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Non-parametric Methods in the Analysis of Hydroclimatic Variables

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Abstract

Analysis on hydroclimatic variables can provide information on how the climate has evolved over time. This can be accomplished through time series analysis. Trend analysis, as one of the methods of Time Series Analysis, in hydroclimatic variables is challenging due to non-stationary nature of the series and the presence of noise and stochastic components in them. In this study an attempt has been made to detect the trend in rainfall and temperature, using two non-parametric methods- Mann-Kendall test and Sen's slope estimator. This analysis has covered 7 and 6 stations of NEI for rainfall and temperature respectively. From the analysis no specific trend has been found out for rainfall. But, minimum and maximum temperature has given a clear indication of increasing trend for all the stations for most recent fifty year (1966-2015).

Keywords: Mann-Kendall, rainfall, Sen's slope, temperature, trend.

1. Introduction

In hydroclimatological time series, there might happen many changes such as, step change or trend or might yield more multifaceted forms. If there exist positive or negative correlation between the observations and time, then the time series is said to have trends. Due to natural or artificial changes, the change in trends and shifts take place in hydroclimatic time series (Salas 1993). Change in climate through global and regional scale is the main reason behind the natural changes in hydroclimatic variables. Alternatively, the artificial changes or step changes is usually noted in the inclusive record at a monitoring site (Goswami et al. 2017). However, this statistics is not constantly accessible with the locations' documents. Thus, trend in variables may just represent the climate change of the monitoring place. In such circumstances, the pretentious data should be adapted to get better results about the study area (Hameed et al. 1997). Therefore, it is essential to trace whether a trend is present or not in the hydroclimatic data and if it is present then, quantify this trend. (Machiwal and Jha 2006).

2. Short Review

Most of the researcher has carried out various studies to determine trend in annual and seasonal rainfall on international, national and regional level. There is no clear trend has witnessed in the studies

in annual rainfall and monsoon rainfall as well but a long time significant changes was noticed in some pockets in national scale (Mooley and Parthasarathy 1984, Sarker and Thapliyal 1988, Thapliyal and Kulshreshtha 1991, Lal 2001, Sinha and De 2003, Kumar et al. 2010, Kumar et al. 2005, Dash et al. 2007). An increasing trend was observed in north and central India where as some parts of eastern India witnessed with decreasing behaviour in trend (Parthasarathy and Dhar 1974, Pant and Hingane 1988). Again, steady behaviour in northeast India was observed according to the study of Jain et al (2013). Analysis of rainfall data at Kashmir Valley showed a decreasing trend in annual rainfall for the period 1903-1982 but Srinagar showed increasing annual rainfall for the period 1962-2002 (Kumar and Jain 2010). In 2009, Krishnakumar et al. (2009) studied the temporal variation of rainfall over Kerala for the period 1871-2005. The analysis revealed a downward trend in south-west monsoon rainfall and an upward trend in post-monsoon season. Furthermore, rainfall during winter and summer showed an increasing trend. From the analysis of 80 years data of rainfall over the Indian Himalayan region, Basistha et al.(2009) found an upward trend between 1901 and 1964, and a downward trend between 1965 and 1980. In 2010, Pal and Al-Tabbaa (2011) analyzed the rainfall data over India during the period 1954-2003. Their analysis revealed decreasing and increasing trends in the spring and summer, and autumn and winter rainfall respectively. The surface air temperature is another crucial factor of climate change of a region. It varies seasonally and annually with respect to river, lake or sea, mountains etc. over that region (Jain and Kumar 2010). The hydrologic cycle (water->vapor->cloud->rain->water) is a thermally driven system. Hence, the rise in temperature is likely to quicken this cycle. So, it is a necessary subject matter to identify the temperature trends and their projection over a region. Srivastava et al. (1992) showed that the temperature trend is not identical throughout the day in case of India and which is unlike many other region of the globe. The analysis of Pant and Kumar (1997) revealed that there is a significant increasing trend per 100 years over the Indian region. However the temperature of monsoon period has not showed a significant trend over the country region. During the period 1901–1982, it was found increasing temperature over the north central and northeastern regions of India along with the whole of India (Hingane et al. 1985). For the same period, Pant and Hingane (1988) found decreasing trend in temperature over the northwest Indian region and Rao (1993) found highly significant increasing trend over the Mahanadi river basin. Again for the period 1901–1987, Kumar et al. (1992) found increasing maximum temperature and trendless minimum temperature in 121 different stations throughout in India. Sinha and De (2003), in their study, detected increasing temperature trend of 0.35°C over India. Kothiyari and Singh (1996) observed, around the second half of 1960s, an upward maximum temperature over the Ganga basin and annual temperature for India. The Brahmaputra is the biggest river in NEI. Its valley receives 2,293 mm. mean rainfall throughout the year (Deka et al. 2013). Study of Mirza et al. (1998) revealed an upward trend for the period of 1901-1981 in some part of the Brahmaputra valley like north Assam sub-division. A decreasing trend was found for rainfall in respect of annual as well as monsoon and post-monsoon seasons for NEI (Deka et al. 2013, Roy and Balling 2004).

3. Data and Methodology

The data used for this study is secondary in nature. The same have been collected from India Meteorological Department (IMD), Guwahati, for the seven stations of North-East India (NEI) viz., Guwahati, North Lakhimpur, Cherrapunjee, Shillong, Imphal, Lengpui and Agartala. In this study, the magnitude of trend in a hydroclimatic time series has been determined by the well-known nonparametric method Sen's estimator (Sen 1968) and statistical significance of the trend has been analyzed by Mann–Kendall (MK) test (Mann 1945, Kendall 1955). For Seasonal analysis of the trend, the data set has been divided into four different seasons: winter (December to February), per-monsoon

(March to May), monsoons (June to September) and post-monsoons (October and November). Again, for decadal trend detection, the entire fifty years (1966-2015) data have been sub-divided into five ten year's groups having 10x12 months. The monthly, seasonal, annual and decadal rainfall and temperature data for 1966-2015, are subjected to test for determining trend and magnitude.

