CHAPTER 3

Characterization of Trends in Rainfall and Other Meteorological Variables in NE India

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Contents

3.1 Introduction

The extent of climate change, identifiable by the changes in the mean or the variability of its properties, enduring an extended period, typically decades or longer, is considered as the greatest environmental threats to sustenance and livelihoods of human beings. Climate, in broad sense, is described as the statistical description in terms of the mean and variability of relevant quantities over a period ranging from months to thousands or millions of years [1]. In the current scenario, it becomes essential to evaluate the climate induced changes for determining the appropriate climate resilient strategies especially for the countries whose agriculture is primarily dependent on rainfall [2]. This evaluation can be achieved by investigation of the spatio-temporal dynamics of meteorological variables, such as temperature, rainfall, relative humidity, atmospheric pressure, wind etc. The studies pertinent to the detection of climate change focuses on the long-term changes i.e., on 30-year averaging window (as per World Meteorological Organization) in the climatic variables. Analysis of long-term trends in the climatological variables help in understanding the potential behavior of natural and anthropogenic systems at different regional and global scales [3]. The long-term trends in different meteorological variables especially temperature and rainfall were often cited as evidence for changing climate scenarios [3-5]. However, the data availability and consistency are the biggest challenge in analyzing the long-term trends in these variables. Non-climatic factors such as changes in the instrument, measurement and observation procedures give rise to inhomogeneities in a dataset, which in turn induces artificial shifts or jumps that can imitate as real climatic signals [6—8]. Such artificial shifts or jumps corresponds to abrupt changes in the statistical properties of a time series, i.e., changes in the mean with respect to time and artificial trends due to non-climatic factors.

In this context, the knowledge about the state of homogeneity in a climatic dataset becomes significant due to its inherent impact on prevalent trend [9][7]. Among many homogeneity tests, the standard normal homogeneity test [9], Buishand Range test [10], Pettitt test [11], von Neumann ratio test [12] and the Craddock test [13] are the most common and widely suggested methods for detecting the inhomogeneities (change points) in a data series [7][14-25].

The trend analysis has been widely used in the climatic data series; however little attention was paid to the presence of discontinuity in the data series initially. To address the challenges imposed by the inhomogeneity in a data series, Pettitt [11] devised a non-parametric method to test the null hypothesis of no change against the alternate hypothesis of the presence of a change point. The efficiency of the test as discussed in revealed that the method was efficient for testing continuous data and with normal/near normal samples. Buishand [10] examined the annual rainfall records of a total of 264 stations in Netherlands for homogeneity with the help of cumulative deviations from the mean. The method was able to present strong evidence of departures from homogeneity in the data. The test results, when compared to the classical von-Neumann ratio test (VNRT) for detection of single shift in the mean, showed superiority over VNRT. Similarly, large scale inhomogeneities inherent in precipitation and snowfall over Canada and United States (US), was studied by Groisman and Easterling [26], for the period 1950-1990. The statistical structure of annual and monthly precipitation and snowfall was parameterized. As evident from trend analysis, annual precipitation was increasing by 13% and 4% in southern Canada and contiguous US respectively. Decadal variation was showing up to a 20% increase in annual snowfall and precipitation for the last four decades in Canada to the north of 55^0N. It was found that negative anomaly in the Southern Oscillation Index (SOI) was associated with increase in precipitation in the southern region of the country. Further, Alexandersson and Moberg [27] proposed a new method like standard normal homogeneity test (SNHT) for detection of artificially induced trends in a time series. The mathematical structure of both the trend and shift in the time series was statistically explained. Gonzalez-Rouco et al. [28] deals with outliers and inhomogeneities in precipitation time series of southwest region of Europe for the period 1899-1989. Their analysis reveals that the inhomogeneities in the dataset could be associated with historical changes in the rain gauge despite scarce metadata. Bohm et al. [29] has generated of an Alpine-wide dataset of homogenized monthly temperature analyzed the annual and seasonal series trends. The results showed divergence from the global datasets that was attributed to the time extension of the 240 years Alpine dataset by hundred years and to the homogenized regional dataset. Wijngaard et al. [7] proposed a two–step approach to homogeneity classification in a data set. The daily European temperature and rainfall station data series from the European Climate Assessment were tested for homogeneity and classified into useful (homogeneous), doubtful and suspect (inhomogeneous) series. Majority of the temperature series and relatively a lower percentage of precipitation series were labeled as doubtful or suspect (94% and 25% respectively) for the period 1901-1999. The percentage for the same in the period 1946-1999 was found to be 61% and 13% respectively for the two variables. It was stated that ~65% of the statistically detected inhomogeneities in the temperature series labelled as doubtful/suspect in the later period could be attributed to observational changes.

Begert et al. [30] reviewed standard homogenization procedure developed by MeteoSwiss, that was a combination of metadata analysis and twelve different homogeneity tests, namely, Craddock, Potter, Group of SNHT, Cumulative residuals, Cumulative differences, Easterling and Peterson, Jarušková, Lanzante and Normalized q-series, on twelve stations data in Switzerland for 12 for 1864-2000. It was evident that most of the inhomogeneities were induced as an effect of station relocation. In case of trend analysis, most of the significant increasing trends were detected in the yearly and seasonal temperature time series. The similar nature of trend in precipitation series were observed only in the areas north of Alpine main crest in winter season and a few of the yearly series. It could be noticed that the method developed by the Federal Office of Meteorology and Climatology when combined along with the station history in detailed study, showed effectiveness in detection and adjustments of inhomogeneities in long term temperature and precipitation datasets in Switzerland.

In the west Asia region, Partal and Kahya [3] studied long term trends in annual average and monthly total rainfall from 1929-1993 at 96 stations in Turkey with the help of non-parametric trend tests- Mann-Kendall and Sen’s T test. Downward trend was observed in the annual precipitation over the regions west and south Turkey and alongside of Black Sea. Also, significant trends were detected in the monthly precipitation series (mostly for January, February, and September). they observed that the large-scale climatic influence on trend characteristics at each individual station was not masked totally by the local effects in the region.

Guhathakurta et al. (2008) analyzed monthly, seasonal, and annual rainfall time series of 36 meteorological sub-divisions of India for the period 1901-2003. Linear trend analysis revealed the decreasing contribution of June, July, and September rainfall, while increasing contribution of August rainfall to the annual rainfall, for few sub-divisions in India. The rainfall data from 211 gauged stations in the southern Italy were subjected to trend analysis with a view to detect significant changing patterns for the period 1918-1999 by Longobardi and Villani [19]. It was found that negative trends were present predominantly in annual and seasonal scale (apart from summer). The findings depicted presence of significant positive as well as negative trends over 9% and 27% of the total stations respectively. Prevalence of significant downward rainfall trend was seen for 97% stations for the last thirty years. Also, decreasing trend was dominant both at annual and seasonal time scale except for summer.

Jain and Kumar [32] reviewed the studies related to rainfall, rainy days, and temperature trends over India. It was evident that Sen’s slope and Mann-Kendall test were widely used for the detection of magnitude and significance of trend, respectively. Most of the studied stations showed increasing trend in mean maximum temperature, on the other hand, mean minimum temperature trends were of both rising and falling nature across

India. It was also noticed that most of the data used in various studied were acquired for stations in urban areas that represent heat islands that may induced false trend, hiding the actual changes in patterns related to climate change. It, therefore, highlighted the need of a network of baseline climatic studies. Further, Jain et al. [33] also analyzed rainfall in the region for the duration 1871–2008. In NER, Rainfall data didn't show any clear trend, but for some of the hydro-meteorological sub-divisions seasonal rainfall displayed presence of trends for some seasons. The study included four temperature variables also (minimum, maximum, mean temperature and diurnal temperature trend), that showed rising trends over the observations. Jaiswal [24] applied non-parametric tests on temperature (maximum and minimum), relative humidity, wind speed, sunshine hour and pan evaporation data for Raipur, India with the aim of assessment of detection of change points along with trend. The Buishand range test (BRT), Pettitt's test (PT), VNRT and SNHT were used for change detection, whereas linear regression, Spearman rho and Mann-Kendall test were applied for the detection of significance in trend. Significant (at 95 % significance level) change points were detected in case of annual minimum temperature, sunshine hour and wind speed and doubtful status was observed in evaporation and maximum temperature series. Maximum shifts were observed in the years around 1995. Rapid changes associated with urbanization and industrial activities in the studied location were concluded as the possible causes behind these maximum number of shifts.

A study on temperature, specific humidity and relative humidity changes averaged over 40^{o}N- 40^{o}S using reanalysis data by Byrne and O'Gorman [34] showed how changes in land humidity and temperature were related to warming in the ocean. Changes in these parameters in terms of trends were investigated with ordinary least-square regression methods. The results were indicative of an increase in land temperatures by 42% quicker rate than the ocean temperature. The opposite nature of behavior was observed in case of Specific humidity. A decreasing trend was observed in relative humidity over land with large variability around the linear trend in this study.

The annual means of relative humidity, temperature and specific humidity over South Korea were investigated for long term trend and variability by Shin et al. [35]. The overall temperature in South Korea was found to be decreasing, specifically during winter. Significant decreasing trends were observed in the annual mean of relative humidity while the same for the specific humidity remained constant. Cséplő et al. [36]

also studied the long-term changes in relative humidity and its association with long term temperature change in Hungary in another study. In their finding the seasonal analyses revealed significant increase in temperature in each season, while decrease in relative humidity was observed in spring and summer season only. It was concluded that the reduction in relative humidity in summer was influenced by the increasing temperature, and the increasing temperature leading to the enhancement of evaporation might mitigate the impact of increase in temperature in other seasons. In the Indian context, a recent study pertinent to long-term changes in relative humidity alongside convective available potential energy (CAPE) and convective inhibition (CIN) was performed by Khan et al. [37] in 2022, for the period 1980-2020. Robust regression analysis was used for detection of trends. In this study, the relative humidity was found to be increasing during monsoon, while the opposite was observed for the same in pre-monsoon. The monthly analysis revealed increasing nature in the relative humidity from January to August, after which it was found to be decreasing for the stations in the East coasts, while exactly opposite behavior in relative humidity was observed for the other regions (South, Northwest, and Central India). It was concluded that the findings might provide additional evidence with respect to the role of relative humidity as a factor influencing an increase in CAPE over India.

Rainfall is one of the key meteorological variables on which water availability, food security and livelihood depend, especially in an agrarian society like the northeast region (NER) of India. It is an ecologically sensitive zone, harbouring world's three biodiversity hot-spots and the world's highest rainfall zone. The assessment of variability and trend in the rainfall regime in this region is imperative as the economy of NER is based on rainfed agriculture. As it is well enumerated in literatures that the rainfall along with other meteorological variables govern the agricultural productivity of an agrarian region, hence the trend and variability studies on these meteorological variables should also be taken into consideration. Besides rainfall, temperature is another variable of importance over which all global initiatives have focused on. The intended objectives of various global initiatives were to arrest the mean global temperature rise by less than 1.5°C from the pre-industrial level (IPCC AR4, Working group II report). Failure to achieve the target may lead to severe alterations in climate and local weather conditions viz. erratic rainfall, drought, increase in the frequency of cyclonic events.

Therefore, in this chapter a detailed study of homogeneity and trend analysis had been carried out for all the considered meteorological variables including rainfall, temperature, relative humidity, mean sea level pressure and WS (as discussed in Chapter 2) in NER. All the analyses included in this chapter were performed in R software.

3.2 Methods

In general, a time series comprises of three components, namely, a) seasonal, b) trend and c) error component. Thus, the generalized time series model can be expressed as:

$y_t = S_t + T_t + e_t$ ………………………………………………………… (3.3.1)

where, S_t is the seasonal component, T_t is the trend component and e_t is the reminder or error component of the time series. To characterize the trend presents in the rainfall time series, at first the daily rainfall time series has been segregated into monthly as well as seasonal time series. In case of seasonal time series, the rainfall data were arranged into four seasons as per Koppen's classification, i.e., winter (JF), pre-monsoon (MAM), monsoon (JJAS) and post-monsoon (OND). Next, the monthly and seasonal series were tested for homogeneity prior to checking the presence of (any) trend.

3.2.1 Homogeneity testing

Climatic studies are often interrupted by the inhomogeneities associated with the time series. Such inhomogeneities are caused due to several reasons such as changes in observation conditions and techniques (e.g., station relocation, instrumental changes), inaccurate data management (e.g., use of faulty instrumentation, error in data handling) or environmental changes over time (changes in land use/ land cover), thereby hiding the real climate signal. Sometimes, break points are detected in the time series because of these inhomogeneities, dividing the series into two or more parts, thereby inducing false trends. Therefore, it is of prior concern to test the homogeneity of a particular time series of interest, as a part of data preprocessing; and if found non-homogenized, then to homogenize taking help of necessary techniques.

In the present work four tests were considered for checking the homogeneity of a time series [7], namely, Buishand range test (BRT), Pettitt test (PT), standard normal homogeneity test (SNHT) and von-Neumann ratio test (VNRT). The p-values in each test are estimated with the help of Monte-Carlo simulation.

Buishand range test (BRT)

The BRT is a parametric test for homogeneity of a data series and, is more sensitive towards the shift in mid portion of a time series [38]. Here the null hypothesis is assumed as the data values of the test series are independent and identically normally distributed with mean and variance [10]. The null hypothesis is then tested against the alternative hypothesis of the data series having a shift or jump in the mean after some observation point 'm'. The test statistics, i.e., the adjusted partial sums (cumulative deviations from the mean), is defined as

$$S_0^* = 0 \text{ and } S_k^* = \frac{n\sum_{i=1}^{k}(Y_i - \bar{Y})}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2} \qquad k = 1, 2, \ldots, n$$

which means, the value of statistics fluctuates around zero for a homogeneous series, as there will be no systematic deviations of the data value Y_i with respect to their mean. In case of departure from homogeneity, a statistic Q is sensitive, and is defined as

$$Q = \max_{0 \leqslant k \leqslant n} |S_k^*|$$

A high value of Q indicates a change in level. The statistic reaches a maximum (negative shift)/ minimum (positive shift) near the year k = K, if a shift happens in year K.

Another statistic for checking homogeneity is the range (R), defined as

$$R = \max_{0 \leqslant k \leqslant n} S_k^* - \min_{0 \leqslant k \leqslant n} S_k^*$$

Like Q, high values of R also indicate towards shifts in mean. Critical values for the test statistic of BRT along with those of other homogeneity tests are tabulated at the end of section 3.2.1.

