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Variations of Daily Extreme Precipitation over Stations of Humid North-East India

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ABSTRACT

It's a known fact that climate change will bring about increases in the occurrence of extreme weather events such as increased temperature, droughts and floods. Northeast India is one such region which receives much rainfall than all the India average which cause flooding, drought, damage crops and bring life to standstill. Based on the daily precipitation data from two stations in the humid North-East India, this study examined the characteristics of daily extreme precipitation in Imphal and Shillong for the period from 1985 to 2003. The daily records of precipitation data were collected from ICAR Manipur and Meghalaya. Six extreme precipitation indices out of 11 extreme precipitation indices recommended by the Expert Team on Climate Change Detection and Indices (ETCCDI) were applied. Trends in the daily precipitation extreme indices were also identified using a non-parametric Mann–Kendall test, while the significance of trend at 90% confidence level was estimated using Sen's slope estimator. The results of the analysis indicated a significant increase in the consecutive dry days (CDD) in Shillong. The non-significant decrease in the wet day precipitation (PRCPTOT) and R10 were found in both the stations. The consecutive dry days, CWD exhibits an increasing non-significant trend in Imphal while there was no change in Shillong. The 1-day maximum precipitation shows non-significant decreasing (increasing) trend in Imphal (Shillong). Both the stations indicate a non-significant increasing trend in the 5-day maximum precipitation respectively.

1. Introduction

The major climate changes predicted for this century include changes in rainfall spatial distribution, an increase in average temperature, increase in the evapotranspiration during summer, elevated CO_2 concentration in the atmosphere and greater occurrence of extreme events such as windstorms, hail and heavy rainfall (de Melo *et al.,* 2015). One aspect of climate that may be modified by current climate changes is extreme precipitation events that may affect water, agricultural and food security. Extreme events can cause short or long-term side effects and therefore it needs to investigate in response to current and future climate change. The fourth Assessment Report (AR4) of Intergovernmental Panel on Climate Change (IPCC 2007) suggested that climate change may lead to changes in water availability and runoff due to alterations in rainfall pattern. Population and infrastructure are becoming more vulnerable to intense and severe weather and it is essential to closely monitor the extreme events and to continue to search for evidence of changes in climate extremes. Rainfall over India is subject to a high degree of variation leading to the occurrence of extreme monsoon rainfall excess or deficit over extensive areas of the country. Because of large spatial variability of monsoon rainfall, there are cases when some regions experience floods due to intense rains while at the same time other areas experience severe rainfall deficiency

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leading to meteorological drought (Pal and Al-Tabbaa, 2010). The Northeast region of India is one of the such region where the seasonal mean (June–September) rain over the region (approximately 151.3 cm) being much larger than the all India average (86.5 cm) coupled with the local topography makes the region flood prone (Goswami *et al.,* 2010). Flash floods associated with extreme rain events are a major hydrological disaster in the northeast Indian region because of the unique topographic features of the region as well as increased frequency of occurrence of such events. The variations and trends in extreme precipitation have been receiving more and more attention as a part of the changing trends in the global climate (Easterling *et al.,* 2000; Karl and Easterling 1999). Since the late 1990s, many efforts have been made to assess changes in spatial and temporal patterns of extreme climate events using observational climatic data. Analyses of long-term climatic characteristics of extreme events, including their intensity, duration, and frequency, are necessary for developing mitigation and adaptation plans (Choi *et al.,* 2009). The objective of this study is to investigate the changes precipitation extremes during the period 1985-2003 in the two stations, Imphal and Shillong of humid northeast India through the analysis generated by the Expert Team (ET) on Climate Change Detection and Indices (ETCCDI). Analyzing these indices will hopefully lead to a better understanding of variability and changes in the frequency, intensity and duration of extreme climate events in the Northeast India.

2. Materials and Methods

2.1 Study area

For the present study, two stations namely Imphal and Shillong from the region of North East India are selected. The location of the study area is shown in Figure 1. Imphal is located at 24.49 to 24.82°N latitude and 93.57 to 93.95°E longitude with an average elevation of 786m. It has a humid sub-tropical climate with mild, dry winters, and a hot monsoon season. July is the hottest month with temperatures averaging around 29°C, while January is the coldest with average lows 4°C. The average annual rainfall is 1320 mm with June being the wettest month. Shillong is located at 25.34° to 25.57°N latitude and 91.53° to 91.88°E longitude. It has an average elevation of 1525 m. The climate is sub-tropical highland with cool, rainy summers and cool, dry winters. Shillong is subject to vagaries of the monsoon. The monsoons arrive at June and it rains almost until the end of August. The temperature varies from 23 °C in summer and 4 °C in winter. The average annual rainfall is 2160 mm with July being the wettest month.