3.1. Sen's slope

To determine the magnitude of trend in hydroclimatological time series, researcher generally used Sen's slope technique (Partal and Kahya 2006). This technique is more demanding than that of regression slopes as it is unaffected to outliers or missing data and provides accurate measure of the trends in the data series (Hirsch et al. 1982). The approach involves computing slopes for all the pairs of ordinal time points using the median of these slopes as an estimate of the overall slope (Sen 1968, Gilbert 1987). In this method, the slopes (T_i) for all data pairs are first calculated by the following way,

$$T_i = \frac{x_j - x_k}{j - k} \text{ for } i = 1, 2, \dots, N.$$

Here x_j are the values at time j and x_k are the values at time k ($j > k$). The median of these N values of (T_i) is Sen's estimator of slope, which is calculated as

$$L = \begin{cases} T_{N+1/2} & \text{if } N \text{ is odd,} \\ \frac{1}{2}(T_{N/2} + T_{N+1/2}) & \text{if } N \text{ is even.} \end{cases}$$

A positive value of L indicates an Increasing (upward) trend where a negative value indicates a decreasing (downward) trend in the time series.

3.2. Mann-Kendall test

To establish statistically significant trend in the series, Mann-Kendall (MK) technique (Mann 1945, Kendall 1955) has been employed. It is a non-parametric rank-based procedure, robust to the influence of extremes, and suitable for application with skewed variables (Hamed 2008). More particularly, this technique can be adopted in cases with non-normally distributed data, data containing outliers, and non-linear trends (Helseland Hirsch 1992). The MK test investigates the null hypothesis of no trend versus the alternative hypothesis of the existence of upward or downward trend. The MK test statistic (S) is given by

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(x_j - x_k)$$

$$\text{sgn}(x_j - x_k) = \begin{cases} +1 & \text{if } (x_j - x_k) > 0 \\ 0 & \text{if } (x_j - x_k) = 0 \\ -1 & \text{if } (x_j - x_k) < 0 \end{cases}$$

$$\text{var}(S) = \frac{n(n-1)(2n+5) - \sum t(t-1)(2t+5)}{18}.$$

The notation t is the extent of any given tie and $\sum t$ denotes the summation over all ties. In cases where the sample size $n > 10$, the standard normal variate z is computed by (1) (Douglas et al. 2000).

$$z = \begin{cases} \frac{S-1}{\sqrt{\text{var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{var}(S)}} & \text{if } S < 0. \end{cases} \quad (1)$$

For a two-sided test, H_0 should be accepted if $|z| \leq |z_{\alpha/2}|$ at the given level of significance. A positive value of S indicates an upward trend and a negative value of S indicates downward trend.

4. Findings of the Study

In the following three sub-sections we have analyzed the presence and absence of monotonic trend in rainfall, minimum temperature and maximum temperature of NEI through their magnitudes and graphically represented the changes occurred. The values with + (plus) sign indicates the upward trend and values with – (negative) sign indicates the downward trend. The highlighted values indicate the presence of statistically significant trend.

4.1. Rainfall

From Table 1, downward trend for monthly as well as seasonal data has been observed for Agartala station in two decades 1976-1985 and 1986-1995. April and August of the last decade showed an upward trend with the slope 17.5200 and 10.9375 respectively. The rainfall of post-monsoon period has gone down for the last decade. However, no significant trend can be seen for this station either upward or downward. Cherrapunjee, which is known for its heavy rainfall in monsoon season, showed a decreasing trend for forty-five years (1971-2015) as a whole but a little improvement has been viewed in the last decade 2006-2015 (Table 2). Rainfall has gone down in the decade 1996-2005 as compared to the previous decade. June of 1986-1995 with quite high slope 206.4875 turned down with values –15.3667 in 1996-2005 but again in the last decade it took an upward momentum. July showed some decreasing rainfall after 1985. In season-wise analysis, pre and post-monsoon seasons showed downward trend in last decade. On the contrary, a very high slope is witnessed in the month of July and September for the period 1976-1985. In the month of July, from 1986 onwards, a downward rainfall pattern has been noticed. In the last decade, as an outcome of season-wise analysis, a downward trend has been observed both in pre and post monsoon seasons while monsoon showed a little upward trend. Guwahati have come up with a mixed scenario of increasing and decreasing tendency subject to monthly, season-wise and decadal analysis. The month of November has showed a downward trend when the analysis has done for fifty years as well as decadal time period (Table 3). Out of which fifty years and last decade showed downward trend with significant values –0.3045 and –1.8000, respectively. The rainfalls of April and June have gone down in the last decade as compared to 1966-2005. Also, pre and post monsoon seasons witnessed some downward trend for 2006-2015. Seasons showed an upward trend for 1971-2015 (Table 4). Here, the month of May showed positive significant slope of the value 2.9921. However, in the decade 1986-1995 except February, March, May and June, all other months showed decreasing trend. But if the focused has been given to the last decade, it revealed that the rainfall has been rising as compared to the previous decade. The same results are true for most of the months and seasons as well.