Pettitt test (PT)

PT is also more sensitive towards change points in the middle of a time series, like BRT, (Costa and Soares, 2009), PT is a non-parametric approach in testing homogeneity of a data series. Here, the statistics are calculated with the use of ranks $r_1, \ldots, r_n$ of the test series values $Y_1, \ldots, Y_n$ [11], as follows:

$$X_k = 2\sum_{i=1}^{k} r_i - k(n+1), \qquad k = 1, 2, \ldots, n$$

In case of a shift occurring in the year K, the statistic is maximum/ minimum near the year k = K and the equation becomes $X_k = \max_{0 \leqslant k \leqslant n} |X_k|$

Standard normal homogeneity test (SNHT)

SNHT is one of the most widely used tests for homogeneity. The null and alternative hypotheses are like BRT, except that, it is more sensitive to the breaks near the beginning and end of a series [38]. It assumes invariance of the ratio of the values of the test series and those of a reference series built using information from several neighboring stations [28]. An inhomogeneity in the test series will be revealed by a systematic change in this ratio. However, if there exists not a priori knowledge of which ones are the homogeneous time series, the test must be applied several times to decide which stations have good quality records and can be used as a reference.

Alexandersson [9] developed the SNHT and applied it to precipitation data series. The statistic, *T(k)* of the test compares the mean of first *k* years of the record with that of the last *n-k* years:

$$T(k) = k\bar{z}_1{}^2 + (n-k)\bar{z}_2{}^2 \qquad k = 1, \ldots\ldots, n$$

Here, $\bar{z}_1 = \frac{1}{k}\sum_{i=1}^{k}\frac{(Y_i-\bar{Y})}{s}$ and $\bar{z}_2 = \frac{i}{(n-k)}\sum_{i=k+1}^{n}\frac{(Y_i-\bar{Y})}{s}$

Like BRT and PT, here also, T(k) reaches a maximum value near the year k = K, if a change point is located at year K. The test statistic T_0 is, $T_0 = \max_{1 \leqslant k \leqslant n} T(k)$. The null hypothesis is rejected if T_0 reaches a value beyond a certain level dependent on sample size.

von-Neumann ratio test (VNRT)

von Neuman [12] developed the von-Neumann ratio, N as the ratio of the mean square year to year (successive) difference to the variance. Thus,

$$N = \frac{\sum_{i=1}^{n-1}(Y_i - Y_{i+1})^2}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}$$

In case if the sample series is homogeneous, then N =2. On the other hand, If the series contains a change point, then the value of N tends to be lower than 2. The value of N may become >2 if the data series bears rapid variations in the mean.

The VNRT however, does not give any information regarding the location of shift, unlike either of BRT, PT or SNHT does.

Classification approach

Based on the outputs of these four homogeneity tests (BRT, PT, SNHT and VNRT), a classification approach is adopted [7]. As per the classification scheme, the test series was concluded as:

a) Suspect or Non-homogeneous: if three or all tests fail the null hypothesis at 95% confidence level.

b) Doubtful: if two of the tests reject the null hypothesis at 95% confidence level.

c) Homogeneous: if only one or none of the tests reject(s) the null hypothesis at 95% confidence level.

Among these three classes, a) is discarded for further use, b) may be used conditionally and c) may be used in further analyzing the characteristics of the trends present in the time series.

N →	**20**	**30**	**40**	**50**	**70**	**100**
Tests with critical values						
BRT						
1%	1.60	1.70	1.74	1.78	1.81	1.86
5%	1.43	1.50	1.53	1.55	1.59	1.62
PT						
1%	71	133	208	293	488	841
5%	57	107	167	235	393	677
SNHT						
1%	9.56	10.45	11.01	11.38	11.89	12.32
5%	6.95	7.65	8.10	8.45	8.80	9.15
VNRT						
1%	1.04	1.20	1.29	1.36	1.45	1.54
5%	1.30	1.42	1.49	1.54	1.61	1.67

Table 3. 1 1% and 5% critical values for the statistics of the BRT, PT, SNHT and VNRT as a function of N [7]

3.2.2 Trend Testing

The trend component of the time series can be determined with the help of parametric as well non-parametric methods. Among them, Sen's slope estimator test and Mann-Kendall (MK) test were widely used, especially in case of hydrological data series.

Sen's slope estimation

Sen's slope estimation method [39] was adopted for the detection of a trend in terms of its nature (positive/negative or, increasing/ decreasing) and magnitude. The trend detected with the help of this method is assumed to be linear. The data of the time series are treated as pairs at first and then all their slopes, T_i are computed as follows,

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

Here, x_j and x_k are the data values that are treated as a pair, corresponding to time j and k respectively, where j > k. The median of these N values of T_i is called the Sen's Estimator of slope (SS), denoted by β, and, is calculated as

$$\beta = \begin{cases} T_{\frac{(N+1)}{2}}; & \text{N is odd} \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right); & \text{N is even} \end{cases}, \quad \text{here N= no. of data points}$$

An upward (increasing)/ downward (decreasing) trend in the selected time series is indicated by a positive/ negative value of β. As for instance, let's assume two SS β_1 and β_2 of the time series Y_1 and Y_2 are -0.122 and -0.142 respectively. From the values of SS, it can be concluded that in both cases the trend detected is downward (negative, decreasing) and magnitude of trend of $Y_2 > Y_1$.

Mann-Kendall (MK) test

The MK test [40-41] is applied on a time series to ascertain the statistical significance of a detected trend. It has been broadly used in climate studies [33]. It is a non-parametric approach, where the null hypothesis is assumed as presence of no trend and is checked by the alternative hypothesis of existence of an upward/ downward trend. Here, at first the statistics S is defined as

$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} sgn(x_j - x_i)$, here N= no. of data points ……………… (3.3.2.2.1)

Replacing $(x_j - x_i)$ in equation 3.3.2.2.1 by θ, we get

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

In case of a large data length (N>10). The variance of S is calculated by the following equation:

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

Here, N= number of data in the time series

n = no. of tied groups

t_k = no. of data points in k^{th} tied group.

This *var(S)* value is then used for the calculation of Z-statistics:

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

The null hypothesis is rejected at significance level α, if the calculated |Z| value> $Z_{1-\alpha/2}$.

In our analyses, the significance of detected trends is tested at α = 0.2, 0.1, 0.05 and 0.01 (80%, 90%, 95% and 99% confidence level).

3.3 Results and discussion

3.3.1 Rainfall time series

The homogeneity test and subsequently trend analysis were carried out on annual, seasonal and monthly dataset to understand the extent of climate change impact on the rainfall over the NER of India.

The results of different homogeneity tests namely, BRT, PT, SNHT and VNRT on annual data series of rainfall at six selected locations in NER are presented in Table 3.2. The results for annual rainfall revealed that except GHY, none of the sites have any shift in the annual rainfall series at 95% significance level for all the four-homogeneity test. The significant shift was detected for the year 1996 (p value = 0.026) at GHY in BRT only. This discontinuity in GHY was apparent in other three homogeneity tests also, but, as a non-significant shift. However, non-significant shifts were seen in the year 2000 (as calculated in BRT and SNHT) and 1983 (PT) in CHR; 1996 (BRT and PT) and 1974 (SNHT) in DBR; 1987 (BRT and PT) and 2015 (SNHT) in KSH and in 1981 (PT), 1985 (SNHT) and 1989 (BRT) in TUL. Using the classification approach the annual rainfall time series at all six studied locations fails to reject the null hypothesis at 95% significant level in more than one site. Therefore, the annual precipitation in NER India were classified as "Homogenous" in nature.

Sites	BRT				PT				SNHT				VNRT			Final Status
	Stats	Est	p	Year with CP	Stats	Est	p	Year with CP	Stats	Est	p	Year with CP	Stats	p	Result	
CHR	0.824	32	0.875	2000	134	15	0.815	1983	1.596	32	0.950	2000	2.518	0.968	N	**H**
DBR	1.055	28	0.539	1996	196	28	0.293	1996	5.016	6	0.301	1974	2.212	0.771	N	**H**
GHY	1.643	28	**0.026**	**1996**	204	28	0.250	1996	4.645	28	0.356	1996	1.808	0.250	N	**H**
KSH	1.432	19	0.107	1987	220	19	0.178	1987	5.741	47	0.215	2015	1.603	0.080	N	**H**
TUL	1.363	21	0.155	1989	150	17	0.650	1985	2.789	13	0.722	1981	1.832	0.278	N	**H**

Table 3. 2 Result of homogeneity tests applied on annual rainfall series

The homogeneity tests applied on the seasonal rainfall data (Table 3.3) indicated the presence of insignificant shifts at all the sites across the seasons, except for KSH, which have highly significant shift in the year 1990 (p = 0.01). Following the results of all homogeneity tests, therefore, seasonal time series were also classified as homogenous as the test fails to reject the null hypothesis of absence of shift in all the seasons across the NER.

The outputs of annual trend tests in the rainfall series of the selected sites are presented in the following Table 3.4. From the table except DBR and GHY, all other three stations showed presence of increasing but, all insignificant trends. Among the increasing trends, the maximum magnitude was observed for KSH (SS=5.236) and minimum for CHR (SS=1.103). DBR was the only station where rainfall has been found to be decreasing significantly (90% confidence interval) and between the stations showing decreasing trends, the magnitude of trend at DBR was higher (p= 0.064, SS= -7.259) than that of GHY (SS= -2.281).

Seasons_site	BRT				PT				SNHT				VNRT			Final Status
	Stats	Est	p	Year with CP	Stats	Est	p	Year with CP	Stats	Est	p	Year with CP	Stats	p	Result	
Win_CHR	0.887	20	0.790	1988	160	19	0.556	1987	9.080	48	0.038	2016	1.711	0.155	N	**H**
Win_DBR	0.931	15	0.733	1983	196	39	0.293	2007	9.580	4	0.027	1972	1.666	0.119	N	**H**
Win_GHY	1.628	28	0.031	1996	238	29	0.118	1997	4.179	28	0.427	1996	1.525	0.046	N	**H**
Win_KSH	1.784	22	**0.009**	**1990**	158	19	0.574	1987	4.621	22	0.359	1990	1.861	0.313	N	**H**
Win_TUL	1.551	30	0.054	1998	227	30	0.152	1998	3.183	30	0.642	1998	1.430	0.021	Y	**H**
Prmon_CHR	0.896	15	0.785	1983	126	15	0.905	1983	2.116	15	0.869	1983	2.377	0.909	N	**H**
Prmon_DBR	1.010	25	0.604	1993	126	24	0.905	1992	1.874	25	0.906	1993	2.757	0.997	N	**H**
Prmon_GHY	1.414	18	0.120	1986	264	18	0.061	1986	5.938	18	0.198	1986	1.758	0.198	N	**H**
Prmon_KSH	1.226	28	0.295	1996	144	28	0.709	1996	3.075	47	0.666	2015	1.952	0.434	N	**H**
Prmon_TUL	1.451	11	0.093	1979	264	11	0.061	1979	8.489	11	0.054	1979	1.726	0.167	N	**H**
Mon_CHR	0.729	32	0.954	2000	112	13	1.068	1981	2.340	6	0.823	1974	2.413	0.928	N	**H**
Mon_DBR	1.311	25	0.200	1993	208	25	0.230	1993	5.674	47	0.228	2015	2.606	0.985	N	**H**
Mon_GHY	1.414	28	0.122	1996	298	28	0.024	1996	8.161	28	0.063	1996	1.786	0.226	N	**H**
Mon_KSH	1.241	18	0.273	1986	200	18	0.271	1986	5.238	18	0.274	1986	2.040	0.556	N	**H**
Mon_TUL	1.108	20	0.463	1988	110	20	1.092	1988	1.757	48	0.926	2016	2.163	0.716	N	**H**
Pomon_CHR	0.848	12	0.847	1980	118	37	0.997	2005	2.942	7	0.691	1975	2.072	0.600	N	**H**
Pomon_DBR	0.895	37	0.787	2005	202	37	0.260	2005	5.368	3	0.258	1971	1.995	0.493	N	**H**
Pomon_GHY	1.348	36	0.166	2004	128	17, 39	0.882	1985, 2007	2.603	41	0.769	2009	2.351	0.892	N	**H**
Pomon_KSH	1.473	17	0.088	1985	228	17	0.149	1985	5.388	17	0.248	1985	2.210	0.769	N	**H**
Pomon_TUL	1.061	28	0.533	1996	146	34	0.689	2002	2.873	28	0.709	1996	2.004	0.505	N	**H**

Table 3. 3 Result of homogeneity tests applied on seasonal rainfall series (The prefixes of the sites in the 1st column of the table, Win, Prmon, Mon and Pomon denote the four seasons winter, pre-monsoon, monsoon, and post-monsoon respectively)

SITES	ANNUAL	
	P	SS
CHR	0.924	1.103
DBR	0.064*	-7.259
GHY	0.474	-2.281
KSH	0.274	5.236
TUL	0.464	2.367

*Table 3. 4 Result of trend analysis performed on the annual rainfall series over the selected regions; here P= p value obtained from MK test, SS= Sen's slope estimator value; +, *, ** and *** denotes significance level at 80%, 90%, 95% and 99% respectively.*

Changes in seasonal patterns of rainfall in the studied locations can be explained with the help of Table 3.5. Both upward as well as downward trends were seen in the seasonal rainfall across the studied sites. In winter, three stations namely, DBR, GHY and TUL showed the presence of decreasing trends, of which only DBR rainfall was significant, and its magnitude was the highest of the other detected trends in this season (p= 0.202, SS= 0.867). Winter rainfall in the other two sites, i.e., CHR and KSH was found in increasing manner, but none were significant. In the pre-monsoon season however, all the sites displayed the presence of increasing rainfall trends. Among these, GHY and TUL rainfall trends were significant (p= 0.080 and 0.107 respectively). The pre-monsoonal trend at CHR had the highest magnitude among all (SS= 6.019), but the trend was non-significant. The monsoonal rainfall, on the other hand was found to be decreasing at three sites, CHR, DBR and GHY; among these, DBR and GHY rainfall trend were significant (p= 0.214 and 0.066). GHY monsoonal rainfall showed the highest significant decreasing trend in rainfall (SS= 3.789). In case of postmonsoonal rainfall, four out of five studied locations showed decreasing trends (CHR, DBR, GHY and TUL), among which, trend in CHR rainfall had the highest magnitude (SS= -3.348). KSH was the only station with increasing trend in rainfall (SS= 1.123). However, none of these rainfall trends in postmonsoon season was significant.

