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ORIGINAL ARTICLE

Trend Analysis and Change Point Detection of Mean Air Temperature: A Spatio-Temporal Perspective of North-Eastern India

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Abstract The climate change phenomenon has become more imminent in the present century than ever before, as indicated by the unabated rise in atmospheric temperature aberrations from local to regional scales. Our study focuses on the changes in mean air temperature (Tavg) in the parts of eastern Himalaya, representing Naga, Lusai and Khashi hills, extended over the regional boundaries of seven northeast Indian states. We observed statistically significant increase in annual Tavg, for the majority of ground meteorological stations in northeast India. Monthly values depict significant increase for Basar, Imphal and Gangtok in the majority of the months, followed by Umiam, Kolasib and Kailashahar. Despite the spatial variability, the overall range of increase in Tavg is 0.2 °C to 1.6 °C per decade across the study region. Significant rise in Tavg during the winter is experienced by five out of seven places. Change-point detection analysis revealed that Tavg values of Imphal experienced maximum number of shifts during the early to late 1990s, followed by Gangtok, Basar, Umiam and Kolasib. Shifts

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in Tavg during winter months are also most common and occurred during the late-1990s. The results may be used in modelling the impact of changing climate on the ecosystem and agriculture of north-east India.

Keywords Climate Change · Mann-Kendall Test · Pettitt Test · North-eastern India

1 Introduction

The certainty of the expected climate change keeps on raising several questions regarding the amassed effect of these ecological changes on food security in the near future. The dynamics of change in different climatic parameters play a crucial role in deciding the net cumulative influence of climate change on the agricultural production of a region, surface hydrology etc. However, the spatiotemporal behaviour and the extent of these environmental changes are highly location-specific and variable. The phenomenon of climate change has already left its footprint globally, with the change of its indicators such as increase in temperature and mean sea level, rise in the extreme rainfall events, retreat of glaciers etc. Researchers have long been exploring different strategies to find out the extent of changes in different weather variables over several parts of the globe. Sometimes, they have utilized the global/regional level gridded data to understand the change and variability in climatic variables over a large region of the globe (Frich et al. 2002; Alexander et al. 2006), to the scale of continents like Asia (Klein Tank et al. 2006) and even, to much finer scale of specific country like China (Liu et al. 2005). Though these studies can show a large spatio-temporal trend over a broad region, many times they lack the local perspective. Contrary to these, there are several studies, which have analysed the historical observed climatic point data, i.e., pertaining to a particular place, to understand the changes at the local level. These studies are also conducted at different scale, at country level, e.g., Rao et al. (2005) and Kothawale et al. (2010) analysed climatic data from 103 and 121 different weather stations, respectively, to understand the changes in temperature over India. While, at the regional level, Jhajharia and Singh (2011) and Machiwal and Jha (2016) studied station data from 8 and 10 different weather stations, respectively, pertaining to humid and arid regions of India for understanding the changes in climatic variables in those areas. Such studies are also done at the scale of small states, like Mizoram (Saha et al. 2015), or even at the scale of a city, like Raipur (Jaiswal et al. 2015). It is needless to say that all these changes are bound to have several impacts on the ecosystem as well as agriculture, although these impacts will vary based on region, crop, its variety and different cultural management practices. Nevertheless, the food security and sustainability of the globe, as well as that of Indian agriculture, are facing serious challenges from these global climate change impacts (Jain et al. 2013).

The northeast India is a resource rich region. It receives much higher rainfall (about 2.5 times higher) as compared to other regions of India. Hence, the region was thought to be out of the adverse effects of environmental change (Dash et al. 2009). The region harbours a large number of agro-biodiversity and ethnic tribal communities. It is also presently facing the negative consequences of climate change in the form of altered rainfall distribution and amount (Jhajharia et al. 2012a; Jain et al. 2013; Saikia et al. 2013; Goyal 2014; Saha et al. 2015; Chakraborty et al. 2017), increase in air temperature (Deka et al. 2009; Chattopadhyay et al. 2011; Chakraborty et al. 2014; Saha et al. 2016), changes in sunshine duration (Jhajharia and Singh 2011; Choudhury et al. 2012), humidity (Choudhury et al. 2012), cloud cover,

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evaporation (Jhajharia et al. 2009), wind etc. These changes pose a great threat to the unexplored diverse biodiversity and natural resources in particular, and environmental security and sustainability of this region in general (Jhajharia and Singh 2011; Jha et al. 2013; Jain et al. 2013; Saha et al. 2015). Apart from flood condition, this high rainfall receiving zone has even faced some unprecedented drought like situations in recent past (Das et al. 2009). There is evidence that heavy rainfall events during the monsoon months are significantly increasing in northeast India, making the region more flood prone (Dash et al. 2009).

Temperature is one of the dominant atmospheric variables having significant and direct influence on almost all hydrological variables (Sonali and Nagesh Kumar 2013). Increase in temperature in the recent times is mainly attributed to the rise in concentration of greenhouse gases resulting from enhanced anthropogenic activities (Feidas et al. 2004). The Intergovernmental Panel on Climate Change (IPCC 2007) reported that mean temperature of the globe has increased by 0.74 °C over the last century, though the rates differed significantly from region to region (IPCC 2007). The growth of population, deforestation, changes in land use, industrialization and increasing atmospheric concentrations of greenhouse gases constitute the main anthropogenic drivers of this warming. These factors are prevalent all over the world; even the north-east Indian region is not far from its reach. Temperature being one of the most important weather variables not only determines the suitability of a particular crop to a zone but it also determines the water requirement of the plants/crops through evapotranspiration. Apart from that, it also indirectly influences the metabolisms like respiration, photosynthesis and above all the reproduction, i.e., viability of the pollens etc. The general expectation is that increase in temperature, i.e., global warming, will lead to an increase in evaporation or evapotranspiration, a key component of the hydrologic cycle leading to increase in the water demand by the plants (Jhajharia and Singh 2012b). However, some reports indicate that despite the increase in air temperature, evaporation and/or evapotranspiration decreased in some regions across the globe. The attribution analysis using widely used Penman potential evaporation (Ep) could clearly show that the largest change (increase) in Ep was due to temperature, but all other remaining variables like humidity, radiation and wind speed acted to reduce Ep, resulting in an overall decrease in Ep (Donohue et al. 2010; Jhajharia and Singh 2012b). Hence, it is quite clearly shown that temperature and mostly its mean or average over a particular duration still remains the most crucial factor governing many hydrological processes of the ecosystem as well as physiological processes of the plants.

Several researchers have explored the temperature data over India and its different part for analysis of trend and fluctuations. One of the earlier studies by Hingane et al. (1985) reported an increase of 0.4 °C in annual mean temperature (Tmean) in India over the past century. The mean air temperature data (1901–2000) from well-distributed representative stations over India was used by Rupa Kumar et al. (2002), to reach the conclusion that warming trends were evident during all four seasons, but the rate was higher during winter (0.04 °C/decade) and post-monsoon (0.05 °C/decade) seasons, compared to that of annual average (0.03 °C/decade). Increasing trend in temperature over large plains spreading across the countries, such as the Ganga basin in India and neighbouring Bangladesh, was reported by Kothyari and Singh (1996) and Ahmad and Warrick (1996), respectively. Also, Shrestha et al. (1999) reported a substantial warming in the climatologically cooler region of mountainous Himalaya at the rate ranging from 0.06 to 0.12 °C/year.

The north-eastern region of India experienced increase in mean maximum temperature at a rate of 0.11 °C/decade (Das 2004). The annual mean temperature was found to be increasing at a rate of 0.04 °C/decade over this region (Pant and Rupa Kumar 1997; Das 2004). Recent studies could also find significant increase in annual maximum (Tmax) and Tmean from 1901 to 2003 to the extent of 1.02 °C and 0.60 °C/100 years, respectively (Deka et al. 2009). Tmax

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increased by 1.5 °C and 1.2 °C during the post-monsoon season and winter months, respectively. Deka et al. (2009) also observed the tendency of significant increase in minimum temperature during post-monsoon (~0.64 °C/100 years) and winter season (0.61 °C/100 years). The rise in mean atmospheric temperature was highest during post-monsoon (1.09 °C) followed by winter (0.92 °C) season. They argued that the temperature did not rise during monsoon months which might be due to the cooling effect of rainfall as it balances a portion of the increasing trend in temperature. Jhajharia and Singh (2011) analysed the data from eight sites spreading over north-eastern India and showed the significant increasing trends in Tmax, between 0.1 to 0.9 °C/decade in three sites, while Tmin increased in five sites and Tmean over four sites. Increase in Tmean ranged between 0.2 to 0.8 °C/decade over this region. They have reported an increase in temperature during monsoon and post-monsoon seasons, while the changes were not significant during other seasons.

