consecutive wet days	Maximum number of consecutive days with RR>=1mm	Days
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days (defined as PRCP>=1.0 mm) in the year	Mm/day
R10	Number of heavy precipitation days	Annual count of days when PRCP>=10mm	Days
R20	Number of very heavy precipitation days	Annual count of days when PRCP>=20mm	Days
Rnn (nn=100)	Number of days above nn mm	Annual count of days when PRCP>=nn mm, nn is user defined threshold	Days
PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (RR>=1mm)	mm
R95P	Very wet days	Annual total PRCP when RR>95th percentile	mm
R99P	Extremely wet days	Annual total PRCP when RR>99th percentile	mm

Table 2. List of ETCCDI temperature based climatic extreme indices with definitions used in this study.

ID	*Indicator name*	*Definitions*	*Units*
SU25	Summer days	Annual count when TX (daily maximum)>25ºC	Days
TR20	Tropical nights	Annual count when TN (daily minimum)>20ºC	Days
TMAXMEAN	Mean Tmax	Monthly mean value of daily maximum temp	ºC
TXX	Max Tmax	Monthly maximum value of daily maximum temp	ºC
TNX	Max Tmin	Monthly maximum value of daily minimum temp	ºC
TMINMEAN	Mean Tmin	Monthly mean value of daily minimum temp	ºC
TXN	Min Tmax	Monthly minimum value of daily maximum temp	ºC
TNN	Min Tmin	Monthly minimum value of daily minimum temp	ºC

Table 3. List of precipitation based climate extreme indices derived from Rnn according to IMD convention with definitions used in this study.

ID	*Indicator name*	*Definitions*	*Units*
VLR	Very Light Rain	Annual count of days when Precipitation is 0.1 to 2.4 mm	Days
LR	Light Rain	Annual count of days when Precipitation is 2.5 to 7.5 mm	Days
MR	Moderate Rain	Annual count of days when Precipitation is 7.6 to 35.5 mm	Days
RHR	Rather Heavy Rain	Annual count of days when Precipitation is 35.6 to 64.4 mm	Days
HR	Heavy Rain	Annual count of days when Precipitation is 64.5 to 124.4 mm	Days
VHR	Very Heavy Rain	Annual count of days when Precipitation is 124.5 to 244.4 mm	Days
EHR	Extremely Heavy Rain	Annual count of days when Precipitation >= 224.5 mm	Days

2. Mann-Kendall Test:

Trend analysis is a mathematical technique that uses historical results to predict future outcome. Whether the trend in a time series is statistically significant or not that can be determined using the Mann-Kendall (MK) test. Mann-Kendall (Mann 1945; Kendall 1975) test is a widely used non-parametric test to detect the trend in hydro-meteorological time series (Subash and Sikka 2014; Oza and Kishtawal 2014; Yao and Chen 2015; Chakraborty et al. 2017; Bhuyan et al. 2018). It does not require that the data be normally or linearly distributed and also no autocorrelation is required. This is one of the robust methods to ascertain the presence of statistical significance in a time series. The MK test is based on the Statistics, which is defined as (Mann 1945; Kendall 1975)

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(X_j - X_k) \quad (1)$$

With

$$sgn(x) = \begin{cases} 1 & if \quad x > 0 \\ 0 & if \quad x = 0 \\ -1 & if \quad x < 0 \end{cases} \quad (2)$$

Where X_j and X_k represents sequential data values at times j and k respectively. For higher n (≥ 10), the S statistics assumes a normal distribution with zero mean and variance computed as follows (Partal and Kahya 2006):

$$\sigma^2 = \left\{n(n-1)(2n+5) - \sum_{j=1}^{p} t_j(t_j - 1)(2t_j + 5)\right\}/18 \quad (3)$$

Where, p is the number of the tied groups in the data set and t_j is the number of data points in the jth tied group. Then the normalized test statistics Z is computed as follows:

$$Z = \begin{cases} \frac{S-1}{\sigma} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sigma} & \text{if } S < 0 \end{cases} \quad (4)$$

A positive value of Z indicates increasing or upward trend, while a negative value of Z indicates a decreasing or downward trend. When $|Z| > Z_{1-\alpha/2}$, the null hypothesis is rejected and there exists a significant trend. The $Z_{1-\alpha/2}$ can be obtained from any standard normal distribution table at different values of α. The null hypothesis (no trend) is rejected if $|Z| > 1.96$ and $|Z| > 2.58$ at a significance level of $\alpha = 0.05$ (i.e. at 95%) and $\alpha = 0.01$ (i.e. at 99%). In our study we have rejected the null hypothesis if Z value is found to be greater than 1.96 i.e., at 95% significance level.