Table 1 Sen's slope of monthly rainfall data for Agartala

Month	1966-2015	1966-1975	1976-1985	1986-1995	1996-2005	2006-2015
January	-0.0067	-1.5200	0.4257	0.2619	0.0000	0.0000
February	0.0000	2.2444	-1.0667	4.9233	-0.5111	0.4000
March	-0.2312	-0.7667	3.0696	-7.3500	-7.0500	0.7000
April	-1.1172	5.2000	-26.8000	-10.2661	11.5000	17.5200
May	1.6000	14.5000	1.1771	-1.2783	-0.4000	-2.1000
June	0.4722	0.5143	-17.0810	-0.4417	28.5167	-5.7167
July	-1.8250	14.1333	-20.1500	-11.0300	-23.6833	-5.2143
August	-0.0182	-4.8875	-5.5738	-0.7333	9.5250	10.9375
September	-0.6853	-2.2833	-6.3958	-10.8333	11.1778	1.5571
October	0.6231	6.2750	-11.6500	-13.9833	-0.3200	-9.6200
November	-0.1200	-1.5286	-3.4833	2.1708	-0.0667	-0.4625
December	0.0000	-0.0143	-0.1125	-1.0000	0.0000	0.1333
Season						
Pre-Monsoon	-0.0061	2.2111	0.4333	-0.3500	0.3647	1.6000
Monsoon	-0.2098	-0.9450	-3.2393	-0.8882	0.4106	0.3210
Post-Monsoon	-0.0148	-1.2147	-2.1250	-5.6883	-0.0875	-4.7300
Winter	0.0000	0.0000	0.0230	0.0387	0.0000	0.0000

Table 2 Sen's slope of monthly rainfall data for Cherrapunjee

Month	1971-2015	1971-1975	1976-1985	1986-1995	1996-2005	2006-2015
January	0.0000	-6.3000	0.8000	0.7571	-0.6714	0.0000
February	0.3107	-1.3250	-1.1333	8.0500	-2.2100	-13.5000
March	0.7284	-20.0000	-8.1000	25.3750	15.1000	-4.1400
April	-4.2398	405.1500	35.6125	-87.1000	31.6167	-54.9833
May	5.1473	165.7083	1.6000	153.0429	-96.8500	29.7000
June	10.4961	-4.6750	20.6667	206.4875*	-15.3667	56.4750
July	-16.3022	608.4625	226.8000*	-213.9750	-43.9750	-179.0200
August	7.6571	113.2500	-30.7000	22.6000	-10.7750	185.2667
September	-0.6559	234.2917	168.1000*	-91.8750	-14.6333	42.7000
October	-2.2577	235.1208	-29.3600	-36.0000	42.9600	-17.4000
November	-0.1920	-24.0250	-3.8600	-5.7000	2.1429	-1.3000
December	0.0000	0.0000	4.3400	-0.9000	0.5000	0.0000
Season						
Pre-Monsoon	0.5776	73.3556	5.8875	10.5500	1.7917	-0.7889
Monsoon	-0.3765	38.7274	17.3707	-3.2785	-13.4873	1.3400
Post-Monsoon	-0.2750	-15.6400	-4.1850	-6.1662	1.8187	-1.3583
Winter	0.0000	0.0000	0.3333	0.2259	0.1250	0.0000

*Indicates the rejection of null hypothesis of no trend at 5% level of significance

Analysis of Lengpui showed some increasing behaviour in rainfall in the periods 2001-2005 and 2006-2015 except June, September and November (Table 5). June and November witnessed downward trend for the last two decades and, for September, the rainfall has sink heavily from positive to negative trend. From the table, it could be seen that all the seasons stand with an indication of decreasing trend for the period 2001-2015. The station North-Lakhimpur showed a clear downward

trend in rainfall in the last decade. Almost same results have been obtained from monthly and season-wise analysis for the period 2006-2015 (Table 6). Again, mixed results came to view when the analysis has done for 1971-2015 period. Though July and October witnessed downward trend with significant value -5.2195 and -1.9000 , respectively, but some other months like March, May, June, August and November showed increasing trend. The results of post-monsoon, monsoon and winter in 1971-2015 periods as well as in the last decade showed downward behaviour. Like the other NEI stations discussed so far, Shillong showed near about same results of decreasing tendency of rainfall. Most of the month of a year showed downward trend for 1971-2015. But, August witnessed an increasing trend with significant value 2.6806 . July showed an upward trend in the periods 1971-1975, 1976-1985 and 1996-2005 with slope 82.5792 , 55.5800 and 17.8600 , respectively. Interestingly the same month witnessed some downward trend in rainfall for the periods 1986-1996 and 2006-2015 with slope -27.0000 and -34.4500 , respectively. In Table 7, August in the last decade showed much higher value 36.6167 as compared to others and witnessed some increasing rainfall. Monsoon, post-monsoon and, winter seasons observed decreasing trend for 1971-2015 as a whole with significant slope of winter -0.0390 .

Table 3 Sen's slope of monthly rainfall data for Guwahati

Month	1966-2015	1966-1975	1976-1985	1986-1995	1996-2005	2006-2015
January	-0.0481	0.3500	0.0000	1.1500	0.9000	0.2250
February	-0.0054	0.0000	0.0889	1.0222	-2.1250	0.4000
March	-0.1950	-8.0250	-0.6833	2.1000	5.0667	-1.7667
April	0.5933	-5.2550	4.0333	-13.7500*	28.0500	-12.2571
May	0.1810	3.9333	2.1000	5.1500	-20.1000	19.0333
June	-0.7250	4.4560	-17.5333	29.5714*	23.5500	12.0000
July	-2.1000	15.5250	15.7000	-0.7400	6.3000	-8.1750
August	-0.4069	-10.8167	-16.7143	15.7500	3.1000	5.4714
September	0.1267	-0.8513	19.2500	-2.7167	-15.4800*	6.9500
October	1.0382	3.3000	-3.2750	-11.9250	4.2400	-1.2000
November	-0.3045*	-0.1500	-2.2100	-0.1500	0.4625	-1.8000*
December	0.0000	0.0000	1.2500	-1.0694	-0.3000	-0.5500
Season						
Pre-Monsoon	0.0800	-0.3800	0.5556	0.6385	3.4500	-0.2636
Monsoon	-0.2087	-0.5437	-0.3283	2.4600	-0.8702	0.9506
Post-Monsoon	-0.0674	0.5900	-1.3458	-2.1517	0.3083	-1.0607
Winter	-0.0013	0.0000	0.0900	0.2429	-0.0882	0.0000

*Indicates the rejection of null hypothesis of no trend at 5% level of significance

