Trends in extreme climate indices in Cherrapunji for the period 1979 to 2020

RAJU KALITA*, DIPANGKAR KALITA and ATUL SAXENA

Department of Physics, North-Eastern Hill University, Shillong, India.
*Corresponding author. e-mail: kalita.raju.nehu@gmail.com

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Mann–Kendall trend test and Sen’s slope estimator method were used to find out significant changes in extreme climate indices for daily temperature and precipitation in Cherrapunji over the period from 1979 to 2020. In this study, 21 precipitation and temperature-based extreme climate indices were calculated using RClimDex v 1.9-3, among which six were derived from the number of days above nn mm rainfall (Rnn) according to India Meteorological Department (IMD) convention and the rest 15, 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/yr, respectively, while only consecutive wet days (CWD) decreased significantly with 0.36 days/yr. A slight negative trend was observed in the case of tropical nights (TR20) and among the other precipitation indices as well. Again, the indices associated with daily maximum temperature increased significantly with 0.06–0.07°C/yr. For the 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 monthly minimum of daily minimum temperature (TNN) only. The analysis revealed that some of the extreme climate indices which explain the climatic conditions of Cherrapunji have shown statistically significant change over the period of 42 years and if this trend continues, then Cherrapunji will be under threat when it comes to climate change.

Keywords. Trend analysis; extreme climate indices; Mann–Kendall test; Cherrapunji.

1. Introduction

Change is the law of nature and hence the climate of the globe is also changing. However, anthropogenic activities have forced the climate to change at a faster rate (IPCC 2021). Evidences clearly show that after the industrialisation 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 0.99°C higher global temperature during the period 2001–2020 than the period 1850–1900, as reported by Intergovernmental Panel on Climate Change’s 6th Assessment Report (IPCC 2021). Also, occurrences of extreme weather and climate events such as flash flood, severe drought, heat waves and changing pattern of precipitation, etc., have become some of the notable adverse effects of...
climate change (Arndt et al. 2010; Tabari 2020). This has led to diverse consequences on the livelihood of people, taking and risking their lives and causing severe economic damages (Walsh et al. 2020). Therefore, the study on variation of extreme climate indices over a long period of time at extreme climatic places is very important.

In order to assess such kind of changes, the extraction of proper climate indices is important. The joint CCI/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI) has recommended 27 core climate indices based on daily temperature and precipitation, which are essential to define extreme climate at a particular location (Zhang and Yang 2004). These are popularly used as a tool to detect and monitor the changes in extreme climate. To detect 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 using time series of different hydro-meteorological parameters like temperature, precipitation, humidity, atmospheric pressure, wind speed, solar radiation, and evaporation (Brown et al. 2010). A global study by Alexander et al. (2006) showed that the extreme temperature and precipitation indices observed a significant warming tendency and wetter conditions throughout the 20th century. An extensive study by Zhang et al. (2005) with data from 75 meteorological stations from 15 countries in the Middle East concluded a significant increase in the frequency of warm days, summer nights, while a significant decrease in the frequency of cold days, daily temperature range for the period 1950–2003. Also, in the Central and South Asian region, among 116 meteorological stations, 70% station’s warm nights/days increased significantly and cold nights/days decreased significantly during the period 1961–2000 (Klein et al. 2006).

In the Indian context, several studies on climate extremes have been carried out using both ground-based station and rain gauge data in search of a trend and variability among the parameters. Roy and Balling (2004) studied 129 uniformly distributed rainfall stations across the country during 1910–2000 and found that most of the Deccan Plateau in the south and the north-western Himalayas in Kashmir showed an increasing trend, whereas decreasing trend was found in the Eastern part of the Gangetic Plain and parts of Uttarakhand (now known as Uttarakhand). Also, the frequency of hot days and nights has increased and cold days and nights have decreased significantly for the pre-monsoon (March–May) season during the period 1970–2005 across India (Kothawale et al. 2010). Though studies have confirmed a trendless rainfall in the North Eastern Region (NER) of India, the rising trend in temperature is an adverse consequence of global warming (Jain and Kumar 2012; Jain et al. 2013). NER of India receives the highest annual rainfall throughout the country, which is mainly contributed by the southwest monsoon. Due to hilly terrain, large forest cover and unique geographical conditions, the climate of this region has a significant impact on the livelihood of people and the biodiversity (Das et al. 2009). Having the fact that NER of 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 places on earth (Kuttippurath et al. 2021). In this study, 15 climate indices, as recommended by ETCCDI, have been extracted from the time series of daily precipitation and temperature (both maximum and minimum) of the meteorological station at Cherrapunji. Six more precipitation indices have been introduced and extracted according to IMD convention with number of days with different amounts of rainfall occurring in a year (Forecasting Circular No. 5/2015 (3.7)). This study mainly focuses on (i) analysis of trend in ETCCDI recommended precipitation and temperature-based indices and (ii) analysis of trend in IMD conventional precipitation-based indices.