3. Sen's Slope Estimator:

Sen's Slope is a non-parametric procedure developed in order to estimate the magnitude of change or slope of trend, in a time series (Sen 1968). It has been widely used by various researcher in hydro-meteorological time series (Partal and Kahya 2006; Tabari et al. 2011; Subash et al. 2011). First of all, the slopes of n data pairs are calculated as follows:

$$d_m = \frac{X_j - X_i}{j - i} \qquad \text{For } m = 1, 2, 3\ldots\ldots, n \quad (5)$$

Where X_i and X_j are the data values at the corresponding times i and j ($1 \le i < j \le n$) respectively. Then the median of all those d_m s, gives the Sen's Slope which is then calculated as,

$$\beta = \begin{cases} d_{\frac{n+1}{2}} & n \text{ is odd} \\ \frac{1}{2}\left(d_{\frac{n}{2}} + d_{\frac{n+2}{2}}\right) & n \text{ is even} \end{cases} \quad (6)$$

Thus, β gives the magnitude of trend and its positive value indicates an upward or increasing trend while its negative value indicates a downward or decreasing trend.

Results and Discussions:

The annual and seasonal climatology of precipitation and diurnal temperature range (DTR) at Cherrapunji is represented as Box-Whisker plot in Fig. 2. The figure (Fig. 2 (left)) shows that annual precipitation is distributed normally (Shapiro-Wilk statistics = 0.97, p = 0.28) throughout the last 42 years with a mean value of 11477 mm/year. Almost 73% (8395 mm/year) of mean annual rainfall is due to the monsoon (June-September) only. Winter is almost dry, while post and pre-monsoon is slightly humid with 27% contribution to mean annual rainfall all together. The mean annual DTR shown as Box plot in the Fig. 2 (right) is positively skewed (skewness = 0.89) with a mean value of 7.16 °C/year. While seasonal DTR is maximum during winter and minimum during monsoon with mean values 9.46 °C/year and 4.91 °C/year respectively. Due to continuous and extreme precipitation Cherrapunji can retain such a low value of DTR during monsoon.

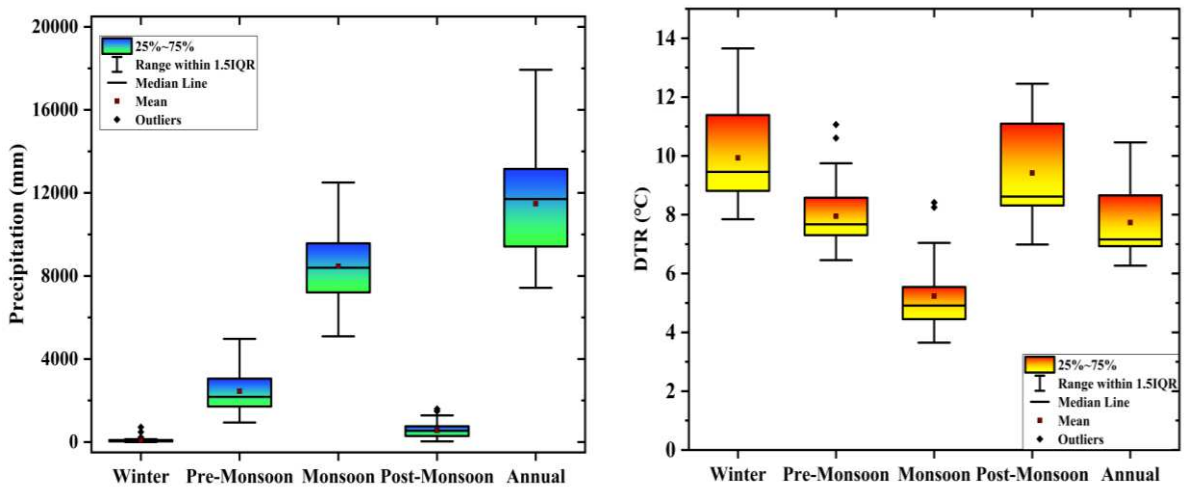

Fig. 2 Box-Whisker plot of annual and seasonal precipitation (left) and DTR (right).

The results of Mann-Kendall trend test and Sen's Slope of the extreme indices are represented in various subsections which are based on precipitation and temperature indices respectively.

1. Precipitation Based Indices

1.1 ETCCDI recommended Indices

Table 4 represents results for Z statistics of MK test and magnitude of Sen's Slope of nine ETCCDI recommended indices and the corresponding trends are shown in the Fig. 3. It is observed that Consecutive Dry Days (CDD) has increased significantly with 0.54 days/year, while Consecutive Wet Days (CWD) has decreased significantly with 0.36 days/year. This implies that in every two years, one consecutive dry day is adding up while in every 3 years one consecutive wet day is diminishing. Being the wettest place on Earth, Cherrapunji usually encounters a smaller number of CDD and a greater number of CWD compared to other places (Berhane et al. 2020; Sharma et al. 2020). So, a significant increasing trend of CDD and a significant decreasing trend of CWD can certainly affect livelihood of the people. As most of the CDD occur during winter, hence, the increasing value of CDD can cause the winter to be more harsh and dry leading to scarcity of water, which is a well know problem for people living in Cherrapunji (Mawroh and Husain 2012; Mawroh 2019). Moreover, since most of the CWD occur during monsoon, so its decreasing value can cause intense precipitation leading to damage of cultivation and local crops. One important observation is that except one index, all other indices have shown a decreasing trend throughout the period of 1979 to 2020. The total annual precipitation (PRCPTOT), very wet days (R95P) and extremely wet days (R99P) all showed an insignificant decreasing trend of 27.15 mm/year, 7.77 mm/year and 3.48 mm/year respectively. It infers that Cherrapunji has been losing 27.15 mm of annual rainfall every year over the last 42 years. The consequence of this is that the wettest spot has started shifting towards Mawsynram, 15 Km west to Cherrapunji. Now, in the last two decades Mawsynram has received a slightly greater amount of annual rainfall than Chearrapunji (Kuttippurath et al. 2021).