SEASONS	CHR		DBR		GHY		KSH		TUL	
	P	SS	P	SS	P	SS	P	SS	P	SS
Win	0.648	0.274	0.202+	-0.867	0.317	-0.209	0.911	0.031	0.352	-0.257
Premon	0.623	6.019	0.474	1.349	0.080*	3.136	1.000	0.052	0.107*	2.395
Mon	0.952	-1.111	0.214+	-3.700	0.066*	-3.789	0.266	3.437	0.660	0.834
Postmon	0.375	-3.348	0.190	-0.985	0.924	-0.104	0.384	1.123	0.541	-0.691

*Table 3. 5 Result of trend analysis performed on the seasonal rainfall series over the selected regions; here Win= winter, Premon= pre-monsoon, Mon= monsoon and Postmon= post-monsoon; P= p value obtained from MK test, SS= Sen's slope estimator value; +, *, ** and *** denotes significance level at 80%, 90%, 95% and 99% respectively.*

Trend in monthly rainfall was investigated and the results are discussed in Table 3.6. A total of 31 increasing and 29 decreasing trends were detected in this monthly analysis, of which only 13 number of trends were found as significant at various confidence levels. Of these 13 detected significant trends, 6 were positive and 9 were negative in nature.

MONTHS	CHR		DBR		GHY		KSH		TUL	
	P	SS	P	SS	P	SS	P	SS	P	SS
Jan	0.567	-0.005	0.031**	-0.553	0.189+	-0.090	0.800	0.000	0.677	0.000
Feb	0.273	0.328	0.309	-0.458	0.918	-0.003	0.480	0.254	0.277	-0.291
Mar	0.924	0.274	0.750	0.116	0.809	-0.096	0.737	0.289	0.856	-0.078
Apr	0.993	0.183	0.897	0.080	0.083*	1.758	0.541	-1.319	0.890	0.143
May	0.623	2.850	0.389	1.059	0.496	0.862	0.979	0.070	0.003**	2.521
Jun	0.711	2.195	0.789	0.306	0.403	-1.172	0.897	-0.195	0.518	-0.419
Jul	0.131*	-16.480	0.003**	-3.249	0.029*	-2.586	0.512	-0.780	0.469	0.809
Aug	0.737	1.611	0.599	-0.742	0.453	-1.028	0.384	1.206	0.496	-0.524
Sep	0.979	0.224	0.692	-0.418	0.823	-0.193	0.052**	2.632	0.025**	1.343
Oct	0.648	-1.507	0.541	-0.407	0.370	0.669	0.313	1.150	0.704	0.280
Nov	0.079*	-0.328	0.211+	-0.222	0.018**	-0.366	0.085*	-0.415	0.020**	-0.563
Dec	0.772	0.000	0.142*	-0.295	0.676	0.000	0.059*	0.085	0.438	0.005

*Table 3. 6 Result of trend analysis performed on the monthly rainfall series over the selected regions; here P= p value obtained from MK test, SS= Sen's slope estimator value; +, *, ** and *** denotes significance level at 80%, 90%, 95% and 99% respectively.*

CHR rainfall in January, July, October, and November showed decreasing trends, but all of them were non-significant. The July rainfall at CHR was the strongest in magnitude (SS= -16.480) as compared to all detected trends over NER. On the other hand, none of the increasing trends at CHR rainfall was significant, among which May was detected to be the strongest in magnitude (SS= 2.850). In case of DBR, rainfall for 8 months (January, February and July-December) was following decreasing trends, among which only January, July, November and December trends were significant (p= 0.031, 0.003, 0.211 and 0.142 respectively). Here also, trend in July month had the highest magnitude of all (SS= -3.249). Rainfall at GHY also showed the same number of decreasing trends in the monthly series similar to DBR (8 in number), and the months following these declining trends were January-March, June-September and November. Here also, July was the trend with the highest magnitude (SS= -2.586). Only 4 rainfall trends were found to be significant at GHY (January, April, July, November), among which the April trend was the only positive significant trend (p= 1.758, SS= 1.758). At KSH, April, June, July and November trends were found to be decreasing, and except November (p= 0.085, SS= -0.415) all were non-significant. Here, the only significant positive trend was found for September (p= 0.052), and it was the trend with the highest magnitude (SS= 2.632). In case of TUL, rainfall in February, March, June, August and November were decreasing and among them only November was significant (p= 0.020, SS= -0.563). Here, 2 significant positive trends were observed (the maximum number of positive trends in a monthly series) for the month of May (p= 0.003, SS= 2.521 and November (p= 0.020, SS= 0.005).

3.4.2 Temperature time series

Maximum temperature (MaxT)

As depicted in table 3.7, it was seen that the annual MaxT across all the selected sites bears significant change points in the time series, making all of them non-homogeneous. Both the sites CHR and DBR detected significant series breaks in two segments: in the year 1997 and 2008. Similarly, the GHY, KSH and TUL MaxT time series were also detected with the significant breaks in two years: 1993 and 2005 (GHY), 1993 and 2004 (KSH) and 1993 and 1997 (TUL). These change points were confirmed in all the four homogeneity tests, thus, indicating the time series to be non-homogeneous.

Sites	BRT				PT				SNHT				VNRT			Final Status
	Stats	Est	p	Year with CP	Stats	Est	p	Year with CP	Stats	Est	p	Year with CP	Stats	p	Result	
CHR	2.637	29	**0.000**	**1997**	533	29	**0.000**	**1997**	30.458	40	**0.000**	**2008**	0.549	**0.000**	**Y**	**S**
DBR	2.199	29	**0.000**	**1997**	410	29	**0.000**	**1997**	26.640	40	**0.000**	**2008**	1.131	**0.001**	**Y**	**S**
GHY	2.492	37	**0.000**	**2005**	459	25	**0.000**	**1993**	32.950	37	**0.000**	**2005**	0.774	**0.000**	**Y**	**S**
KSH	2.118	25	**0.000**	**1993**	459	25	**0.000**	**1993**	19.916	36	**0.000**	**2004**	1.070	**0.000**	**Y**	**S**
TUL	2.615	29	**0.000**	**1997**	539	25	**0.000**	**1993**	28.305	29	**0.000**	**1997**	0.638	**0.000**	**Y**	**S**

Table 3. 7 Result of homogeneity tests applied on annual MaxT series

The results of homogeneity tests on seasonal series of MaxT, as depictde in the Table 3.8 indicates the presence of two homogeneous time series in the pre-monsoon season at DBR and KSH. Other than that, all the seasons across all the sites were confirmed to have at least one break points the the seasonal time series of MaxT, making them to be non-homogeneous. In case of winter season, the significant break points occurred in the years 1998 and 2008 in all the sites. During premonsoon, except DBR and KSH, CHR, GHY and TUL MaxT time series shows the presence of significance break points in the years 1998 and 2005 (CHR), 2005 (GHY) and 1994 and 2005 (TUL). In case of monsoon, CHR and DBR detected two break points in the years 2001 and 2004 (CHR) & 2000 and 2008 (DBR), GHY detected three significant series break points in the years 1993, 2002 and 2004, KSH in the years 1993 and 2004 & TUL in the years 1993, 2000 and 2004. The postmonsoonal MaxT in all five locations also showed the presence of significant break points: CHR in 1986, 1992 and 2009, DBR in 1992 and 1994, GHY in 1994, 1995 and 2005, and both KSH and TUL in 1992.

Seasons_site	BRT				PT				SNHT				VNRT			Final Status
	Stats	**Est**	**p**	**Year with CP**	**Stats**	**Est**	**p**	**Year with CP**	**Stats**	**Est**	**p**	**Year with CP**	**Stats**	**p**	**Result**	
Win_CHR	2.362	30	**0.000**	**1998**	464	30	**0.000**	**1998**	24.390	40	**0.000**	**2008**	1.121	**0.001**	**Y**	**S**
Win_DBR	1.882	30	**0.004**	**1998**	359	30	**0.003**	**1998**	18.574	40	**0.000**	**2008**	1.518	**0.043**	**Y**	**S**
Win_GHY	1.749	30	**0.013**	**1998**	315	30	**0.014**	**1998**	16.379	40	**0.001**	**2008**	1.606	0.082	N	**S**
Win_KSH	1.733	30	**0.013**	**1998**	326	30	**0.010**	**1998**	15.060	40	**0.001**	**2008**	1.681	0.130	N	**S**
Win_TUL	2.408	30	**0.000**	**1998**	480	30	**0.000**	**1998**	24.434	30	**0.000**	**1998**	1.047	**0.000**	**Y**	**S**
Prmon_CHR	2.267	30	**0.000**	**1998**	400	30	**0.001**	**1998**	21.071	37	**0.000**	**2005**	1.199	**0.002**	**Y**	**S**
Prmon_DBR	1.820	37	**0.007**	**2005**	251	37	0.086	2005	7.986	37	0.071	2005	1.736	0.177	N	**H**
Prmon_GHY	1.972	37	**0.001**	**2005**	324	37	**0.011**	**2005**	13.446	37	**0.003**	**2005**	1.387	**0.014**	**Y**	**S**
Prmon_KSH	1.222	37	0.299	2005	195	37	0.299	2005	5.218	37	0.272	2005	1.983	0.477	N	**H**
Prmon_TUL	1.781	26	**0.010**	**1994**	335	26	**0.007**	**1994**	11.312	37	**0.010**	**2005**	1.534	**0.049**	**Y**	**S**
Mon_CHR	2.580	33	**0.000**	**2001**	464	33	**0.000**	**2001**	25.816	36	**0.000**	**2004**	0.752	**0.000**	**Y**	**S**
Mon_DBR	1.628	40	**0.030**	**2008**	307	32	**0.018**	**2000**	17.332	40	**0.000**	**2008**	1.744	0.184	N	**S**
Mon_GHY	2.535	34	**0.000**	**2002**	509	25	**0.000**	**1993**	32.646	36	**0.000**	**2004**	0.792	**0.000**	**Y**	**S**
Mon_KSH	2.215	25	**0.000**	**1993**	428	25	**0.000**	**1993**	20.736	34	**0.000**	**2002**	1.334	**0.008**	**Y**	**S**
Mon_TUL	2.561	32	**0.000**	**2000**	491	25	**0.000**	**1993**	28.978	36	**0.000**	**2004**	0.880	**0.000**	**Y**	**S**
Pomon_CHR	2.266	24	**0.000**	**1992**	491	18, 24	**0.000**	**1986, 1992**	24.539	41	**0.000**	**2009**	0.817	**0.000**	**Y**	**S**
Pomon_DBR	2.273	26	**0.000**	**1994**	478	24	**0.000**	**1992**	20.752	26	**0.000**	**1994**	0.983	**0.000**	**Y**	**S**
Pomon_GHY	2.357	27	**0.000**	**1995**	507	26	**0.000**	**1994**	27.794	37	**0.000**	**2005**	0.849	**0.000**	**Y**	**S**
Pomon_KSH	2.037	24	**0.000**	**1992**	405	24	**0.001**	**1992**	16.602	24	**0.000**	**1992**	1.483	**0.033**	**Y**	**S**
Pomon_TUL	2.343	24	**0.000**	**1992**	470	24	**0.000**	**1992**	21.961	24	**0.000**	**1992**	1.188	**0.001**	**Y**	**S**

Table 3. 8 Result of homogeneity tests applied on seasonal series of MaxT (The prefixes of the sites in the 1st column of the table, Win, Prmon, Mon and Pomon denote the four seasons winter, pre-monsoon, monsoon and post-monsoon respectively)

As evident from the Table 3.9, the annual MaxT time series bore significant increasing trends (α= 0.01) across the selected locations of NER. Among these increasing trends, the magnitude of CHR and TUL trends were found to be equally the highest (SS= 0.040), followed by GHY (SS= 0.033), DBR (SS= 0.026) and KSH (SS= 0.020).

SITES	**ANNUAL**	
	P	**SS**
CHR	0.000***	0.040
DBR	0.000***	0.026
GHY	0.000***	0.033
KSH	0.000***	0.020
TUL	0.000***	0.040

*Table 3. 9 Result of trend analysis performed on the annual MaxT series over the selected regions; here P= p value obtained from MK test, SS= Sen's slope estimator value; +, *, ** and *** denotes significance level at 80%, 90%, 95% and 99% respectively*

From the seasonal trend analyses results of MaxT (Table 3.10) it was evident that except for the pre-monsoon season, all seasons across all the selected study areas displayed the presence of significant increasing trends in MaxT ($p<<0.05$), with varied degrees of magnitude. In winter, the highest magnitude of the increasing trends was observed for TUL (SS= 0.062), followed by CHR (SS= 0.059), while the lowest one was observed at GHY (SS= 0.029). In monsoon however, the significant increasing trend with the highest magnitude was observed for GHY (SS= 0.040), followed by TUL (SS= 0.035) and the lowest was at DBR (SS= 0.013). In post-monsoon, CHR time series had the significant increasing trend with highest magnitude (SS= 0.053), followed by TUL (SS= 0.043) and the lowest one was at KSH (SS=0.026). In case of pre-monsoon, CHR time series was with the significant positive trend of the highest magnitude (SS= 0.032), followed by TUL (SS= 0.027) at α= 0.01. Of all five locations, the increasing MaxT trend at GHY was with the magnitude of 0.018 at α= 0.1 (p= 0.072). However, the MaxT at DBR and KSH in pre-monsoon did not show the presence of any significant trend (p= 0.384 and 0.231 respectively).

SEASONS	CHR		DBR		GHY		KSH		TUL	
	P	SS	P	SS	P	SS	P	SS	P	SS
Win	0.000***	0.059	0.000***	0.045	0.004**	0.029	0.003***	0.031	0.000***	0.062
Premon	0.000***	0.032	0.384	0.011	0.072*	0.018	0.231	0.013	0.006***	0.027
Mon	0.000***	0.026	0.010***	0.013	0.000***	0.040	0.000***	0.021	0.000***	0.035
Postmon	0.000***	0.053	0.000***	0.042	0.000***	0.039	0.000***	0.026	0.000***	0.043

Table 3. 10 Result of trend analysis performed on the seasonal MaxT series over the selected regions; here Win= winter, Premon= pre-monsoon, Mon= monsoon and Postmon= post-monsoon; P= p value obtained from MK test, SS= Sen's slope estimator value; +,, ** and *** denotes significance level at 80%, 90%, 95% and 99% respectively.*

The trend analysis results performed on the monthly MaxT (Table 3.11) revealed the presence of all increasing trends across all the selected locations of NER, in all the twelve months, except at DBR, where one negative trend was found for the month of March (SS= -0.001). Among the significant positive trends, TUL in February month showed the highest magnitude (SS= 0.067), followed by January at CHR (SS= 0.061). The trend with the lowest magnitude was found for the month of April at DBR (SS= 0.000), followed by GHY in the same month (SS= 0.003).

