

Chapter 11

Temporal and Spatial Variability of Daily Rainfall Extremes in Humid Northeast Assam State of India



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11.1 Introduction

Climate change is one of the greatest environmental concerns facing mankind in the twenty-first century. It is likely to produce more extreme precipitation events (Allan and Soden 2008). One of the most substantial consequences of global warming would be an increase in the frequency and magnitude of extreme precipitation events carried by increased atmospheric moisture levels, large-scale storm activity and/or thunder-storm activity. According to the climatic model simulations made by Hennessey et al. (1997) and experimental evidences showed that warmer climates are responsible for increase in water vapor, which may result in more extreme precipitation events and consequently increased risks of floods (IPCC 2007).

Extreme rainfall leads to flash floods, landslides and crop damage that have major impacts on society, the economy and the environment. Although prediction of such extreme weather events is still fraught with uncertainties, a proper assessment of likely future trends would help in setting up infrastructure for disaster preparedness (Goswami et al. 2006; Swain et al. 2018). The most severe damages seem to result from extreme precipitation on a regional scale such as heavy precipitation and rain-storms events accounting for high percentages of the yearly total in a few rainy days are directly responsible for flood occurrence (Zhang et al. 2001).

Findings of extremes climate are also beneficial for the substantiation of climate model results and thus growing confidence in future climate projections (Kruger 2006; Shrestha et al. 2016). In different parts of the world, numerous studies (Haylock and Nicholls 2000; Manton et al. 2001; Salinger and Griffiths 2001; Rajeevan et al. 2008; Swain et al. 2017) have been made to identify trends in the climate extremes and

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149

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increasing trends for extreme precipitation events were revealed. The most up-to-date and comprehensive global scenario of the observed trends in extremes in precipitation was presented (Alexander et al. 2006). They have reported a general increase in the heavy precipitation indices. However, compared with temperature variations, variations in extremes precipitation were found to be less spatially coherent and at a lower level of statistical significance. Their analysis showed that the major decreasing trends were found in the annual number of CDD for the Indian Region (Revadekar et al. 2011).

In India also many studies have been made of climate extremes. Bhaskaran et al. (1995) have observed a significant increase in moisture transport over India under doubled CO₂ environment that would lead to an increase in extreme rainfall events in the area. Soman et al. (1988) investigated annual extreme precipitation for stations in the state of Kerala, India and found declining trends, which were mainly observed in hilly terrain stations. Sen Roy and Balling (2004) studied extreme daily precipitation indices for 129 stations around India during the period 1910–2000 and observed that, 61 stations had a significantly decreasing trend and 114 stations had a significantly increasing trend from the 903 different time series (for seven variables); the percentage of the time series exhibited an increasing trend was found to be 61%. Most of the studies on extreme rainfall over India have used a limited number of stations.

The daily gridded rainfall data for the period 1951–2003 were used by the Goswami et al. (2006) to examine the trend of rainfall extreme over Central part of India and identified a rise in the magnitude and frequency of extreme rain events and significantly falling trend in the frequency of moderate events. Guhathakurta et al. (2011) have analyzed daily rainfall data for 1901–2005 period over 2599 stations spread all over the India and revealed an increase in the intensity of rainfall extreme over Orissa, Saurashtra and Kutch, West Bengal, coastal Andhra Pradesh and its adjoining areas, east Rajasthan and parts of northeast India in 1-day extreme rainfall. However, trends were significantly decreasing in rainy day, heavy rainfall days and rain days over Central and many portions of northern India.

For the preparation of disaster management and mitigation plan, it is a good practice to consider the variations in extreme weather events rather than the variations in mean (Guhathakurta et al. 2011). The use of climate extreme indices is now gaining popularity among researchers to investigate climate extremes. To facilitate research community, the Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI) have developed set of climate extreme indices. Very few studies have been made of precipitation extremes over the northeastern part of India in spite of the fact that the region comes under high rainfall area.