Table 4. Z values and Sen's slope for Precipitation based ETCCDI indices.

Sl. No.	*Indices*	*Z value*	*Sen's Slope*
1	CDD	**2.48***	0.54
2	CWD	**-2.5***	-0.36
3	SDII	-0.39	-0.08
4	R10	-1.41	-0.2
5	R20	-1.14	-0.16
6	R100	-1.12	-0.13
7	PRCPTOT	-0.89	-27.15
8	R95P	-0.43	-7.77
9	R99P	-1.05	-3.48

**bold number indicates Z values at 95% significance level.*

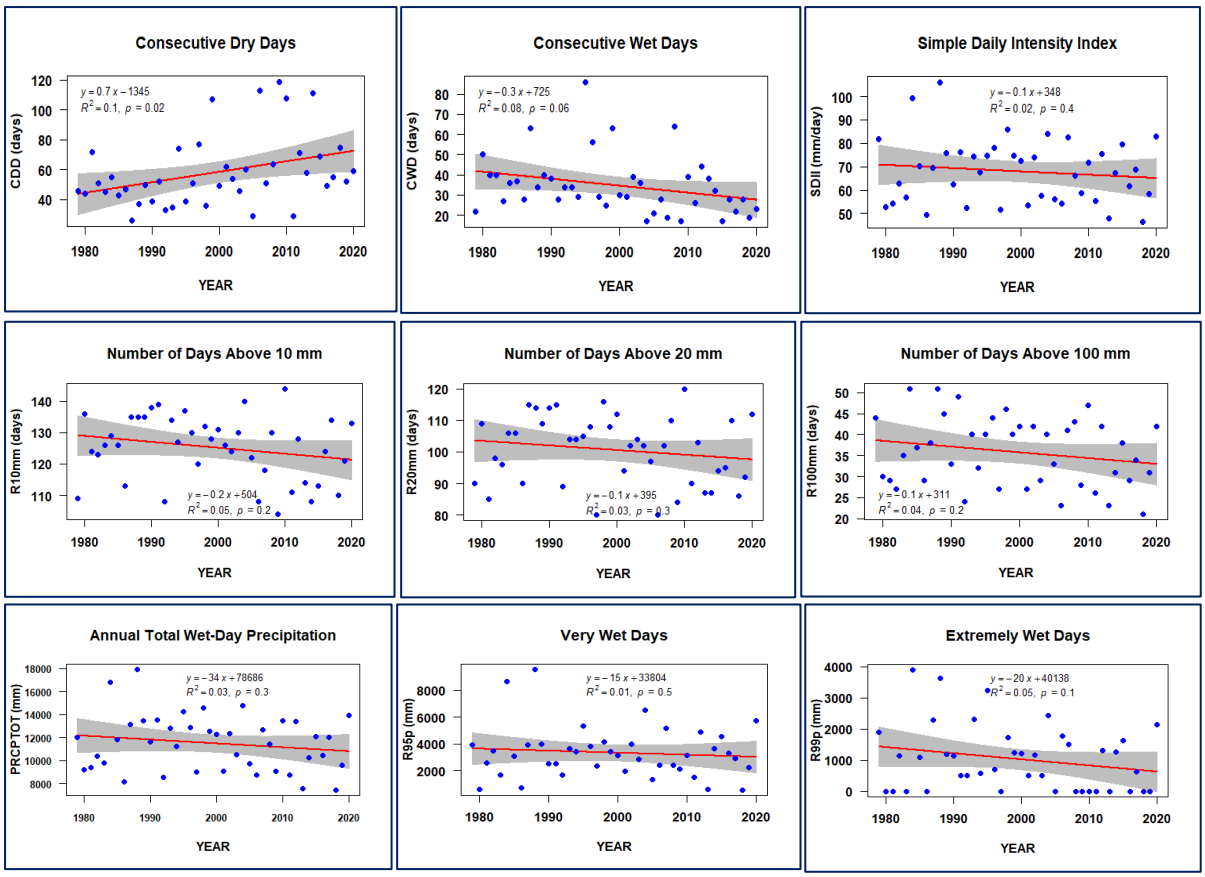

Fig. 3 Variation of ETCCDI recommended precipitation based indices over the period 1979-2020.