Nowadays, along with the gradual trends in all the climatic parameters, exploring the abrupt change, i.e., shift in time series has also become integrated part of climate change and variability analysis. It can be said that a trend indicates a gradual change occurring over a certain time period, while the change point occurs abruptly and often changes the weather variable such as rainfall or temperature into a completely altered regime (Shahin et al. 1993; Machiwal et al. 2017). Though there are several studies related to trend analysis of climatic variables, change point analysis has recently gained importance all over the globe. Zarenistanak et al. (2014) and Talaee et al. (2014) have studied the change points in temperature and evapotranspiration time series, respectively. Malekian and Kazemzadeh (2016) studied the shift changes of auto-correlated temperature series in Urmia lake basin of north-western Iran. While in India, Jaiswal et al. (2015) studied the change points of different climatic variables of Raipur city belonging to Chhattisgarh state. Recently, Machiwal et al. (2017) have also explored the abrupt changes or change points in the annual rainfall time series of arid regions of western India.

Several studies have been reported regarding the trend of meteorological variables in the North Eastern region of India. However, the reports suffer from two major limitations: (a) the results are derived from the gridded dataset of variable resolutions, which are not ground validated for the undulating and difficult topography (Jha et al. 2013; Saikia et al. 2013), as there may be issues of interpolation or lack of altitude wise evenly distributed meteorological data; (b) these studies did not have separate representation from each of the northeast Indian states (Jhajharia and Singh 2011; Jain et al. 2013). Hence, in the present study, we have considered the weather variability in the entire north-east Indian seven sister hill states, namely, Arunachal Pradesh, Sikkim, Nagaland, Meghalaya, Manipur, Mizoram and Tripura, after analysing at least one data point from each state. The present approach will enable us to capture the spatio-temporal variability in air temperature trend across the region in a better way, if not completely. Our study also aims to identify the abrupt changes in the time series of mean air temperature through widely used change-point test statistics, which may reveal crucial information regarding the exact time/year when the shift has started over the region.

2 Data and Methodology

2.1 Data Sets

The meteorological data recorded at seven different locations/places corresponding to the seven hill states of north-east India, namely, Arunachal Pradesh, Sikkim, Nagaland,

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Meghalaya, Manipur, Mizoram and Tripura were used in the analysis. The location and detailed description is given in Fig. 1 and Table 1. All the meteorological data were recorded at the different state centres of Indian Council of Agricultural Research (ICAR) Research Complex for North-Eastern Hill Region (ICAR RC NEHR) (except Kailashahar in Tripura availed from India Meteorological Department, Pune). We have analysed the average air temperature of all these seven locations, which is the mean of daily average temperature over that particular period (month, season or year). Monthly, seasonal as well as annual trends and change points of the Tavg time series are analysed with the appropriate tests discussed in the following section. We studied the seasonal trends in mean air temperature by categorizing the monthly period in a calendar year into four distinct seasons likely January–February (winter), March–May (pre-monsoon), June–September (monsoon) and October–December (post monsoon). For maintaining the continuity of the time series data, missing values are replaced by the corresponding monthly average wherever necessary. Results are categorized for three significance levels likely, highly significant for $p \leq 0.01$, significant for $0.01 < p \leq 0.05$ and less significant for $0.05 < p \leq 0.1$.

2.2 Methods for Trend Analysis

Several statistical tests are available for identification and quantification of monotonic trends, which are mainly grouped into parametric and non-parametric tests. Though the parametric tests are more robust than the non-parametric tests, in such situations where the data does not follow normal distribution, non-parametric tests yields better results than the former.

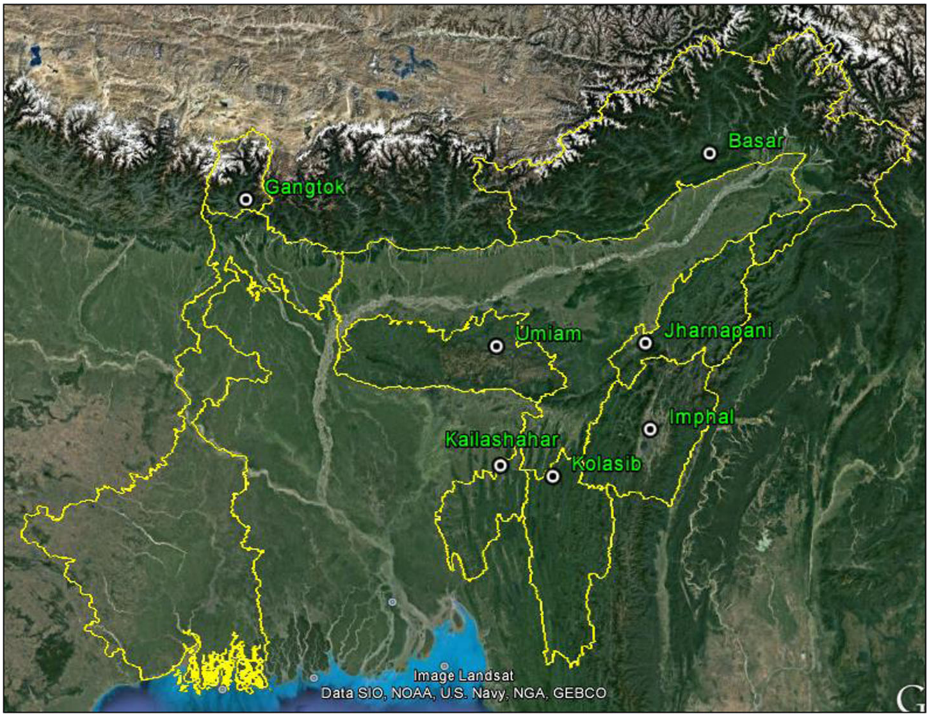

Fig. 1 Location of the meteorological observatories (created using GoogleEarth)

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Table 1 Detailed information about the location and duration of the meteorological data

State	Place	Latitude	Longitude	Altitude (meter)	Data Duration	Missing Value
Arunachal Pradesh	Basar	27°59′ N	94°42′ E	725	1979–2014	-
Sikkim	Gangtok	27°19′ N	88°36′ E	1322	1983–2014	-
Nagaland	Jharnapani	25°45’ N	93°50’ E	250	1998–2014	-
Meghalaya	Umiam	25°41′ N	91°55′ E	1010	1983–2014	-
Manipur	Imphal	24°45′ N	93°54′ E	774	1954–2014	-
Tripura	Kailashahar	24°19′ N	92°00′E	29	1980–2014	1998–1999
Mizoram	Kolasib	24°12′ N	92°40′ E	635	1980–2014	-

2.2.1 Mann- Kendall Test

Mann-Kendall test (MK test) is widely used for trend analysis in climatologic (Mavromatis and Stathis 2011) and hydrologic time series datasets (Yue and Pilon 2004). This test is advantageous in two counts: first, being a non-parametric test, it does not require the data to be normally distributed; and second, the test has low sensitivity to abrupt breaks in time series, i.e., inhomogeneity (Tabari et al. 2011). According to this test, assumption of the null hypothesis H_0 is of having no trend or in other words all data points are independent and random, which is tested against the alternative hypothesis H_1, assuming presence of trend. Here, each value in the series is compared to others in a sequential manner. The following is the expression of the Mann-Kendall test statistic:

$$S = \sum_{i=1}^{n} \sum_{j=1}^{i-1} sign\left(x_i - x_j\right) \tag{1}$$

where, n denotes total number of elements of the data, x_i and x_j are two sequential values of data, and function $sign(x_i - x_j)$ gets the values as expressed below-

$$sign\left(x_i - x_j\right) = \begin{bmatrix} 1, & \left(x_i - x_j\right) > 0 \\ 0, & \left(x_i - x_j\right) = 0 \\ -1, & \left(x_i - x_j\right) < 0 \end{bmatrix} \tag{2}$$

The MK-test statistic (S) follows an asymptotically normal distribution with mean as zero and variance computed as follows (Partal and Kahya 2006):

$$E(S) = 0 \tag{3}$$

$$Var(S) = \frac{1}{n}\left[n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)\right] \tag{4}$$

where, t denotes the extent of any given tie and ∑t denotes the summation over all tie number of values (Jaiswal et al. 2015). The standardized statistics Z of the MK-test is computed as follows:

$$Z = \begin{bmatrix} \frac{S+1}{\sqrt{Var(S)}}, & if\ S > 0 \\ 0, & if\ S = 0 \\ -1, & if\ S < 0 \end{bmatrix} \tag{5}$$

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Positive value of standardized statistic Z indicates an increasing or upward trend, while a negative value implies a decreasing or downward trend in series. To ascertain the test significance, comparison of computed absolute value of Z with the standard normal cumulative value of Z(1-p/2) at p % significance level obtained from a standard table is done for accepting or rejecting the null hypothesis (Partal and Kahya 2006).

