

Spatio-temporal trend and change point detection of winter temperature of North Bengal, India

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Received: 1 November 2018 / Revised: 6 January 2019 / Accepted: 8 January 2019 / Published online: 19 January 2019
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Abstract The trend of temperature and homogeneity are the most significant issue for climate change allied research. This research aims to identify the long-term trend and change point detection of winter maximum (t_{\max}), minimum (t_{\min}) and average (t_{mean}) temperature of six meteorological stations of North Bengal, India using 102 years' time series data (1915–2016). To detect the monotonic trend and the rate of change, non-parametric Mann–Kendall (MK) test and Sen's slope estimator were used. Homogeneity of winter temperature was studied using Buishand's range test (B test) and Pettit's test (P test). From the results, it was observed that most of the stations were showed significant ($P < 0.05$) warming trend in winter season. The rate of increasing was highest at station English Bazar in the month of December. On the other hand, significant changed of winter t_{\max} and t_{mean} occurred in around 1959 and 1952 respectively, while for t_{\min} it was quite late, occurred in the year 1988. The populations of North Bengal who are dependent on temperature-related primary economic activities are getting benefitted from this study. In addition, these analyses will be helpful for policymakers and scientist to focus on micro-

level planning and sustainable Rabi crops management in this region.

Keywords Mann–Kendall test · Sen's slope estimator · Homogeneity test · Winter warming

1 Introduction

Climate change and global warming are considered to be the most significant environmental encounters to the water resource management and food security of any county. Worldwide environmental phenomena such as the melting of ice sheets, increasing ocean surface temperature, shifting of plant and animal ranges etc. have depicted that the climate has been changing adequately within the past few thousand years [1] and the practice has been encouraged predominantly by the concentration of greenhouse gas and aerosol in the atmosphere. Such climate change is severe to the intensity of rainfall, heat balance, annual and seasonal temperature in recent and forthcoming circumstances. According to Singh [2], climate change plays a significant role in drastic or secular modifications in the heat balance of the earth-atmosphere structure. However, the increasing trend and magnitude of temperature has been the largest in the northern high latitudes and smallest in the tropical region [1]. In addition, the warming trend is stronger throughout winter than in the summer [1, 3] and the warming trend of winter temperature is more prominent during the month of February in India for the period 1970–2007 and the amount of increase of t_{\max} and t_{\min} are 0.25 °C/decade and 0.23 °C/decade, respectively [4].

Winter Season is one of the greatest and coldest seasons of India as well as in North Bengal. This season plays the crucial role in plantation agriculture (Tea, Orange, and

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Pineapple) and Rabi crops cultivation in North Bengal. Moreover, the season is very useful for boosting the human brain, improving allergies, lowering inflammation, lowering the risk of diseases, rejuvenating skin etc. But in a recent period, the winter temperature has been increased due to some human activities, e.g. burning of fossil fuels, deforestation, industrialization, and emission of greenhouse gases in the atmosphere. According to Raha et al. [5], North Bengal showed an increasing trend in the diurnal range of temperature in the winter season. Some other study in the recent and past century have witnessed the increasing winter temperature globally, for instance; Hunter et al. [6] showed a warming trend of temperature in the wintertime above 60°N latitudes. Dammo et al. [7] observed a significant increasing trend of annual and seasonal temperature over North-eastern Nigeria during 1981–2010. Similarly, a warming trend over India was observed by Pramanik and Jagannathan [8], Hingane et al. [9], Arora et al. [10], Dash et al. [11] and Mandal et al. [12] which was roughly consistent with the trend and magnitude of the world. A study by Jain et al. [13], Oza and Kishtawal [14] and Tomar et al. [15] over north-east India clearly revealed a rising trend in annual and seasonal temperature. Typically, these warming trends of temperature are capable of ice melting, heat wave incidents, illness and obviously premature death of some species; in addition, it can cause a reallocation of some types of plants and animals [16].

Non-parametric tests are the ultimate choice to identify the significant trend in time series data as it can sustain outliers in the time series data that should be simply autonomous precondition [17, 18]. However, parametric tests are more influential than non-parametric tests but required data should be independent and normally circulated, which is seldom possible for time series data. Usually, Mann–Kendall (MK) test and Sen's slope estimator are the example of non-parametric tests that are commonly used throughout the world for working with hydrological time series data. Equally, Buishand's range Test (B test) and Pettit's test [19–21] are very sensitive to detect the changes in the time series; however, these two methods are more suitable for identifying the changes in the centric period of a series [21]. However, methodologies used by the earlier authors from North Bengal do not consider the chance of inhomogeneities, familiarized by a significant change in the temperature or rainfall time series. Easterling and Peterson [22] revealed that inhomogeneities in hydrological series may be familiarized by a sudden change or jump, by a regular trend or by a jump overlaid on a trend. In addition, inhomogeneities produce either regular bias or severe discontinuities in the data series. Therefore, a comprehensive evaluation of long-term temperature trend and rate of change or homogeneity is necessary. In this study, an attempt has therefore been made to analyze the

recent trends, the magnitude of trends and changing period of winter temperature over six meteorological stations during the period from 1915 to 2016.

2 Method and materials

2.1 Study area and data collection

The study was conducted over six meteorological stations of North Bengal considering one station from each district, namely Koch Bihar (Koch Bihar), Jalpaiguri (Jalpaiguri), Siliguri (Darjeeling), Raiganj (Uttar Dinajpur), Balurghat (Dakshin Dinajpur) and English Bazar (Malda). North Bengal, the gateway of North-east India lies between latitudes 24°39'22"N to 27°13'24"N and longitudes of 87°48'18"E to 89°51'26"E. It is surrounded by the international borders of Nepal, the state border of Bihar and Jharkhand in the west, the international border of Bhutan and the state border of Sikkim in the north, the state border of Assam and the international border of Bangladesh in the east and its southern boundary is delineated by the River Ganges. The study area experiences great variation in climatic condition with tropical savannah over the southern part and humid sub-tropical over the northern part. The region is classified into three agro-climatic zones based on soil and climatic characteristics e.g. Northern Hill Zone (Darjeeling), Terai-Teesta Alluvial Zone (Koch Bihar, Jalpaiguri, and Uttar Dinajpur) and Vindhyan Alluvial Zone (Dakshin Dinajpur and Malda).

In the present study, series of monthly maximum (t_{\max}), minimum (t_{\min}) and average (t_{mean}) winter air temperature were analyzed. The dataset was collected from six meteorological stations of North Bengal (Table 1) for the period 1915–2016 and are obtained from the India water portal and other government websites. After collecting, the data were subjected to check error or missing in the time series and found only less than 1% data were missing which was calculated using multiple imputation method. Spatial distribution of the selected stations in the North Bengal map is

Table 1 Stations considered for the study

Sl. no.	Station	Latitude	Longitude	Altitude (msl)
1	Koch Behar	26°20'N	89°28'E	47 m
2	Jalpaiguri	26°32'N	88°43'E	75 m
3	Siliguri	26°43'N	88°23'E	125 m
4	Raiganj	25°37'N	88°08'E	40 m
5	Balurghat	25°13'N	88°46'E	25 m
6	English Bazar	25°10'N	88°15'E	17 m

shown in Fig. 1 while mean with standard deviation of the temperature variables used in this study are summarized in Table 2.