1.2 IMD Convention Indices

Depending on the amount of precipitation in a particular day, the index Rnn has been split into seven indices according to IMD convention. The results for Z statistics of MK test and magnitude of Sen's Slope of the seven IMD convention indices are represented in Table 5 and their corresponding trends are shown in Fig. 4. Only Very Light Rain (VLR) has shown significant increasing trend with 0.14 days/year. MR, RHR and VHR has shown a slight insignificant negative trend which can attribute to the decreasing trend of PRCPTOT. While LR, HR and EHR are almost trendless. Though it is insignificant, but from the results of Sen's Slope Estimator, it is clear that the number of rainy days with more than 2.5 mm of precipitation at Cherrapunji are decreasing throughout the period of 42 years. Moreover, from the figure it is observed that MR shows an average of almost 55 days/year, which is comparatively high with respect to the other IMD convention indices.

Table 5. Z values and Sen's slope for Precipitation based IMD convention indices.

Sl. No.	*Indices*	*Z value*	*Sen's Slope*
1	VLR	**2.36***	0.14
2	LR	0.57	0.03
3	MR	-0.59	-0.07
4	RHR	-0.88	-0.06
5	HR	0	0
6	VHR	-0.95	-0.06
7	EHR	0.43	0

**bold number indicates Z values at 95% significance level.*

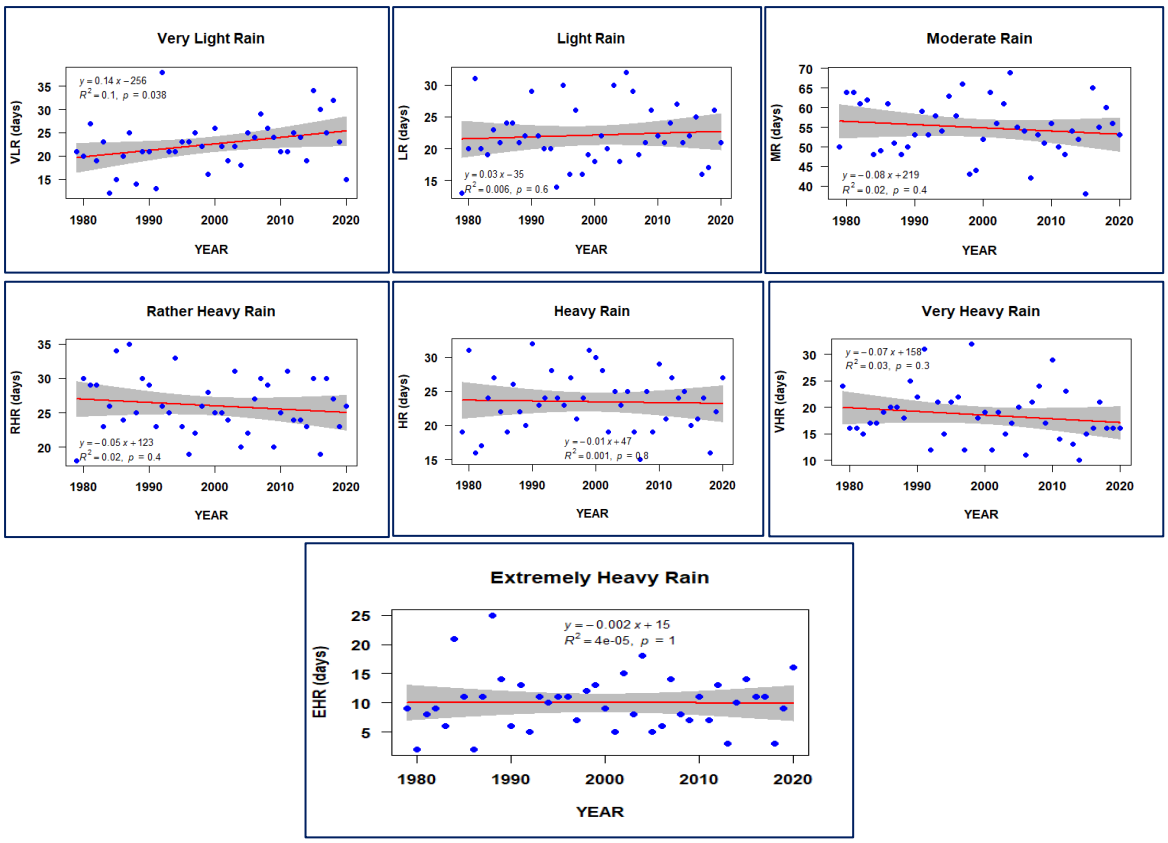

Fig. 4 Variation of IMD convention precipitation based indices over the period 1979-2020.

2. Temperature Indices

The results of trend analysis as represented in Table 6, shows that SU25 (summer days) has increased significantly at 99% with 1.58 days/year while no significant change is observed in case of TR20 (cold nights). Fig. 5 depicts a gradual increase in SU25 from 1979 to 2004 and then a sharp increase from 2005 onwards. The maximum number of SU25 occurred in the year 2013 with 96 days, while the subsequent peaks were observed on 2014, 2016 and 2019 with 91, 89 and 88 days respectively. These years can be considered as warmest, as nearly for almost three months, the maximum temperature has crossed the mark of 25 °C. Although there was no significant trend in TR20 (Fig. 5), but some sharp peaks were observed with 16 days in the years 2006 and 2009 respectively.