2.2.2 Sen's Slope Estimator

It is also a non-parametric test for estimation of true slope of a linear trend in a time series developed by Sen (1968). The slope estimating N pairs of data are calculated as:

$$Q_i = \left(\frac{X_i - X_k}{i - k}\right) \; for\ i = 1, \ldots\ldots\ldots\ldots, N \tag{6}$$

where x_j and x_k denotes data value at time i and k (i > k), respectively. Sen's estimator of slope is indicated by the median of N values of Q_i. For even value of N, Sen's estimator is calculated as $Q_{med} = [Q_{N/2} + Q_{(N+2)/2}]/2$ N and for odd, by $Q_{med} = Q_{(N+1)/2}$. Finally, the actual or true slope is calculated by a non-parametric test and Q_{med} is checked by a two-sided test at the 100(1-α)% confidence interval (Partal and Kahya 2006; Malekian and Kazemzadeh 2016).

2.3 Methods for Change-point Analysis

The change point detection in the time series of average temperature for each monthly and seasonal series is done using four different change point tests, namely Pettitt's test (P), Standard Normal Heterogeneity Test (SNHT written as S), Buishand Test (B) and von Neumann's test (V), as recommended by the European Climate Assessment & Dataset project (ECA&D). Specific descriptions of the tests are following.

2.3.1 Pettitt Test

This statistical test is a non-parametric rank test, widely used for evaluation of presence of abrupt changes in the time series of the climatic data, given by Pettitt (1979). The reason for its usefulness is its sensitivity to capture the change points in the middle of any time series (Jaiswal et al. 2015). This test can identify the significant change in mean of a time series when the exact time of the shift is not known. In this test, the ranks r_1, r_2, r_3,..., r_n of the series Y_1, Y_2, Y_3,..., Y_n are used for calculation of the statistics (Zarenistanak et al. 2014):

$$X_k = 2\sum_{i=1}^{k} r_i - k(n+1) \;\; k = 1, \ldots\ldots, n \tag{7}$$

According to the test, if the time series shifts or breaks in year E, then the value of the statistic is maximal or minimal near the year k = E. Critical values of X_E are calculated after Pettitt (1979).

$$X_E = max\,|X_k| \qquad for\ 1 \le k \le n \tag{8}$$

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2.3.2 Standard Normal Homogeneity Test

This particular statistical test was developed by Alexandersson (1986) for comparing the mean of first k years of the record with that of last n − k years:

$$T(k) = k\bar{z}_1^{\,2} + (n-k)\bar{z}_2^{\,2} \quad k = 1, \dots\dots, n \tag{9}$$

where,

$$\bar{z}_1 = \frac{1}{k}\frac{\sum_{i=1}^{k}\left(Y_i - \overline{Y}\right)}{\sigma} \tag{10}$$

$$\bar{z}_2 = \frac{1}{n-k}\frac{\sum_{i=k+1}^{n}\left(Y_i - \overline{Y}\right)}{\sigma} \tag{11}$$

where, $\overline{Y}$ and σ are the mean and standard deviation of the time series. If a change-point or break occurs in the k^{th} year, then *T(k)* reaches a maximum near the year $k = K$. The test statistic T_0 is computed as:

$$T_0 = max\ (T(k))\ for\ 1 \le k \le n \tag{12}$$

The null hypothesis is rejected if T_0 is above a certain level, depending on the size of sample.

2.3.3 Buishand Range Test

Buishand (1982) developed this statistical test. Here the adjusted partial sum, which is the cumulative deviation from mean for k^{th} observation of a series x_1, x_2, x_3,..., x_n with mean $(\overline{x})$ can be calculated as (Klein Tank 2007):

$$S_0^* = 0 \quad and \quad S_k^* = \sum_{i=1}^{k}\left(Y_i - \overline{Y}\right) \quad k = 1, \dots\dots, n \tag{13}$$

For homogeneous series, the S_k^*values will fluctuate around zero as in the random time series the deviation from its mean is generally distributed on both sides of the mean of the series. If the series breaks in year K, then S_k^*reaches a maximum (negative shift) or minimum (positive shift) near the year k = K. The statistical significance test of the realized shift is tested with the 'rescaled adjusted range' R, the difference between maximum and minimum of S_k^*values scaled by sample standard deviation:

$$R = \frac{\left(\max S_k^* - \min S_k^*\right)}{s} \quad 0 \le k \le n \quad for\ \max\ \&\ \min\ separately \tag{14}$$

2.3.4 von Neumann Ratio Test

The von Neumann ratio test is related to the first-order serial correlation coefficient. The von Neumann ratio (N) is defined as the ratio of the mean square successive (year-to-year)

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difference to the variance (von Neumann 1941). Its test statistics for change-point detection in the time series of x_1, x_2, x_3, …, x_n is described as:

$$N = \frac{\sum_{i=1}^{n}(x_i - x_{i-1})^2}{\sum_{i=1}^{n}\left(x_i - \overline{x}\right)^2} \tag{15}$$

For homogeneous series, the expected value E(N) = 2 according to the null hypothesis with constant mean. Inhomogeneous series or samples with a break will get a value of N lower than 2; any other value implies that the time series has rapid variation in its mean.

All the tests were performed using the open source R software (R Core Team 2016).

3 Results

3.1 Trend Analysis

The mean monthly air temperature (Tavg) varied between 12 °C to 29 °C over the entire study region (Table 2; Fig. 2). The variation of mean monthly temperature was almost similar at Gangtok, Basar, Imphal and Umiam, ranging between 12 °C to 25.3 °C. Jharnapani, Kolasib and Kailashahar experienced similar variation in mean monthly temperature, ranging between 15.7 °C to 28.8 °C. The average annual temperature was lowest for Gangtok Station (18.8 °C) and highest for Kailashahar (25.2 °C). The minimum Tavg always occurred in January while the maximum Tavg occurred mostly in either July or August. During January, Gangtok experienced the lowest Tavg (~11.8 °C) and Kailashahar experienced the highest Tavg (~18.2 °C) among the seven locations under the present study, while Gangtok experienced the warmest Tavg during June (23.6 °C), which was lesser than all other points, and Kailashahar was exposed to highest Tavg during August (28.8 °C). The latitudinal effect was evident for the hill stations distributed over different states of North East India. The year round range of variation between the minimum and maximum value of Tavg was lesser for the stations located at the southern parts of the study region viz. Kolasib (lowest- 9.2 °C) and Kailashahar but it was highest for Basar (lowest- 13.1 °C), located at the northern-most part in our study region. During the winter months, the mean Tavg of Umiam and Imphal stations were ~1.5 °C warmer than Gangtok and Basar. However, the Gangtok and Umiam stations were ~1 °C cooler than Imphal and Basar stations during the monsoon months. The seasonal Tavg was highest for Kailashahar station, across the year.