In the present study, the districts of Assam in northeast region of India have been selected to investigate temporal and spatial variability and trends in ETCCDMI developed climate extreme indices.

11.2 Study Area and Data Used

11.2.1 Study Area

Assam in Northeast India covers an area of 78,438 km². The average annual rainfall of Assam varies between 1500 and 3750 mm and the temperature ranges from 35 to 38 °C in summer and 6 to 8 °C in winter. With the “Tropical Monsoon Rainforest Climate,” the state experiences heavy rainfall and high humidity. During monsoon season, flood is a common feature in Assam. The details of the stations used are given in Table 11.1 and their locations are shown in Fig. 11.1.

Table 11.1 Details of the districts and data period

District	Latitude °N	Longitude °E	Elevation (m)	Data period
Tinsukia	27.598	95.727	149.1	1901–2013
Dhemaji	27.624	94.912	108	1901–2013
Dibrugarh	27.393	95.156	111	1901–2013
Lakhimpur	27.218	94.250	87.3	1901–2013
Sivasagar	27.016	94.890	100.7	1901–2013
Jorhat	26.815	94.327	100.9	1901–2013
Sonitpur	26.860	93.003	92	1901–2013
Kokrajhar	26.668	90.220	111.9	1901–2013
Udalguri	26.816	92.151	133	1901–2013
Chirang	26.726	90.722	203.7	1901–2013
Baksa	26.738	91.417	112.2	1901–2013
Golaghat	26.485	93.910	95.6	1901–2013
Nagaon	26.303	92.923	390.3	1901–2013
Darrang	26.515	92.114	65.0	1901–2013
Karbi Anglong	26.244	93.494	839.8	1901–2013
Barpeta	26.375	91.063	41.0	1901–2013
Nalbari	26.421	91.459	51.3	1901–2013
Bongaigaon	26.428	90.646	207.2	1901–2013
Dhubri	26.139	90.053	46.4	1901–2013
Morigaon	26.345	92.364	57.7	1901–2013
Kamrup	26.197	91.653	159.4	1901–2013
Goalpara	26.142	90.698	41.9	1901–2013
Cachar	24.872	92.907	44.3	1901–2013
Karimganj	24.643	92.417	15.0	1901–2013
Hailakandi	24.545	92.635	31.0	1901–2013