MONTHS	CHR		DBR		GHY		KSH		TUL	
	P	SS	P	SS	P	SS	P	SS	P	SS
Jan	0.000***	0.061	0.001***	0.038	0.085*	0.019	0.035**	0.023	0.000***	0.056
Feb	0.000***	0.057	0.001***	0.052	0.009***	0.044	0.002***	0.040	0.000***	0.067
Mar	0.006***	0.036	0.924	-0.001	0.238	0.015	0.789	0.004	0.021**	0.041
Apr	0.107*	0.019	0.986	0.000	0.803	0.003	0.789	0.005	0.221+	0.018
May	0.000***	0.032	**0.196+**	**0.016**	0.004***	0.032	**0.170+**	**0.018**	0.072*	0.021
Jun	0.050**	0.015	0.654	0.005	0.000***	0.036	0.029**	0.018	0.007***	0.021
Jul	0.007***	0.023	0.036**	0.019	0.000***	0.046	0.004***	0.020	0.000***	0.032
Aug	0.004***	0.021	0.666	0.005	0.000***	0.039	0.006***	0.020	0.000***	0.040
Sep	0.000***	0.039	0.006***	0.030	0.000***	0.040	0.001***	0.027	0.000***	0.043
Oct	0.000***	0.050	0.000***	0.042	0.000***	0.044	0.001***	0.024	0.000***	0.038
Nov	0.000***	0.055	0.000***	0.043	0.000***	0.044	0.001***	0.029	0.000***	0.051
Dec	0.000***	0.057	0.000***	0.047	0.000***	0.036	0.015**	0.022	0.000***	0.043

*Table 3. 11 Result of trend analysis performed on the monthly MaxT series over the selected regions; here P= p value obtained from MK test, SS= Sen's slope estimator value; +, *, ** and *** denotes significance level at 80%, 90%, 95% and 99% respectively*

At CHR, the strongest significant increasing trend was found for the month of January (p<<0.01, SS= 0.061), while the weakest significant one was in June (p= 0.050, SS= 0.015). In case of DBR, trend in March was the only decreasing one, but this trend was insignificant. Here, except for the month of April, June, and August all other positive trends were significant. The significant trend with the highest and the lowest magnitude were observed for the months of February (p= 0.001, SS= 0.052) and September (p= 0.006, SS= 0.030) respectively. All positive trends were observed for GHY, and here all the months except March and April were significant. Among them, the highest and the lowest magnitude were observed for the months of July (p<<0.01, SS= 0.046) and January (p= 0.085, SS= 0.019) respectively. MaxT at KSH also displayed structures in monthly trends like GHY, but here May (p= 0.170) and June (p= 0.029) were the months with the lowest magnitude (SS= 0.018). The significant trend with higher magnitude was observed for the month of February at KSH (SS= 0.002, SS= 0.040) and TUL too (p<<0.01, SS= 0.067). In case of significant trend at TUL the lowest magnitude was observed for the month of April (p= 0.221, SS= 0.018).

Minimum temperature

From the homogeneity tests applied on the annual MinT time series at different selected locations (Table 3.12), it was evident that MinT at all the selected locations except at CHR were non-homogeneous in nature. The MinT time series at CHR was doubtful in nature, with a significant breakpoint found in the year 1993 (p<<0.05), confirmed by two homogeneity tests BRT and VNRT but not confirmed by SNHT and PT. The year 1992 had one significant break point in MinT at DBR, that makes the time series inhomogeneous. GHY and KSH MinT had two break points in the time series. Here, GHY and KSH time series was detected with a significant shift (p<<0.01) in the year 1986. Other than the 1986's break point, 1984 (in case of GHY) and 1978 (in case of KSH) also had significant series breaks. In case of TUL, a significant break (p<<0.01) in the year 1990 as detected by the homogeneity tests makes the MinT time series at this location inhomogeneous.

Sites	BRT				PT				SNHT				VNRT			Final Status
	Stats	Est	p	Year with CP	Stats	Est	p	Year with CP	Stats	Est	p	Year with CP	Stats	p	Result	
CHR	1.563	25	**0.049**	**1993**	235	29	0.127	1997	3.659	25	0.536	1993	1.073	**0.000**	**Y**	**D**
DBR	2.737	24	**0.000**	**1992**	460	24	**0.000**	**1992**	22.070	24	**0.000**	**1992**	0.578	**0.000**	**Y**	**S**
GHY	2.485	18	**0.000**	**1986**	416	18	**0.000**	**1986**	17.235	16	**0.000**	**1984**	0.767	**0.000**	**Y**	**S**
KSH	2.161	18	**0.000**	**1986**	454	18	**0.000**	**1986**	22.448	10	**0.000**	**1978**	0.526	**0.000**	**Y**	**S**
TUL	2.426	22	**0.000**	**1990**	523	22	**0.000**	**1990**	23.786	22	**0.000**	**1990**	0.614	**0.000**	**Y**	**S**

Table 3. 12 Result of homogeneity tests applied on annual MinT series

From the results of homogeneity tests applied on the seasonal MinT (Table 3.13), most of the MinT time series at the NER were non-homogeneous in nature, due to the presence of significant ($p<0.05$) change points. However, MinT series during winter and post-monsoon at CHR were found to be homogeneous, i.e., none of the tests rejected the null hypothesis at 95% confidence level. Other than these, the MinT time series during premonsoon at CHR was doubtful in nature, with the detection of single break point in the year 1993, as confirmed by BRT and VNRT.

During winter, other than CHR, all the selected study locations in NER exhibits significant break points in the MinT time series, as confirmed by more than two homogeneity tests. The MinT time series at DBR and KSH showed the presence of two break points each (1987 and 1989 in DBR; 1979 and 1986 in KSH), while the MinT at GHY and TUL exhibited one break point each (1984 in GHY; 1988 in KSH). The year 1993 carried one significant breakpoint during pre-moonsoon at DBR and GHY. At GHY, another break point was present during pre-monsoon in 1983. In case of premonsoon at KSH two significant break points were detected in 1978 and 1984, whereas in TUL itwas detected in the year1988 only.

During monsoon at CHR, the MinT time series had significant change points in 1993 and 1996, as confirmed by BRT, PT and VNRT. Likewise, DBR MinT during monsoon also exhibited two significant break points (1978 and 1993). GHY and TUL during monsoon showed the presence of single break point each (1997 at GHY; 1990 at TUL). Among all the five sites during monsoon, KSH showed the presence of three significant break points (1977, 1978 and 1986).

During post-monsoon, the MinT time series revealed two significant change points per site (except CHR and TUL)- 1992 and 1994 for DBR; 1986 and 1994 for GHY; 1985 and 1986 for KSH. In post-monsoon, the MinT at TUL was detected with single significant break point in the year 1994.

Seasons_site	BRT				PT				SNHT				VNRT			Final Status
	Stats	Est	p	Year with CP	Stats	Est	p	Year with CP	Stats	Est	p	Year with CP	Stats	p	Result	
Win_CHR	1.450	29	0.095	1997	143	29	0.720	1997	2.593	1	0.769	1969	1.562	0.060	N	**H**
Win_DBR	2.322	21	**0.000**	**1989**	450	21	**0.000**	**1989**	20.405	19	**0.000**	**1987**	1.028	**0.000**	**Y**	**S**
Win_GHY	2.144	16	**0.000**	**1984**	377	16	**0.002**	**1984**	17.006	16	**0.000**	**1984**	1.330	**0.008**	**Y**	**S**
Win_KSH	2.168	18	**0.000**	**1986**	442	18	**0.000**	**1986**	21.619	11	**0.000**	**1979**	0.452	**0.000**	**Y**	**S**
Win_TUL	2.195	20	**0.000**	**1988**	434	20	**0.000**	**1988**	19.952	20	**0.000**	**1988**	0.811	**0.000**	**Y**	**S**
Prmon_CHR	1.572	25	**0.043**	**1993**	191	30	0.323	1998	4.589	1	0.363	1969	1.273	**0.004**	**Y**	**D**
Prmon_DBR	2.353	25	**0.000**	**1993**	368	25	**0.002**	**1993**	12.513	25	**0.005**	**1993**	1.134	**0.001**	**Y**	**S**
Prmon_GHY	2.012	25	**0.002**	**1993**	349	25	**0.005**	**1993**	13.276	15	**0.003**	**1983**	1.393	**0.015**	**Y**	**S**
Prmon_KSH	1.674	16	**0.022**	**1984**	323	16	**0.011**	**1984**	13.844	10	**0.003**	**1978**	1.376	**0.013**	**Y**	**S**
Prmon_TUL	2.138	20	**0.000**	**1988**	432	22	**0.000**	**1990**	18.929	20	**0.000**	**1988**	1.290	**0.005**	**Y**	**S**
Mon_CHR	1.627	25	**0.030**	**1993**	312	28	**0.015**	**1996**	7.295	25	0.097	1993	0.903	**0.000**	**Y**	**S**
Mon_DBR	2.399	25	**0.000**	**1993**	345	25	**0.005**	**1993**	10.345	10	**0.019**	**1978**	0.637	**0.000**	**Y**	**S**
Mon_GHY	2.184	29	**0.000**	**1997**	384	29	**0.001**	**1997**	11.659	29	**0.009**	**1997**	0.843	**0.000**	**Y**	**S**
Mon_KSH	1.904	10	**0.003**	**1978**	384	18	**0.001**	**1986**	22.588	9	**0.000**	**1977**	0.812	**0.000**	**Y**	**S**
Mon_TUL	2.406	22	**0.000**	**1990**	534	22	**0.000**	**1990**	23.394	22	**0.000**	**1990**	0.600	**0.000**	**Y**	**S**
Pomon_CHR	1.381	15	0.142	1983	188	13	0.342	1981	4.302	6	0.412	1974	1.072	**0.000**	**Y**	**H**
Pomon_DBR	2.470	26	**0.000**	**1994**	477	24	**0.000**	**1992**	23.088	26	**0.000**	**1994**	0.966	**0.000**	**Y**	**S**
Pomon_GHY	2.146	18	**0.000**	**1986**	300	26	**0.022**	**1994**	9.529	18	**0.032**	**1986**	1.291	**0.005**	**Y**	**S**
Pomon_KSH	1.947	17	**0.001**	**1985**	396	18	**0.001**	**1986**	16.728	17	**0.000**	**1985**	0.984	**0.000**	**Y**	**S**
Pomon_TUL	1.944	26	**0.002**	**1994**	402	26	**0.001**	**1994**	15.180	26	**0.001**	**1994**	1.317	**0.007**	**Y**	**S**

Table 3. 13 Result of homogeneity tests applied on seasonal MinT series (The prefixes of the sites in the 1st column of the table, Win, Prmon, Mon and Pomon denote the four seasons winter, pre-monsoon, monsoon, and post-monsoon respectively)

From the Table 3.14 it is evident that the annual MinT time series at all five locations except at CHR exhibited significant positive trends (p<0.01). The trend in MinT time series at CHR was also positive (SS=0.002), but it was insignificant. Among the detected MinT trends, the one with the greatest magnitude was found at KSH and TUL (equal in magnitude; SS=0.035), followed by DBR (SS=0.030) and GHY (SS=0.024).

SITES	ANNUAL	
	P	SS
CHR	0.704	0.002
DBR	0.000***	0.030
GHY	0.000***	0.024
KSH	0.000***	0.035
TUL	0.000***	0.035

*Table 3. 14 Result of trend analysis performed on the annual MinT series over the selected regions; here P= p value obtained from MK test, SS= Sen's slope estimator value; +, *, ** and *** denotes significance level at 80%, 90%, 95% and 99% respectively*

The seasonal MinT time series across all the sites (Table 3.15) displayed increasing trends except at CHR during winter (SS=-0.001) and post-monsoon (SS=-0.010). The decreasing trend at CHR during winter was insignificant (p=0.924) and the one during post-monsoon was significant at α=0.2 (p=0.179). The MinT at CHR exhibited significant, increasing trends during monsoon (p=0.052, SS=0.011). The pre-monsoonal MinT at CHR was also found to have an increasing trend (SS=0.005) but it was insignificant. In case of DBR, MinT time series during all the seasons were detected with significant increasing trends (p<0.01), among which the season of the highest and the lowest magnitude were post-monsoon (SS=0.044) and monsoon (SS=0.015) respectively. MinT at GHY was detected with significant increasing trends at α=0.05 throughout the seasons. Among them, the trend with the highest magnitude was detected during winter and monsoon (SS=0.023) and the trend with the lowest magnitude was found during pre-monsoon (SS=0.019). The seasonal analysis of MinT trend at the rest of the sites KSH and TUL display significant increasing trends at α=0.01. At KSH, the trends with the highest and the lowest magnitude were detected during winter (SS=0.055) and monsoon (SS=0.021) respectively. The MinT during Winter at TUL was also with the highest magnitude (SS=0.047). Here, the premonsoonal time series was detected with a significant increasing trend with the lowest magnitude (SS=0.030).

SEASONS	CHR		DBR		GHY		KSH		TUL	
	P	SS	P	SS	P	SS	P	SS	P	SS
Win	0.924	-0.001	0.000***	0.038	0.015**	0.023	0.000***	0.055	0.000***	0.047
Premon	0.581	0.005	0.000***	0.025	0.002***	0.019	0.001***	0.029	0.000***	0.030
Mon	0.052*	0.011	0.001***	0.015	0.000***	0.023	0.000***	0.021	0.000***	0.034
Postmon	0.179+	-0.010	0.000***	0.044	0.030**	0.020	0.000***	0.047	0.002***	0.036

*Table 3. 15 Result of trend analysis performed on the seasonal MinT series over the selected regions; here Win= winter, Premon= pre-monsoon, Mon= monsoon and Postmon= post-monsoon; P= p value obtained from MK test, SS= Sen's slope estimator value; +, *, ** and *** denotes significance level at 80%, 90%, 95% and 99% respectively*

The dominance of increasing trends over decreasing trends was noticed from the monthly trend analysis of MinT over NER (Table 3.16). All positive trends were observed throughout the twelve months in all selected locations except CHR and most of these positive trends were significant at α=0.05. A total of 54 increasing and 6 decreasing trends were observed throughout the months across all the selected locations for monthly MinT in NER. In case of CHR, equal numbers of positive and negative trends were observed. Here, among the positive trends May, June, July, and August were significant at α<0.2. At CHR, of these significant positive trends, the highest and the lowest magnitude were observed for the months of May (SS=0.012) and June (SS=0.008) respectively. To the contrary, the trend in the MinT time series for the months January, March, April, October, November, and December were decreasing in nature with varied magnitudes. Among these negative trends, only November trend was significant (p= 0.050, SS= -0.024). The magnitude of this negative trend was the highest among the other months. In DBR, MinT in all twelve months showed the presence of significant increasing trends at α<0.05 except in June (p= 0.136, SS= 0.007). Of these increasing trends (α<0.05), the trend with the highest and the lowest magnitude was observed for the months January (SS=0.047) and August (SS=0.012) respectively. In GHY, MinT in all the eleven months except April displayed significant increasing trends. The January trend was significant with p=0.184 and with a magnitude of 0.014. Other than April and January, trend in other months were significant at α<0.05, of which the one with the highest and the lowest magnitude were observed in the month of February (SS=0.042) and April (SS=0.008) respectively. In KSH, all twelve increasing trends those were detected for MinT were significant at α<0.05. Among these, the highest magnitude of trend was observed for December (SS=0.060) and the lowest magnitude was observed for June (SS=0.017). In TUL, MinT in all twelve months had increasing trends at α<0.05, except for the month November (p=0.199, SS=0.018). The highest magnitude of trend in monthly MinT at TUL was observed for the month December (SS=0.065), like KSH. On the other hand, the lowest magnitude of trend in monthly MinT at this location was observed for the month of April (SS=0.027).