2.2 Mann–Kendall test

The Mann–Kendall test has been used by several researchers to detect the trend of time series [23–26]. The test statistic (S) of the series $x_1, x_2, x_3, \dots,$ and x_n are calculated by using the following equation:

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

where n is the quantity of information points, x_j and x_k represents to the information points of time j and k .

$$\begin{aligned} \text{sign}(x_j - x_k) &= 1 & \text{if } x_j - x_k > 0 \\ &= 0 & \text{if } x_j - x_k = 0 \\ &= -1 & \text{if } x_j - x_k < 0 \end{aligned} \tag{2}$$

The variance of S is computed by the following equation:

$$\text{VAR}(S) = \frac{1}{18} \left\{ n(n-1)(2n+5) - \sum_{p=1}^g t_p(t_p-1)(2t_p-5) \right\} \tag{3}$$

where n denotes the number of data points, g denotes the tied groups number and t_p denotes the point p ties number.

The statistic S is closely related to Kendall’s τ as given by:

$$\tau = \frac{S}{D} \tag{4}$$

where

$$D = \sqrt{\frac{1}{2}n(n-1) - \frac{1}{2}\sum_{p=1}^g t_p(t_p-1)} \sqrt{\frac{1}{2}n(n-1)}$$

The values of S and VAR(S) are used to compute the test statistic Z as follows

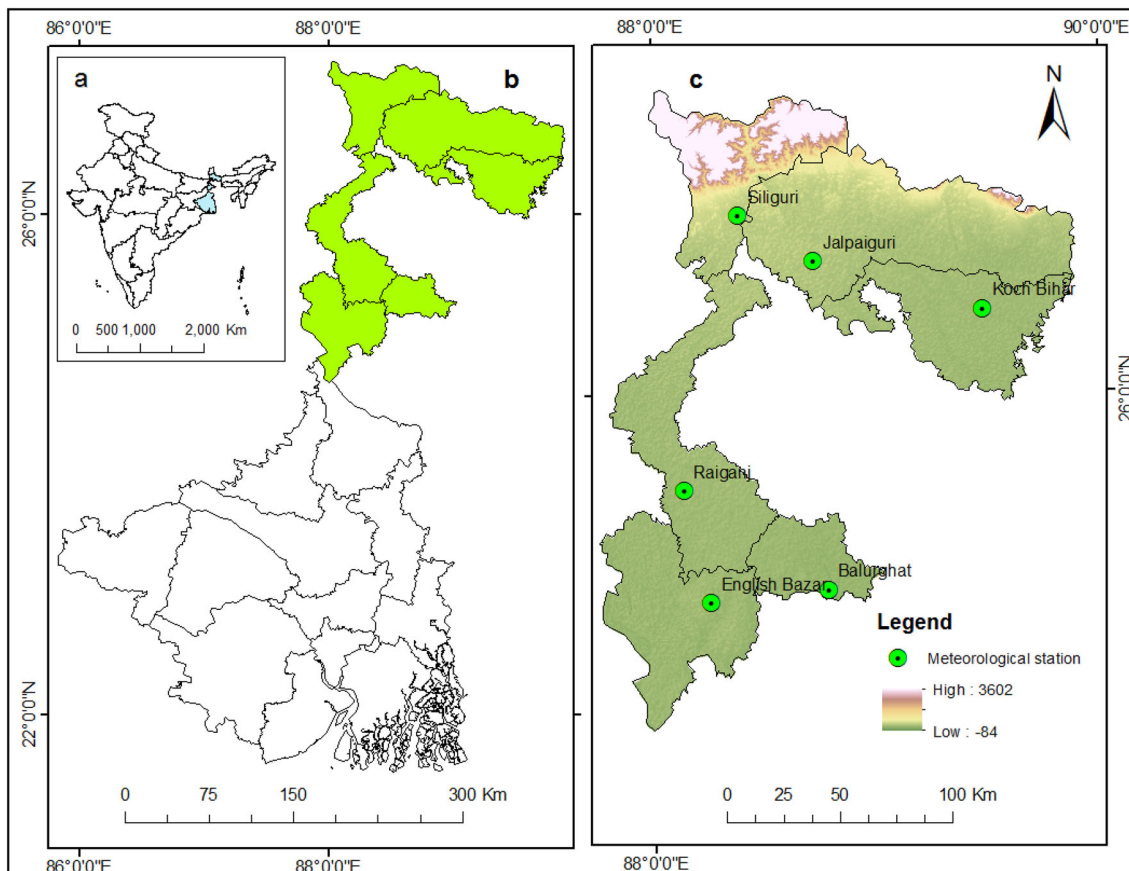


Fig. 1 Location map of the study area, **a** India, **b** West Bengal, **c** North Bengal along with meteorological stations

Table 2 Mean values with standard deviation of temperature at six meteorological stations (1915–2016)

Station	Months	T _{mean}	T _{max}	T _{min}
Koch Bihar	Nov	22.58 ± 0.81	28.64 ± 0.88	16.56 ± 0.91
	Dec	18.69 ± 0.77	25.34 ± 0.84	12.09 ± 0.88
	Jan	17.32 ± 0.83	24.23 ± 0.92	10.44 ± 0.94
	Feb	19.27 ± 0.91	26.41 ± 1.06	12.18 ± 0.98
	Winter	19.47 ± 0.56	26.15 ± 0.58	12.82 ± 0.65
Jalpaiguri	Nov	22.19 ± 0.88	28.32 ± 0.97	16.09 ± 0.95
	Dec	18.59 ± 0.79	25.24 ± 0.89	11.99 ± 0.90
	Jan	16.85 ± 0.88	23.60 ± 0.98	10.13 ± 0.96
	Feb	18.64 ± 0.91	25.58 ± 1.05	11.75 ± 0.96
	Winter	19.07 ± 0.56	25.68 ± 0.59	12.49 ± 0.64
Siliguri	Nov	20.67 ± 0.89	27.09 ± 0.97	14.29 ± 0.94
	Dec	16.95 ± 0.80	23.69 ± 0.88	10.24 ± 0.91
	Jan	15.01 ± 0.86	21.67 ± 0.95	8.39 ± 0.96
	Feb	16.87 ± 0.89	23.71 ± 1.05	10.06 ± 0.92
	Winter	17.38 ± 0.55	24.04 ± 0.58	10.75 ± 0.63
Raiganj	Nov	21.92 ± 0.79	28.71 ± 0.79	15.16 ± 0.98
	Dec	17.82 ± 0.81	25.18 ± 0.86	10.51 ± 0.96
	Jan	16.50 ± 0.78	23.84 ± 0.86	9.19 ± 0.94
	Feb	18.80 ± 0.92	26.53 ± 1.10	11.11 ± 0.97
	Winter	11.49 ± 0.67	26.07 ± 0.61	11.49 ± 0.67
Balurghat	Nov	23.23 ± 0.77	29.30 ± 0.77	17.18 ± 0.99
	Dec	19.21 ± 0.83	25.91 ± 0.86	12.53 ± 1.00
	Jan	18.01 ± 0.78	24.79 ± 0.84	11.28 ± 0.96
	Feb	20.39 ± 0.96	27.70 ± 1.12	13.15 ± 1.03
	Winter	20.21 ± 0.59	26.92 ± 0.62	13.54 ± 0.70
English Bazar	Nov	22.09 ± 0.80	28.77 ± 0.80	15.45 ± 1.05
	Dec	18.05 ± 0.88	25.37 ± 0.92	10.77 ± 1.04
	Jan	17.14 ± 0.78	24.485 ± 0.85	9.84 ± 0.97
	Feb	19.75 ± 0.95	27.42 ± 1.14	12.10 ± 1.00
	Winter	19.26 ± 0.60	26.51 ± 0.65	12.04 ± 0.72