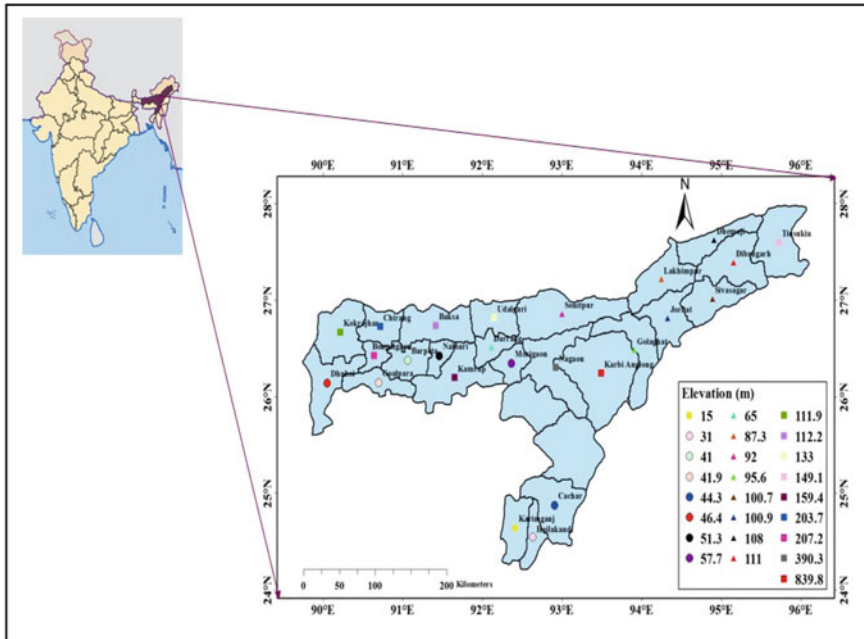


Fig. 11.1 Location of the study area

11.2.2 Data Used

The gridded daily rainfall data for the period 1901–2013 for 25 districts of Assam were extracted from the $0.25^\circ \times 0.25^\circ$ India Meteorological Department (IMD), Pune grid dataset. The data were processed using the software, RCLimDex, which executes data quality control, RH test, which performs homogeneity tests and calculates indices.

11.3 Methodology

The RCLimdex1.0 software (available at <http://cccma.seos.uvic.ca/ETCCDI/>) was used in this study to obtain the extremes climatic indices (Zhang and Yang 2004). Five out of 11 extreme precipitation indices defined by ETCCDI were used in this present study to investigate the temporal and spatial variability of daily rainfall extremes in each district of Assam of humid northeast India. The slope of the trend in climate indices was obtained using Sen's slope estimator whereas the significance of upward (downward) trend of all the indices used was established using Mann-Kendall trend test (Jain et al. 2012). The details of indices used in the present study are given in Table 11.2.

Table 11.2 Extreme precipitation indices with their definitions and units

ID	Indicator name	Definition	Unit
CDD	Consecutive dry days	Maximum number of consecutive days with PRCP < 1 mm	days
CWD	Consecutive wet days	Maximum number of consecutive days with PRCP ≥ 1 mm	days
PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (PRCP ≥ 1 mm)	mm
RX1day	Maximum 1-day precipitation	Annual Maximum 1-day precipitation	mm
R20	Number of very heavy precipitation days	Annual count of days when rainfall ≥ 20 mm	days

11.3.1 Magnitude of Trend

The magnitude of trend is tested using Sen’s slope estimator (Jain et al. 2012). This test computes the slope (i.e., linear rate of change) in the time series. First, a set of linear slopes is calculated as follows:

$$T_i = \frac{x_j - x_k}{j - k} \tag{11.1}$$

for $(I \leq j < k \leq N)$, where T_i is the slope, x denotes the variable, N is the number of data, and j, k are indices.

Sen’s slope is then calculated as follows:

$$\beta = \begin{cases} T_{\frac{N+1}{2}} & N \text{ is odd} \\ \frac{1}{2} (T_{\frac{N}{2}} + T_{\frac{N+2}{2}}) & N \text{ is even} \end{cases} \tag{11.2}$$

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

11.3.2 Mann-Kendall Trend Test

The Mann-Kendall trend test is a nonparametric test most commonly employed to detect the presence of statistically significant trends in series of environmental data, climate data or hydrological data. In the present analysis of trend, the Mann-Kendall trend test (Jain et al. 2012) is used with the null hypothesis, H_0 , that there is no trend in the data. The alternative hypothesis, H_A , is that the data follow a monotonic trend. The Mann-Kendall trend test statistics is calculated as follows:

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^N \operatorname{sgn}(x_j - x_i) \quad (11.3)$$

where N is the number of data points. Assuming $(x_j - x_i) = \theta$, the value of $\operatorname{sgn}(\theta)$ is computed as follows:

$$\operatorname{sgn}(\theta) = \begin{cases} 1 & \text{if } \theta > 0 \\ 0 & \text{if } \theta = 0 \\ -1 & \text{if } \theta < 0 \end{cases} \quad (11.4)$$

For large samples ($N > 10$), the test is conducted using a normal distribution (Z statistics) with the mean S is $E[S] = 0$ and the variance is

$$\operatorname{Var}(S) = \frac{N(N-1)(2N+5) - \sum_{k=1}^n t_k(t_k-1)(2t_k+5)}{18} \quad (11.5)$$

where n is the number of the tied groups in the data set and t_k is the number of data points in the k th tied group. The statistic S is approximately normally distributed provided that the following Z -transformation is employed:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\operatorname{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\operatorname{Var}(S)}} & \text{if } S < 0 \end{cases} \quad (11.6)$$

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 the analysis, the statistically significant trends were tested at 90% confidence level.