Figure 1. Map showing the location of the study area.

2.2 Data used

In this study, daily precipitation data observed at 2 weather stations namely Imphal and Shillong located in the humid northeast India are used to construct interannual time series of 6 extreme precipitation indices over the 1985 - 2003 period. The data of Imphal were collected from the ICAR, Manipur whereas the Shillong data have been taken from the Published Book of ICAR, Shillong.

2.3 Methods

2.3.1 Investigation of precipitation extreme indices

In this study, 6 extreme precipitation indices (Table 1) are selected from the list of out of 11 indices recommended by the ETCCDI. The RClimdex software developed by Zhang and Yang (2004) is used to construct time series of the indices, and to extract their trends and an assessment of statistical significance for each individual weather station.

2.2.1 Trend in the precipitation extreme indices

The magnitude of trend in the extreme precipitation indices time series was determined using a nonparametric method known as Sen's estimator and statistical significance of the trend was analyzed using Mann-Kendall (MK) test (Jain and Kumar, 2012).

Magnitude of trend

Sen's method assumes a linear trend in the time series and has been widely used for determining the magnitude of trend in hydro-meteorological time series (Lettenmaier *et al.,* 1994). In this method, the slopes (Ti) of all data pairs are first calculated by

$$T_i = \left(\frac{X_j - X_k}{j-k}\right) \quad \text{for } i = 1, 2 \ldots N \quad (1)$$

Table 1. Six precipitation indices

Abbreviation	Indicator Name	Definition	Units
CDD	Consecutive dry days	Maximum number of consecutive days with PRCP<1mm	days
CWD	Consecutive wet days	Maximum number of consecutive days with PRCP≥1mm	days
PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (PRCP≥1mm)	mm
R10	Heavy precipitation days	Annual count of days when PRCP≥10mm	days
RX1day	Maximum 1-day precipitation	Annual Maximum 1-day precipitation	mm
RX5day	Maximum 5-day precipitation	Annual Maximum 5-day precipitation	mm

where xj and xkare data values at time j and k (j>k), respectively. The median of these N values of Ti is Sen's estimator of slope, which is calculated as follows:

β={█(T_((N+1)/2) N is odd @1/2 (T_(N/2) + T_((N+2)/2)) N is even) ┤ (2)

A positive value of β indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series.

Significance of trend

To ascertain the presence of statistically significant trend in hydrologic climatic variables such as temperature, precipitation, and stream flow, nonparametric MK test has been employed by a number of researchers (Jain and Kumar, 2012). The purpose of the Mann-Kendall (MK) test is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear. In this study, the MK test was also applied. The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend. The statistics (S) is defined as follows:

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} sgn\left(x_j - x_i\right) \quad (3)$$

Where N is the number of data points. Assuming $(x_j - x_i) = \theta$, the value of sign (θ) is computed as follows:

$$sgn(\theta) = \begin{cases} 1 & if\ \theta > 0 \\ 0 & if\ \theta = 0 \\ -1 & if\ \theta < 0 \end{cases} \quad (4)$$

This statistic represents the number of positive differences minus the number of negative differences for all the differences considered. For large samples (N> 10), the test is conducted using a normal distribution (Helsel and Hirsch, 1992) with the mean and the variance as follows:

E[S] = 0

$$Var\ (S) = \frac{N\,(N-1)(2N+5) - \sum_{k=1}^{n} t_k\left(t_k - 1\right)\left(2t_k + 5\right)}{18} \quad (5)$$

Where n is the number of tied (zero difference between compared values) groups and t_k the number of data points in the k^{th} tied group. The standard normal deviate (Z-statistics) is then computed as (Hirsch *et al.,* 1993) follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if\ S < 0 \end{cases} \quad (6)$$

If the computed value of $|Z| > Z_{\alpha/2,}$ the null hypothesis (H_0) is rejected at α level of significance in a two-sided test. In this analysis, the null hypothesis was tested at 90% confidence level.

3. Results and Discussion

3.1 Precipitation analysis

The variations in the annual daily mean values of precipitation for Imphal and Shillong are shown in Figure 2. From the visual inspection, it is observed that the annual rainfall for Shillong varies in the range of 1808.2 mm to 3322.6 mm while the range of its variation for Imphal is 1240.4 mm to 2257.56 mm. The linear trends of annual rainfall have decreased for both the stations with greater rate of decrease in Shillong where it is decreasing at the rate of 135 mm/decade as compared to 96.6 mm in Imphal.