4.2. Minimum and maximum temperature

Contrasting the results of rainfall, temperature analysis has given an indication of rise and fall of the minimum and maximum temperature throughout the years. From Table 8, five months January, March, October, November, December and January in minimum temperature analysis, have exhibited slight downfall behaviour with significant value -0.0333 in November for Cherrapunjee. The analysis of 2006-2015 has led to a conclusion that minimum temperature of each month and each season moved down. From Table 9, Cherrapunjee witnessed increasing trend in maximum temperature subject to all months and all seasons during 1971-2015 and 2001-2015 with positive significant values 0.2000 , 0.3000 and 0.0850 for October, November and winter season respectively. Four seasons have

Table 4 Sen's slope of monthly rainfall data for Imphal

Month	1971-2015	1971-1975	1976-1985	1986-1995	1996-2005	2006-2015
January	0.0000	-2.2000	0.6600	-0.3625	1.4750	0.0000
February	-0.4019	-7.2167	0.8000	5.6000	1.8000	-5.2000*
March	-0.5668	5.9583	4.0250	2.0600	-12.1333	1.2875
April	-0.7962	-0.5917	7.9600	-10.2600	9.9667	1.0143
May	2.9921*	-4.1750	9.3714	13.3000	-5.9750	11.8000
June	-0.3781	24.5417	6.2667	9.8111	-1.5800	7.3250
July	0.4343	21.2000	-5.6143	-5.3000	13.1778	11.1250
August	0.1301	-43.0500	-18.9000*	-0.4778	-1.9556	17.2000
September	0.6932	12.2000	5.8333	-1.8500	4.3200	6.2500
October	0.0793	21.2125	0.1000	-18.8000	16.7000	-3.5400
November	-0.7374*	19.7125	-4.0000	-8.5571	0.8667	-2.2160
December	0.0000	-0.8375	0.7286	-0.1000	0.5333	-0.0286
Season						
Pre-Monsoon	0.0294	0.9553	2.6000	-0.3129	-0.1964	0.3124
Monsoon	0.0407	1.6125	-0.9324	-0.2346	0.8261	2.1529
Post-Monsoon	-0.3726	10.0946	-0.9500	-4.2786	2.4167	-2.0688
Winter	0.0000	0.1149	0.2525	0.1816	0.2658	0.0000

*Indicates the rejection of null hypothesis of no trend at 5% level of significance

Table 5 Sen's slope of monthly rainfall data for Lengpui

Month	2001-2015	2001-2005	2006-2015
January	0.0000	0.4000	0.0000
February	0.1000	-7.6875	1.0167
March	-1.9308	17.8583	2.0833
April	-1.1167	8.8500	2.2.18
May	5.9667	13.1250	20.7800
June	-12.8000	-60.9583	-17.2250
July	-4.5182	55.8625	11.7143
August	5.7875	-5.6250	5.9556
September	-2.8000	30.0667	-11.6250
October	-3.4000	-25.5000	-7.9000
November	-1.3200	-14.0542	-0.6429
December	0.0000	1.2375	0.0000
Season			
Pre-Monsoon	-0.1431	2.0857	1.4643
Monsoon	-0.4689	4.4400	-0.1667
Post-Monsoon	-0.6775	-6.8687	-0.7875
Winter	0.0000	0.0000	0.0000

given the same indication of rise in maximum temperature for the period 1971-2015. A slight different result has obtained for Guwahati station. Though the fifty year (1966-2015) analysis showed an upward trend for maximum and minimum temperature as a whole with significant values but, the last decade of minimum temperature has appeared some decreasing trend subjected to all the months and

Table 6 Sen's slope of monthly rainfall data for North-Lakhimpur

Month	1971-2015	1971-1975	1976-1985	1986-1995	1996-2005	2006-2015
January	-0.6000	-5.8125	2.0833	4.2250	1.3000	-0.8429
February	-0.5566	-0.9750	-3.7571	6.5143	0.9429	-6.0250
March	0.4795	-3.0250	5.2000	0.4667	2.1714	-1.8000
April	-1.1059	-29.3250	5.5200	-10.5667	5.8250	-5.2667
May	0.7144	39.1667	2.8000	38.3857	-13.4667	12.2100
June	1.5322	48.1375	15.9800	18.8667	-23.1500	-25.1000
July	-5.2195*	10.4125	36.7500	-42.0750	-13.4600	-23.9556
August	2.2400	-81.8000	5.9714	2.1000	18.5375	-0.3125
September	-2.0528	47.5583	43.1000	-20.6200	-6.8000	-0.0333
October	-1.9000*	44.0000	-5.4000	-1.9000	5.3000	-11.2000
November	0.0936	2.7750	-6.9333*	0.7714	0.5000	-2.0000
December	-0.4072	4.2083	6.4857	-0.3714	0.0800	-0.4250
Season						
Pre-Monsoon	0.1476	11.2000	3.1737	2.5167	2.2417	0.1941
Monsoon	-0.1568	0.2635	4.6292	-3.5015	-2.1936	-2.7731
Post-Monsoon	-0.2892	-1.6375	-3.9054	-0.8417	0.8048	-2.8167
Winter	-0.1733	0.1100	0.4545	1.6833	0.6667	-0.3600

*Indicates the rejection of null hypothesis of no trend at 5% level of significance