11.4 Results and Discussion

11.4.1 Analysis of Extreme Precipitation Indices for the Entire Assam

Five out of 11 extreme precipitation indices recommended by ETCCDI are used. The annual variation in the CDD, CWD, PRCPTOT, RX1day and R20 over Assam during 1902–2013 is shown in Fig. 11.2 whereas Table 11.3 is presented with maximum values of all the considered indices for different districts of Assam. It is clear from Fig. 11.2a that there is an insignificant increase in the values of CDD. Most of the values fluctuate around 40 days. In contradiction to CDD, a decreasing pattern is observed in CWD with a lowest value of 15 days in the year 2006 (Fig. 11.2b). The effect of decreasing pattern is seen, the PRCPTOT, which is also found to

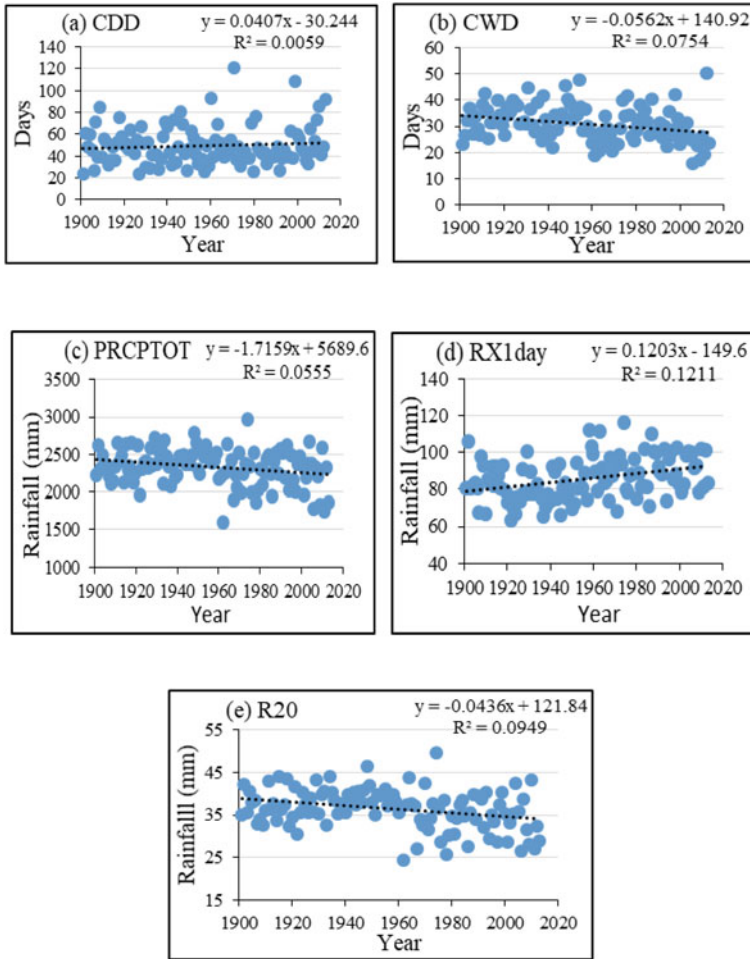


Fig. 11.2 Annual variation in daily extreme precipitation indices **a** CDD, **b** CWD, **c** PRCPTOT, **d** RX1day and **e** R20 during 1901–2013 over Assam

be decreasing (Fig. 11.2c). The highest maximum 1-day precipitation, RX1day is detected in the year 1974 (116 mm) and the lowest in the year 1922 (Fig. 11.2d). On average, an increasing rate of 1.2 mm/decade during the study period was observed. The extreme heavy precipitation, R20 on average, shows a decrease in the value and it is observed to be highest in the year 1974 (50 days) and lowest in 1962 during the study period.