$$Z = \begin{cases} = \frac{S - 1}{[\text{VAR}(S)]^{\frac{1}{2}}} & \text{if } S > 0 \\ = 0 & \text{if } S = 0 \\ = \frac{S + 1}{[\text{VAR}(S)]^{\frac{1}{2}}} & \text{if } S < 0 \end{cases} \quad (5)$$

Positive and negative value of Z indicates increasing and decreasing trends. To test null hypothesis (H_0), of no trend against the alternative hypothesis (H_a), of an upward or downward trend at the $\alpha = 0.05$ level of significance, H_0 is rejected if the estimation of Z is more prominent than $Z_{1-\alpha/2}$, which is acquired from the Pearson and Hartley's [27] standard ordinary distribution table.

2.3 Homogeneity test

There are two groups of homogeneity test e.g. 'absolute' and 'relative' method. According to Wijngaard et al. [28] each station is considered separately in absolute method whereas, neighboring stations are essential part of relative method. In this study, the absolute method is used for homogeneity test due to areal expansion of the study area. Moreover, the Buishand's range test and Pettitt's test were used in this study to detect change point of the temperature time series data. These two tests are capable of locating the year where a break is likely.

2.3.1 Buishand's range test

Let X represents a normal random variable, and then a single change-point is calculated by following equation [29]:

$$x_i = \begin{cases} \mu + \varepsilon_i & i = 1, \dots, m \\ \mu + \Delta + \varepsilon_i & i = m + 1, \dots, n \end{cases} \quad (6)$$

$\varepsilon \approx N(0, \sigma)$. The null hypothesis $\Delta = 0$ is checked against the alternative $\Delta \neq 0$. In the Buishand’s range test [29], the rescaled familiar partial totalities are calculated by the following equation:

$$S_k = \sum_{i=1}^k (x_i - \hat{x}) \quad (1 \leq i \leq n) \quad (7)$$

The test statistic is calculated by the following equation:

$$R_b = \frac{\max S_k - \min S_k}{\sigma} \quad (8)$$

The Monte Carlo simulation is being used to estimate the $P < 0.05$ value by replicates.

2.3.2 Pettitt’s test

This method is frequently used to identify a single change-point in hydrological time series or climate series with uninterrupted data. It tests the H_0 : Data are uniform, against the alternative H_a : There is a date at which there is a change in the data. The method is defined as [30]

$$K_T = \max |U_{t,T}| \quad (9)$$

where

$$U_{t,T} = \sum_{i=1}^t \sum_{j=t+1}^T \text{sgn}(X_i - X_j) \quad (10)$$

The change-point of the series is located as K_T , provided that the statistics is significant. The significant probability of K_T is approximated for $P \leq 0.05$ with

$$p \simeq 2 \exp\left(\frac{-6K_T^2}{T^3 + T^2}\right) \quad (11)$$

2.4 Sen’s slope estimator

To find out the exact quantity of slope (change/unit time) in a hydro-meteorological time series data Sen’s slope [31] estimator was performed. To obtain an estimate of slope Q , the slopes of N pairs of data were calculated using following equation:

$$Q_i = \frac{x_k - x_j}{k - j}, \quad i = 1 \dots N \quad (12)$$

where x_k and x_j are the data values at times k and j ($k > j$) respectively. The median of these N values of Q_i is Sen’s estimators of slope. Since, in the present study, there is only one datum in each time period, hence $N = n(n - 1)/2$, where, n represents number of time

periods. The N values of Q_i are ranked from smallest to largest and Sen’s slope estimator (median of slope) is calculated by the following equation:

$$Q_{\text{Med}} = \begin{cases} Q_{(N+1)/2} & \text{If } N \text{ is odd} \\ \frac{Q_{N/2} + Q_{(N+2)/2}}{2} & \text{If } N \text{ is even} \end{cases} \quad (13)$$

The $100(1 - \alpha)$ percentage two sided certainly interim about the accurate slope [32] can be estimated by the non-parametric technique based on the normal distribution by following way:

$$C_\alpha = Z_{1-\alpha/2} [\text{VAR}(S)]^{1/2} \quad (14)$$

where $\text{VAR}(S)$ is computed from Eq. 3. Then compute $M_1 = (N - C_\alpha)/2$ and $M_2 = (N + C_\alpha)/2$. The lesser and greater limits of the assurance interval are the M_1 th the leading and (M_2+1) th leading of the N ordered slope projected Q_i , which are generalized by Gilbert [32].

3 Result and discussion

The annual average temperature of North Bengal is 24.65 °C whereas the winter (November–February) t_{mean} is 19.02 °C. Mean (of 102 years) winter t_{max} and t_{min} were recorded 25.90 °C and 12.18 °C respectively. The highest winter t_{max} experienced by the North Bengal was at Koch Bihar in November, 1993 (31.14 °C) and the lowest winter t_{min} was found at Siliguri in January 1992 (6.08 °C).

The monotonic trends analysis for the data sets of winter t_{max} , t_{min} and t_{mean} described in Table 2, Table 4 and Table 6 were carried out using Mann–Kendall non-parametric test with Sen’s Slope estimator. For two-sided test the value of 0.05 was chosen as significance level. The Pettitt’s test (P test) and Buishand’s range test (B test) were applied in order to the existence of a change, if any, in case of winter t_{max} , t_{min} and t_{mean} in the time series during the study period.

3.1 Analysis of trend and change point of winter maximum temperature

The winter t_{max} of North Bengal varied from 24.67 to 27.18 °C with a long-term mean 25.90 ± 0.58 °C with coefficient of variation (CV) only 2.24% during the study period. The t_{max} during the winter season was highest at Balurghat 26.92 ± 0.62 °C with CV 2.29% and lowest at Siliguri 24.04 ± 0.58 °C with CV 2.42%. The long-term average monthly t_{max} of North Bengal during the winter season was highest in November 28.47 ± 0.80 °C with CV 2.81% and lowest in January 23.77 ± 0.86 °C with CV

3.60%. Thus, the month of November experiences more consistency than other months in terms of t_{\max} .