Table 7 Sen's slope of monthly rainfall data for Shillong

Month	1971-2015	1971-1975	1976-1985	1986-1995	1996-2005	2006-2015
January	-0.0418	-1.3750	0.2375	2.2857	-0.1667	0.0000
February	-0.2286	2.9125	0.1222	-0.0333	-0.1750	0.4000
March	-0.0683	-4.6375	0.1000	-2.6500	2.4800	0.7000
April	-0.5644	-45.8292	-1.8000	-7.8000	-0.8250	-0.9000
May	0.0481	0.1708	-9.1500	-14.2200	8.7556	-12.2000
June	-1.6237	-80.4000	-15.3000	15.6000	14.0000	-9.3000
July	-1.7067	82.5792	55.5800*	-27.0000	17.8600	-34.4500
August	2.6806*	-19.3042	12.8000	-0.6250	-20.2500	36.6167
September	0.2199	36.0000	17.6500	-10.5500	3.4000	8.7250
October	0.6929	34.3917	1.7556	-27.0000	8.7571	-8.3125
November	-0.4146	-18.3625	-0.6400	-4.4000	0.3286	-3.6111*
December	-0.1063	0.0250	1.2200	-1.3500	0.3333	0.0500
Season						
Pre-Monsoon	-0.0060	-1.1667	0.3750	-1.1217	2.6704	0.6318
Monsoon	0.0720	2.8692	2.7649	-1.9602	-0.1080	-0.0646
Post-Monsoon	-0.1386	-6.0750	-0.7312	-5.7583	0.2333	-2.6083
Winter	-0.0390*	0.0000	0.0875	0.2100	0.0500	0.0100

*Indicates the rejection of null hypothesis of no trend at 5% level of significance

all the seasons with significant slopes -0.2200, -0.2333, -0.1500, -0.1667, -0.2250, -0.2667, -0.2000, -0.0545 and -0.0647 for the months April, May, June, July, August, September, December and, monsoon and winter seasons, respectively (Table 10). This type of downward tendency in

Table 8 Sen's slope of minimum temperature data for Cherrapunjee

Month	1971-2015	1971-1975	1976-1985	1986-1995	1996-2005	2006-2015
January	-0.0025	-0.0833	-0.0125	-0.2000	0.0833	0.0333
February	0.0000	0.0583	-0.2000*	-0.3400	0.0714	-0.2286
March	-0.0057	0.0500	-0.0250	-0.4500	0.1250	-0.1111
April	0.0026	0.3708	0.0000	-0.1500	0.0429	-0.1000
May	0.0167*	0.3500	0.0375	0.0333	0.0000	-0.1000
June	0.0082	0.1000	0.0000	-0.4000	0.0000	-0.0250
July	0.0117	-0.0750	-0.0400	-0.3000	0.0400	-0.0778
August	0.0073	0.1708	-0.0667	-0.2000	0.0667	-0.1333*
September	0.0077	-0.1583	-0.0500	-0.1000	0.0800	-0.1000
October	-0.0128	-0.1500	0.0400	-0.2000	0.0750	-0.1125
November	-0.0333*	0.0750	-0.2000	-0.0857	-0.0400	-0.1857
December	-0.0116	-0.7125	-0.0857	-0.1000	0.0125	-0.1750
Season						
Pre-Monsoon	0.0029	0.1556	0.0100	-0.0429	0.0222	-0.0167
Monsoon	0.0022*	0.0029	-0.0085	-0.0500	0.0121	-0.025*
Post-Monsoon	-0.0117	-0.1125	-0.0646	-0.1000	-0.0250	-0.0888
Winter	-0.0016	-0.0667	-0.0385	-0.0600	0.0200	-0.0333

*Indicates the rejection of null hypothesis of no trend at 5% level of significance

Table 9 Sen's slope of maximum temperature data for Cherrapunjee

Month	1971-2015	1971-1975	1976-1985	1986-1995	1996-2005	2006-2015
January	0.0600*	0.0333	0.0000	-0.1167	0.1000	0.2750
February	0.0556*	-0.2286	-0.1000	-0.2167	0.0286	0.0800
March	0.0424*	-0.1111	-0.1000	-0.0556	-0.0667	0.1600
April	0.0333*	-0.1000	-0.0250	0.2000	0.0222	0.0667
May	0.0368*	-0.1000	0.0857	0.0000	0.0000	-0.0250
June	0.0174*	-0.0250	0.0750	-0.0857	0.0000	0.0000
July	0.0333*	-0.0778	-0.1250	0.0667	0.0667	0.1000
August	0.0200*	-0.1333*	0.0750	0.0500	0.0833	-0.1250
September	0.0412*	-0.1000	-0.1800*	0.0400	0.0571	0.0500
October	0.0500*	-0.1125	0.1667	0.1250	-0.0444	0.2000*
November	0.0500*	-0.1857	0.1000	0.1000	-0.1200*	0.3000*
December	0.0644*	-0.1750	-0.0667	-0.0143	0.0000	0.2333
Season						
Pre-Monsoon	0.0132*	0.0429	0.0000	0.0292	0.0074	0.0200
Monsoon	0.0070*	0.0000	-0.0029	0.0100	0.0100	0.0095
Post-Monsoon	0.0241*	-0.0250	0.0500	0.0268	-0.0536	0.1155
Winter	0.0209*	-0.0375	-0.0190	-0.0333	0.0267	0.0850*

*Indicates the rejection of null hypothesis of no trend at 5% level of significance

minimum temperature has also noticed for the period 1986-1995. In 1996-2005, maximum temperature showed negative trend but again it has moved towards upward direction in the next decade (Table 11). Minimum temperature for Imphal station showed a decreasing tendency for most of the months during the decade 2006-2015 but during 1986-1995 it has showed trend in upward direction

in both monthly and season-wise analysis (Table 12). On the contrary maximum temperature has given a clear indication of increasing tendency for the period 1971-2015 as a whole. With significant slopes for each month and each season of the last decades also arrived to the same indication of rising of maximum temperature (Table 13).