Table 11.3 Maximum values of all the extreme precipitation indices

Districts	CDD (days)	CWD (days)	PRCPTOT (mm)	RX1day (mm)	R20 (days)
Tinsukia	81	69	5069.8	219.30	81
Dhemaji	81	73	4216.7	167.48	81
Dibrugarh	77	79	3874.8	148.08	75
Lakhimpur	104	74	3513.4	154.55	66
Sivasagar	138	69	3038.8	156.53	59
Jorhat	149	99	3101.4	136.00	54
Sonitpur	121	83	2979.4	125.42	57
Kokrajhar	153	60	4650	243.42	78
Udalguri	121	69	3073.6	374.15	51
Chirang	149	64	4337.6	339.40	70
Baksa	140	86	4425.3	168.08	78
Golaghat	140	82	2583.4	136.39	47
Nagaon	116	76	2334.7	117.54	39
Darrang	124	73	2698.9	302.15	47
Karbi Anglong	122	100	3984.1	116.98	67
Barpeta	176	57	3380.7	337.40	52
Nalbari	166	91	2879.3	175.50	51
Bongaigaon	148	71	4031.7	178.65	65
Dhubri	187	80	4039.7	280.88	69
Morigaon	144	82	3550.6	188.55	49
Kamrup	144	83	3300.6	165.23	50
Goalpara	148	92	3499	222.40	62
Cachar	133	95	4866.1	192.24	86
Karimganj	133	103	4113.1	224.05	73
Hailakandi	133	109	3732.9	267.30	70

11.4.2 District-Wise Analysis of Extreme Precipitation Indices

It is evident from Table 11.3 that the CDD had a variation from 77 days (minimum at Dibrugarh) to 187 days (maximum at Dhubri). Except Tinsukia, Dhemaji and Dibrugarh located at the north of Assam, the values of CDD are found to be more than 100 days indicating better moisture availability as compared with other districts. In case of CWD, maximum numbers of 109 days were observed in Hailakandi followed by 103 days in Karimganj at the south Assam exhibiting receiving of more precipitation. It is of significance to mention (from Table 11.3) that maximum amount of annual total precipitation was obtained in Tinsukia, which also supports the finding of less number of CDD. The RX1day that is important for designing of structures

was 374.15 mm, the highest, observed in Udalguri indicating proper planning for control of runoff which may be generated through the 1 day maximum amount. As seen in that table, Cachar showed maximum number of days (86 days) for R20 as against 39 days for Nagaon (middle Assam).

11.4.3 Trend Analysis of Extreme Precipitation Indices

Table 11.4 shows the Mann-Kendall trend test results of the indices of extreme precipitation used in the present analysis. The significance of trend is tested at 90%

Table 11.4 Mann-Kendall trend test result of extreme precipitation indices

District	CDD	CWD	PRCPTOT	RX1day	R20
Tinsukia	1.179	-1.211	-2.484	-0.109	-3.196
Dhemaji	1.489	-1.303	-3.737	-1.387	-3.211
Dibrugarh	2.412	-1.943	-3.382	2.427	-3.112
Lakhimpur	0.529	0.037	-3.330	0.045	-3.449
Sivasagar	0.851	1.546	-4.476	-2.536	-4.799
Jorhat	1.943	-1.174	-4.528	-2.747	-3.866
Sonitpur	0.362	-0.859	-2.548	-0.839	-1.429
Kokrajhar	-1.598	-2.387	-1.298	0.340	-2.181
Udalguri	1.963	-2.710	-2.094	3.677	-1.189
Chirang	-1.714	-3.255	2.809	4.853	1.439
Baksa	1.642	0.266	-0.300	0.933	-0.017
Golaghat	0.325	1.625	-3.908	-3.084	-4.501
Nagaon	1.082	-3.151	-6.424	-1.978	-4.749
Darrang	0.466	-1.012	-0.266	3.030	0.459
Karbi Anglong	0.734	-2.558	-4.360	0.119	-2.402
Barpeta	-0.462	-1.992	-0.739	4.109	-0.412
Nalbari	0.568	-4.612	-0.891	2.769	0.159
Bongaigaon	-1.104	-1.186	2.042	4.072	0.859
Dhubri	-1.203	-3.270	-0.375	0.199	-0.499
Morigaon	0.638	-2.913	-3.796	-0.447	-2.308
Kamrup	0.506	-1.571	-0.960	3.119	0.829
Goalpara	-1.677	-0.859	1.695	3.392	1.332
Cachar	1.030	-5.724	-1.620	2.317	-1.881
Karimganj	1.112	-5.987	-1.861	2.762	-1.697
Hailakandi	-0.104	-5.583	-2.662	1.506	-2.496