This study accounted for a large degree of spatial variability in the temporal trends of different weather variables across different state boundaries of the region. The changes followed dissimilar pattern among the states. The gradual increase in Tavg was evident across all the northeast Indian states, except Jharnapani in Nagaland (Table 3). The increasing trend of monthly and annual Tavg was significant for Basar, Imphal and Gangtok stations in the majority of the months. The magnitude of year round increase in Tavg varied from: 0.5 °C to 1.6 °C per decade for Basar; 0.2 °C to 0.6 °C per decade for Gangtok; 0.2 °C to 0.3 °C per decade for Imphal. The recorded mean air temperature data at Kailashahar station (Tripura) depicted significant change during monsoon months as it increased in July and September while decreased in June. The Tavg during the winter months significantly increased at Umiam and Kolasib, at a rate varying from 0.3 °C to 0.9 °C per decade. The mean annual air

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Table 2 Mean temperature (°C) and its standard deviation at different places of north-eastern India

Year	Basar		Gangtok		Jharnapani		Umiam		Imphal		Kolasib		Kailashahar	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Jan	12.0	1.2	11.8	1.1	15.7	0.6	12.7	1.0	12.9	0.8	17.5	1.0	18.2	0.6
Feb	13.4	1.7	13.8	1.7	18.1	1.1	15.2	1.6	15.2	1.2	20.2	1.8	20.6	1.0
Mar	15.8	1.5	17.1	1.0	21.8	0.8	19.0	1.2	19.0	1.1	23.6	1.8	24.7	0.9
Apr	18.8	2.0	19.5	1.1	24.7	0.8	21.6	1.3	21.8	1.2	25.1	1.7	26.9	0.9
May	21.8	1.6	21.4	1.1	26.6	1.0	22.5	0.8	23.7	0.8	26.1	1.6	27.5	0.9
Jun	24.1	1.6	23.6	2.0	28.0	0.8	23.7	0.7	25.1	0.8	26.7	1.2	28.5	0.4
Jul	25.0	1.6	23.1	0.6	28.2	0.6	24.1	0.7	25.3	0.8	26.6	0.9	28.6	0.4
Aug	25.1	1.6	23.2	0.5	28.0	0.7	24.0	0.5	25.3	0.8	26.4	1.0	28.8	0.4
Sep	24.1	2.2	22.3	0.7	27.2	0.6	23.1	0.7	24.7	0.7	26.5	1.5	28.4	0.5
Oct	21.8	1.9	20.0	0.8	25.0	0.7	21.0	0.7	22.5	1.0	25.2	1.4	27.0	0.5
Nov	17.4	1.8	16.4	0.8	21.1	0.9	17.1	0.9	18.0	1.1	22.9	1.8	23.2	1.6
Dec	14.0	1.4	13.3	0.9	17.1	0.6	14.2	0.8	13.9	0.9	19.2	1.6	19.6	0.7

temperature increased significantly for all the stations except Jharnapani (Nagaland). We also observed a significant rise in Tavg during March and December for all the stations except Jharnapani. The seasonal analysis revealed that five out of seven stations experienced significant rise in Tavg during winter (i.e., Basar, Gangtok, Umiam, Imphal and Kolasib; Fig. 3). The rise in Tavg during pre-monsoon season was significant for Basar and Gangtok stations. The rise was significant for four stations during the monsoon (Basar, Gangtok, Umiam, and Imphal) and post-monsoon months (Basar, Gangtok, Imphal and Kailashahar). The magnitude of changes were quite higher for the northern-most points viz. Basar and Gangtok stations, but quite low for the southern points of Kolasib and Kailashahar stations.

3.2 Change Point Analysis

The change point detection tests were used to assess the hidden shift in the time series of Tavg data. The test detects the year of significant shift, if any. We adopted four different tests for the

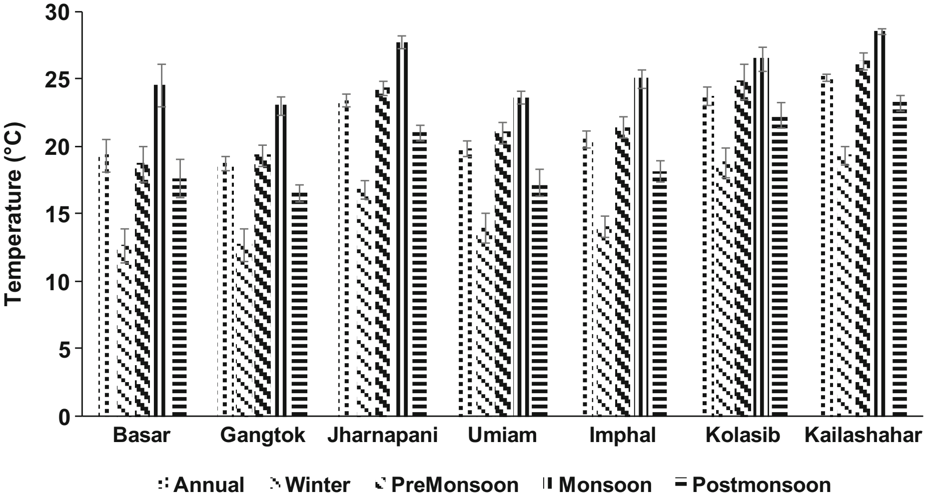

Fig. 2 Annual and seasonal variation in Mean Temperature (°C) at different places of NE India

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detection of change point in the time series of Tavg (Table 4; Fig. 4). Results from all the four tests adopted often agreed to the presence of change point in almost all the stations. Tavg values of Imphal experienced maximum number of shifts during early and late 1990s, followed by Gangtok, Basar, Umiam and Kolasib. The monthly pattern of changes also varied from place to place. Shift in Tavg during February–March has occurred in almost all places except Jharnapani and Kailasahar. Seasonal analysis revealed that the changes in Tavg during the winter months were most common and mostly occurred during the late 1990s, particularly during 1997–1998, except in Kolasib, where the shifting pattern was prominent during 2001–2002. The Tavg time series also shifted in monsoon and pre-monsoon months, but at a lesser frequency than winter. The patterns of shifting during these seasons were temporally dissimilar unlike winter. The change point of the mean annual temperature time series is depicted in Fig. 4. It is quite clear from the figure that there were temporal differences in the time of shifts. However, the changes mostly occurred during the mid-1990s to early years of 2000s (Table 4). Most of the changes in Imphal (11), Gangtok (9) and Basar (7) occurred during the 1990s, while in Umiam (6) and Kolasib (4) it was in early 2000s. In general, the stations which experienced the lesser Tavg values viz. Basar, Imphal and Gangtok, experienced early shifting (except Umiam), and for the stations which experienced higher Tavg values, the shifting pattern was either absent (Jharnapani and Kailashahar) or occurred late (Kolasib).

Table 3 Trends in the mean temperature (Tavg) at different locations of north-eastern India

Year	Basar	Gangtok	Jharnapani	Umiam	Imphal	Kolasib	Kailashahar
Jan	3.3***	1.3	0.6	1.3	3.5***	2.0**	0.9
	(0.7)	(0.3)	(0.3)	(0.3)	(0.2)	(0.4)	(0.1)
Feb	3.0***	2.3***	−0.2	2.2**	3.2***	3.0***	1.1
	(0.9)	(0.6)	(−0.2)	(0.8)	(0.3)	(0.9)	(0.1)
Mar	4.1***	3.0***	1.1	2.2**	2.1**	2.2**	1.6*
	(1.1)	(0.6)	(0.4)	(0.5)	(0.2)	(0.6)	(0.2)
Apr	1.9**	1.6*	−0.7	0.3	0.3	0.6	0.6
	(0.5)	(0.3)	(−0.2)	(0.1)	(0.0)	(0.2)	(0.1)
May	3.2***	4.0***	0.5	2.2**	1.1	0.0	1.1
	(1.0)	(0.6)	(0.2)	(0.4)	(0.1)	(0.0)	(0.2)
Jun	3.8***	2.4***	−1.1	0.3	3.2***	1.3	−1.7*
	(1.0)	(0.3)	(−0.5)	(0.0)	(0.2)	(0.3)	(−0.1)
Jul	2.8***	3.9***	0.7	1.1	3.4***	0.9	1.6*
	(1.0)	(0.4)	(0.2)	(0.2)	(0.2)	(0.2)	(0.1)
Aug	3.0***	2.5***	−0.2	1.4	3.8***	−0.1	1.2
	(0.8)	(0.2)	0(.0)	(0.1)	(0.2)	(0.0)	(0.1)
Sep	3.7***	3.6***	0.5	2.7***	2.5***	−0.6	2.2**
	(1.6)	(0.5)	(0.2)	(0.4)	(0.2)	(−0.1)	(0.1)
Oct	3.6***	2.3**	0.1	0.9	3.1***	0.4	2**
	(1.0)	(0.3)	(0.1)	(0.1)	(0.3)	(0.1)	(0.1)
Nov	3.1***	1.8*	−1.0	0.5	3.5***	−0.2	0.3
	(0.9)	(0.3)	(−0.3)	(0.2)	(0.3)	(−0.1)	(0.0)
Dec	1.6*	0.1	0.0	0.9	3.6***	1.6	1.7*
	(0.5)	(0.0)	(0.0)	(0.2)	(0.2)	(0.4)	(0.2)
Annual	4.0***	3.8***	0.2	2.3***	4.2***	1.7*	2.6***
	(1.0)	(0.4)	(0.0)	(0.2)	(0.2)	(0.2)	(0.1)