The results of the monotonic trend of winter t_{\max} depict significant ($P < 0.05$) increasing trends over all stations and all months except January during the study period (Table 3). The t_{\max} during the winter season at Balurghat and English Bazar shows the highest increasing trend at the rate of 0.12 °C/decade, closely followed by Raiganj (0.11 °C/decade), Koch Bihar (0.10 °C/decade) Jalpaiguri (0.09 °C/decade) and Siliguri (0.09 °C/decade). The noticeable degree of warming in terms of winter t_{\max} over Balurghat and English Bazar are explained as the reason for infrastructural development and urbanization in the region. The results of our study more or less similar to the study of Raha et al. [5], since they observed more pronounced warming trend over most rapidly developing towns of Malda and Jalpaiguri. However, the magnitude of significant ($P < 0.05$) increasing trend in t_{\max} of 0.11 °C/decade to 0.17 °C/decade in November and December, and of values 0.10 °C/decade to 0.11 °C/decade in February was observed. These results of t_{\max} of North Bengal illustrated the winter warming trend in the given time period (Fig. 2a–f). These findings apparently equivalent earlier results of Jangra and Singh [33], who showed a quick upswing of winter t_{\max} at Bajaura (Kullu Valley, India) in the data period from 1981–1990 to 2001–2009. Similarly, Jain and Kumar [34] revealed that the t_{\max} has amplified significantly in all seasons over India.

The analysis of homogeneity of winter t_{\max} showed several significant changes in the time series of the temperature data in all meteorological stations and all months except January during the study period (Table 4), finding a

significant change in before and after the identified change point. The winter t_{\max} of North Bengal was shifted as a whole in between 1951 and 1989 where, November indicates significant changed in 1955(P test) or 1989 (B test), February in 1959 and December in 1970 but January shows no significant change during the period 1915–2016. On the other hand, change of winter t_{\max} was similar over all the stations except English Bazar and year 1959 has been found to be the changing year at stations Koch Bihar, Jalpaiguri, Siliguri, Raiganj and Balurghat (Fig. 3a–d). While, the t_{\max} of English Bazar has been shifted in the year 1952 (P test) or 1959 (B test).

3.2 Analysis of trend and change point of winter minimum temperature

The mean t_{\min} in the winter season varied over these stations from 10.75 ± 0.55 °C for the Siliguri to 13.54 ± 0.70 °C for the Balurghat, with an overall mean 12.19 ± 0.64 °C. The long-term average monthly t_{\min} of North Bengal during the winter season was highest in November 15.79 ± 0.93 °C with CV 5.90% and lowest in January 9.88 ± 0.91 °C with CV 9.17%. Thus, November reveals again the more consistent temperature than others months in case of mean t_{\min} .

The results of the monotonic trend of winter t_{\min} show statistically significant ($P < 0.05$) positive trends ($Z = 2.04$ – 5.80) in all the months and all the stations during the study period. Table 5 depicts that the months of December and February (estimated trend slope of 0.15 °C/decade) having the highest warming trend followed by November (0.11 °C/decade) and January (0.07 °C/decade)

Table 3 Trend of winter maximum temperature at six stations of North Bengal (1915–2016)

Station	Test	November	December	January	February	Winter
Koch Bihar	Z	4.38*	3.78*	1.84	3.06*	5.17*
	Q	0.12	0.12	0.06	0.11	0.10
Jalpaiguri	Z	3.47*	3.48*	1.53	2.89*	4.45*
	Q	0.12	0.11	0.05	0.11	0.09
Siliguri	Z	3.17*	3.59*	1.47	2.91*	4.21*
	Q	0.11	0.11	0.05	0.10	0.09
Raiganj	Z	5.57*	4.74*	1.47	2.74*	5.11*
	Q	0.15	0.14	0.05	0.10	0.11
Balurghat	Z	6.11*	5.47*	1.52	2.86*	5.72*
	Q	0.15	0.15	0.05	0.11	0.12
English Bazar	Z	6.49*	5.61*	1.49	2.54*	5.52*
	Q	0.17	0.17	0.05	0.10	0.12
North Bengal	Z	4.93*	4.62*	1.67	2.96*	5.29*
	Q	0.13	0.13	0.05	0.11	0.10

Z normalized test statistics, Q Sen's slope per decade

*Statistically significant trends at the 5% significant level

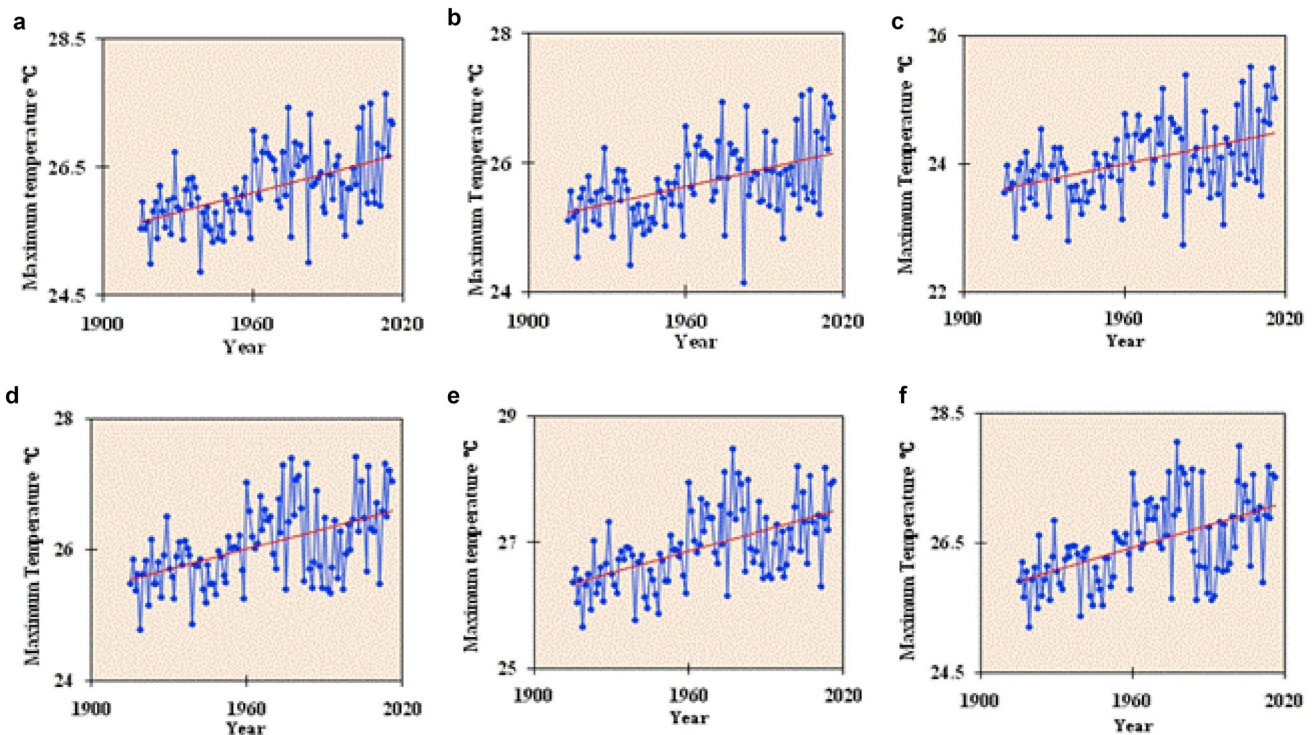


Fig. 2 Trend of maximum temperature, **a** Koch Bihar, **b** Jalpaiguri, **c** Siliguri, **d** Raiganj, **e** Balurghat, **f** English Bazar