Values in boldface indicate significant at 90% confidence level

confidence level and the spatial variations of the trend of all the extreme precipitation indices used over Assam during the period 1901–2013 is depicted in Fig. 11.3a–e.

From the results of the trend analysis (Table 11.4), it can be observed that CDD is increasing in 18 districts and decreasing in 7 districts with significantly increasing in Dibrugarh, Jorhat and Udalguri districts while significantly decreasing in Chirang and Goalpara. The increase in the CDD may lead to drought-like situation in future over upper and central part of Assam (Fig. 11.3a). CWD is found to be increasing in 4 districts and decreasing in 21 districts, respectively, with significantly decreasing in 13 districts, i.e., Dibrugarh, Kokrajhar, Udalguri, Chirang, Nagaon, Karbi Anglong, Barpeta, Nalbari, Dhubri, Morigaon, Cachar, Karimganj and Hailakandi. Decrease in CWD is found to be more toward west of Assam (Fig. 11.3b). This finding of decrease in CWD also supports the reduction in the precipitation over Assam. A significant

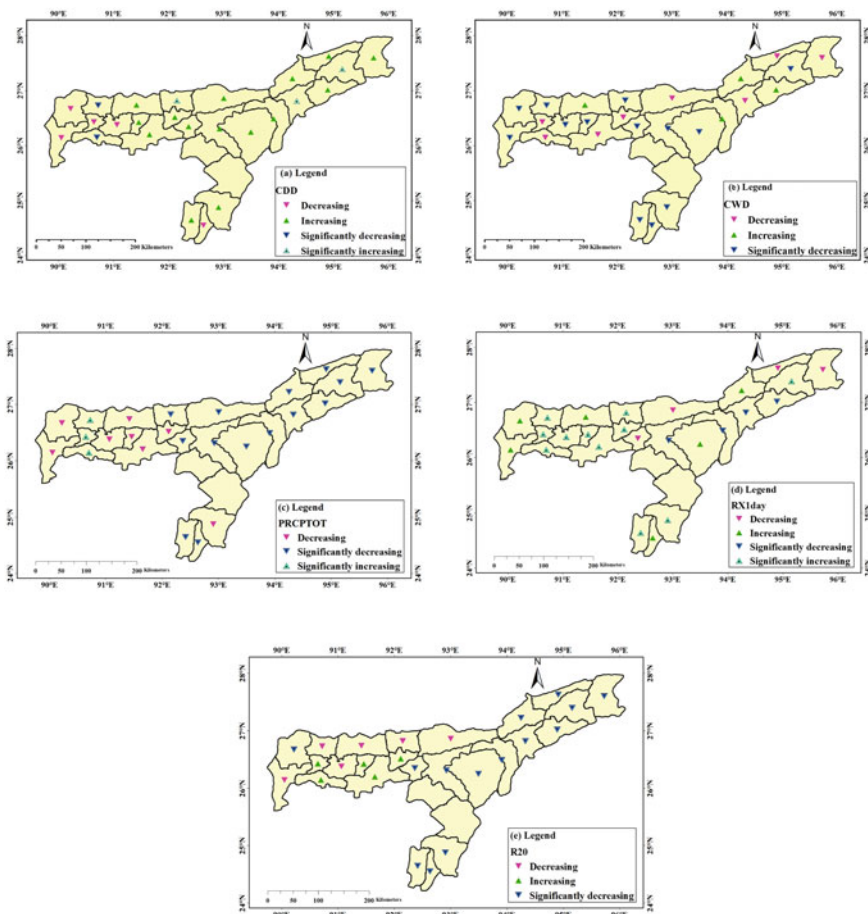


Fig. 11.3 Spatial variations of the trend in extreme precipitation indices **a** CDD, **b** CWD, **c** PRCPTOT, **d** RX1day and **e** R20 over Assam during the period 1901–2013

upward trend is revealed for PRCPTOT in three districts, i.e., Chirang, Bongaigaon and Goalpara located at the west of Assam indicating better water availability over this part of Assam. The remaining districts showed downward trend of which 14 are significant and uniformly scattered over the entire Assam (Fig. 11.3c). It is evident from Table 11.4 and Fig. 11.3d that RX1day is increasing in 17 districts of which 11 are significant, i.e., Dibrugarh, Udalguri, Chirang, Darrang, Barpeta, Nalbari, Bongaigaon, Kamrup, Goalpara, Cachar and Karimganj while decreasing trend is found in 8 districts with significantly decreasing in Sivasagar, Jorhat, Golaghat and Nagaon. The R20 index