Table 6. Z values and Sen's slope for Temperature based indices, SU25 and TR20.

Sl. No.	*Indices*	*Z value*	*Sen's Slope*
1	SU25	**5.99****	1.58
2	TR20	-0.92	-0.03

***bold number indicates Z values at 99% significance level.*

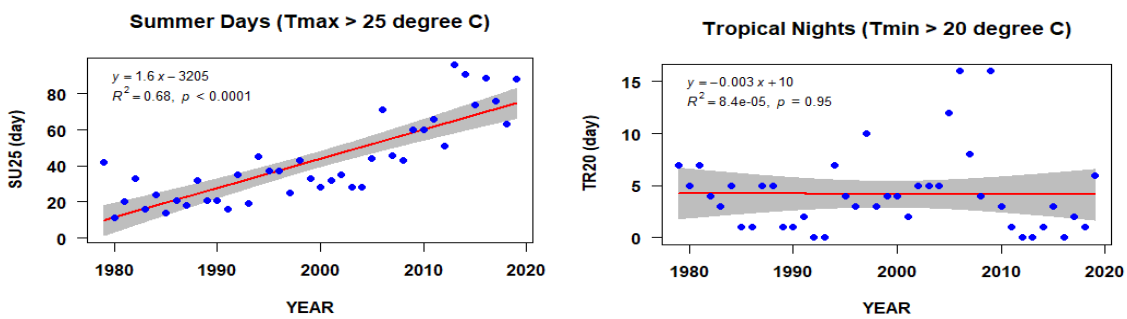

Fig. 5 Variation of ETCCDI recommended temperature based indices (SU25 and TR20) over the period 1979-2020.

2.1 Maximum Temperature based Indices

When MK test was done for maximum temperature-based indices such as TMAXMEAN, TXX and TXN, a very significant monthly as well annual trend was observed for all the indices as represented in Table 7. Results of Sen's Slope estimator shows that TMAXMEAN, TXX and TXN were increasing annually with 0.06, 0.07 and 0.06 °C/year respectively. Moreover, the monthly analysis reveals that highest change was observed during the months of December to February for all the three indices. Most importantly February witnessed a maximum change of 0.09°C/year for TMAXMEAN, 0.11 °C/year for TXX and 0.08 °C/year for TXN respectively. A recent study on 102 years of data on maximum temperature of Meghalaya has also shown a maximum value of increasing trend in the month of February only (Kalita et al. 2020). On the other hand, the increasing trend was insignificant and minimum in the month of June (0.02°C/year) for TMAXMEAN, while a significant minimum increasing trend of 0.03 °C/year was observed in the months of May and August in case of TXX. A slight positive or no trend was observed in the months of March-May and October for TXN. For rest of the months, all indices have shown a significant positive trend.

Table 7. Z values and Sen's slope for maximum temperature based indices.

Sl. No.	*Time*	*TMAXMEAN*		*TXX*		*TXN*	
		Z value	*Sen's Slope*	*Z value*	*Sen's Slope*	*Z value*	*Sen's Slope*
1	Jan	**4.08****	0.08	**4.11****	0.09	**2.78****	0.07
2	Feb	**4.51****	0.09	**4.66****	0.11	**2.5***	0.08
3	Mar	**3.67****	0.07	**3.32****	0.07	1.54	0.04
4	Apr	**2.22***	0.03	**3.8****	0.07	-0.16	0
5	May	**3.3****	0.03	**2.98****	0.03	1.83	0.03
6	Jun	1.86	0.02	**2.55***	0.04	**2.62****	0.02
7	Jul	**4.63****	0.04	**3.14****	0.05	**3.81****	0.03
8	Aug	**3.58****	0.04	**2.34***	0.03	**3.04****	0.03
9	Sep	**4.75****	0.06	**4.11****	0.08	**2.36***	0.02
10	Oct	**5.61****	0.06	**4.51****	0.09	0.26	0
11	Nov	**4.52****	0.07	**4.01****	0.09	**3.01****	0.06
12	Dec	**5.48****	0.09	**4.88****	0.1	**3.45****	0.08
13	Annual	**6.38****	0.06	**4.84****	0.07	**2.41***	0.06

**bold and **bold number indicates Z values at 95% and 99% significance level respectively.*

2.2 Minimum Temperature based Indices

From the results of MK test and Sen's slope as represented in Table 8, it is interesting to note that the three minimum temperature-based indices, TMINMEAN, TNN and TNX has not shown any significant changes annual basis as well as in any months, except February and November for TNN only. February of TNN was found to be increasing significantly with 0.04 °C/year, while November of TNN was found to decreasing significantly with 0.05 °C/year. The annual change is almost 0 °C/year for TMINMEAN and 0.01 °C/year for both TNN and TNX respectively. The results indicates that minimum temperature of Cherrapunji has least affected by global warming.

Table 8. Z values and Sen's slope for minimum temperature based indices.