MONTHS	CHR		DBR		GHY		KSH		TUL	
	P	SS	P	SS	P	SS	P	SS	P	SS
Jan	0.823	-0.003	0.000***	0.047	0.184+	0.014	0.000***	0.052	0.000***	0.047
Feb	0.724	0.004	0.001***	0.034	0.002***	0.042	0.001***	0.051	0.006***	0.044
Mar	0.485	-0.007	0.004***	0.025	0.019**	0.019	0.031**	0.036	0.003***	0.039
Apr	0.756	-0.003	0.011**	0.020	0.289	0.008	0.001***	0.024	0.002***	0.027
May	0.100+	0.012	0.018**	0.018	0.012***	0.017	0.003***	0.028	0.001***	0.028
Jun	0.145+	0.008	0.136+	0.007	0.008***	0.016	0.002***	0.017	0.000***	0.028
Jul	0.155+	0.010	0.001***	0.015	0.000***	0.022	0.000***	0.023	0.000***	0.034
Aug	0.129*	0.011	0.018**	0.012	0.000***	0.022	0.000***	0.025	0.000***	0.033
Sep	0.309	0.006	0.014**	0.013	0.000***	0.023	0.000***	0.021	0.000***	0.045
Oct	0.704	-0.004	0.019**	0.024	0.091*	0.016	0.001***	0.031	0.021**	0.042
Nov	0.050**	-0.024	0.004***	0.037	0.389	0.012	0.046**	0.032	0.199+	0.018
Dec	0.611	-0.006	0.000***	0.061	0.002***	0.032	0.000***	0.060	0.000***	0.065

*Table 3. 16 Result of trend analysis performed on the monthly MinT series over the selected regions; here P= p value obtained from MK test, SS= Sen's slope estimator value; +, *, ** and *** denotes significance level at 80%, 90%, 95% and 99% respectively*

3.4.4a Relative Humidity (RH) time series

The results of homogeneity tests performed on the annual time series of RH were presented in Table 3.17. From the results it was revealed that among the selected locations of NER, only the annual RH in GHY was homogeneous. RH series in three locations- CHR, DBR and TUL were inhomogeneous. The RH time series at these two locations were detected with two change points each; CHR time series had change points in the years 1973 and 1977 (detected by SNHT, BRT and VNRT) and TUL had in the years 1989 and 2015 (detected by PT, SNHT and VNRT). DBR time series was detected with only one change point in the year 1995 (by BRT, PT, SNHT and VNRT. Other than these, the annual RH at KSH was found to be doubtful in nature (a change point in the year 1980, detected by only BRT and VNRT).

Sites	**BRT**				**PT**				**SNHT**				**VNRT**			**Final Status**
	Stats	**Est**	**p**	**Year with CP**	**Stats**	**Est**	**p**	**Year with CP**	**Stats**	**Est**	**p**	**Year with CP**	**Stats**	**p**	**Result**	
CHR	1.911	9	**0.003**	**1977**	257	0.074	9	1977	19.412	5	**0.000**	**1973**	1.141	**0.001**	**Y**	**S**
DBR	1.748	27	**0.011**	**1995**	334	**0.008**	27	**1995**	10.763	27	**0.014**	**1995**	1.396	**0.015**	**Y**	**S**
GHY	1.287	18	0.226	1986	233	0.133	18	1986	6.480	18	0.149	1986	1.849	0.298	N	**H**
KSH	1.804	12	**0.008**	**1980**	223	0.167	12	1980	7.069	7	0.110	1975	1.344	**0.009**	**Y**	**D**
TUL	1.510	21	0.069	1989	302	**0.021**	21	**1989**	11.333	47	**0.012**	**2015**	1.469	**0.029**	**Y**	**S**

Table 3. 17 result of homogeneity tests applied on annual RH series

Unlike the results of homogeneity tests on the seasonal temperature time series (MaxT and MinT), the seasonal RH time series across the study sites were homogeneous in nature, as evident from the Table 3.18. During winter it was observed that RH at DBR, GHY and KSH was non-homogeneous, with the presence of at least one break points in the series. The years with break points observed were 1993 1995 and 1998 (detected by PT, SNHT and VNRT) in DBR, 1989 (detected by all four tests) in GHY and 1980 in KSH (detected by all four tests). RH time series at CHR during this season was identified as doubtful in nature, with the presence of break point in the year 1973, that was confirmed by SNHT and VNRT only. Other than these study locations of NER, RH at TUL only was found to be homogeneous. In the premonsoon season however, RH series at four of the selected locations of NER, namely CHR, DBR, GHY and KSH were identified as homogeneous. Other than these four locations, the nature of RH time series at TUL was doubtful with the detection of two break points (1979 and 1989) but confirmed by only PT and SNHT. In case of monsoon, five selected locations of NER (CHR, DBR and GHY) were found to be homogeneous in RH time series. In this season, nature of the RH time series at KSH and TUL was doubtful and non-homogeneous respectively (KSH detected with break points in the years 2001 and 2004, confirmed by only BRT and PT; while TUL detected with break points in the years 1996 and 2006, confirmed by BRT, PT and SNHT). In post-monsoon season, RH at GHY and KSH was homogeneous, while the same at CHR and TUL was doubtful (CHR detected with break points in 1971 and 1979, confirmed by only BRT and SNHT; TUL detected with break point in 1998, confirmed by only BRT and PT). RH at DBR during post-monsoon was non-homogeneous, with the presence of two break points in the years 1982 and 1984 (detected by all the four homogeneity tests.

Seasons_site	BRT				PT				SNHT				VNRT			Final Status
	Stats	Est	p	Year with CP	Stats	Est	p	Year with CP	Stats	Est	p	Year with CP	Stats	p	Result	
Win_CHR	1.470	5	0.085	1973	134	0.815	5	1973	12.102	5	**0.005**	**1973**	1.463	**0.028**	**Y**	**D**
Win_DBR	1.462	30	0.091	1998	281	**0.039**	25, 27	**1993, 1995**	9.004	30	**0.040**	**1998**	1.496	**0.037**	**Y**	**S**
Win_GHY	2.085	21	**0.000**	**1989**	411	**0.000**	21	**1989**	16.976	21	**0.000**	**1989**	1.459	**0.027**	**Y**	**S**
Win_KSH	1.857	12	**0.005**	**1980**	336	**0.007**	12	**1980**	16.177	12	**0.001**	**1980**	1.151	**0.001**	**Y**	**S**
Win_TUL	1.222	21	0.292	1989	153	0.621	30	1998	3.929	47	0.488	2015	1.096	**0.000**	**Y**	**H**
Prmon_CHR	1.547	24	0.051	1992	231	0.139	24	1992	9.530	6	**0.029**	**1974**	1.768	0.207	N	**H**
Prmon_DBR	0.822	11	0.877	1979	129	0.871	11	1979	5.181	46	0.280	2014	2.088	0.620	N	**H**
Prmon_GHY	1.085	18	0.492	1986	184	0.368	18	1986	6.173	11	0.177	1979	2.032	0.545	N	**H**
Prmon_KSH	1.655	7	**0.026**	**1975**	200	0.271	7	1975	8.221	7	0.063	1975	1.552	0.056	N	**H**
Prmon_TUL	1.535	21	0.058	1989	310	**0.016**	21	**1989**	12.076	11	**0.007**	**1979**	1.550	0.055	N	**D**
Mon_CHR	1.506	32	0.067	2000	195	0.299	32	2000	5.608	33	0.228	2001	1.828	0.273	N	**H**
Mon_DBR	1.386	32	0.140	2000	204	0.250	32	2000	6.335	36	0.165	2004	1.985	0.479	N	**H**
Mon_GHY	1.097	41	0.473	2009	125	0.916	25	1993	2.607	42	0.762	2010	1.968	0.456	N	**H**
Mon_KSH	1.698	33	**0.018**	**2001**	254	0.080	33, 36	2001, 2004	9.654	36	**0.027**	**2004**	1.752	0.191	N	**D**
Mon_TUL	1.842	28	**0.006**	**1996**	385	**0.001**	28	**1996**	14.512	38	**0.001**	**2006**	1.554	0.057	N	**S**
Pomon_CHR	1.961	11	**0.001**	**1979**	264	0.061	11	1979	22.361	3	**0.000**	**1971**	1.332	**0.008**	**Y**	**D**
Pomon_DBR	2.162	16	**0.000**	**1984**	447	**0.000**	16	**1984**	21.327	14	**0.000**	**1982**	1.044	**0.000**	**Y**	**S**
Pomon_GHY	1.124	35	0.429	2003	228	0.149	35	2003	4.069	40	0.457	2008	1.995	0.493	N	**H**
Pomon_KSH	1.331	23	0.182	1991	220	0.178	23	1991	5.368	23	0.255	1991	2.098	0.635	N	**H**
Pomon_TUL	1.771	30	**0.011**	**1998**	286	**0.034**	30	**1998**	8.277	30	0.062	1998	1.587	0.072	N	**D**

Table 3. 18 Result of homogeneity tests applied on seasonal RH series (The prefixes of the sites in the 1st column of the table, Win, Prmon, Mon and Pomon denote the four seasons winter, pre-monsoon, monsoon, and post-monsoon respectively)

The annual RH time series (Table 3.19) revealed the presence of significant trends (α=0.01 and 0.1) at four selected locations except KSH (p=0.635, SS= 0.008). RH at CHR and DBR showed the presence of significant decreasing trends, while the rest of the sites possessed increasing trends. The significant decreasing annual RH trend at DBR (p<<0.01) had the higher magnitude (SS= -0.052) as compared with that of CHR (SS= -0.049). Among the significant increasing annual RH trends, TUL had the highest magnitude (SS= 0.058, p<<0.01), followed by GHY (SS = 0.017, p=0.119).

SITES	**ANNUAL**	
	P	**SS**
CHR	0.086*	-0.049
DBR	0.000***	-0.052
GHY	0.119*	0.017
KSH	0.635	0.008
TUL	0.002***	0.058

*Table 3. 19 Result of trend analysis performed on the RH series over the selected regions; here P= p value obtained from MK test, SS= Sen's slope estimator value; +, *, ** and *** denotes significance level at 80%, 90%, 95% and 99% respectively.*

The seasonal RH during different seasons across the studied locations was detected with significant (significance level ≤80%) equal numbers (a total of 6) of increasing as well as decreasing trends with varied magnitudes (Table 3.20). Among the studied locations of NER, the seasonal RH at CHR followed all negative trends in all four seasons, contrary to TUL (all positive trends in all four seasons). At CHR, the premonsoon RH trend had the highest magnitude (SS= -0.104, p=0.049), followed by the monsoon season (SS= -0.026, p= 0.202). At DBR, only winter and postmonsoonal RH trend was significant (p<<0.01). Both of these significant trends were negative, with postmonsoon being higher in magnitude (SS= -0.131) than that of winter (SS=-0.104). At GHY, winter and premonsoon RH followed upward trends while trends in other two seasons were downward. Except monsoon, trends in all seasons were significant here. The significant positive trend at winter had the highest magnitude here (SS= 0.080, p= 0.002). At KSH, during winter, RH follows significant positive trend (p= 0.039, SS= 0.050), the magnitude of which is the highest (SS=0.050) of all seasonal trends like GHY. Another positive, but insignificant trend was observed here in premonsoon. The monsoonal and post-monsoonal RH trend was negative at KSH, among which only monsoon was significant (p=0.228, SS= -0.015). At TUL, pre-monsoon monsoon and post-monsoon trends in RH were the significant trends (90% significance level, SS= 0.124, 0.050 and 0.055 respectively).

SEASONS	CHR		DBR		GHY		KSH		TUL	
	P	SS	P	SS	P	SS	P	SS	P	SS
Win	0.593	-0.047	0.002***	-0.104	0.002***	0.080	0.039**	0.050	0.485	0.031
Premon	0.049**	-0.104	0.317	0.036	0.143+	0.046	0.635	0.017	0.007***	0.124
Mon	0.202+	-0.026	0.281	-0.020	0.428	-0.009	0.228+	-0.015	0.000***	0.050
Postmon	0.911	-0.004	0.000***	-0.131	0.049**	-0.024	0.469	-0.017	0.123+	0.055

*Table 3. 20 Result of trend analysis performed on the seasonal RH series over the selected regions; here Win= winter, Premon= pre-monsoon, Mon= monsoon and Postmon= post-monsoon; P= p value obtained from MK test, SS= Sen's slope estimator value; +, *, ** and *** denotes significance level at 80%, 90%, 95% and 99% respectively.*

Trend analysis on monthly RH over NER showed the presence of both positive and negative significant trends in the time series as evident in the table 3.21.

RH at CHR followed decreasing trends in all the months except December (trend was positive with SS=0.026, non-significant). Among them, only trends in three months, namely March, April and July were significant, with p= 0.165, 0.145 and 0.011 respectively. The significant trend with the highest magnitude for CHR was observed in March (SS=-0.125), which was followed by Aptil (SS=-0.107) and July (SS=-0.048). RH followed decreasing trends during most of the months (8 months) at DBR, like CHR. Here, RH in January, February, May, July and September to December was negative, among which January, February, July, October, November and December trends were significant (p≤0.1). Among these significant decreasing trends, the trend with the highest magnitude was observed in November (SS=-0.142) and the lowest was observed in July (SS=-0.046). At this location, no significant increasing trend was observed. At GHY, equal numbers of positive as well as negative trends of varied magnitude were detected in the monthly RH time series. Among them, four positive and only one negative trend were significant (p≤0.2). Of the significant positive trends, the highest magnitude was observed in March (SS=0.094) and the lowest one was observed in January (SS=0.064). On the other hand, the significant negative trend was observed in the month of November (p=0.013, SS=-0.054). At KSH, RH in five months followed positive trends, of which January, February and April were significant (p= 0.168, 0.111 and 0.193 respectively). Among these, the trends in February (SS=0.065) and January (SS=0.031) were the highest and the lowest in magnitude. Conversely, seven months followed decreasing trends in RH at KSH, of which only the July, September, October, and November trends were significant (p= 0.208, 0.184, 0.221, 0.039). Among these significant decreasing trends, the trend with the highest and the lowest magnitude were observed in November (SS=-0.048) and July (SS=-0.025) respectively. RH followed all positive trends in all twelve months at TUL, of which majority (March to September and December) were found to be significant (p≤0.2). Here, the highest magnitude in the RH trend was observed in the month of April (SS=0.167, p=0.009), while the lowest magnitude in the RH trend was observed in the month of June (p=0.208, SS=0.037).