***, ** and * denote trends at 1%, 5% and 10% significance level, respectively. Values indicate Mann Kendall's Z statistics and in the parentheses Sen's Slope represent the rate of change (°C) per decade

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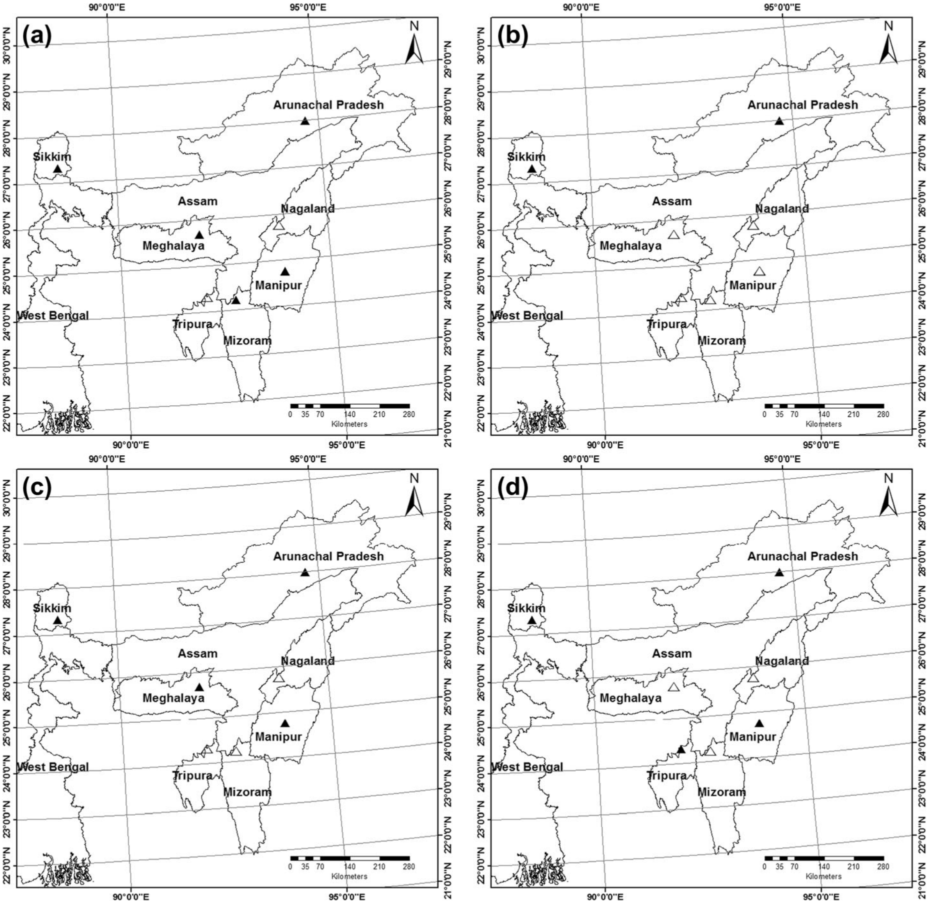

Fig. 3 Seasonal trends in Mean Temperature (°C) at different places of NE India: a) January–February (winter); b) March–May (pre-monsoon); c) June–September (monsoon); d) October–December (post-monsoon). Filled black upright triangle means significantly increase and unfilled black upright triangle indicate non-significant trends

4 Discussion

4.1 Trend Analysis

This study analysed the monthly, seasonal as well as the annual trends in mean air temperature over seven different places situated at various hills of north-eastern India. Overall there was a dissimilar pattern of changes among the stations. It can be clearly seen that for places (Basar, Imphal and Gangtok) where the mean temperature was lower, i.e., those places which are climatologically cooler, the temperature has shown the most significant increase. Jhajharia and Singh (2011) also reported the maximum number of significant increase in the monthly time series of mean temperature for the stations Margherita and Nagrakata, which are comparatively cooler than the other stations in their study. The range of increase in their study varied from 0.1 °C to 1.4 °C per decade, which was quite similar to our analysis. Though both studies

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analysed the data from the north-eastern region of the country, there were differences in the location and physiography of the weather stations used in the two analyses. While Jhajharia and Singh (2011) mostly included the stations located in the plains and foothills of the eastern Himalaya falling in the states of Assam and northern West Bengal, our study included weather stations located mostly at the mid-hills of north-eastern India, representing all hill states, except Kailasahar in Tripura.

The seasonal analysis revealed that five out of seven stations experienced significant rise in Tavg during the winter (Basar, Gangtok, Umiam, Imphal and Kolasib). Deka et al. (2009) also found comparatively higher rate of increase in mean temperature during the winter season over the region. In both the post-monsoon and monsoon months, the mean temperature increased in the four stations. Jhajharia and Singh (2011) also reported significant increase in mean temperature over four locations out of the eight analysed for both seasons. However, the rate was quite higher for the post-monsoon as compared to the monsoon season. The observation of Deka et al. (2009) contradicts Jhajharia and Singh (2011) in their observation during the monsoon months, as the former study argues that less increase in temperature (maximum and minimum) during monsoons is mainly due to the cooling effect of rainfall. It is seen that precipitation may offset the increase in temperature by a sizeable proportion. Quite lower quantity of rainfall along with enhanced Green House Gases (GHG) contents in the atmosphere due to shifting cultivation or *Jhum* burning during this period of the year may have rendered the winter and the post-monsoon significantly warmer.

4.2 Change Point Analysis

This study analysed the abrupt change points through four different statistical tests, namely Pettitt's test, Standard Normal Heterogeneity Test, Buishand Test and von Neumann's ratio test. The results of all the tests showed broad coherence except some dissimilarity to find out the abrupt shifts in some time series. Similar slight deviations in abrupt shifts or change points have also been reported in other studies from several parts of India (Jaiswal et al. 2015; Machiwal et al. 2017). On one hand, the different change points resulting from different tests from a time series may draw some attention. But, on the other hand, the results of this study and those cited above clearly show the need of applying multiple statistical tests for identifying abrupt shifts in a better way, which rather strengthens the idea of using several tests for future studies. This discussion recommends using multiple tests for exploring the abrupt shifts or changes, as it is very much useful to avoid the straightforward and erroneous results.

The abrupt shifts in mean temperature were most common during the winter months. From the temporal point of view, late 1990s to early 2000s was found to be the period with maximum changes over the region. Jaiswal et al. (2015) reported the change points of different weather variables of Raipur city of Chhattisgarh which mostly occurred during the 1995–2001. Machiwal et al. (2017) also found change points in years 2002 and 2005 for rainfall time series of western arid region of India. Our results also show similar change points as these studies, though the stations analysed are distantly different. It indicates that during this time either there may be some large scale phenomenon changes like that in sea surface temperature or cosmic influence on the sun–earth environment (Machiwal et al. 2017) leading to increased climatic variability which have set the change over the broad region. Although minor changes in specific region may be perturbed due to local anthropogenic factors, like increase in population, urbanization, developmental activities along with deforestation and changes in land use. The north-eastern India has experienced almost ten times growth in human population during

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Table 4 Change point detection in mean monthly temperature (Tavg) at different meteorological stations of north-eastern India