3.2 Analysis of precipitation extreme indices

The extreme precipitation indices are estimated using ETCCDI and their variations are shown in Figure 3. Trends in the time series of each index at each weather station over the study period are extracted using Sen's estimator, but statistical significance for the trends in extreme climate indices is performed using the Mann-Kendall test. The trend test result is given in Table 3.

3.2.1 Consecutive dry days (CDD) and Consecutive wet days (CWD)

The annual maximum number of CDD is observed to be highest in the year 1986 (1997) with 80 days/year (81days/year) in Imphal (Shillong). The CDD analysis indicated an increase of 8 days/decade for both the stations (Figure 3a). An increasing trend in CDD was obtained in both the stations with significant increase in Shillong (Table 3). The analysis of CWD is shown in Figure 3b and found to be highest in the year 2003 (1992) with 31days/year (26days/year) in Imphal (Shillong). CWD exhibits anon-significant increasing trend in Imphal while there was no change in Shillong.

3.2.2 Annual total wet day precipitation (PRCPTOT) and Heavy precipitation days (R10mm)

The index PRCPTOT has found to be highest in the year 1991(1988) with 2246.3 mm (3310.2 mm) for Imphal (Shillong) (Figure 3c). PRCPTOT is found to be decreased in both the stations but was not significant (Table 3). R10 shows maximum (Figure 3d) in the year 1991 (1987) with 78days (84 days) in Imphal (Shillong) respectively. Both the stations exhibit a non-significant decreasing trend.

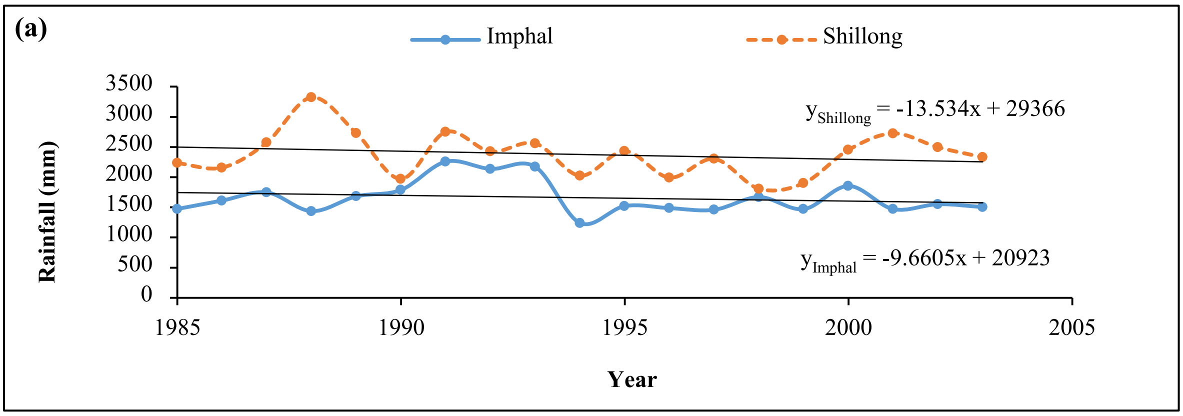
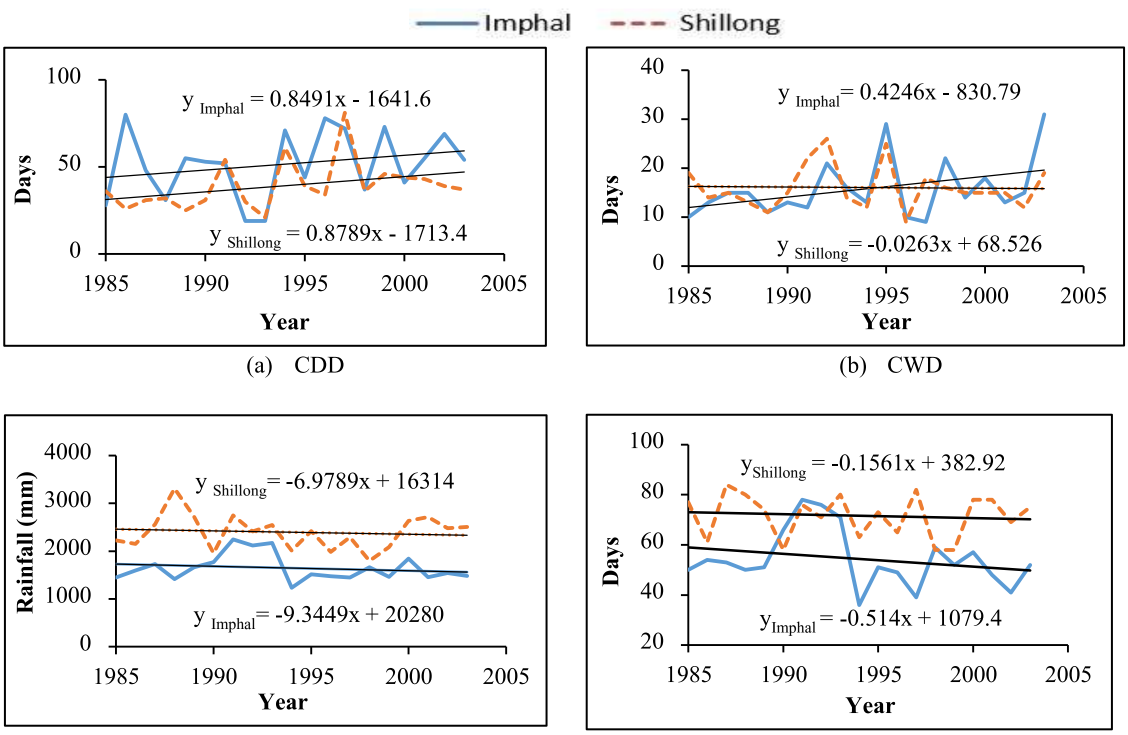
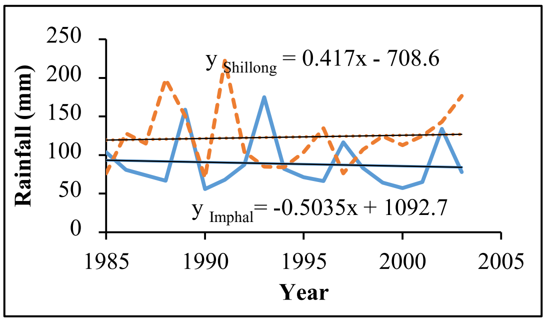