Table 10 Sen's slope of minimum temperature data for Guwahati

Month	1966-2015	1966-1975	1976-1985	1986-1995	1996-2005	2006-2015
January	0.0222*	-0.0667	0.0000	-0.0500	0.1000	-0.1000
February	0.0429*	0.0286	-0.0667	0.0333	0.1000	-0.3000
March	0.0206*	-0.0556	0.1875	-0.0500	0.1250	-0.0625
April	0.0152	0.1333	0.1000	-0.0333	-0.0143	-0.2200*
May	0.0179*	0.0000	0.0143	0.0714	0.0000	-0.2333*
June	0.0212*	0.0000	0.0667	-0.0286	0.1000	-0.1500*
July	0.0212*	-0.0500	0.0000	-0.0333	0.0625	-0.1667*
August	0.0200*	-0.0125	0.2429*	-0.0125	0.1000	-0.2250*
September	0.0194*	-0.0600	0.0000	-0.0333	0.1250*	-0.2667*
October	0.0214*	0.2000	0.1286*	0.0000	-0.0125	-0.2500
November	0.0182	0.1500	-0.2000*	-0.0400	-0.0143	-0.3400
December	0.0308*	-0.1600	0.0333	-0.1200	0.0571	-0.2000*
Season						
Pre-Monsoon	0.0069	0.0185	0.0500	0.0238	0.0375	-0.0333
Monsoon	0.0048*	-0.0120	0.0178*	-0.0063	0.0226*	-0.0545*
Post-Monsoon	0.0088	0.0563	-0.0690	-0.0288	-0.0333	-0.1812
Winter	0.0110*	-0.0190	0.0000	-0.0077	0.0267	-0.0647*

*Indicates the rejection of null hypothesis of no trend at 5% level of significance

Table 11 Sen's slope of maximum temperature data for Guwahati

Month	1966-2015	1966-1975	1976-1985	1986-1995	1996-2005	2006-2015
January	0.0000	0.0429	-0.2000	-0.1429	-0.1250	0.1000
February	0.0333*	-0.0125	-0.2286*	-0.1875	0.0429	0.1333
March	0.0189	0.1000	-0.3625	0.0250	-0.0500	0.0429
April	0.0088	0.2000	-0.2000	0.1667	-0.4833	0.0000
May	0.0333*	-0.0500	0.0000	0.0143	-0.0333	-0.1167
June	0.0333*	0.0400	0.1000	-0.1000	0.0000	0.1000
July	0.0412*	-0.0400	-0.1400	0.0667	0.0000	0.1600
August	0.0296*	-0.0500	0.0429	0.0750	0.0857	-0.1000
September	0.0304*	-0.0714	-0.2667	0.1222*	0.1000	0.0000
October	0.0333*	0.0667	0.1200	0.1833*	-0.1500*	0.0571
November	0.0343*	0.0333	0.0857	0.1000	-0.0750	0.1000
December	0.0231*	-0.1200	-0.0800	0.0444	-0.0857	-0.0500
Season						
Pre-Monsoon	0.0071*	0.0200	-0.0550	0.0190	-0.0550	0.0043
Monsoon	0.0083	-0.0094	-0.0104	0.0167	0.0170	0.0097
Post-Monsoon	0.0162*	0.0167	0.0292	0.0500	-0.0667	0.0200
Winter	0.0060*	-0.0125	-0.0500	-0.0095	-0.0083	0.0200

*Indicates the rejection of null hypothesis of no trend at 5% level of significance

Table 12 Sen's slope of minimum temperature data for Imphal

Month	1971-2015	1971-1975	1976-1985	1986-1995	1996-2005	2006-2015
January	—	-0.3583	0.1000	0.1500	—	0.1500
February	—	0.2125	0.0000	0.1286	—	-0.1000
March	—	0.3250	0.0444	0.3234	—	0.0000
April	—	0.3833	0.0000	0.1750	—	-0.0500
May	—	0.1375	0.0000	0.1500	—	-0.0286
June	—	-0.0833	0.0750	0.1000	—	0.0600*
July	—	-0.1875	-0.1000	0.1773	—	0.0667
August	—	0.1250	0.0000	0.1000	—	0.1000
September	—	-0.0250	-0.0222	0.1000	—	-0.0500
October	—	0.5417	0.1600	0.0000	—	-0.0250
November	—	1.1500	-0.3000	0.2435	—	-0.0500
December	—	-0.3500	0.0625	0.1833	—	-0.0800
Season						
Pre-Monsoon	—	0.1556	0.0267	0.1182	—	0.0000
Monsoon	—	-0.0333	0.0038	0.0360	—	0.0133
Post-Monsoon	—	0.1750	-0.0354	0.0500	—	-0.0417
Winter	—	-0.0500	0.0333	0.0537	—	0.0250

*Indicates the rejection of null hypothesis of no trend at 5% level of significance

Table 13 Sen's slope of maximum temperature data for Imphal

Month	1971-2015	1971-1975	1976-1985	1986-1995	1996-2005	2006-2015
January	0.0535*	-0.0333	0.0250	-0.0667	0.1333	0.1111
February	0.0657*	0.4125	-0.0500	-0.1714*	0.4000*	0.3000
March	0.0362	-0.2375	-0.1250	0.0500	0.1000	0.2000
April	0.0258	0.4375	0.0000	0.0429	0.1200	-0.0750
May	0.0298*	0.1000	-0.0429	-0.0333	-0.0571	-0.0500
June	0.0333*	-0.1333	0.0857	0.0000	0.0333	0.0750
July	0.0361*	-0.2417	-0.0400	0.0500	0.1000	0.0500
August	0.0500*	0.2667	0.1000	0.0000	0.1500	0.1500
September	0.0479*	-0.2583	0.0250	0.1000	0.0750	0.0250
October	0.0317*	0.3000	0.1600	0.1500	-0.0250	0.0167
November	0.0585*	-0.1500	0.0400	0.0222	0.1333	0.2200*
December	0.0460*	-0.2750	-0.0400	-0.1000	0.1000	-0.0333
Season						
Pre-Monsoon	0.0111*	0.0929	-0.0091	0.0187	0.0267	0.0077
Monsoon	0.0105*	-0.0396	0.0114	0.0082	0.0250*	0.0148
Post-Monsoon	0.0214*	-0.0750	0.0250	0.0274	-0.0028	0.0354
Winter	0.0178*	0.0111	0.0000	-0.0300	0.0538*	0.0444