MONTHS	CHR		DBR		GHY		KSH		TUL	
	P	SS	P	SS	P	SS	P	SS	P	SS
Jan	0.339	-0.076	0.002***	-0.105	0.004***	0.064	0.168+	0.031	0.972	0.002
Feb	0.546	-0.077	0.046**	-0.091	0.013***	0.093	0.111*	0.065	0.375	0.061
Mar	0.165+	-0.125	0.266	0.063	0.096*	0.094	0.587	0.027	0.165+	0.102
Apr	0.145+	-0.107	0.245	0.057	0.228+	0.075	0.193+	0.051	0.029**	0.167
May	0.389	-0.040	0.904	-0.005	0.809	-0.006	0.575	-0.022	0.009***	0.105
Jun	0.546	-0.018	0.789	0.010	0.408	-0.025	0.605	-0.010	0.208+	0.037
Jul	0.011***	-0.048	0.093*	-0.046	0.301	-0.016	0.208+	-0.025	0.000***	0.076
Aug	0.829	-0.008	0.890	0.005	0.518	0.010	0.365	-0.017	0.005***	0.065
Sep	0.660	-0.024	0.221	-0.047	0.413	-0.015	0.184+	-0.034	0.039**	0.053
Oct	0.870	-0.006	0.012***	-0.101	0.218	-0.034	0.221+	-0.031	0.856	0.006
Nov	0.322	-0.094	0.003***	-0.142	0.013***	-0.054	0.039**	-0.048	0.317	0.052
Dec	0.816	0.026	0.001***	-0.119	0.083*	0.042	0.507	0.021	0.039**	0.089

*Table 3. 21 Result of trend analysis performed on the monthly RH series over the selected regions; here P= p value obtained from MK test, SS= Sen's slope estimator value; +, *, ** and *** denotes significance level at 80%, 90%, 95% and 99% respectively.*

3.4.5a Mean Sea Level Pressure (SLP) time series

As evident from the Table 3.22, the time series of annual mean sea level pressure (SLP) at GHY and KSH were homogeneus, the same for CHR and TUL was non-homogeneous. The SLP at CHR and TUL was detected with single significant break point in the year 1976 at CHR and 1998 at TUL (identified by all four homogeneity tests), The SLP series at DBR was of doubtful in nature (break point in the year 1976, detected by only BRT and VNRT).

	BRT				**PT**				**SNHT**				**VNRT**			**Final Status**
	Stats	**Est**	**p**	**Year with CP**	**Stats**	**Est**	**p**	**Year with CP**	**Stats**	**Est**	**p**	**Year with CP**	**Stats**	**p**	**Result**	
CHR	1.636	8	**0.029**	**1976**	294	8	**0.027**	**1976**	17.644	8	**0.000**	**1976**	1.083	**0.000**	**Y**	**S**
DBR	1.656	8	**0.025**	**1976**	199	8	0.276	1976	6.945	8	0.120	1976	1.377	**0.013**	**Y**	**D**
GHY	1.302	17	0.210	1985	203	8	0.255	1976	7.825	46	0.079	2014	1.063	**0.000**	**Y**	**H**
KSH	1.448	30	0.097	1998	168	30	0.488	1998	3.516	8	0.565	1976	1.288	**0.005**	**Y**	**H**
TUL	2.385	30	**0.000**	**1998**	468	30	**0.000**	**1998**	23.951	30	**0.000**	**1998**	0.957	**0.000**	**Y**	**S**

Table 3. 22 Result of homogeneity tests applied on annual SLP series

The homogeneity tests applied on seasonal SLP over the NER (Table 3.23) revealed relative dominance of homogeneous series over suspect and doubtful series in winter followed by pre-monsoon season. The SLP at CHR, DBR, GHY and KSH was homogeneous during winter. Time series of SLP at TUL during winter was found to be non-homogeneous, with the presence of a break point in the year 1998 (detected by BRT, PT and SNHT).

The SLP during pre-monsoon season was homogeneous for the same four locations, i.e., CHR, DBR, GHY and KSH like winter. The SLP at TUL was non-homogeneous in this season also, with the presence of a break point in the year 1998 (detected by BRT, PT and SNHT).

In monsoon, SLP at CHR, DBR and TUL was found to be non-homogeneous. Break points were detected in the years 1978 and 1985 at CHR, 1985 at DBR and 1998 at TUL (detected by BRT, PT, SNHT and VNRT in all three studied locations). SLP in this season at GHY was doubtful.

During post-monsoon however, SLP only at GHY was homogeneous. SLP at DBR and KSH was non-homogeneous, with the presence of break points in the years 2004 and 2006 at DBR (detected by all four tests) and 1997 at TUL (detected by BRT, PT and SNHT). Two locations of NER were identified with doubtful nature in the SLP time series, namely CHR and KSH.

The trend analysis performed on annual SLP series (Table 3.24) revealed the presence of significant increasing and decreasing trends for three selected locations of NER, viz. CHR, GHY and TUL. Among them, CHR and GHY were detected with significant increasing trends at 90% significance level (SS=0.090 and SS=0.009 respectively). Annual SLP at TUL was significantly decreasing (p<<0.01, SS=-0.024). It was found that CHR trend was of the highest in magnitude among all detected trends (SS=0.090).

SITES	**ANNUAL**	
	P	**SS**
CHR	0.076*	0.090
DBR	0.877	0.001
GHY	0.134*	0.009
KSH	0.717	-0.001
TUL	0.000***	-0.024

*Table 3. 23 Result of trend analysis performed on the SLP series over the selected regions; here P= p value obtained from MK test, SS= Sen's slope estimator value; +, *, ** and *** denotes significance level at 80%, 90%, 95% and 99% respectively.*

The seasonal trend analysis results as displayed in the Table 3.25 revealed dominance of increasing trends in SLP over decreasing trends over NER. It was seen that three seasons at CHR, namely, winter, pre-monsoon and post-monsoon displayed significant increasing trends (SS=0.184, 0.151, 0.144 respectively) at 95% significance level. It is noteworthy that the magnitude of these seasonal trends was relatively stronger than the seasonal trends detected at other locations. The highest magnitude of all was found at CHR during winter. The post-monsoonal SLP followed a decreasing trend here, but the trend was insignificant.

SLP at DBR followed the same pattern of trends as shown by CHR. Here also SLP followed increasing trends in winter, premonsoon and monsoon, however, only the monsoonal SLP was significant (p=0.017, SS=0.013). The postmonsoonal SLP followed decreasing trend in the time series, and it was significant (p=0.043, SS=-0.021).

Seasons_site	BRT				PT				SNHT				VNRT			Final Status
	Stats	Est	p	Year with CP	Stats	Est	p	Year with CP	Stats	Est	p	Year with CP	Stats	p	Result	
Win_CHR	1.090	17	0.485	1985	222	17 NA	0.170	1985	10.609	1	**0.016**	**1969**	1.631	0.096	N	**H**
Win_DBR	1.071	9	0.515	1977	133	9 NA	0.826	1977	2.778	9	0.729	1977	1.911	0.378	N	**H**
Win_GHY	0.879	44	0.806	2012	171	44 NA	0.464	2012	7.533	44	0.089	2012	1.582	0.070	N	**H**
Win_KSH	1.111	19	0.447	1987	118	44 NA	0.997	2012	3.350	45	0.599	2013	1.848	0.298	N	**H**
Win_TUL	1.702	30	**0.017**	**1998**	305	30 NA	**0.019**	**1998**	10.814	30	**0.014**	**1998**	1.577	0.067	N	**S**
Prmon_CHR	0.921	8	0.749	1976	208	22 NA	0.230	1990	7.654	45	0.083	2013	1.576	0.066	N	**H**
Prmon_DBR	0.686	21	0.974	1989	122	11 NA	0.951	1979	2.362	45	0.812	2013	1.929	0.402	N	**H**
Prmon_GHY	0.960	41	0.690	2009	175	41 NA	0.433	2009	8.615	45	**0.049**	**2013**	1.583	0.070	N	**H**
Prmon_KSH	0.753	45	0.937	2013	114	45 NA	1.000	2013	4.234	45	0.421	2013	1.737	0.177	N	**H**
Prmon_TUL	1.577	30	**0.042**	**1998**	294	30 NA	**0.027**	**1998**	8.718	30	**0.049**	**1998**	1.600	0.079	N	**S**
Mon_CHR	1.736	17	**0.014**	**1985**	348	17 NA	**0.005**	**1985**	14.488	10	**0.001**	**1978**	1.310	**0.006**	**Y**	**S**
Mon_DBR	1.840	17	**0.005**	**1985**	355	17 NA	**0.004**	**1985**	11.705	17	**0.009**	**1985**	1.367	**0.011**	**Y**	**S**
Mon_GHY	1.392	17	0.132	1985	304	17 NA	**0.020**	**1985**	9.041	41	**0.037**	**2009**	1.589	0.073	N	**D**
Mon_KSH	1.186	19	0.346	1987	250	17 NA	0.088	1985	5.555	17	0.235	1985	1.783	0.223	N	**H**
Mon_TUL	1.618	30	**0.033**	**1998**	354	30 NA	**0.004**	**1998**	10.655	30	**0.016**	**1998**	1.586	0.072	N	**S**
Pomon_CHR	2.169	38	**0.000**	**2006**	232	38 NA	0.136	2006	8.096	8	0.064	1976	1.349	**0.010**	**Y**	**D**
Pomon_DBR	1.958	36	**0.002**	**2004**	304	36 NA	**0.020**	**2004**	13.098	38	**0.003**	**2006**	1.469	**0.029**	**Y**	**S**
Pomon_GHY	1.745	29	**0.012**	**1997**	259	29 NA	0.070	1997	6.359	29	0.160	1997	1.576	0.067	N	**H**
Pomon_KSH	1.916	36	**0.002**	**2004**	267	36 NA	0.057	2004	11.622	41	**0.008**	**2009**	1.615	0.087	N	**D**
Pomon_TUL	2.034	29	**0.001**	**1997**	425	29 NA	**0.000**	**1997**	17.135	29	**0.000**	**1997**	1.304	0.006	N	**S**

Table 3. 24 Result of homogeneity tests applied on seasonal SLP series (The prefixes of the sites in the 1st column of the table, Win, Prmon, Mon and Pomon denote the four seasons winter, premonsoon, monsoon and postmonsoon respectively)

GHY also followed the similar pattern of trends as followed by CHR and DBR in SLP. Here too, winter, pre-monsoon and monsoon followed decreasing trends while postmonsoon was detected with a decreasing trend although non-significant. At GHY, only the increasing trends in premonsoon and monsoon seasons were found to be significant (p=0.089 in case of premonsoon and p=0.003 in case of monsoon). Of the detected significant trends, the magnitude of monsoonal trend was higher (SS=0.017) than that of pre-monsoon (SS=0.014)

At KSH, the SLP time series in winter and post-monsoon followed decreasing trends while the other two seasons followed the opposite. However, among all, the increasing trend in monsoon and the decreasing trend in post-monsoon were only significant (p=0.055 and 0.140 respectively). Of the detected significant trends, magnitude of the trend in post-monsoon was higher (SS=-0.016).

All decreasing trends were detected for SLP at TUL in the seasonal trend analysis. It is noteworthy that these all-decreasing trends were significant at 90% significance level. The highest magnitude of trend was observed for post-monsoon (SS=-0.040) while monsoonal trend was the lowest in magnitude (SS=-0.016).

SEASONS	CHR		DBR		GHY		KSH		TUL	
	P	SS	P	SS	P	SS	P	SS	P	SS
Win	0.030**	0.184	0.823	0.002	0.241	0.015	0.850	-0.003	0.024**	-0.023
Premon	0.030**	0.151	0.438	0.007	0.089*	0.014	0.605	0.004	0.061*	-0.017
Mon	0.010***	0.144	0.017**	0.013	0.003***	0.017	0.055*	0.009	0.017**	-0.016
Postmon	0.474	-0.068	0.043**	-0.021	0.393	-0.009	0.140*	-0.016	0.000***	-0.040

*Table 3. 25 Result of trend analysis performed on the seasonal SLP series over the selected regions; here Win= winter, Premon= pre-monsoon, Mon= monsoon and Postmon= post-monsoon; P= p value obtained from MK test, SS= Sen's slope estimator value; +, *, ** and *** denotes significance level at 80%, 90%, 95% and 99% respectively.*

The trend analysis of monthly SLP over selected locations of NER (Table 3.26) displayed trends with varied nature and magnitudes. In case of CHR it was observed that SLP in all the months except November and December followed increasing trends, of which ten (January to August) were significant. Among the significant positive trends, the one with the highest magnitude was observed in June (SS=0.211, p=0.046), while the one with the lowest magnitude was observed in May (SS=0.129, p=0.176).

The negative trends were non-significant. It is noteworthy that the trends detected in SLP at CHR were with comparatively higher magnitude than that of the other studied locations of NER.

At DBR, six months (February to August and October) displayed presence of increasing trends in SLP. Among the increasing trends only June (p=0.053), July (p=0.103) and August (p=0.054) were significant. The highest and the lowest magnitude among the increasing trends were found for the month of June (SS=0.023) and August (SS=0.013) respectively. The rest four months, i.e., January, September, November, and December displayed trends of opposite nature, among which only the December trend was significant (p=0.009, SS=-0.036).

The monthly SLP time series at GHY exhibited increasing trends in all the months except December (negative trend, SS= -0.023; significant with p=0.076). Among the increasing trends, the trend in the month of February (p=0.121), April (p=0.208), June (p=0.058), July (p=0.160) and August (p=0.003) were significant. The significant positive trend with the highest and the lowest magnitude were detected for the month of August (SS=0.024) and April (SS=0.016) respectively.

In case of KSH, an equal amount (6 in numbers) of both increasing (April to August and October) and decreasing (January to March, September, November, and December) trends were detected in the monthly SLP series. Among these detected trends only two were significant, which are- August (p= 0.052, SS=0.017) and December (p=0.010, SS= -0.032), with the negative trend in December being comparatively higher in magnitude.