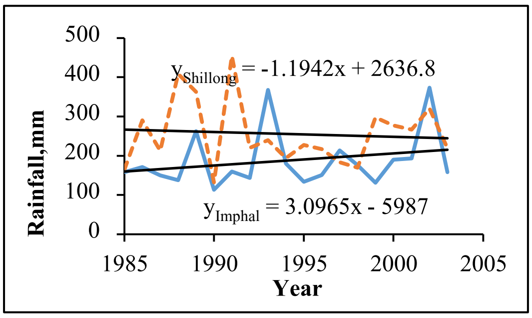
Figure 2. Evolution and linear trend in the annual rainfall.



(a) CDD (b) CWD

(c) PRCPTOT (d) R10





(e) RX1day (f) RX5day

Figure 3. Evolution and linear trend in the six extreme precipitation indices for Imphal and Shillong during 1985-2003.

3.2.3 1-day maximum precipitation (RX1day) and 5-day maximum precipitation (RX5day)

RX1day has found to be maximum in the year 1993 (1991) with 175 mm (222.4 mm) in Imphal (Shillong) (Figure 3e). The RX1day shows non-significant decreasing in Imphal while Shillong shows non-significant increasing trend (Table 3). The RX5day is highest (Figure 3f) in the year 2002 with 373.4 mm in Imphal while highest in the year 1988 with 408.8 mm in Shillong respectively. Both the stations show a non-significant increasing trend.

Table 3. Trends in indices for Imphal and Shillong during the period 1985 to 2003.

Indices	Z statistics	
ID	Imphal	Shillong
CDD	0.84	1.78*
CWD	1.47	0.0
PRCPTOT	-0.35	-0.21
R10	-0.87	-0.59
RX1day	-0.70	0.91
RX5day	1.05	0.14

Asterisk mark indicates significant at 90% confidence level.

Summary and Conclusion

In this paper, an attempt was made in order to characterize the extreme precipitation indices for Imphal and Shillong located in humid northeast region of India during 1985-2003. Six extreme precipitation indices out of 11 indices defined by the ETCCDI were used in the study. Significant trends in the indices were detected by the Mann-Kendall test and Sen's slope estimator test. From the analysis, we can predict that since the annual rainfall are decreasing and CDD are increasing for both the stations indicating that a scarcity of rainfall may be faced by the study area.

Despite the small number of rainfall series, the study provided evidence that during the last 19 years Imphal was particularly affected by warm extremes. Particularly CWD and RX5day showed pronounced warming during 1985 - 2003 period indicating an increase in the frequency, intensity and duration of rainfall can be expected in future. This also indicates that a flood like situation may occur in Imphal in the future. A decrease in total rainfall and increase of cumulative dry days is an alarming situation for these two stations especially for Imphal where rainfall is decreasing.

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