*Indicates the rejection of null hypothesis of no trend at 5% level of significance

Lengpui showed downward trend in minimum and upward trend in maximum temperature for the period 2001-2015 (Table 14). This conclusion communicated with both season-wise and monthly analysis. A clear picture has come to view in case of maximum temperature in winter and pre-monsoon seasons, as in both cases, the temperature has gone down in the last decade. This result also stands for

those months corresponding to winter and pre-monsoon seasons in monthly analysis (Table 15). Monsoon and winter seasons for minimum temperature analysis are unchanged with slope values zeroes (Table 16) for North-Lakhimpur. Most of the seasons showed a downward hint for trend in the last decade and those which have showed upward direction with positive values have small magnitude. Clear indication has come out in focused in maximum temperature analysis (Table 17) of North-Lakhimpur, as each months and each seasons have appeared with a high slope and partially which have continued to the last decade except May, August and December. Both maximum and minimum temperature analysis for Shillong station have revealed increasing trend throughout the year 1971-2015 for the each months and seasons (Tables 18 and 19). Additionally, they appeared with statistically significant values. Some of the months like September, October, November, January and March in the last decade demonstrated downfall in minimum temperature. However, those results are slightly greater than their values of previous decades. On contrary, an opposite event has confirmed for maximum temperature in the last decade. Furthermore, June reposted a positive significant value 0.1286.

Table 14 Sen's slope of minimum temperature data for Lengpui

Month	1966-2015	1996-2005	2006-2015
January	-0.0273	0.2000	0.0750
February	-0.0714	0.6083	-0.1500
March	-0.1000	0.8000	-0.2200
April	-0.0800	-0.0500	-0.1286
May	-0.0167	0.0167	-0.0500
June	0.0286	0.5667	0.1000
July	-0.0571	0.1000	-0.0600
August	-0.0556	0.3000	-0.0833
September	-0.0714	0.3500	-0.1143
October	-0.0889	0.5250	-0.2000*
November	-0.1667	-0.8000	-0.3200
December	-0.1200*	0.4375	-0.0750
Season			
Pre-Monsoon	-0.0035	0.1333	-0.0111
Monsoon	-0.0091	0.0775	-0.0143
Post-Monsoon	-0.0813	-0.3000	-0.1500
Winter	-0.0264	0.1333	-0.0200

*Indicates the rejection of null hypothesis of no trend at 5% level of significance

4.3. Concluding remarks

In this paper, trend analysis has been made to examine the long term variation in rainfall, minimum and maximum temperature in monthly, season-wise and decadal scales. This analysis has covered 7 and 6 stations of NEI for rainfall and temperature respectively. Although, the spatial and temporal variability in the rainfall trends has been observed in the analysis, yet no specific trend has been found out. In most cases, the rainfall has gone down for the months having a place with the post monsoon season for the most recent decade. In any case, these outcomes are not statistically significant. But, minimum and maximum temperature has given a clear indication of increasing trend for all the stations for most recent fifty year (1966-2015). Dibrugarh, Guwahati and Shillong witnessed an upward indication in minimum temperature with statistically significant slope for the last fifty years

as a whole. However, in the most recent decade, i.e., amid 2006-2015, minimum temperature has gone down for Guwahati. On the other hand, in all the stations under study, such as Cherrapunjee, Guwahati, Lengpui, North-Lakhimpur, Imphal and Shillong, an increasing trend has been observed throughout the years for maximum temperature.

Table 15 Sen's slope of maximum temperature data for Lengpui

Month	1966-2015	1996-2005	2006-2015
January	0.1625*	0.0917	-0.0250
February	0.0429	0.1500	-0.0600
March	0.1857*	-0.2125	0.1000
April	0.1000	-0.0500	-0.0200
May	0.0875	0.2750	-0.0875
June	0.0900*	0.4500	0.0500
July	0.0750	0.0000	0.0625
August	-0.0500	-0.0667	-0.0667
September	0.0286	-0.0417	0.0286
October	0.0700*	0.1000	0.0667
November	0.1000*	0.0000	0.1000
December	0.0154	0.2125	-0.0333
Season			
Pre-Monsoon	0.0343*	0.0000	-0.0067
Monsoon	0.0070	0.0059	0.0000
Post-Monsoon	0.0375	0.0000	0.0264
Winter	0.0333	0.0667	0.0176

*Indicates the rejection of null hypothesis of no trend at 5% level of significance

Table 16 Sen's Slope of Minimum Temperature data for North-Lakhimpur

Month	1966-2015	1966-1975	1976-1985	1986-1995	1996-2005	2006-2015
January	0.0000	0.1875	0.0400	-0.0375	0.1000	-0.0875
February	0.0000	0.6000*	-0.1000	-0.0500	0.5000	-0.2333
March	0.0000	0.4750	0.1125	0.1000	0.2625	0.0250
April	-0.0059	0.3625	-0.0500	-0.0333	0.0333	0.0333
May	0.0038	0.4250	-0.0250	0.0857	-0.1600	-0.0500
June	-0.0056	0.3583	0.0143	-0.0400	0.0667	0.0333
July	0.0000	0.2542	-0.0500	0.0000	0.0667	0.0333
August	0.0000	0.4875	0.0333	0.0250	0.0167	-0.0800
September	0.0064	0.3500	-0.0571	0.0750	0.0600	0.0000
October	-0.0089	0.8500	0.1667*	0.0000	-0.1125	-0.1571
November	-0.0146	0.7583	-0.3800*	0.1800	-0.3000	-0.1444
December	0.0071	0.4750	-0.0333	-0.0400	0.0000	-0.0500
Season						
Pre-Monsoon	0.0013	0.2846	0.0375	0.0417	0.0429	0.0167
Monsoon	0.0000	0.0809*	-0.0028	0.0000	0.0088	0.0000
Post-Monsoon	-0.0081	0.3250	-0.0500	0.0050	-0.1472	-0.1031
Winter	0.0000	0.2000	0.0000	0.0000	0.0273	-0.0235