	P	S	B	V	P	S	B	V	P	S	B	V	P	S	B	V
	Basar				Gangtok				Jharnapani							
Jan	262*** (1993)	15.9*** (1993)	11.9*** (1993)	0.89***	81 (NO)	4.6 (NO)	4.5 (NO)	2.13	25 (NO)	2.1 (NO)	2.1 (NO)	1.95				
Feb	182*** (1997)	8.3** (2008)	8.0** (1997)	1.66	175*** (1997)	9.7*** (1997)	8.9*** (1997)	1.99	28 (NO)	5.5* (1999)	3.2 (NO)	2.31				
Mar	210*** (1997)	12.8*** (2005)	10.4*** (1997)	1.27***	158*** (1998)	9.5*** (1998)	8.9*** (1998)	1.76	20 (NO)	1.0 (NO)	2.0 (NO)	3.07				
Apr	127 (NO)	9.9* (1980)	6.7* (1984)	1.33***	136** (1994)	7.2* (1993)	7.3** (1993)	1.60	30 (NO)	2.5 (NO)	2.8 (NO)	1.57				
May	188*** (1992)	8.4* (2006)	8.6*** (1992)	0.97***	195*** (1993)	12.2** (2013)	9.3*** (1993)	0.97***	22 (NO)	5.4 (NO)	2.2 (NO)	2.01				
Jun	136* (1983)	10.6*** (1983)	6.8* (1983)	0.54***	129** (2007)	1.1 (NO)	2.7 (NO)	2.17	37 (NO)	6.7** (1999)	4.0 (NO)	1.22**				
Jul	130 (NO)	5.3 (NO)	5.8 (NO)	0.77***	172*** (1992)	11.7*** (1992)	9.1*** (1992)	1.05***	28 (NO)	1.9 (NO)	2.8 (NO)	1.70				
Aug	113 (NO)	6.1 (NO)	6.2 (NO)	0.60***	148*** (2000)	9.5* (1988)	6.9** (1988)	1.10***	22 (NO)	3.3 (NO)	2.5 (NO)	2.41				
Sep	192*** (1992)	8.4* (1992)	8.6*** (1992)	0.72***	169*** (1993)	15.1*** (1987)	9.5*** (1993)	1.20***	36 (NO)	2.8 (NO)	3.1 (NO)	1.60				
Oct	157** (1994)	10.3*** (1979)	5.4 (NO)	0.93***	121* (1997)	9.1* (1987)	7.3** (1997)	1.57*	34 (NO)	3.1 (NO)	3.1 (NO)	0.81***				
Nov		6.2 (NO)		1.32***				1.58	32 (NO)			1.26**				

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Table 4 (continued)

	P	S	B	V	P	S	B	V	P	S	B	V	P	S	B	V
	188*** (1992)		7.4** (1992)		142** (1994)	7.4** (1989)	7.3** (1994)			10.4*** (1998)	3.7 (NO)					
Dec	155** (2003)	7.0** (2003)	7.4** (2003)	1.73	60 (NO)	3.2 (NO)	3.4 (NO)	1.91	20 (NO)	4.2 (NO)	2.5 (NO)	1.76				
Annual	169** (2003)	8.6** (2003)	8.7*** (1992)	0.46***	185*** (1997)	15.5*** (1987)	10.0*** (1997)	0.95***	29 (NO)	6.4* (1999)	3.5 (NO)	1.07***				
Winter	210*** (1998)	11.4*** (1993)	10.2*** (1997)	1.07***	145** (1997)	7.5** (1997)	7.9** (1997)	2.00	26 (NO)	5.3 (NO)	3.1 (NO)	2.17				
Pre-Monsoon	185*** (2005)	10.3*** (2006)	8.2** (2005)	1.03***	210*** (1994)	14.6*** (1993)	10.4*** (1993)	1.09***	28 (NO)	2.2 (NO)	2.8 (NO)	1.94				
Monsoon	144* (2006)	6.7* (1983)	7.0* (1992)	0.38***	144** (1988)	9.7* (1988)	7.0** (1988)	1.72	32 (NO)	4.0 (NO)	3.2 (NO)	1.41*				
Post-monsoon	152* (1992)	6.2 (NO)	6.6 (NO)	1.10***	116* (1992)	9.2*** (1987)	6.3 (NO)	1.77	30 (NO)	9.4*** (1998)	3.7 (NO)	0.81***				
	Umiam				Imphal				Kolasib				Kailashahar			
Jan	97 (NO)	4.2 (NO)	5.6 (NO)	1.82	418*** (1997)	11.7*** (1997)	11.9*** (1997)	1.75	196*** (2001)	10.0** (2001)	1.6** (2002)	1.25***	88 (NO)	1.9 (NO)	0.7 (NO)	2.81
Feb	106* (1998)	4.5 (NO)	5.9 (NO)	2.17	432*** (1997)	16.0*** (1998)	13.7*** (1997)	1.54**	193*** (2000)	9.1** (2000)	1.5 (NO)	1.58	116 (NO)	4.0 (NO)	1.2 (NO)	1.75
Mar	119** (2003)	7.0 * (2003)	7.1** (2003)	2.02	270* (1998)	6.6 (NO)	8.9* (1990)	2.10	164* (2005)	5.9 (NO)	1.3 (NO)	1.74	102 (NO)	2.6 (NO)	0.7 (NO)	2.22
Apr	63 (NO)	2.3 (NO)	3.7 (NO)	2.10		4.4 (NO)	5.9 (NO)	1.79	87 (NO)	6.6 (NO)		1.59	53 (NO)		0.6 (NO)	2.31

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Table 4 (continued)

	P	S	B	V	P	S	B	V	P	S	B	V	P	S	B	V
					211 (NO)						1.0 (NO)			1.4 (NO)		
May	129** (2003)	4.9 (NO)	5.6 (NO)	1.74	344** (1993)	7.6* (1993)	10.1** (1993)	1.65*	70 (NO)	4.0 (NO)	1.2 (NO)	1.34**	90 (NO)	2.6 (NO)	0.8 (NO)	2.03
Jun	80 (NO)	3.2 (NO)	4.5 (NO)	2.02	412*** (1987)	11.7*** (2010)	12.7*** (1987)	1.38***	108 (NO)	2.7 (NO)	1.2 (NO)	1.69	124* (1996)	4.4 (NO)	1.0 (NO)	1.91
Jul	122** (2004)	6.9* (2004)	6.9** (2004)	1.66	475*** (1990)	19.5*** (2010)	14.3*** (1996)	1.00***	89 (NO)	3.8 (NO)	1.2 (NO)	1.48**	97 (NO)	3.1 (NO)	0.9 (NO)	2.40
Aug	128** (2002)	7.2* (2002)	7.3** (2002)	1.35**	551*** (1996)	22.0*** (1996)	16.5*** (1996)	1.28***	119 (NO)	9.5** (1984)	1.7** (1985)	1.35**	116 (NO)	6.4 (NO)	1.2 (NO)	1.94
Sep	130** (2002)	8.0** (2004)	7.4** (2004)	1.95	430*** (1997)	15.0*** (1997)	13.5*** (1993)	1.36***	111 (NO)	5.1 (NO)	1.0 (NO)	1.76	119 (NO)	5.3 (NO)	1.1 (NO)	2.05
Oct	67 (NO)	1.7 (NO)	3.6 (NO)	2.50	474*** (1994)	15.7*** (1994)	14.3*** (1994)	1.67*	107 (NO)	5.1 (NO)	1.3 (NO)	1.87	115 (NO)	4.5 (NO)	1.0 (NO)	2.14
Nov	52 (NO)	0.9 (NO)	2.6 (NO)	2.28	455*** (1993)	14.3*** (1971)	13.6*** (1993)	1.51**	111 (NO)	6.3 (NO)	1.1 (NO)	2.35	76 (NO)	1.0 (NO)	0.9 (NO)	2.44
Dec	73 (NO)	2.5 (NO)	3.9 (NO)	2.45	554*** (1994)	17.9*** (1994)	15.3*** (1994)	1.31***	147 (NO)	5.6 (NO)	1.2 (NO)	1.88	105 (NO)	4.8 (NO)	1.3 (NO)	1.60
Annual	154*** (2004)	8.6** (2004)	7.8*** (2003)	1.74	594*** (1994)	26.6*** (1994)	18.7*** (1994)	0.91***	167* (2004)	6.8* (2004)	1.7** (2005)	1.35**	150** (2000)	7.8* (2002)	1.3 (NO)	1.86
Winter		5.7 (NO)		1.76				1.43***				1.28***	115 (NO)		1.1 (NO)	1.78

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Table 4 (continued)

	P	S	B	V	P	S	B	V	P	S	B	V	P	S	B	V
	116* (1998)		6.6* (1998)		512*** (1997)	21.4*** (1997)	16.1*** (1997)		230*** (2001)	12.9*** (2001)	1.8*** (2002)			4.1 (NO)		
Pre-Monsoon	99 (NO)	6.1 (NO)	6.6* (2003)	1.90	302* (1994)	6.8 (NO)	9.1* (1997)	1.88	129 (NO)	4.5 (NO)	1.4 (NO)	1.35**	88 (NO)	3.3 (NO)	0.8 (NO)	2.40
Monsoon	144*** (2004)	10.2*** (2004)	8.4*** (2004)	1.64	529*** (1990)	21.5*** (1997)	16.1*** (1996)	0.94***	87 (NO)	7.4* (1984)	1.4 (NO)	1.61	119 (NO)	5.1 (NO)	1.1 (NO)	2.18
Post-monsoon	72 (NO)	1.2 (NO)	2.7 (NO)	2.33	570*** (1994)	22.9*** (1994)	17.3*** (1994)	1.24***	79 (NO)	2.4 (NO)	1.1 (NO)	2.15	127 (NO)	4.4 (NO)	1.1 (NO)	2.30