TUL among all the selected locations of NER exhibited all negative trends throughout the twelve months. Among these, 8 trends were significant for the months January (p=0.020), February (p=0.127), March (p=0.063), April (p=0.168), September (p=0.002), October (p=0.045), November (p=0.010) and December ($p<<0.01$). The highest and the lowest magnitude of the significant trends for monthly SLP at TUL was observed in the month of December (SS= -0.053) and February (SS= -0.030) respectively.

MONTHS	CHR		DBR		GHY		KSH		TUL	
	P	SS	P	SS	P	SS	P	SS	P	SS
Jan	0.136*	0.161	0.850	-0.002	0.496	0.010	0.507	-0.006	0.020**	-0.030
Feb	0.100*	0.210	0.546	0.005	0.121*	0.018	0.796	-0.003	0.127*	-0.019
Mar	0.091*	0.136	0.750	0.006	0.423	0.012	0.966	-0.001	0.063*	-0.025
Apr	0.066*	0.191	0.393	0.010	0.208+	0.016	0.737	0.005	0.168+	-0.020
May	0.176+	0.129	0.993	0.000	0.569	0.007	0.769	0.003	0.266	-0.017
Jun	0.046**	0.211	0.053**	0.023	0.058*	0.021	0.228	0.015	0.558	-0.008
Jul	0.107*	0.169	0.103*	0.015	0.160+	0.017	0.673	0.005	0.208	-0.016
Aug	0.010***	0.205	0.054**	0.013	0.003***	0.024	0.052*	0.017	0.313	-0.010
Sep	0.904	0.007	0.717	-0.003	0.490	0.007	0.698	-0.003	0.002***	-0.029
Oct	0.393	0.129	1.000	0.000	0.679	0.005	0.877	0.002	0.045**	-0.032
Nov	0.453	-0.073	0.181	-0.015	0.993	0.000	0.403	-0.009	0.010***	-0.034
Dec	0.330	-0.141	0.009***	-0.036	0.076*	-0.023	0.010***	-0.032	0.000***	-0.053

*Table 3. 26 Result of trend analysis performed on the monthly SLP series over the selected regions; here P= p value obtained from MK test, SS= Sen's slope estimator value; +, *, ** and *** denotes significance level at 80%, 90%, 95% and 99% respectively.*

3.4.7a Wind speed (WS) time series

The homogeneity tests performed on the annual WS series over NER resulted into the identification of non-homogeneous series for four locations- CHR, GHY, KSH and TUL (Table 3.27). Three breakpoints were detected in the years 1971, 1993 and 1995 (by all four homogeneity tests) in case of CHR. Only one break point was detected at GHY and TUL, in the year 1989 (GHY) and 1991 (TUL) by all four homogeneity tests. KSH was detected with two break points in the years 1982 and 1996 (by all four homogeneity tests). On the other hand, annual WS at DBR was found to be doubtful in nature.

	BRT				PT				SNHT				VNRT			Final Status
	Stats	Est	p	Year with CP	Stats	p	Est	Year with CP	Stats	Est	p	Year with CP	Stats	p	Result	
CHR	2.069	25	**0.001**	**1993**	583	**0.000**	27	**1995**	34.330	3	**0.000**	**1971**	0.214	**0.000**	Y	S
DBR	1.354	20	0.163	1988	163	0.530	20	1988	9.029	47	**0.039**	**2015**	1.020	**0.000**	Y	D
GHY	2.438	21	**0.000**	**1989**	485	**0.000**	21	**1989**	23.451	21	**0.000**	**1989**	0.515	**0.000**	Y	S
KSH	2.305	28	**0.000**	**1996**	519	**0.000**	28	**1996**	22.417	14	**0.000**	**1982**	0.536	**0.000**	Y	S
TUL	2.236	23	**0.000**	**1991**	408	**0.000**	23	**1991**	16.065	23	**0.000**	**1991**	0.487	**0.000**	Y	S

Table 3. 27 Result of homogeneity tests applied on annual WS series

The homogeneity tests applied on the seasonal series of WS (Table 3.28) revealed the detection of inhomogeneity in most cases (16 out of 20), followed by only 3 series to be identified as homogeneous.

WS during winter in NER was non-homogeneous except at DBR (homogeneous) and TUL (doubtful). WS n winter season at CHR, GHY and KSH was detected with two break points in each series. CHR series was detected with break points in the years 1971 and 1995 (detected by all four homogeneity tests), GHY with break points in the years 1989 and 1990 (detected by all four homogeneity tests) and KSH with break points in the years 1996 and 1999 (detected by all four homogeneity tests).

In pre-monsoon season again, WS series at DBR was homogeneous and all the other locations were detected with one to three break points by all four tests in WS series, thus, making them non-homogeneous. The year(s) with break points detected at CHR were 1971, 1993 and 1995, at GHY it was the year 1988, at KSH the years were 1985 and 1992 and at TUL 1991 was the year with break points.

The monsoonal WS across the studied locations in NER was non-homogeneous. The break points were detected in the years 1970 and 1993 for CHR series (detected by all four homogeneous tests). In case of DBR, the years 1989 and 2015 carried break points (detected by all four homogeneous tests) and in case of GHY, the years 1988 and 1989 were detected with break points (detected by all four homogeneous tests). TUL series was also detected with break points in the years 1991 and 1992.

The nature of WS time series during post-monsoon was similar to that of pre-monsoon. In this season, WS at all locations except DBR was detected with break points identified by all four homogeneous tests. The years with detected break points at these locations were-1971 and 1994 for CHR, 1989 and 1990 for GHY, 1999 and 2002 for KSH and 1998 for TUL.

As evident in Table 3.29, the annual time series of WS exhibited significant (at 99% significance level) decreasing trends at all selected locations of NER except DBR. Among these significant trends, CHR trend had the highest magnitude as compared with the other trends (SS= -0.142) and TUL trend had the lowest magnitude (SS= -0.025). The trend at DBR was positive, byt insignificant.

SITES	ANNUAL	
	P	SS
CHR	0.000***	-0.142
DBR	0.945	0.000
GHY	0.002***	-0.042
KSH	0.000***	-0.067
TUL	0.004***	-0.025

*Table 3. 28 Result of trend analysis performed on the WS series over the selected regions; here P= p value obtained from MK test, SS= Sen's slope estimator value; +, *, ** and *** denotes significance level at 80%, 90%, 95% and 99% respectively.*

The results of seasonal trend analysis on WS are presented in Table 3.30. As seen in the table, negative trends were prevalent in the seasonal analysis at most of the sites (all decreasing at CHR, GHY, KSH and TUL, decreasing in winter and pre-monsoon at DBR). At CHR, all the detected decreasing seasonal trends were highly significant ($p<<0.01$) and of higher magnitude as compared to the other selected locations of NER. Among these seasonal trends, the one during monsoon had the highest magnitude (SS= -0.161) while the one in post-monsoon was with the lowest magnitude (SS= -0.125).

At DBR, winter and pre-monsoon season exhibited negative whereas monsoon and post-monsoon season exhibited positive trends. Both the detected negative trends were significant, between which the trend in winter was stronger (SS= -0.024, p=0.046) than that in pre-monsoon (SS= -0.019, p=0.165). Conversely, the detected positive trend in monsoon only was significant (p= 0.059, SS= 0.022). WS at GHY followed all significant decreasing trends across the seasons, of which the season with the greatest magnitude in trend was found for pre-monsoon season (SS= -0.055, p=0.005) and the opposite was found for winter (SS= -0.032, $p<<0.01$). KSH also followed the similar pattern of exhibiting all significant negative trends at $\alpha=0.01$. The highest magnitude was observed for the pre-monsoon season (SS=-0.094) and the lowest was observed for the post-monsoon season (SS= -0.043). In case of TUL, trends in WS detected during pre-monsoon, monsoon and post-monsoon were found to be significant (p= 0.018, 0.001 and 0.123 respectively). Among them, the trend with the highest and the lowest magnitude were observed in pre-monsoon (SS= -0.040) and winter (SS= -0.007) respectively.

In the monthly analysis of WS (Table 3.31), three locations of NER, viz., CHR, GHY and KSH were detected with all months exhibiting significantly decreasing trends at 95% significance level.

At CHR the magnitude of the detected trends was higher than that of the other locations. Here, the highest magnitude of trend was observed in the month of July (SS= -0.195) and the lowest was observed in October (SS= -0.119). At DBR however, an equal number of months, i.e., from May to October displayed increasing trends in WS, of which only June (p=0.143), July (p=0.111), September (p=0.016) and October (p=0.050) trends were significant. Among these significant increasing trends, the highest and the lowest magnitudes were observed for the months of September (SS= 0.040) and June (SS= 0.022) respectively. To the contrary, only the decreasing trends in January (p=0.143), February (p=0.113) and March (p= 0.077) were significant. Among these significant decreasing trends, the highest magnitude was observed for the month of March (SS= -0.027) and the opposite was observed for the month of January (SS= -0.022). Trend in WS series at GHY revealed that the highest magnitude of trend was observed in the month of May (SS= -0.062) and the lowest was observed in January and December (SS= -0.025). At KSH again, the highest magnitude of the detected all decreasing trends was observed in the month of July (SS= -0.102) and the lowest was observed in December (SS= -0.025). WS at TUL followed significant decreasing trends (at least 90% significance level) in all months except in January, February, and December. Of the significant trends, the highest and the lowest magnitude of trend were observed for the month of May (SS= -0.046, p= 0.006) and November (SS= -0.014, p=0.120) respectively.

Seasons_site	BRT				PT				SNHT				VNRT			Final Status
	Stats	Est	p	Year with CP	Stats	Est	p	Year with CP	Stats	Est	p	Year with CP	Stats	p	Result	
Win_CHR	2.052	27	**0.001**	**1995**	544	27	**0.000**	**1995**	25.311	3	**0.000**	**1971**	0.535	**0.000**	**Y**	**S**
Win_DBR	1.402	37	0.128	2005	234	36	0.130	2004	6.178	48	0.168	2016	1.659	0.115	N	**H**
Win_GHY	2.126	21	**0.000**	**1989**	451	21, 22	**0.000**	**1989, 1990**	18.456	21	**0.000**	**1989**	1.102	**0.000**	**Y**	**S**
Win_KSH	2.069	28	**0.001**	**1996**	413	28	**0.000**	**1996**	17.097	31	**0.000**	**1999**	0.909	**0.000**	**Y**	**S**
Win_TUL	1.689	28	**0.021**	**1996**	259	28	0.070	1996	6.384	28	0.154	1996	1.129	**0.001**	**Y**	**D**
Prmon_CHR	2.257	25	**0.000**	**1993**	528	27	**0.000**	**1995**	22.961	3	**0.000**	**1971**	0.526	**0.000**	**Y**	**S**
Prmon_DBR	1.339	10	0.176	1978	196	32	0.293	2000	5.955	47	0.197	2015	1.045	**0.000**	**Y**	**H**
Prmon_GHY	2.338	20	**0.000**	**1988**	438	20	**0.000**	**1988**	19.967	20	**0.000**	**1988**	0.491	**0.000**	**Y**	**S**
Prmon_KSH	2.389	17	**0.000**	**1985**	497	24	**0.000**	**1992**	25.185	17	**0.000**	**1985**	0.684	**0.000**	**Y**	**S**
Prmon_TUL	2.521	23	**0.000**	**1991**	426	23	**0.000**	**1991**	17.973	23	**0.000**	**1991**	0.659	**0.000**	**Y**	**S**
Mon_CHR	1.823	25	**0.007**	**1993**	558	25	**0.000**	**1993**	35.264	2	**0.000**	**1970**	0.395	**0.000**	**Y**	**S**
Mon_DBR	1.645	21	**0.027**	**1989**	286	20	**0.034**	**1988**	9.974	47	**0.022**	**2015**	1.115	**0.001**	**Y**	**S**
Mon_GHY	2.049	21	**0.001**	**1989**	402	21	**0.001**	**1989**	15.265	20	**0.001**	**1988**	0.933	**0.000**	**Y**	**S**
Mon_KSH	2.470	23	**0.000**	**1991**	466	23	**0.000**	**1991**	21.942	23	**0.000**	**1991**	0.590	**0.000**	**Y**	**S**
Mon_TUL	2.356	23	**0.000**	**1991**	466	24	**0.000**	**1992**	20.228	23	**0.000**	**1991**	0.430	**0.000**	**Y**	**S**
Pomon_CHR	2.020	26	**0.001**	**1994**	561	26	**0.000**	**1994**	36.291	3	**0.000**	**1971**	0.364	**0.000**	**Y**	**S**
Pomon_DBR	1.406	19	0.126	1987	178	19	0.410	1987	5.054	47	0.301	2015	1.450	**0.025**	**Y**	**H**
Pomon_GHY	2.254	21	**0.000**	**1989**	495	22	**0.000**	**1990**	19.143	21	**0.000**	**1989**	0.745	**0.000**	**Y**	**S**
Pomon_KSH	1.721	31	**0.015**	**1999**	330	31	**0.009**	**1999**	11.837	34	**0.007**	**2002**	0.999	**0.000**	**Y**	**S**
Pomon_TUL	1.842	30	**0.004**	**1998**	316	30	**0.014**	**1998**	9.518	30	**0.030**	**1998**	1.011	**0.000**	**Y**	**S**

Table 3. 29 Result of homogeneity tests applied on seasonal WS series (The prefixes of the sites in the 1st column of the table, Win, Prmon, Mon and Pomon denote the four seasons winter, premonsoon, monsoon and postmonsoon respectively)

SEASONS	CHR		DBR		GHY		KSH		TUL	
	P	SS	P	SS	P	SS	P	SS	P	SS
Win	0.000***	-0.134	0.046**	-0.024	0.000***	-0.032	0.000***	-0.052	0.379	-0.007
Premon	0.000***	-0.155	0.165+	-0.019	0.005***	-0.055	0.000***	-0.094	0.018***	-0.040
Mon	0.000***	-0.161	0.059*	0.022	0.012***	-0.042	0.000***	-0.088	0.001***	-0.037
Postmon	0.000***	-0.125	0.756	0.004	0.000***	-0.040	0.003***	-0.043	0.123*	-0.013

*Table 3. 30 Result of trend analysis performed on the seasonal WS series over the selected regions; here Win= winter, Premon= pre-monsoon, Mon= monsoon and Postmon= post-monsoon; P= p value obtained from MK test, SS= Sen's slope estimator value; +, *, ** and *** denotes significance level at 80%, 90%, 95% and 99% respectively.*

MONTHS	CHR		DBR		GHY		KSH		TUL	
	P	SS	P	SS	P	SS	P	SS	P	SS
Jan	0.000***	-0.138	0.143*	-0.022	0.005***	-0.025	0.009***	-0.043	0.500	-0.004
Feb	0.000***	-0.144	0.113*	-0.025	0.001***	-0.043	0.000***	-0.066	0.593	-0.007
Mar	0.000***	-0.145	0.077*	-0.027	0.030**	-0.044	0.000***	-0.097	0.060*	-0.030
Apr	0.000***	-0.147	0.469	-0.014	0.014***	-0.051	0.000***	-0.099	0.082*	-0.030
May	0.000***	-0.150	0.890	0.002	0.018**	-0.062	0.001***	-0.078	0.006***	-0.046
Jun	0.000***	-0.150	0.143*	0.022	0.021**	-0.048	0.001***	-0.087	0.000***	-0.047
Jul	0.000***	-0.195	0.111*	0.029	0.036**	-0.038	0.000***	-0.102	0.000***	-0.045
Aug	0.000***	-0.171	0.361	0.016	0.018**	-0.036	0.001***	-0.084	0.005***	-0.041
Sep	0.000***	-0.147	0.016**	0.040	0.015**	-0.031	0.001***	-0.064	0.109*	-0.020
Oct	0.000***	-0.119	0.050**	0.029	0.001***	-0.047	0.002***	-0.070	0.118*	-0.015
Nov	0.000***	-0.143	0.822	-0.002	0.002***	-0.046	0.007***	-0.041	0.120*	-0.014
Dec	0.000***	-0.129	0.763	-0.004	0.001***	-0.025	0.032**	-0.025	0.573	-0.002

*Table 3. 31 Result of trend analysis performed on the monthly WS series over the selected regions; here P= p value obtained from MK test, SS= Sen's slope estimator value; +, *, ** and *** denotes significance level at 80%, 90%, 95% and 99% respectively.*

3.5 Summary

In the context of a changing climate scenario, it is essential to rule out the climate induced long-term trends from those which imitate as the climatic trends. With this aim we investigated the homogeneity in rainfall as well as in other meteorological variables such as temperature, relative humidity, sea level pressure and WS, and subsequently subjected them to trend analysis (for the detection of significant trends).