Table 4 Change point detection of winter maximum temperature at six stations of North Bengal (1915–2016)

Station	Test	November	December	January	February	Winter
Koch Bihar	P-Test	1269* (1955)	1043* (1970)	779 (No)	1204* (1959)	1759* (1959)
	B-Test	20.55* (1955)	16.83* (1970)	12.7 (No)	22.82* (1959)	28.56* (1959)
Jalpaiguri	P-Test	1068* (1955)	984* (1970)	652 (No)	1134* (1959)	1543* (1959)
	B-Test	16.74* (1955)	14.13* (1970)	9.78 (No)	22.24* (1959)	25.33* (1959)
Siliguri	P-Test	938* (1955)	988* (1970)	568 (No)	1140* (1959)	1424* (1959)
	B-Test	16.36* (1988)	14.27* (1970)	8.5 (No)	20.64* (1959)	23.77* (1959)
	P-Test	1456* (1955)	1271* (1970)	756 (No)	1120* (1959)	1571* (1959)
	B-Test	24.54* (1989)	18.84* (1970)	12.82 (No)	19.95* (1959)	27.36* (1959)
Balurghat	P-Test	1559* (1955)	1442* (1956)	845 (No)	1183* (1959)	1823* (1959)
	B-Test	25.61* (1964)	24.76* (1964)	15.80* (1959)	20.74* (1959)	30.83* (1959)
English Bazar	P-Test	1611* (1953)	1493* (1952)	865* (1951)	1078* (1959)	1678* (1952)
	B-Test	25.90* (1989)	23.24* (1956)	15.59* (1959)	19.41* (1959)	28.60* (1959)
North Bengal	P-Test	1361* (1955)	1266* (1970)	777 (No)	1191* (1959)	1695* (1959)
	B-Test	22.42* (1989)	19.31* (1970)	12.91 (No)	21.55* (1959)	28.64* (1959)

*Denote trends at 5% significance level. Values indicate Pettit’s test (P Test) and Buishand’s test (B Test) statistics and in the parentheses the year of change in the time series if the test was significant

in North Bengal. Similar results were observed by Khan et al. [3], since they revealed temperatures have been increased extreme in the months of December and February, followed by November and October in Kolkata, West Bengal from 1941 to 2010. However, station English Bazar ($Q = 0.14$ °C/decade) on the other hand, depicts the

highest significant increasing trend in winter t_{min} , closely followed by Balurghat ($Q = 0.13$ °C/decade), Raiganj ($Q = 0.12$ °C/decade), Koch Bihar ($Q = 0.11$ °C/decade), Jalpaiguri ($Q = 0.10$ °C/decade), and Siliguri ($Q = 0.09$ °C/decade) (Fig. 3a–f). Such typical degree of warming in terms of t_{min} over English Bazar, Balurghat and

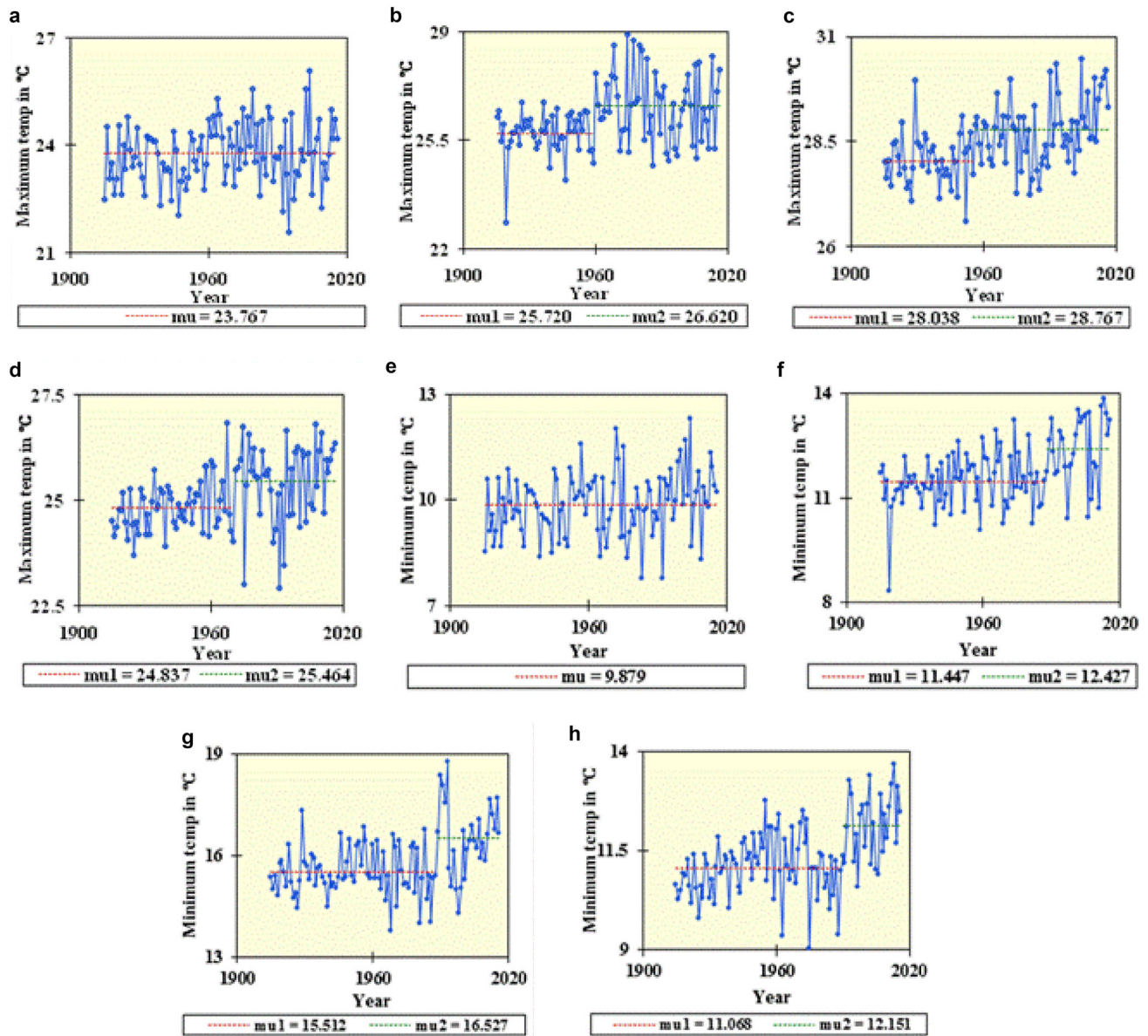


Fig. 3 Winter Month Homogeneity, **a** January, **b** February, **c** November, **d** December; (maximum temperature), **e** January, **f** February, **g** November, **h** December (minimum temperature)

Raiganj are explained as the reason of some human activities, such as, emission of greenhouse gases, infra-structural development and urbanization. The significant increasing trend of winter t_{\min} is consistent with the formerly result obtained by some climate researcher. Warwade et al. [35] showed a largest positive trend for winter t_{\min} in the hilly region of North-Eastern India, indicating a trend of winter warming.