2. Study area and data used

2.1 Location and climate

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 (figure 1). Cherrapunji, locally known as Sohra, is one small town at the southern edge of Meghalaya plateau, at
an altitude of about 4823 feet (1484 m) above mean sea level (MSL) and has a mild subtropical highland climate with the influence of Indian Summer Monsoon (ISM) (Beck et al. 2018). In just 8 months, i.e., from March to October, Cherrapunji receives 98% of the annual rainfall. However, a small 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 months 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, 2017). And the rain observed in the pre- and post-monsoons is 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, the minimum temperature reaches up to 0°C or less. The average temperature fluctuates between 11.6°C during

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 < 1 mm                            | Days    |
| CWD         | Consecutive wet days                  | Maximum number of consecutive days with RR >= 1 mm                           | 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  |
| Run (mm=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 >= 1 mm)                                  | 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      |
January (winter) and 20.6°C during August (summer), respectively (Prokop 2020).

2.2 Dataset

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 Cherrapunjee Holiday Resort, located at Cherrapunji (Daily Weather Data). This website maintains the data from India Meteorological Observatory situated at Cherrapunji (Sohra) 91°44′ East Longitude and 25°15′ 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. Quality control was performed to identify those missing values and was filled using Linear Regression Forecast method in an excel sheet (Nadler and Kros 2007).

3. Methodology

3.1 RClimDex

RClimDex computes 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 interface (Zhang and Yang 2004). Three steps involved in the entire process are:

- The installation of R and setting up the user environment,
- Quality control of daily climate data,
- Calculation of the 27 core indices.

The current study involves the analysis of only 15 precipitation and temperature-based indices (tables 1 and 2) as recommended by ETCCDI and 6 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 21 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.

| ID   | Indicator name     | Definitions                                                                 | Units |
|------|--------------------|----------------------------------------------------------------------------|-------|
| SU25 | Summer days        | Annual count when TX (daily maximum) > 25°C                                 | Days  |
| TR20 | Tropical nights    | Annual count when TN (daily minimum) > 20°C                                 | Days  |
| TMAXMEAN | Mean $T_{\text{max}}$ | Monthly mean value of daily maximum temp °C                                 | Days  |
| TXX  | Max $T_{\text{max}}$ | Monthly maximum value of daily maximum temp °C                              | Days  |
| TNX  | Max $T_{\text{min}}$ | Monthly maximum value of daily minimum temp °C                              | Days  |
| TMINMEAN | Mean $T_{\text{min}}$ | Monthly mean value of daily minimum temp °C                                 | Days  |
| TXN  | Min $T_{\text{max}}$ | Monthly minimum value of daily maximum temp °C                              | Days  |
| TNN  | Min $T_{\text{min}}$ | Monthly minimum value of daily minimum temp °C                              | Days  |

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

| ID  | Indicator name  | Definitions                                                                 | Units |
|-----|-----------------|----------------------------------------------------------------------------|-------|
| VLR | Very light rain | Annual count of days when precipitation is trace to 2.4 mm                 | Days  |
| LR  | Light rain      | Annual count of days when precipitation is 2.5 to 15.5 mm                  | Days  |
| MR  | Moderate rain   | Annual count of days when precipitation is 15.6 to 64.4 mm                 | Days  |
| HR  | Heavy rain      | Annual count of days when precipitation is 64.5 to 115.5 mm               | Days  |
| VHR | Very heavy rain | Annual count of days when precipitation is 115.6 to 204.4 mm              | Days  |
| EHR | Extremely heavy rain | Annual count of days when precipitation >= 204.4 mm       | Days  |

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

Mann–Kendall (Mann 1945; Kendall 1975) test is a widely used nonparametric test to detect the trend in hydro-meteorological time series (Subash and Sikka 2014; Oza and Kishawal 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 statistics, which is defined as (Mann 1945; Kendall 1975):

\[ S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}(X_j - X_k), \]

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

\[ \sigma^2 = \left\{ \frac{n(n-1)(2n+5) - \sum_{j=1}^{p} t_j(t_j - 1)(2t_j + 5)}{18} \right\} \]

\[ \text{where } p \text{ is the number of the tied groups in the dataset and } t_j \text{ is the number of data points in the } j\text{th tied group. Then the normalised test statistics } Z \text{ is computed as follows:} \]

\[ Z = \left\{ \begin{array}{ll} \frac{S - 1}{\sigma}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \frac{S + 1}{\sigma}, & \text{if } S < 0 \end{array} \right. \]

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 \( \alpha \). 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 \( \geq 1.96 \), i.e., at 95% significance level.
3.3 Sen’s slope estimator