From the analysis of homogeneity and trend in rainfall it was noticed that the annual and seasonal rainfall in NER is homogeneous in nature. The annual rainfall was significantly decreasing at DBR, while at three locations (CHR, KSH and TUL) it had been found increasing, though the increase was insignificant. In seasonal analysis of rainfall, it came to notice that the winter rainfall at DBR, GHY and TUL was declining. The decrease in winter rainfall was significant at DBR, which may be the cause for the declining annual rainfall at this site. The pre-monsoonal rainfall at all the sites of NER was increasing, and among them the increasing trends at GHY and TUL were significant. To the opposite, monsoonal rainfall in most of the sites of NER (CHR, DBR and GHY) was found to be declining and this decline was significant at DBR and GHY. Rainfall during the post-monsoon season was also declining in NER but this decline was insignificant. The presence of significant trends in different seasons can be elaborated well from the monthly trend analysis. The rainfall at DBR during the winter months was decreasing and the decline in January rainfall was significant, that may be cause for the overall decline in rainfall during winter at this site. Among the pre-monsoonal months (March, April and May), rainfall in April and May at GHY was increasing, and the increase in April was significant, that may be contributing to the significant increase in pre-monsoon at this site. Likewise, April and May rainfall at TUL was also following increasing trends (March rainfall was decreasing; insignificant), and the increase in May was significant, that may lead to the overall significant increase in the premonsoonal rainfall at TUL. The dominance of decreasing trends during monsoonal months (June, July, August, and September) was observed at all the selected locations of NER. At GHY, this decreasing trend persisted across all the monsoonal months and the July trend was significant, thus may be leading to the overall significant decline in the monsoonal rainfall at this site. The same may be conferred from the DBR rainfall. Here, rainfall also showed decreasing trends in three of the monsoonal months, of which the July trend was significant. Other than DBR and GHY, monsoon of CHR, KSH and TUL also showed significant trends in rainfall, but this trend persisted for only one month. This may be the reason why monsoonal rainfall at the other sites were declining, but non-significantly. Among the post-monsoonal months (October, November, and December), only the November (all the sites) and December (DBR, KSH) months were bearing significant declining trends. Rainfall trend in two months (October and November) at CHR were declining, but the overall postmonsoonal trend was insignificant. The presence of declining trends in these two months may lead to the relatively higher magnitude (SS= -3.348, Table 3.5) of the postmonsoonal trend at CHR. The same reason may be conferred for DBR too. At KSH the October and December trends were positive (December trend was also significant), which may compensate the effect of the significant decreasing trend in November, thus making the overall post-monsoonal rainfall to be increasing, but insignificant at KSH.

From the homogeneity tests on maximum temperature (MaxT), it was seen that the annual maximum temperature over NER was non-homogeneous. The inhomogeneous nature of annual MaxT was confirmed further when these time series were detected with highly significant ($p<<0.01$) increasing trends upon subjected to trend analysis. These highly significant trends denote the shifts in the time series of MaxT at various studied locations in NER causing inhomogeneities and signifies artificially induced trends. The further testing of the seasonal series also revealed inhomogeneity in majority of the seasonal series (suspect series), except for pre-monsoon at DBR and KSH. It was later noticed that these seasonal MaxT also exhibited significant ($p<0.05$) increasing trends except for pre-monsoon at DBR and KSH. Thus, it could be concluded that MaxT at none of the studied locations of NER followed significant climatic trends. The significant seasonal trends may be the result of the presence of the break points present in time time series. The MaxT time series upon segregation into monthly series displays the confirmation of inhomogeneity in the seasonal series. It could be visualized from the monthly trend analysis that the monthly MaxT at almost all the locations were detected with mostly significant increasing trends, that may be the results of the inherent inhomogeneities in the seasonal series. The pre-monsoonal months of March, April and May at DBR and KSH were deprived of significant trends except in May (weak increasing trend at 80% significance level, Table 3.11). Thus. it could be assumed that this significant monthly trend may be contributing to the the increase in the pre-monsoonal MaxT (though insignificant) at these two sites.

The annual MinT over NER was found to be inhomogeneous at all the sites except CHR. Further on, the trend analysis performed on annual MinT resulted into the detection of highly significant ($p<<0.01$) positive trends except at CHR, which could be described as the effect of these inhomogeneities at those sites. The annual trend in MinT at CHR was insignificant, thereby implying the absence of any climatic trend in the series. The seasonal MinT on homogeneity testing revealed inhomogeneity in the time series except CHR for winter (homogeneous), pre-monsoon (doubtful) and post-monsoon (homogeneous) as evident in Table 3.13. When trend analysis was performed on the seasonal MinT series later, it was observed that MinT at all selected locations of NER were increasing significantly except in winter and post-monsoon of CHR. The homogeneous series of post-monsoonal MinT at CHR followed a significant decreasing trend (80% confidence level), which could be the signature of climatic trend in this region. Further on, upon analysing the monthly trends in MinT, significant increasing trends were detected in the series over NER except CHR (January, March to April, October, November, and December, Table 3.16), thus, implying the influence of seasonal break points on these false trends. It was observed that MinT in the post-monsoonal months was decreasing, among which the decline in November was significant ($p=0.050$). This indicated that this decreasing November trend may be contributing to the significant decline in the post-monsoonal MinT time series at CHR.

The nature of relative humidity (RH) at annual scale over NER was found to be different at different locations. RH at GHY was homogeneous, while at CHR, DBR and TUL it was non-homogeneous. The nature of annual RH at KSH was doubtful. The presence of significant annual trends at CHR, DBR and TUL (90% confidence level for CHR, 99% for both DBR and TUL) confirmed the non-homogeneous nature of annual RH at these locations. Annual trend in RH at KSH was insignificant, however, the homogeneous RH series at GHY was detected with a significant increasing trend (at 80% confidence level), which could be described as an effect of changing climate over this region.

When RH series was segregated into seasonal series, it was found that the RH at CHR in winter and post-monsoon was doubtful in nature, while in pre-monsoon and monsoon it was homogeneous. When these seasonal series were analysed for trend, significant decreasing trends were observed only in the homogeneous series, i.e., pre-monsoon and monsoon. The detection of significant decline in these trends in the homogeneous series thus may indicate towards the declining climatic trends in pre-monsoon and monsonal RH over CHR. Subsequently, in monthly trend analysis the March and April months were detected with significant (80% confidence level) decreasing trends, thus, implying decreasing pre-monsoonal RH. The detection of significant decreasing trend in July (99% significance level) may also be the indicative of climatic trend at CHR.

RH in winter and post-monsoon was non-homogeneous with the presence of several break points in DBR. The effect of these break points may be seen as the presence of significant trends in the corresponding seasonal and monthly RH series. Other than that, RH in pre-monsoon and monsoon season at DBR was homogeneous and did not follow any significant trend, implying not significant change in RH. This was reflected in the monthly analysis also, where among the pre-monsoon and monsoon season, only the July RH was significantly declining (90% confidence level), may be contributing toward the non-significant decreasing trend in monsoon.

In case of KSH, RH in the pre-monsoon and post-monsoon seasons was homogeneous. No significant trend was detected in these homogeneous series too. On the other hand, here the winter series was non-homogeneous and the inhomogeneities could be the result of the significant winter trend (95% confidence level) at KSH. This result was confirmed by the presence of significant positive trends in the winter months in monthly analysis. Monsoonal RH series at KSH was doubtful in nature, and it was detected with a significant declining trend. For clarity of the nature of trend here, a prolonged observational period may be needed.

RH at TUL was homogeneous in winter and lacking any significant trend both in the seasonal series and winter series. Conversely, RH was non-homogeneous in monsoon and displayed the presence of a significant increasing trend (99% confidence level), which may be resulted because of the presence of break points, that may have induced significant positive trends in the rain bearing months. RH was of doubtful in nature during pre-monsoon and post-monsoon at TUL. The presence of significant trends during these seasons may be given emphasis and a prolonged observational record of data may be needed to clarify if the doubtful series becomes homogeneous.

The seasonal RH at GHY was homogeneous entirely during pre-monsoon, monsoon, and post-monsoon, while the winter RH at GHY was non-homogeneous. The non-homogeneous winter RH was seen to be inducing false significant positive trends also (evident in the seasonal and monthly trend analysis of RH). At GHY, the detection of significant trends in respective seasonal as well as monthly time series of pre-monsoon (increasing trends, 80% confidence level) and in post-monsoon (decreasing trends, 95% confidence level) may be indicative of climate induced changes in these seasons.

The annual SLP was found to be non-homogeneous at CHR and TUL and as both series were identified with significant positive trends, the trends may be concluded as false trends. At GHY and KSH, the time series were homogeneous, and no significant trend was detected here, thus, indicating the sustenance of constant properties of the time series. DBR series was doubtful in nature and displayed no significant trend in trend analysis. Thus, a further prolonged observational period may be needed to investigate this doubtful series in detail. In case of seasonal analysis of SLP, winter and premonsoon season was homogeneous at CHR. These two seasons were identified with significant increasing trends in seasonal and annual trend analysis too, thus indicating an increase in SLP over CHR. The monsoon at CHR was with a significant increasing trend, which may be conferred as an induced artificial shift due to the non-homogeneous nature of the series. The presence of significant increasing trends in the monsoonal months (except September) may be the contribution to this seasonal change. At DBR, winter and pre-monsoon SLP series were homogeneous, and no significant trend was observed in both of them. The monthly analysis supports these findings. During monsoon however, the SLP series at DBR was non-homogeneous. Significantly increasing SLP (95% confidence level) may be the result of the break points detected in the seasonal homogeneity testing. The presence of significant increasing trends in the monsoonal months trend analysis results also reveal the same. The same can be conferred for post-monsoon series also; the inhomogeneities inducing artificial trends in the series. At GHY, SLP in all the seasons except monsoon were homogeneous (monsoon was doubtful). Among the homogeneous seasonal series, only pre-monsoon was detected with significant upward trend, thus, implying increase in SLP over time during pre-monsoon for this region. From the monthly analysis it could be noticed that April month (80% confidence level) may be contributing to this increasing trend. Monsoon at GHY was doubtful in the SLP series. The presence of significant increasing trend in monsoon (also in the monsoonal months) should be noted for further investigation since the series was doubtful. In case of SLP at KSH, all the seasons were found to be homogeneous except post-monsoon. The presence of the only significant positive trend in monsoon (90% confidence level) suggested the increasing SLP over KSH as a climatic signature. From the monthly analysis it could be said that the overall increasing trends in the three monsoonal months with August being the significant one (95% confidence level) may have contributed to the monsoonal increasing trend. SLP series at TUL was non-homogeneous for all the seasons. Also, the seasonal trend analysis detected significant decreasing trends (90% confidence level) in all of these seasons (revealed in the monthly analysis too). Thus, these trends although are very significant may be attributed to the inhomogeneities caused by the shifts in time series, implying no change in SLP over this region.

In case of WS (WS), the annual series at CHR, GHY, KSH and TUL were non-homogeneous and detected with significant (99% confidence level) decreasing trends. These trends were therefore concluded to be the results of the inhomogeneities present in the series. WS at DBR was found to be doubtful, also no significant trend was observed here. Thus, it may be concluded that the annual WS over NER has not changed over time.

In the seasonal series, it could be seen that WS was non-homogeneous across the selected locations of NER except DBR and TUL during winter season. The inhomogeneities in winter series of WS seemed to result into significant decreasing trends, imitating as climatic trends. Similar illustrations could be made for the significant monthly trends in winter months. The DBR series at winter was homogeneous and was detected with significant (95% confidence level) decreasing trend, implying a decrease in WS during winter. TUL series was doubtful, and it didn't have any significant trend, thus indicating similar inferences made for monsoonal SLP at GHY. Pre-monsoonal WS was non-homogeneous for all the series except for DBR and the shifts due to the inhomogeneity inducing significant false trends could be seen clearly in seasonal as well as monthly analysis of trend. WS in pre-monsoon at DBR was homogeneous and a significant declining trend (80% confidence level) was detected in this series. Among the pre-monsoonal months, significantly declining March trend may be attributing to the overall seasonal decrease in pre-monsoon at this site. WS during monsoon at all the selected location of NER was non-homogeneous. The significant trends detected in the trend analysis during this season, thus, can be concluded as the results of inhomogeneities. Further on, the monsoonal months throughout the selected locations could be seen with significant increasing or decreasing trends in the monthly trend analysis, which confirms the inhomogeneity induced effects on the WS time series. The nature of post-monsoonal WS series across the selected location in NER was like the pre-monsoonal WS. Therefore, similar inferences could be drawn for WS in post-monsoon also. However, the seasonal analysis for post-monsoon confirms no significant trends in WS.

3.6 References

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