The analysis of homogeneity of winter t_{\min} shows significant changed over all stations and all months except January during the study period (Table 6). The monthly results reveal that the temperature of February has been shifted around 1987–1988, November in 1988 and

December in 1989 (P test) or 1991(B test) while January shows no significant change in t_{\min} except stations Koch Bihar and Balurghat. The change of winter t_{\min} over Koch Bihar and Jalpaiguri were found in 1986 and rest of the stations e.g. over Siliguri, Raiganj, Balurghat and English Bazar were found in the year of 1988. However, the changes of winter t_{\min} as a whole over North Bengal have been occurred in between 1944 and 1991 (Fig. 3e–h).

Table 5 Trend of winter minimum temperature at six stations of North Bengal (2015–2016)

Station	Test	November	December	January	February	Winter
Koch Bihar	Z	3.06*	4.39*	2.57*	4.60*	5.20*
	Q	0.10	0.13	0.08	0.16	0.11
Jalpaiguri	Z	2.49*	3.90*	2.04*	4.46*	4.48*
	Q	0.08	0.12	0.07	0.15	0.10
Siliguri	Z	2.27*	3.89*	2.08*	4.39*	4.24*
	Q	0.08	0.13	0.06	0.13	0.09
Raiganj	Z	4.01*	5.05*	2.07*	4.17*	5.27*
	Q	0.13	0.16	0.07	0.15	0.12
Balurghat	Z	4.59*	5.73*	2.36*	4.37*	5.64*
	Q	0.15	0.17	0.08	0.16	0.13
English Bazar	Z	4.40*	5.80*	2.10*	4.19*	5.81*
	Q	0.15	0.19	0.08	0.15	0.14
North Bengal	Z	3.54*	4.90*	2.32*	4.54*	5.20*
	Q	0.11	0.15	0.07	0.15	0.11

Z normalized test statistics, Q Sen’s slopeper decade

*Statistically significant trends at the 5% significant level

Table 6 Change point detection of winter minimum temperature at six stations of North Bengal (1915–2016)

Station	Test	November	December	January	February	Winter
Koch Bihar	P-Test	1028* (1987)	1211* (1989)	875* (1985)	1239* (1986)	1477* (1986)
	B-Test	19.77* (1987)	22.27* (1989)	13.23* (1985)	22.32* (1986)	26.48* (1986)
Jalpaiguri	P-Test	874* (1988)	1136* (1990)	793 (No)	1232* (1986)	1375* (1986)
	B-Test	16.43* (1988)	21.41* (1990)	12.48 (No)	22.36* (1986)	24.92* (1986)
Siliguri	P-Test	852* (1988)	1136* (1989)	781 (No)	1244* (1986)	1329* (1988)
	B-Test	16.20* (1988)	21.47* (1990)	11.75 (No)	21.61* (1986)	24.86* (1988)
Raiganj	P-Test	1292* (1988)	1325* (1991)	712 (No)	1210* (1988)	1572* (1988)
	B-Test	23.90* (1988)	23.98* (1991)	12.03 (No)	21.08* (1988)	28.41* (1988)
Balurghat	P-Test	1407* (1986)	1407* (1944)	824 (No)	1189* (1988)	1552* (1988)
	B-Test	25.14* (1988)	24.25* (1991)	1196* (1988)	20.49* (1988)	28.33* (1988)
English Bazar	P-Test	1442* (1988)	1394* (1944)	804 (No)	1196* (1988)	1628* (1988)
	B-Test	26.09* (1988)	24.21* (1991)	13.25 (No)	20.73* (1988)	29.03* (1988)
North Bengal	P-Test	1154* (1988)	1301* (1989)	744 (No)	1219* (1987)	1540* (1988)
	B-Test	22.21* (1988)	23.87* (1991)	12.85 (No)	21.64* (1987)	28.02* (1988)

*Denote trends at 5% significance level. Values indicate Pettit’s test (P Test) and Buishand’s test (B Test) statistics and in the parentheses the year of change in the time series if the test was significant

3.3 Analysis of trend and change point of winter average temperature

Winter t_{mean} of North Bengal varied from 17.78 to 20.59 °C, with a long-term (1915–2016) mean of 19.02 ± 0.55 °C, whereas the average monthly temperature of the region during winter season was highest in November (22.11 ± 0.79 °C) and lowest in January (16.81 ± 0.78 °C). On the other hand, the mean long-term t_{mean} during winter season over six stations was highest at

Balurghat 20.21 °C and lowest at Siliguri 17.38 °C. The CV for long-term winter t_{mean} of North Bengal was maximum in the month of February (4.73%) and lowest in the month of November (3.57%). However, CV for t_{mean} over six stations was highest at Siliguri in the month of January (5.70%) and lowest at Jalpaiguri in November (3.98%). So, the month of November and the station Jalpaiguri experienced more consistent temperature than the other months and stations (Fig. 4).