Sl. No.	*Time*	*TMINMEAN*		*TNN*		*TNX*	
		Z value	*Sen's Slope*	*Z value*	*Sen's Slope*	*Z value*	*Sen's Slope*
1	Jan	-0.15	0	0.08	0	0.67	0.01
2	Feb	1.44	0.02	**2.00***	0.04	1.38	0.03
3	Mar	0.68	0.01	1.62	0.03	-0.28	0
4	Apr	-0.39	-0.01	-0.18	0	-0.03	0
5	May	0.39	0.01	0.74	0.01	-0.88	-0.01
6	Jun	-0.55	0	1.13	0.02	-1.88	-0.03
7	Jul	0.55	0	0.64	0.01	0.48	0.01
8	Aug	0.44	0	0.75	0.01	-1.28	-0.02
9	Sep	1.14	0.01	0.89	0.01	1.27	0.02

10	Oct	0.91	0.01	-0.52	-0.01	0.61	0.01
11	Nov	-1.04	-0.02	**-2.06***	-0.05	-0.65	0
12	Dec	-0.77	-0.01	-0.91	-0.02	1.47	0.03
13	Annual	0.16	0	0.47	0.01	-0.89	-0.01

**bold number indicates Z values at 95% significance level.*

Conclusions:

Being the rainiest place on earth, numerous attempts has been made so far to carry out a detailed analysis of rainfall in Cerrapunji, its pattern and effect on neighbouring areas (Prokop and Walanus 2003; Murata et al. 2007; Tomasz et al. 2015; Murata et al. 2017; Basher et al. 2018). But in order to carry out assessment of change in extreme climate, temperature is a key parameter as well. The present study attempts to analyse the trend in extreme climate indices for both daily temperature and precipitation data collected over a period of 42 years (1979-2020) at Cherrapunji. The following conclusions can be drawn from the present study:

1. Results of trend analysis had shown a significant rising trend in CDD, while a significant declining trend in CWD. Rest of the precipitation indices, SDII, R10, R20, R100, PRCPTOT, R95P and R99P also had a declining trend, though insignificant.

2. The IMD convention index, VLR had only shown a significant raising trend. And the rest, LR, MR, RHR, HR, VHR, EHR had remained insignificant and almost trendless.

3. Maximum temperature-based indices; SU25, TMAXMEAN, TXX and TXN all had increased significantly, while minimum temperature-based indices; TR20, TMINMEAN, TNN and TNX had shown insignificant trend.

In general, the analysis suggests that, the amount of rainfall was decreasing while its intensity had increased throughout the years. Increase in CDD, VLR and decrease in CWD, PRCPTOT are some of the clear indications of such kind of changes. Moreover, a very significant increasing trend in maximum temperature-based indices also signifies an accelerating warming of the place. If this trend continues, Cherrapunji may lose its status of being rainiest place and winter would become dry with severe draught situation. This can impact on neighbouring country like Northeastern part of Bangladesh as it also showed decreasing magnitude and intensity of flash flood, monsoon floods, which then could result in water scarcity and could affect the livelihood of the residing community (Basher et al. 2018). Again, the increased temperature could intensify the condensation process occurring in the stiff valley due to the westerly moist air from the Bay of Bengal, this could result in extreme monsoon (Prokop and Walanus 2015). The anthropogenic human activities like limestone mining, coal extraction and puffed-up tourism (Prokop 2020), has also affected the bio-diverse ecosystem of Cherrapunji, which in turn may have contributed to climate change of the region.

Acknowledgement:

The authors are extremely grateful to Indian Meteorological Department and Cherrapunjee Holiday Resort to keep track on daily rainfall and temperature data of Cherrapunji and to make it available publicly. Also, Atul Saxena (Principal Investigator) and Raju Kalita (Junior Research Fellow) are thankful to Department of Science and Technology, Government of India for proving the necessary fund for this work.

References:

Alexander LV, Zhang X, Peterson TC et al (2006) Global observed changes in daily climate extremes of temperature and precipitation. J Geophys Res 111(D05):109. https://doi.org/10.1029/2005JD006290

Alley RB, Marotzke J, Nordhaus WD, Overpeck JT, Peteet DM, Pielke RA, Pierrehumbert RT, Rhines PB, Stocker TF, Talley LD, Wallace JM (2003) Abrupt climate change. Science 299(5615):2005-2010. https://doi.org/10.1126/science.1081056

Basher MA, Stiller-Reeve MA, Islam AS, Bremer S (2018) Assessing climatic trends of extreme rainfall indices over northeast Bangladesh. Theor Appl Climatol 134(1):441-452. https://doi.org/10.1007/s00704-017-2285-4

Beck HE, Zimmermann NE, McVicar TR, Vergopolan N, Berg A, Wood EF (2018) Present and future Köppen-Geiger climate classification maps at 1-km resolution. Sci Data 5:180214. https://doi.org/10.1038/sdata.2018.214

Berhane A, Hadgu G, Worku W, Abrha B (2020) Trends in extreme temperature and rainfall indices in the semi-arid areas of Western Tigray, Ethiopia. Environ Syst Res 9(1):1-20. https://doi.org/10.1186/s40068-020-00165-6

Bhuyan MDI, Islam MM, Bhuiyan MEK (2018) A trend analysis of temperature and rainfall to predict climate change for northwestern region of Bangladesh. Amer J Clim Change 7(2):115-134. https://doi.org/10.4236/ajcc.2018.72009