is found to be increasing in 6 districts with no significantly increasing trend while decreasing in 19 districts with significantly decreasing in 14 districts namely Tinsukia, Dhemaji, Dibrugarh, Lakhimpur, Sivasagar, Jorhat, Kokrajhar, Golaghat, Nagaon, Karbi Anglong, Morigaon, Cachar, Karimganj and Hailakandi mainly cover the upper and lower Assam (Fig. 11.3e) during the study period, respectively.

11.5 Conclusions

The present study analyses the temporal and spatial variability of daily extreme precipitation indices in Assam of humid northeast India for the period 1901–2013. Five out of 11 extreme precipitation indices as recommended by ETCCDI were used for the analysis. The Mann-Kendall trend test was used to detect trend in the indices. The significance of upward (downward) trend is tested at 90% confidence level. From the analysis, the following inferences can be drawn:

1. The consecutive dry days (CDD), consecutive wet days (CWD), annual total wet days precipitation (PRCPTOT), maximum 1-day precipitation (RX1day) and extreme heavy precipitation (R20) were observed to be highest in Dhubri, Hailakandi, Tinsukia, Udalguri and Cachar districts, respectively.
2. Indicated a condition leading to dryness over the area as CDD is increasing, CWD, PRCPTOT and R20 are decreasing.
3. However, RX1day is increasing suggesting for proper conservation of runoff water by suitably designing water conservation structures to encounter the situation which may be faced by the area due to decrease in CWD, PRCPTOT and R20.

References

Alexander LV, Zhang X, Peterson TC, Caesar J, Gleason B, Klein Tank AMG, Haylock M, Collins D, Trewin B, Rahimzadeh F, Tagipour A, Rupa Kumar K, Revadekar J, Griffiths G, Vincent L, Stephenson DB, Burn J, Aguilar E, Brunet M, Taylor M, New M, Zhai P, Rusticucci M, Vazquez-Aguirre JL (2006) Global observed changes in daily climate extremes of temperature and precipitation. *J Geophys Res* 111:D05109. <https://doi.org/10.1029/2005JD006290>