*Indicates the rejection of null hypothesis of no trend at 5% level of significance

Table 17 Sen's slope of maximum temperature data for North Lakhimpur

Month	1966-2015	1966-1975	1976-1985	1986-1995	1996-2005	2006-2015
January	0.0548*	0.0083	-0.1000	-0.0429	0.1333	0.2333
February	0.0739*	0.1875	-0.1000	-0.1857	0.0875	0.2667
March	0.0373	-0.1625	-0.0667	-0.0714	0.2250	0.2571
April	0.0143	-0.0625	-0.1667	0.1000	-0.1500	0.1250
May	0.0385*	-0.0958	0.0333	-0.1250	0.1400	-0.2429*
June	0.0121	0.1125	0.1333	-0.2000	0.1400	0.2167
July	0.0407*	-0.4250	-0.1857*	0.0429	0.1000	0.1167
August	0.0140	0.1333	0.1750	0.0800	0.1000	-0.1143
September	0.0552*	-0.1375	-0.2000*	0.1000	0.0667	0.0500
October	0.0594*	0.2250	0.1800	0.0667	0.0000	0.0400
November	0.0583*	0.4500	0.2000	0.0000	0.0222	0.2000
December	0.0577*	-0.4417	0.0429	-0.1111	-0.1000	-0.1143
Season						
Pre-Monsoon	0.0112*	0.0167	-0.0133	0.0238	0.0286	0.0500
Monsoon	0.0081*	-0.0325	-0.0200	0.0000	0.0273	0.0212
Post-Monsoon	0.0300*	0.0250	0.0781	-0.0031	-0.0143	0.0523
Winter	0.0220*	-0.0286	-0.0222	-0.0444	0.0118	0.0474

*Indicates the rejection of null hypothesis of no trend at 5% level of significance

Table 18 Sen's slope of minimum temperature data for Shillong

Month	1971-2015	1971-1975	1976-1985	1986-1995	1996-2005	2006-2015
January	0.0071	-0.1167	0.0167	-0.0500	0.0667	-0.0333
February	0.0204	-0.7667	-0.0778	-0.1400	0.0400	0.0714
March	0.0093	-0.7000	0.0250	-0.0556	0.0125	-0.0250
April	0.0100	0.2000	0.0600	0.0375	-0.0500	0.0125
May	0.0192*	-0.3250	0.1000	0.1000	-0.1000	0.0286
June	0.0100	-0.3250	0.1000	0.0200	0.0143	0.1167
July	0.0136*	-0.2500	-0.0500	0.0143	-0.0500	0.0250
August	0.0089*	0.1250	0.0000	0.0800	0.0000	0.0000
September	0.0154*	-0.2625	0.0143	0.0375	-0.0200	-0.0167
October	0.0069	-0.2500	0.1571	0.1333	-0.0833	-0.0375
November	-0.0014	0.2500	-0.0667	0.0833	-0.2500*	-0.0500
December	0.0108	-1.0750	0.0250	-0.1400	-0.0250	0.0000
Season						
Pre-Monsoon	0.0054	0.0000	0.0333	0.0444	0.0056	0.0250
Monsoon	0.0030*	-0.0645	0.0000	0.0050	-0.0050	0.0075
Post-Monsoon	0.0000	-0.3750	0.0050	0.0423	-0.1063	-0.0278
Winter	0.0048	-0.1800*	0.0000	-0.0385	0.0083	0.0158

*Indicates the rejection of null hypothesis of no trend at 5% level of significance

In spite of various worldwide arrangements, outflow of ozone depleting substances is persistently rising. Henceforth, the future patterns and fluctuations might be considerably bigger than what has been watched up until this point and the ascent in temperature might be more articulated. While deciphering the consequences of trend investigation, it will be advantageous to remember the

perceptions of Cohn and Lins (2005): “the reported trends are real yet insignificant indicates a worrisome possibility: natural climatic excursions may be much larger than we imagine. So large, perhaps, that they render insignificant the changes, human-induced or otherwise, observed during the past century.”

Table 19 Sen’s slope of maximum temperature data for Shillong

Month	1971-2015	1971-1975	1976-1985	1986-1995	1996-2005	2006-2015
January	0.0333*	-0.0542	-0.0429	-0.2000	0.0625	0.0500
February	0.0283*	0.0250	-0.1750	-0.2000	0.0500	-0.0333
March	0.0164	-0.3125	-0.1000	0.0833	0.0200	0.1167
April	0.0135	0.2000	0.0000	0.1000	-0.1143	0.1143
May	0.0273*	-0.1875	-0.0444	0.1000	-0.1250	0.1333
June	0.0282*	-0.0500	0.0500	-0.0250	-0.0857	0.1286*
July	0.0231*	-1.0000	-0.0600	0.0143	0.0000	0.0286
August	0.0116	-0.0500	-0.0333	0.0750	0.0833	-0.0875
September	0.0214*	-0.3500	-0.0500	0.0000	0.0000	0.0500
October	0.0094	0.0000	0.0500	0.0875	-0.1000	0.0429
November	0.0143	0.0750	-0.1333	-0.0125	-0.0750	0.0200
December	0.0188	-0.5500	-0.0800	-0.1000	-0.0600	0.1000
Season						
Pre-Monsoon	0.0071*	0.0182	0.0000	0.0391	-0.0125	0.0417
Monsoon	0.0054*	-0.0667*	-0.0062	0.0000	0.0000	0.0111
Post-Monsoon	0.0048	-0.0500	-0.0232	0.0097	-0.0500	0.0031
Winter	0.0090*	-0.0714	-0.0300	-0.0500	0.0125	0.0350

*Indicates the rejection of null hypothesis of no trend at 5% level of significance

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