Breitenbach SF, Adkins JF, Meyer H, Marwan N, Kumar KK, Haug GH (2010) Strong influence of water vapor source dynamics on stable isotopes in precipitation observed in Southern Meghalaya, NE India. Earth Planet Sci Lett 292(1-2):212-220. http://doi.org/10.1016/j.epsl.2010.01.038

Brown PJ, Bradley RS, Keimig FT (2010) Changes in extreme climate indices for the northeastern United States, 1870–2005. J Clim 23(24):6555-6572. https://doi.org/10.1175/2010JCLI3363.1

Canadell JG, Le Quéré C, Raupach MR, Field CB, Buitenhuis ET, Ciais P, Conway TJ, Gillett NP, Houghton RA, Marland G (2007) Contributions to accelerating atmospheric CO2 growth from economic activity, carbon intensity, and efficiency of natural sinks. Proc Natl Acad Sci 104(47):18866-18870. https://doi.org/10.1073/pnas.0702737104

Chakraborty D, Saha S, Singh RK, Sethy BK, Kumar A, Saikia US, Das SK, Makdoh B, Borah TR, Chanu AN, Walling I, Rolling Anal PS, Chowdhury S, Daschaudhuri D (2017) Trend analysis and change point detection of mean air temperature: a spatio-temporal perspective of North-Eastern India. Environ Process 4(4):937-957. https://doi.org/10.1007/s40710-017-0263-6

Daily Weather Data, Cherrapunjee Holiday Resort, Cherrapunji. https://www.cherrapunjee.com/daily-weather-data/. Accessed 16 January 2021

Das A, Ghosh PK, Choudhury BU, Patel DP, Munda GC, Ngachan SV, Chowdhury P (2009) Climate change in North East India: recent facts and events–worry for agricultural management. In Proceedings of ISPRS Ahmedabad 2009 Workshop on Impact of Climate Change on Agriculture, ISPRS Archives XXXVIII-8/W3:32-37.

Falkowski P, Scholes RJ, Boyle E, Canadell J, Canfield D, Elser J, Gruber N, Hibbard K, Högberg P, Linder S, Mackenzie FT, Moore B, Pedersen T, Rosenthal Y, Seitzinger S, Smetacek V, Steffen W (2000) The global carbon cycle: a test of our knowledge of earth as a system. Science 290(5490):291-296. https://doi.org/10.1126/science.290.5490.291

Guhathakurta P (2007) Highest recorded point rainfall over India. Weather 62(12):349-349. https://doi.org/10.1002/wea.154

Houze Jr RA (2012) Orographic effects on precipitating clouds. Rev Geophys 50(1). https://10.1029/2011RG000365

IPCC (2013) Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds.)]. Cambridge University Press: Cambridge UK and New York USA 1535

Jain SK, Kumar V (2012) Trend analysis of rainfall and temperature data for India. Curr Sci 102(1):37-49

Jain SK, Kumar V, Saharia M (2013) Analysis of rainfall and temperature trends in northeast India. Int J Climatol 33(4):968-978. https://10.1002/joc.3483

Jennings AH (1950) World's greatest observed point rainfalls. Mon Weather Rev 78(1):4-5. https://doi.org/10.1175/1520-0493(1950)078<0004:WGOPR>2.0.CO;2

Kalita R, Kalita D, Sharma Y, Walia D, Saxena A (2020) Long-term trend analysis of temperature in Meghalaya. Hill Geographer 36(1):31-40

Kendall MG (1975) Rank Correlation Methods, 4th edn. Charles Griffin, London, UK

Klein Tank AMG, Peterson TC, Quadir DA et al (2006) Changes in daily temperature and precipitation extremes in central and south Asia. J Geophys Res 111(D16):105. https://doi.org/10.1029/2005JD006316

Kothawale DR, Revadekar JV, Kumar KR (2010) Recent trends in pre-monsoon daily temperature extremes over India. J Earth Syst Sci 119(1):51-65. https://doi.org/10.1007/s12040-010-0008-7

Kuttippurath J, Murasingh S, Stott PA, Sarojini BB, Jha MK, Kumar P, Nair PJ, Varikoden H, Raj S, Francis PA, Pandey PC (2021) Observed rainfall changes in the past century (1901–2019) over the wettest place on Earth. Environ Res Lett 16(2):024018. https://doi.org/10.1088/1748-9326/abcf78

Mann HB (1945) Nonparametric tests against trend, Econometrica 13(3):245-259. https://doi.org/10.2307/1907187

Mawroh B (2019) Water scarcity in Sohra (Cherrapunjee): A paradox. Transient 8:40-49

Mawroh B, Husain Z (2012) Scarcity of water for domestic consumption in Cherrapunjee. In: Husain Z, Cajee L Eds.) Water Crisis in the Indian Subcontinent, Bookwell & North-Eastern Hill University, Shillong, pp 467-486

Met Glossary – (IMD), Pune. https://www.imdpune.gov.in/Weather/Reports/glossary.pdf. Accessed 16 January 2021