***, ** and * denote trends at 1%, 5% and 10% significance level, respectively. Values indicate Pettitt's test (P), SNHT Test (S), Buishand Test (B) and von Neumann's test (V) statistics and in the parentheses the year of change in the series if the test was significant

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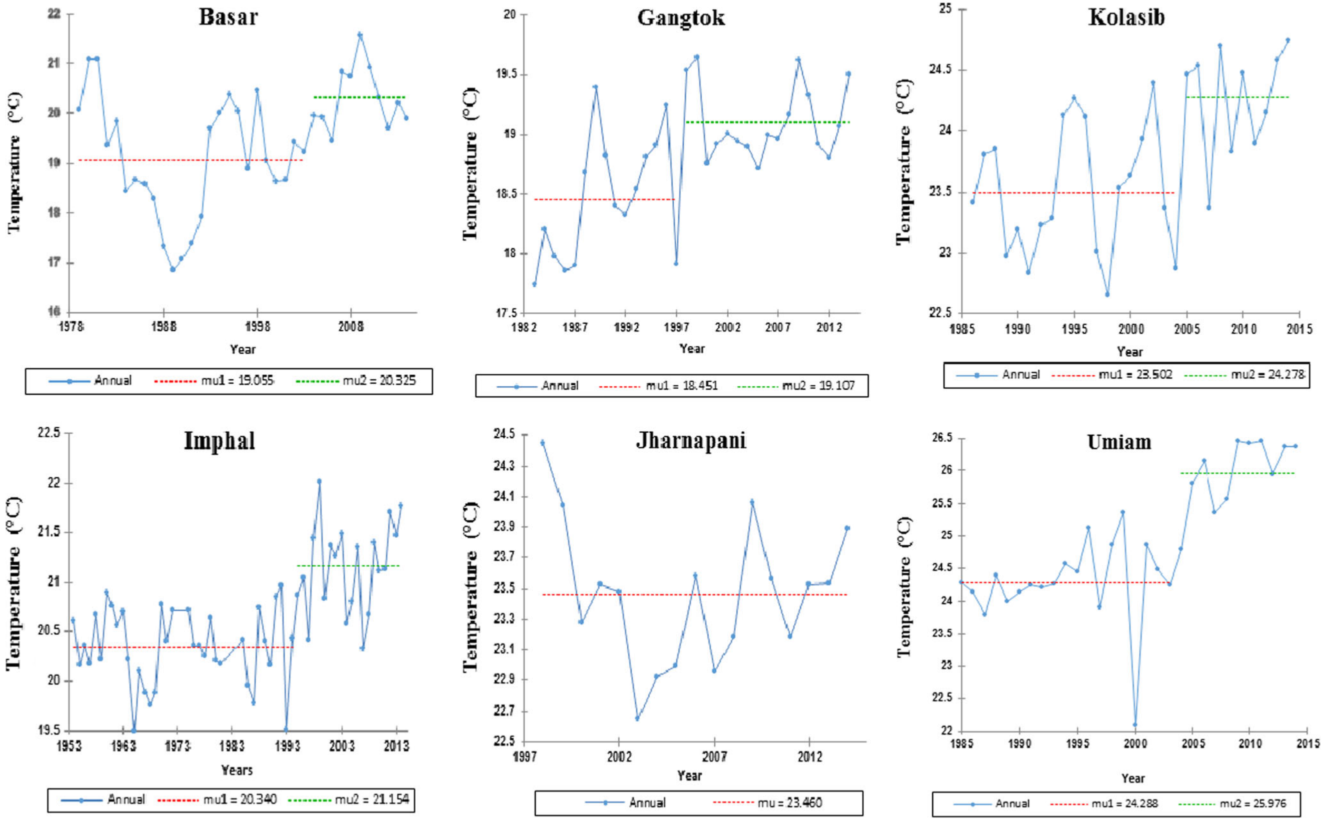

Fig. 4 Change points in time series of mean annual temperature (Tavg) at different places of North East India

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the decade of 1991 to 2001 (population 0.42 crores and 3.9 crores, respectively). Deka et al. (2009) also argued that during this time period there has been a steady increase in GHG concentration over the region and the deforestation leading to alteration in land use followed by its degradation. Steady decrease in the forest area along with increase in the *Shifting* cultivation is also adding to this menace. All these factors have cumulatively taken part in forcing the changes of temperature regime over the region in a direct or indirect way.

5 Conclusions

The study reported the gradual trends in mean air temperature of seven hilly stations spread across seven hill states of north-eastern India along with their abrupt shifts or change points in the time series. The persistent increase in Tavg across all the stations except Kailasahar in Tripura was evident. The results have shown spatial and altitudinal variations in the rate and the timing of the variations at large. Climatologically cooler places, like Imphal, and those in comparatively north and higher altitudes, like Basar and Gangtok, have shown marked increase in the Tavg in almost all the months. These effects dampened in places like Umiam, Kolasib and Kailasahar which lies comparatively southwards to the former and were climatologically hotter. Winter months showed the highest overall rate of increase in the Tavg which was about 0.8 °C per decade. The place Basar, situated in Arunachal Pradesh, showed the highest overall rate of increase in Tavg. The change point detection analysis revealed that maximum number of shifts in time series of Tavg values have occurred in Imphal during early and late 1990s. It was followed in frequency by Gangtok, Basar, Umiam and Kolasib. Monthly pattern of changes also varied from place to place. Alike the trend analysis, the shift in Tavg during winter months was most common and occurred during the late-1990s. In a nutshell, the analysis revealed that Tavg of north-eastern hill states clearly indicated towards a change. These changes may be results of complex intermingled causes, like broad scale phenomenon and small scale regional factors. Further study may be conducted to find out the proper causes of these changes over the region. The present study will be useful in modelling the future projections of regional mean temperature values and impact assessment on agriculture under different climate change scenarios in the northeast India.

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References

Ahmad QK, Warrick RA (1996) The Implications of Climate and Sea-level Change for Bangladesh. Kluwer Academic Publishers, Dordrecht

Alexander LV, Zhang X, Peterson TC, Caesa J, Gleason B, KleinTank AMG, Haylock M, Collins D, Trewin B, Rahimzadeh F, Tagipour A, Rupa Kumar K, Revadekar J, Griffiths G, Vincent L (2006) Global observed

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changes in daily climate extremes of temperature and precipitation. J Geophys Res Atmos 111:D05109. https://doi.org/10.1029/2005jd006290

Alexandersson HA (1986) A homogeneity test applied to precipitation data. Int J Climatol 6:661–675

Buishand TA (1982) Some methods for testing the homogeneity of rainfall records. J Hydrol 58(1–2):11–27

Chakraborty D, Saha S, Singh RK, Sethy BK, Kumar A, Saikia US, Das SK, Makdoh B, Borah TR, Nomita Chanu A, Walling I, Rolling Anal PS, Chowdhury S, Daschaudhuri D (2017) Spatio-temporal trends and change point detection in the rainfall observation series from different North-eastern Indian states. J Agrometeorol 19(2):160–163

Chakraborty D, Singh RK, Roy A, Saha S, Sethy BK, Kumar A, Ngachan SV (2014) Increase in extreme day temperature in hills of Meghalaya: its possible ecological and bio-meteorological effect. J Agrometeorol 16(Special issue-I):147–152

Chattopadhyay S, Jhajharia D, Chattopadhyay G (2011) Univariate modelling of monthly maximum temperature time series over northeast India: neural network versus Yule–Walker equation based approach. Meteorol Appl 18(1):70–82

Choudhury BU, Das A, Ngachan SV, Slong A, Bordoloi LJ, Chowdhury P (2012) Trend analysis of long term weather variables in mid altitude Meghalaya, North-East India. J Agricul Phy 12(1):12–22