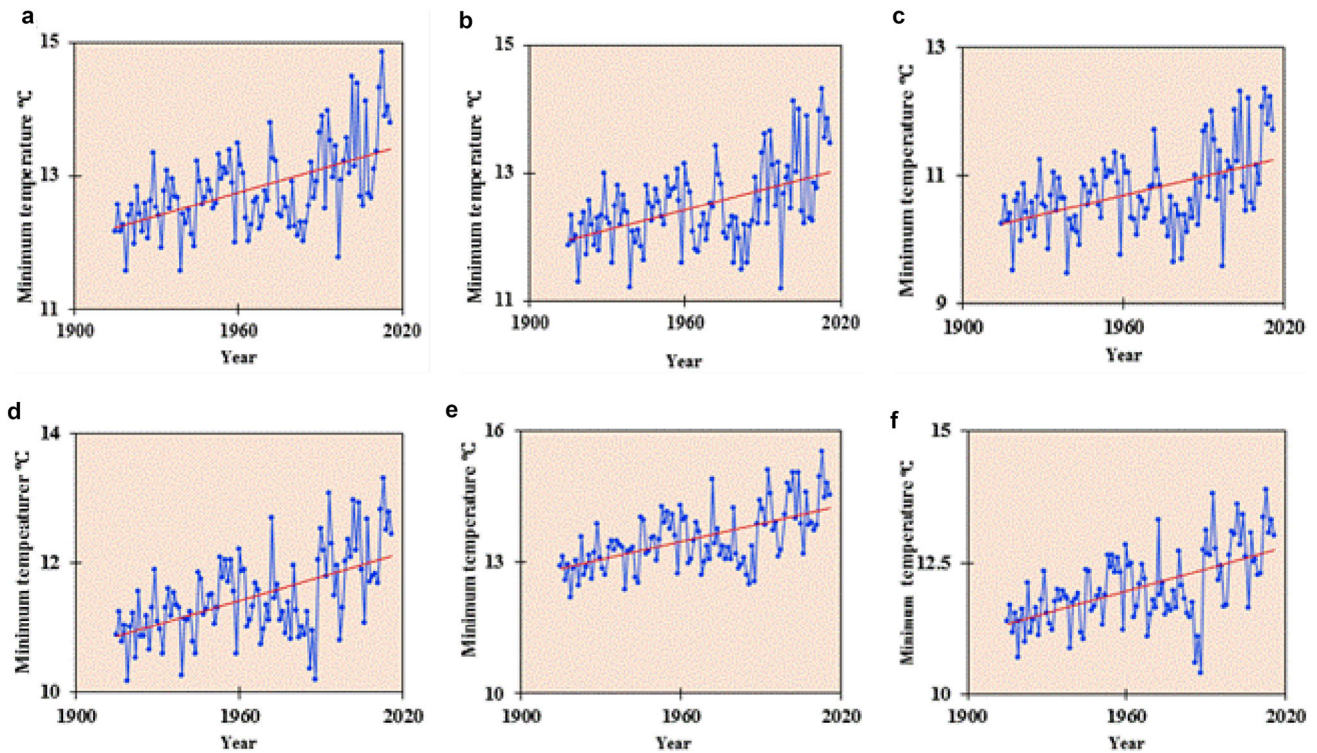


Fig. 4 Trend of minimum temperature, **a** Koch Bihar, **b** Jalpaiguri, **c** Siliguri, **d** Raiganj, **e** Balurghat, **f** English Bazar

Table 7 Trend of winter average temperature at six stations of North Bengal (1915–2016)

Station	Test	November	December	January	February	Winter
Koch Bihar	Z	3.94*	4.58*	2.18*	4.63*	5.94*
	Q	0.11	0.12	0.06	0.14	0.10
Jalpaiguri	Z	3.02*	4.02*	1.84	4.31*	5.09*
	Q	0.09	0.11	0.06	0.13	0.09
Siliguri	Z	2.80*	3.90*	1.74	3.93*	4.81*
	Q	0.09	0.11	0.05	0.12	0.09
Raiganj	Z	5.45*	5.33*	1.95	4.07*	6.13*
	Q	0.14	0.14	0.05	0.12	0.11
Balurghat	Z	6.07*	6.18*	2.13*	4.10*	6.66*
	Q	0.15	0.17	0.06	0.13	0.13
English Bazar	Z	6.26*	6.31*	2.00*	3.68*	6.64*
	Q	0.16	0.17	0.06	0.12	0.13
North Bengal	Z	4.67*	5.24*	2.09*	4.28*	6.20*
	Q	0.12	0.14	0.06	0.12	0.11

Z normalized test statistics, Q Sen's slope per decade

*Statistically significant trends at the 5% significant level

The analysis of the monotonic trend of six stations of North Bengal shows statistically significant ($P < 0.05$) rising trend ($Z = 4.81$ – 6.66) in terms of winter t_{mean} during the study period (Table 7). The increasing trends in t_{mean} for the four months namely, November ($Z = 2.80$ – 6.26), December ($Z = 3.90$ – 6.31), January ($Z = 1.74$ – 2.18) and February ($Z = 3.68$ – 4.63) were also statistically significant

($P < 0.05$). The exceptions to this rule are in the temperature of the month of January at stations Jalpaiguri, Siliguri and Raiganj. The highest rate of increase (estimated trend slope of 0.17 °C/decade) in t_{mean} was observed over Balurghat and English Bazar in the month of December and lowest at the Siliguri and Raiganj in the month of January (estimated trend slope of 0.05 °C/decade)

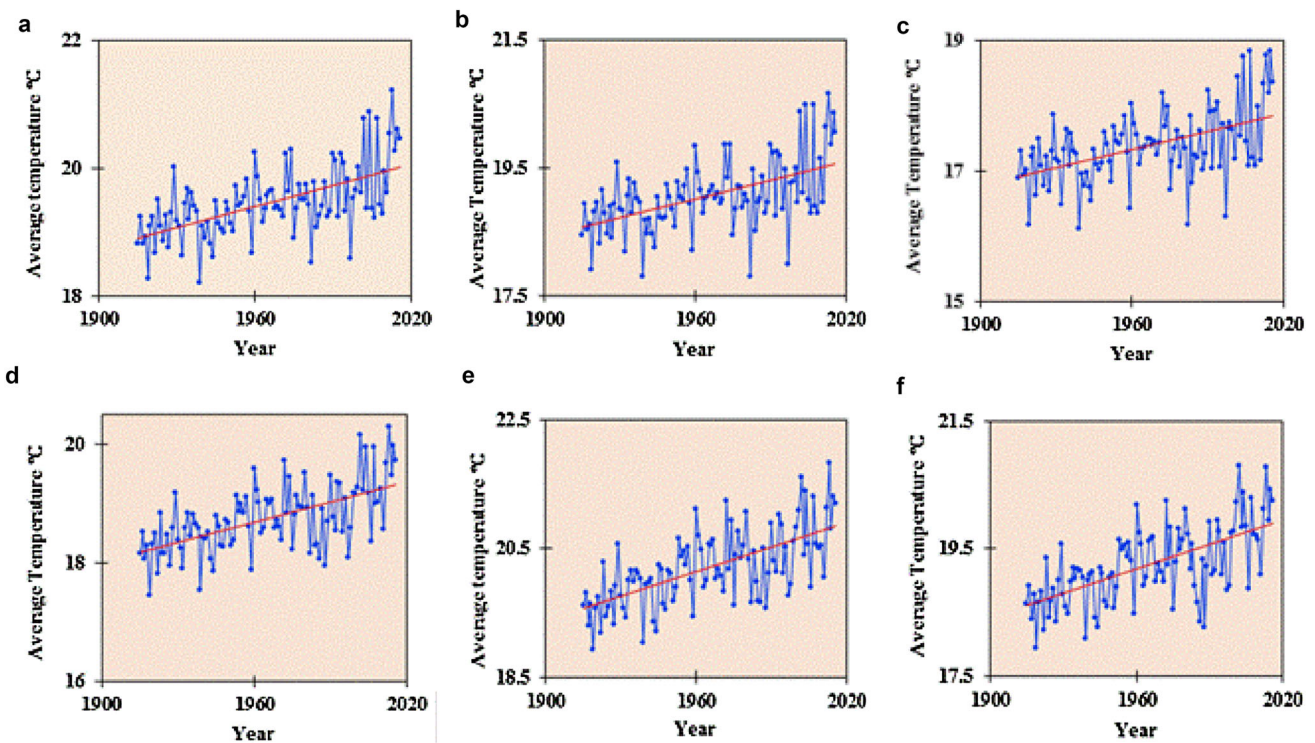


Fig. 5 Trend of average temperature, a Koch Bihar, b Jalpaiguri, c Siliguri, d Raiganj, e Balurghat, f English Bazar

Table 8 Change point detection of winter average temperature at six stations North Bengal (1915–2016)