Mudelsee M (2019) Trend analysis of climate time series: A review of methods. Earth-Sci Rev 190:310-322. https://doi.org/10.1016/j.earscirev.2018.12.005

Murata F, Hayashi T, Matsumoto J, Asada H (2007) Rainfall on the Meghalaya plateau in northeastern India-one of the rainiest places in the world. Nat Hazards 42:391–399. https://doi.org/10.1007/s11069-006-9084-z

Murata F, Terao T, Fujinami H, Hayashi T, Asada H, Matsumoto J, Syiemlieh HJ (2017) Dominant synoptic disturbance in the extreme rainfall at Cherrapunji, Northeast India, based on 104 years of rainfall data (1902–2005). J Clim 30(20):8237-8251. https://doi.org/10.1175/jcli-d-16-0435.1

Nadler S, Kros JF (2007) Forecasting with Excel: Suggestions for Managers. Spreadsheets in Education 2(2):212-31

Oza M, Kishtawal CM (2014) Trends in rainfall and temperature patterns over north east India. Earth Science India 7(4):90-105. https://doi.org/10.31870/esi.07.4.2014.8

Partal T, Kahya E (2006) Trend analysis in Turkish precipitation data. Hydrol Process 20(9):2011-2026. https://doi.org/10.1002/hyp.5993

Prokop P (2020) Remote sensing of severely degraded land: Detection of long-term land-use changes using high-resolution satellite images on the Meghalaya Plateau, northeast India. Remote Sensing Applications: Society and Environment 20:100432. https://doi.org/10.1016/j.rsase.2020.100432

Prokop P, Walanus A (2003) Trend and periodicity in the longest instrumental rainfall series for the area of most extreme rainfall in the world, northeast India. Geogr Pol 76(2):25-35

Prokop P, Walanus A (2015) Variation in the orographic extreme rain events over the Meghalaya Hills in northeast India in the two halves of the twentieth century. Theor Appl Climatol 121(1):389-399. https://doi.org/10.1007/s00704-014-1224-x

Roy SS, Balling RC (2004) Trends in extreme daily precipitation indices in India. Int J Climatol, 24(4):457-466. https://doi.org/10.1002/joc.995

Santos C, Oliveira V (2017) Trends in extreme climate indices for Pará State, Brazil. Revista Brasileira de Meteorologia 32(1):13-24. https://doi.org/10.1590/0102-778632120150053

Sen PK (1968) Estimates of the regression coefficient based on Kendall's tau. J Am Stat Assoc 63(324):1379-1389. https://doi.org/10.1080/01621459.1968.10480934

Sharma S, Khadka N, Hamal K, Baniya B, Luintel N, Joshi BB (2020) Spatial and temporal analysis of precipitation and its extremities in seven provinces of Nepal (2001–2016). Applied Ecology and Environmental Sciences 8(2):64-73. https://doi.org/10.12691/aees-8-2-4

Subash N, Sikka AK (2014) Trend analysis of rainfall and temperature and its relationship over India. Theor Appl Climatol 117(3):449-462. https://doi.org/10.1007/s00704-013-1015-9

Subash N, Ram Mohan HS, Sikka AK (2011) Decadal frequency and trends of extreme excess/deficit rainfall during the monsoon season over different meteorological sub-divisions of India. Hydrol Sci J 56(7):1090-1109. https://doi.org/10.1080/02626667.2011.608677

Tabari H, Somee BS, Zadeh MR (2011). Testing for long-term trends in climatic variables in Iran. Atmos Res, 100(1):132-140. https://doi.org/10.1016/j.atmosres.2011.01.005

Tomasz B, Rafal K, Roman S (2015) Hydrological response of a small catchment located in extremely humid monsoonal climate-the Maw-Ki-Syiem case study (Cherrapunji, Meghalaya Plateau, India). Episodes 38(1):31-38. https://doi.org/10.18814/epiiugs/2015/v38i1/004

Walsh JE, Ballinger TJ, Euskirchen ES, Hanna E, Mård J, Overland JE, Tangen H, Vihma T (2020) Extreme weather and climate events in northern areas: A review. Earth-Sci Rev 209:103324. https://doi.org/10.1016/j.earscirev.2020.103324

Yao J, Chen Y (2015) Trend analysis of temperature and precipitation in the Syr Darya Basin in Central Asia. Theor Appl Climatol 120(3):521-531. https://doi.org/10.1007/s00704-014-1187-y

Zhang X, Yang F (2004) RClimDex (1.0) user manual. Climate Research Branch Environment Canada, 22

Zhang X, Aguilar E, Sensoy S et al (2005). Trends in Middle East climate extreme indices from 1950 to 2003. J Geophys Res, 110(D22):104. https://doi.org/10.1029/2005jd006181

Zhang X, Alexander L, Hegerl GC, Jones P, Tank AK, Peterson TC, Trewin B, Zwiers FW (2011) Indices for monitoring changes in extremes based on daily temperature and precipitation data. Wiley Interdiscip Rev Clim Change 2(6):851-870. https://doi.org/10.1002/wcc.147