- Allan RP, Soden BJ (2008) Atmospheric warming and the amplification of precipitation extremes. *Science* 321:1481–1483
- Bhaskaran B, Mitchell JFB, Lavery JR, Lal M (1995) Climatic response of the Indian subcontinent to doubled CO₂ concentrations. *Int J Climatol* 15:873–892
- Goswami BN, Venugopal V, Sengupta D, Madhusoodanan MS, Xavier PK (2006) Increasing trend of extreme rain events over India in a warming environment. *Science* 314:1442–1445
- Guhathakurta P, Sreejith OP, Menom PA (2011) Impact of climate change on extreme rainfall events and flood risk in India. *J Earth Syst Sci* 120(3):359–373
- Haylock M, Nicholls N (2000) Trends in extreme rainfall indices for an updated high-quality data set for Australia, 1910–1998. *Int J Climatol* 20:1533–1541
- Hennessey KJ, Gregory JM, Mitchell JFB (1997) Changes in daily precipitation under enhanced greenhouse conditions. *Clim Dyn* 13:667–680
- IPCC (2007) *Climate change 2007—the physical science basis. contribution of working group I to the fourth assessment report of the IPCC*. Cambridge University Press, Cambridge, New York
- Jain SK, Kumar V, Saharia M (2012) Analysis of rainfall and temperature trends in northeast India. *Int J Climatol*. <https://doi.org/10.1002/joc.3483>
- Kruger AC (2006) Observed Trends in Daily Precipitation Indices in South Africa: 1910–2004. *Int J Climatol* 26:2275–2285
- Manton MJ, Della-Marta PM, Haylock MR, Hennessey KJ, Nicholls N, Chambers LE, Collins DA, Daw G, Finet A, Gunawan D, Inape K, Isobe H, Kestin TS, Lefale P, Leyuk CH, Lwin T, Maitrepierre L, Ouprasitwong N, Page CM, Pahalad J, Plummer N, Salinger MJ, Suppiah R, Tran VL, Trewin B, Tibig I, Yee D (2001) Trends in extreme daily rainfall and temperature in Southeast Asia and the South Pacific: 1961–1998. *Int J Climatol* 21:269–284
- Rajeevan M, Bhate J, Jaswal AK (2008) Analysis of variability and trends of extreme rainfall events over India using 104 years of gridded daily rainfall data. *Geophys Res Lett* 35:L18707
- Revadekar JV, Patwardhan SK, Rupa Kumar K (2011) Characteristics features of precipitation extremes over India in the warming scenarios. *Adv Meteorol* 11. <https://doi.org/10.1155/2011/138425>
- Salinger MJ, Griffiths GM (2001) Trends in New Zealand daily temperature and rainfall extremes. *Int J Climatol* 21:1437–1452
- Sen Roy S, Balling RC Jr (2004) Trends in extreme daily precipitation indices in India. *Int J Climatol* 24:457–466
- Shrestha AB, Bajracharya SR, Sharma AR, Duo C, Kulkarni A (2016) Observed trends and changes in daily temperature and precipitation extremes over the Koshi river basin 1975–2010. *J Climatol*, Int. <https://doi.org/10.1002/joc.4761>
- Soman MK, Krishnakumar K, Singh N (1988) Decreasing trend in the rainfall of Kerala. *Curr Sci* 57:5–12
- Swain S, Nandi S, Patel P (2018) Development of an ARIMA model for monthly rainfall forecasting over Khordha district, Odisha, India. In: *Recent findings in intelligent computing techniques*. Springer, Singapore, pp 325–331
- Swain S, Patel P, Nandi S (2017) Application of SPI, EDI and PNPI using MSWEP precipitation data over Marathwada, India. In: *2017 IEEE international geoscience and remote sensing symposium (IGARSS)*. IEEE, pp 5505–5507
- Zhang X, Yang F (2004) *RCLimDex (1.0) User manual*. Climate Research Branch Environment Canada: Downsview, Ontario, Canada
- Zhang X, Hogg WD, Mekis F (2001) Spatial and temporal characteristics of heavy precipitation events over Canada. *J Clim* 14:1923–1936