Das A, Ghosh PK, Choudhury BU, Patel DP, Munda GC, Ngachan SV, Chowdhury P (2009) Climate change in northeast India: recent facts and events –worry for agricultural management; ISPRS Archives XXXVIII-8/W3 Workshop Proceedings: Impact of Climate Change on Agriculture, 32–37

Das PJ (2004) Rainfall regime of northeast India: a hydro-meteorological study with special emphasis on the Brahmaputra basin, Unpublished PhD thesis, Guwahati University, Assam, India

Dash SK, Kulkarni MA, Mohanty UC, Prasad K (2009) Changes in the characteristics of rain events in India. J Geophys Res 114:D10109. https://doi.org/10.1029/2008JD010572

Deka RL, Mahanta C, Nath KK (2009) Trends and fluctuations of temperature regime of north east India; ISPRS Archives XXXVIII-8/W3 Workshop Proceedings: Impact of Climate Change on Agriculture, 376–380

Donohue RJ, McVicar TR, Roderick ML (2010) Assessing the ability of potential evaporation formulations to capture the dynamics in evaporative demand within a changing climate. J Hydrol 386:186–197

Feidas H, Makrogiannis T, Bora-Senta E (2004) Trend analysis of air temperature time series in Greece and their relationship with circulation using surface and satellite data: 1955–2001. Theor Appl Climatol 79:185–208

Frich P, Alexander LV, Della-Marta P, Gleason B, Haylock M, Tank AK, Peterson T (2002) Observed coherent changes in climatic extremes during the second half of the twentieth century. Clim Res 19(3):193–212

Goyal MK (2014) Statistical analysis of long term trends of rainfall during 1901-2002 at Assam, India. Water Resour Manag 28(6):1501–1515

Hingane LS, Kumar KR, Murty BVR (1985) Long term trends of surface air temperature in India. Int J Climatol 5(5):521–528

IPCC (2007) Climate Change 2007, The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

Jain SK, Kumar V, Saharia M (2013) Analysis of rainfall and temperature trends in northeast India. Int J Climatol 33(4):968–978

Jaiswal RK, Lohani AK, Tiwari HL (2015) Statistical analysis for change detection and trend assessment in climatological parameters. Environ Process 2(4):729–749

Jha S, Sehgal VK, Raghava RM, Sinha M (2013) Trend of standardized precipitation index during Indian summer monsoon season in agro-climatic zones of India. Earth Syst Dyn Discuss 4:429–449

Jhajharia D, Dinpashoh Y, Kahya E, Singh VP, Fakheri-Fard A (2012a) Trends in reference evapotranspiration in the humid region of northeast India. Hydrol Process 26(3):421–435

Jhajharia D, Shrivastava SK, Sarkar D, Sarkar S (2009) Temporal characteristics of pan evaporation trends under the humid conditions of northeast India. Agr Forest Meteorol 149(5):763–770

Jhajharia D, Singh VP (2011) Trends in temperature, diurnal temperature range and sunshine duration in Northeast India. Int J Climatol 31:1353–1367

Jhajharia D, Yadav BK, Maske S, Chattopadhyay S, Kar AK (2012b) Identification of trends in rainfall, rainy days and 24h maximum rainfall over subtropical Assam in Northeast India. Compt Rendus Geosci 344(1):1–13

Klein Tank AM, Peterson TC, Quadir DA, Dorji S, Zou X, Tang H, Santhosh K, Joshi UR, Jaswal AK, Kolli RK, Sikder AB (2006) Changes in daily temperature and precipitation extremes in central and south Asia. J Geophys Res Atmos 27;111(D16)

Klein Tank AM (2007) EUMETNET/ECSN optional programme: European Climate Assessment & Dataset (ECA&D) Algorithm Theoretical Basis Document (ATBD), version 4. Report EPJ029135

Author's personal copy

Kothawale DR, Revadekar JV, Kumar KR (2010) Recent trends in pre-monsoon daily temperature extremes over India. J Earth Syst Sci 119(1):51–65

Kothyari UC, Singh VP (1996) Rainfall and temperature trends in India. Hydrol Process 10:357–372

Liu B, Xu M, Henderson M, Qi Y (2005) Observed trends of precipitation amount, frequency, and intensity in China, 1960–2000. J Geophys Res Atmos 27;110(D8)

Machiwal D, Jha MK (2016) Evaluating persistence and identifying trends and abrupt changes in monthly and annual rainfalls of a semi-arid region in Western India. Theor Appl Climatol 128(3–4):689–708

Machiwal D, Kumar S, Dayal D, Mangalassery S (2017) Identifying abrupt changes and detecting gradual trends of annual rainfall in an Indian arid region under heightened rainfall rise regime. Int J Climatol 37(5):2719–2733

Malekian A, Kazemzadeh M (2016) Spatio-temporal analysis of regional trends and shift changes of autocorrelated temperature series in Urmia lake basin. Water Resour Manag 30(2):785–803

Mavromatis T, Stathis D (2011) Response of the water balance in Greece to temperature and precipitation trends. Theor Appl Climatol. https://doi.org/10.1007/s00704-010-0320-9

Pant GB, Rupa Kumar K (1997) Climates of South Asia. John Wileyand Sons, New York, p 320

Partal T, Kahya E (2006) Trend analysis in Turkish precipitation data. Hydrol Process 20:2011–2026

Pettitt AN (1979) A non-parametric approach to the change point problem. J Appl Stat 28(2): 126–135

R Core Team (2016) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL- https://www.R-project.org/

Rao GS, Murty MK, Joshi UR, Thapliyal V (2005) Climate change over India as revealed by critical extreme temperature analysis. Mausam 56(3):601

Rupa Kumar K, Krishna Kumar K, Ashrit RG, Patwardhan SK, Pant GB (2002) Climate Change in India: Observations and model projections. In: Shukla PR, Sharma SK, Ramana PV (eds) Climate Change and India Issues, Concerns and Opportunities. Tata McGraw-Hill Publishing Company Limited, New Delhi, pp 24–75

Saha S, Chakraborty D, Singh SB, Chowdhury S, Syiem EK, Dutta SK, Choudhury BU, Boopathi T, Singh AR, Ramakrishna Y, Roy A (2016) Analyzing the trend in thermal discomfort and other bioclimatic indices at Kolasib, Mizoram. J Agrometeorol 18(1):57–61

Saha S, Chakraborty D, Choudhury BU, Singh SB, Chinza N, Lalzarliana C, Dutta SK, Chowdhury S, Boopathi T, Lungmuana AR, Ngachan SV (2015) Spatial variability in temporal trends of precipitation and its impact on the agricultural scenario of Mizoram. Curr Sci 109(2):2278–2282

Saikia US, Goswami B, Rajkhowa DJ, Venkatesh A, Ramachandran K, Rao VUM, Venkateswarlu B, Ngachan SV (2013) Shift in monsoon rainfall pattern in the North Eastern region of India post 1991. J Agrometeorol 15(2):162–164

Sen PK (1968) Estimates of the regression coefficient based on Kendall's tau. J Am Stat Assoc 39:1379–1389

Shahin M, Van Oorschot HJL, De Lange SJ (1993) Statistical Analysis in Water Resources Engineering. AA Balkema, Rotterdam, 394p

Shrestha AB, Wake CP, Mayewski PA, Dibb JE (1999) Maximum temperature trends in the Himalaya and its vicinity: an analysis based on temperature records from Nepal for the period 1971–1994. J Clim 12:2775–2786

Sonali P, Nagesh Kumar D (2013) Review of trend detection methods and their application to detect temperature changes in India. J Hydrol 476:212–227

Tabari H, Marofi S, Aeini A, Talaee PH, Mohammadi K (2011) Trend analysis of reference evapotranspiration in the western half of Iran. Agric Forest Meteorol 151:128–136

Talaee PH, Some'e BS, Ardakani SS (2014) Time trend and change point of reference evapotranspiration over Iran. Theor Appl Climatol 116(3–4):639–647

von Neumann J (1941) Distribution of the ratio of the mean square successive difference to the variance. Ann Math Statist 12(4):367–395

Yue S, Pilon PA (2004) Comparison of the power of the t test, Mann-Kendall and bootstrap tests for trend detection. Hydrol Sci J 49(1):21–37

Zarenistanak M, Dhorde AG, Kripalani RH (2014) Trend analysis and change point detection of annual and seasonal precipitation and temperature series over southwest Iran. J Earth Syst Sci 123(2):281–295