Sen’s slope is a nonparametric 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 researchers in hydro-meteorological time series (Partal and Kahya 2006; Subash et al. 2011; Tabari et al. 2011). First of all, the slopes of $n$ data pairs are calculated as follows:

$$d_m = \frac{X_j - X_i}{j - i}, \text{ for } m = 1, 2, 3, \ldots, n,$$

Figure 3. Variation of ETCCDI recommended precipitation-based indices over the period 1979-2020.
where $X_i$ and $X_j$ are the data values at the corresponding times $i$ and $j$ $(1 \leq i < j \leq n)$, respectively. Then the median of all those $d_{ni}$, gives the Sen’s slope, which is then calculated as:

$$
\beta = \left\{ \begin{array}{ll}
\frac{d_{n+1}}{n} & \text{if } n \text{ is odd} \\
\frac{1}{2} \left( d_{n} + d_{n+2} \right) & \text{if } n \text{ is even.}
\end{array} \right.
$$

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

Table 5. $Z$ values and Sen’s slope for precipitation-based IMD convention indices.

| Sl. no. | Indices | $Z$ value | Sen’s slope | $P$ value |
|---------|---------|-----------|-------------|-----------|
| 1       | VLR     | 2.36*     | 0.14        | 0.018     |
| 2       | LR      | -0.04     | 0           | 0.96      |
| 3       | MR      | -1.59     | -0.13       | 0.11      |
| 4       | HR      | 0.49      | 0           | 0.62      |
| 5       | VHR     | -1.13     | -0.07       | 0.26      |
| 6       | EHR     | -0.66     | -0.04       | 0.51      |

*Bold number indicates $Z$ values at 95% significance level.

Table 6. $Z$ values and Sen’s slope for temperature-based indices, SU25 and TR20.

| Sl. no. | Indices | $Z$ value | Sen’s slope | $P$ value |
|---------|---------|-----------|-------------|-----------|
| 1       | SU25    | 5.99**    | 1.58        | 0         |
| 2       | TR20    | -0.92     | -0.03       | 0.38      |

**Bold number indicates $Z$ values at 99% significance level.

Figure 4. Variation of IMD convention precipitation-based indices over the period 1979–2020.
4. Results and discussions

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

4.1 Precipitation-based indices

4.1.1 ETCCDI recommended indices

Table 4 represents results for \( Z \) statistics of MK test and magnitude of Sen’s slope of seven

| Sl. no. | Time | TMAX | Z value | Sen’s slope | P value | TXX | Z value | Sen’s slope | P value | TXN | Z value | Sen’s slope | P value |
|--------|------|------|---------|-------------|---------|-----|---------|-------------|---------|-----|---------|-------------|---------|
| 1      | Jan  | 4.08** | 0.08   | 0          | 4.11**  | 0.09 | 0       | 2.78**      | 0.07   | 0.003 |
| 2      | Feb  | 4.51** | 0.09   | 0          | 4.66**  | 0.11 | 0       | 2.5*        | 0.08   | 0.005 |
| 3      | Mar  | 3.67** | 0.07   | 0          | 3.32**  | 0.07 | 0       | 1.54        | 0.04   | 0.04  |
| 4      | Apr  | 2.22*  | 0.03   | 0.04       | 3.8**   | 0.07 | 0       | -0.16       | 0      | 0.86  |
| 5      | May  | 3.3**  | 0.03   | 0          | 2.98**  | 0.03 | 0.003   | 1.83        | 0.03   | 0.08  |
| 6      | Jun  | 1.86   | 0.02   | 0.06       | 2.55*   | 0.04 | 0.02    | 2.62**      | 0.02   | 0.015 |
| 7      | Jul  | 4.63** | 0.04   | 0          | 3.14**  | 0.05 | 0       | 3.81**      | 0.03   | 0     |
| 8      | Aug  | 3.58** | 0.04   | 0          | 2.34*   | 0.03 | 0.4     | 3.04**      | 0.03   | 0.002 |
| 9      | Sep  | 4.75** | 0.06   | 0          | 4.11**  | 0.08 | 0       | 2.36*       | 0.02   | 0.02  |
| 10     | Oct  | 5.61** | 0.06   | 0          | 4.51**  | 0.09 | 0       | 0.26        | 0      | 0.78  |
| 11     | Nov  | 4.52** | 0.07   | 0          | 4.01**  | 0.09 | 0       | 3.01**      | 0.06   | 0.004 |
| 12     | Dec  | 5.48** | 0.09   | 0          | 4.88**  | 0.1  | 0       | 3.45**      | 0.08   | 0.001 |
| 13     | Annual | 6.38** | 0.06   | 0          | 4.84**  | 0.07 | 0       | 2.41*       | 0.06   | 0.01  |

*Bold and **bold number indicates \( Z \) values at 95% and 99% significance level, respectively.

Figure 5. Variation of ETCCDI recommended temperature-based indices (SU25 and TR20) over the period 1979–2020.
ETCCDI recommended indices and the corresponding trends are shown in Figure 3. It is observed that consecutive dry days (CDD) have increased significantly with 0.54 days/yr, while consecutive wet days (CWD) have decreased significantly with 0.36 days/yr. 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 the 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-known problem for people living in Cherrapunji (Mawroh and Husain 2012; Mawroh 2019). Moreover, since most of the CWD occur during monsoon, its decreasing value can cause intense precipitation leading to damage to cultivation and local crops. One important observation is that except for one index, all other indices have shown a decreasing trend throughout the period from 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, 7.77 and 3.48 mm/yr, respectively. It infers that Cherrapunji has been losing 27.15 mm of annual rainfall every year over the last 42 yrs. The consequence of this is that the wettest spot has started shifting towards Mawsynram, 15 km west of Cherrapunji. Now, in the last two decades, Mawsynram has received a slightly greater amount of annual rainfall than Chearrapunji (Kuttippurath et al. 2021).

### 4.1.2 IMD convention indices

Depending on the amount of precipitation on a particular day, the index Rnm has been split into six indices according to the IMD convention. The results for Z statistics of MK test and the magnitude of Sen’s slope of the six IMD convention indices are represented in Table 5 and their corresponding trends are shown in Figure 4. Only very light rain (VLR) has shown significant increasing trend with 0.14 day/yr. MR and VHR have 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, 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 is decreasing throughout the period of 42 yrs. Moreover, from the figure, it is observed that MR shows an average of almost 58 days/yr, which is comparatively high with respect to the other IMD convention indices.

### 4.2 Temperature indices

The results of trend analysis in Table 6 show that SU25 (summer days) has increased significantly at 99% with 1.58 days/yr while no significant change is observed in the case of TR20 (cold nights).
Figure 5 depicts a gradual increase in SU25 from 1979 to 2004 and 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 in 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 (figure 5), some sharp peaks were observed with 16 days in the years 2006 and 2009, respectively.

4.2.1 Maximum temperature-based indices

When MK test was done for maximum temperature-based indices such as TMAXMEAN, TXX and TXN (supplementary figures S1–S3 and S7), a very significant monthly as well as 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/yr, respectively. Moreover, the monthly analysis reveals that the highest trends were observed during the months of December–February for all the three indices. Most importantly, February witnessed a maximum change of 0.09°C/yr for TMAXMEAN, 0.11°C/yr 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/yr) for TMAXMEAN, while a significant minimum increasing trend of 0.03°C/year was observed in the months of May and August in the 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.

4.2.2 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 (supplementary figures S4–S7) have not shown any significant changes on an 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 be decreasing significantly with 0.05°C/year. There was no annual trend in TMINMEAN, but 0.01°C/yr for TNN and TNX. The results indicate that minimum temperature of Cherrapunji was least affected by global warming.

5. Conclusions

Being the rainiest place on earth, numerous attempts have been made so far to carry out a detailed analysis of rainfall in Cherrapunji, its pattern and effect on neighbouring areas (Prokop and Walanus 2003; Murata et al. 2007, 2017; Tomasz et al. 2015; 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:

- Results of trend analysis showed a significant rising trend in CDD, while a significant declining trend in CWD. Rest of the precipitation indices, SDII, R100, PRCPTOT, R95P, and R99P, also had a declining trend, though insignificant.
- The IMD convention index, VLR had only shown a significant rising trend. And the rest, LR, MR, HR, VHR, and EHR had remained insignificant and almost trendless.
- 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 trends.

The increasing trend in temperature and decreasing trend in precipitation can be attributed due to the fact that global warming directly influences precipitation (Trenberth 2011). The correlation between the monthly mean anomalies of surface temperature and precipitation during the period 1979–2002 shows that temperature and precipitation change is negatively correlated throughout the tropics year-round and over the continents in summer (Trenberth and Shea 2005). Moreover, in response to rising temperature, the precipitation extremes change with higher magnitude over the Indian region as the extreme
temperature and precipitation indices are strongly teleconnected to large-scale climate indices, ISMI (Indian Summer Monsoon Index) and AO (Arctic Oscillation) as reported by Rehana et al. (2022). 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, and PRCPOT 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 the rainiest place and winter would become dry with severe draught situations. This can impact neighbouring countries 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 precipitation (Prokop and Walanus 2015). The anthropogenic human activities like limestone mining, coal extraction and puffed-up tourism (Prokop 2020) have also affected the bio-diverse ecosystem of Cherrapunji, which in turn may have contributed to climate change in the region.

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Author statement

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

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