Station	Test	November	December	January	February	Winter
Koch Bihar	P-Test	1119* (1987)	1095* (1970)	702 (No)	1405* (1959)	1614* (1952)
	B-Test	21.11* (1987)	19.09* (1991)	12.21 (No)	23.84* (1959)	25.30* (1959)
Jalpaiguri	P-Test	934* (1988)	965* (1970)	568 (No)	1331* (1959)	1408* (1952)
	B-Test	17.83* (1988)	18.05* (1991)	10.09 (No)	23.17 *(1959)	22.12* (1959)
Siliguri	P-Test	886* (1988)	938* (1991)	562 (No)	1217* (1959)	1346* (1952)
	B-Test	17.48* (1988)	18.09* (1991)	9.15 (No)	21.57* (1959)	21.12* (1952)
Raiganj	P-Test	1487* (1988)	1241* (1952)	800 (No)	1267* (1959)	1608* (1952)
	B-Test	26.44* (1988)	22.21* (1991)	14.07* (1951)	20.89* (1959)	26.20* (1952)
Balurghat	P-Test	1603* (1986)	1510* (1952)	940* (1951)	1307* (1959)	1744* (1952)
	B-Test	27.92* (1986)	24.30* (1952)	17.42* (1951)	21.41* (1959)	28.83* (1952)
English Bazar	P-Test	1647* (1988)	1597* (1952)	918* (1951)	1218* (1959)	1740* (1952)
	B-Test	29.12* (1988)	24.38* (1952)	16.65* (1951)	20.48* (1959)	28.79* (1952)
North Bengal	P-Test	1338* (1988)	1233* (1949)	797 (No)	1325* (1959)	1666* (1952)
	B-Test	24.11* (1988)	21.48* (1991)	13.64* (1951)	22.54* (1959)	26.22* (1952)

*Denote trends at 5% significance level. Values indicate Pettit’s test (P Test) and Buishand’s test (B Test) statistics and in the parentheses the year of change in the time series if the test was significant

(Fig. 5a–f). However, Raha et al. [5] revealed that the degree of warming was quite severe over Jalpaiguri and Malda due to rapid urbanization and development of infrastructure facilities and lowest over Balurghat.

The changes of winter t_{mean} of North Bengal was occurred in between 1951 and 1991 over all stations and all months except January (Table 8). The results clearly show that the temperature of January has been shifted in the year 1951, though Koch Bihar, Jalpaiguri and Siliguri show no

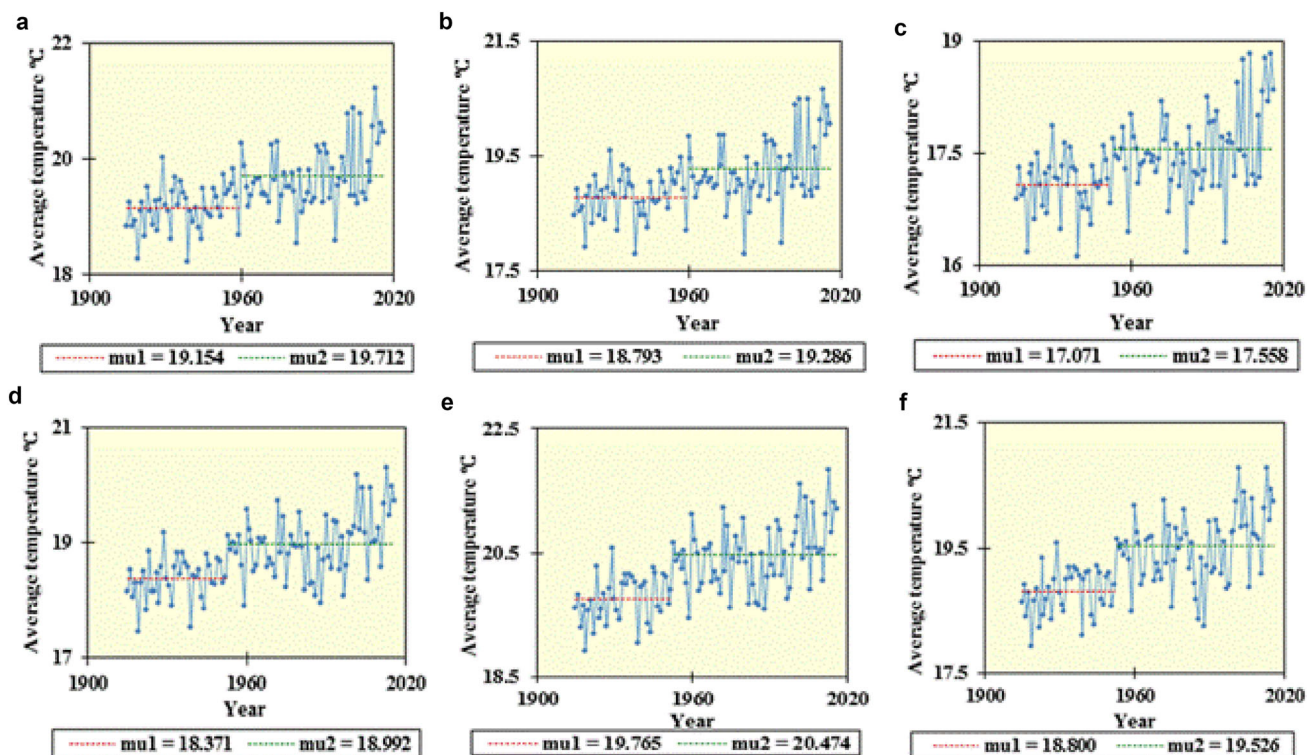


Fig. 6 Change point detection of winter average temperature, **a** Koch Bihar, **b** Jalpaiguri, **c** Siliguri, **d** Raiganj, **e** Balurghat, **f** English Bazar

change in this month. The temperature of February has been changed in 1959, November in 1988 and December in 1991. On the other hand, all stations except Koch Bihar and Jalpaiguri show consistent in changed of winter t_{mean} and year 1952 has been found as changing year while Koch Bihar and Jalpaiguri show significantly changed in 1952 (P test) or in 1959 (B test) (Fig. 6a–f).

It could be observed from the aforesaid discussion, the winter starts by November and carries on till February and the cold weather prevails these months obviously due to northeast monsoon, this period is appropriate for Rabi crop farming in the study area. Thus, these observed changes in winter temperature may result in an increasing demand for water in Rabi crops. However, the result of temperature trend of our study is similar to the other study of the world. For example, Shrestha et al. [36] showed an increasing trend of temperature over Nepal after 1977 and the magnitude of increasing ranged from 0.03 to 0.12 °C/year. A significant warming trend of mean temperature was detected by Domroes and El-Tantawi [37] during their study over Egypt from the period 1941–2000. On the other hand, Gbode et al. [38] observed warming trend since 1960 over Kano of Sahelian region in Nigeria during their study from 1960 to 2007. Likewise, Jacob and Walland [39] witnessed the significant increasing trend of long-term maximum and lowest minimum temperature extremes over

Australia, where, lowest minimum temperature extremes classically exceed over extreme of maximum temperature.

4 Conclusion

The study analyzed monotonic trends and change points of winter temperature over six meteorological stations of North Bengal during the period of 1915–2016. The analysis shows that the winter temperature is increased at every station over North Bengal and the rate of increase is highest at English Bazar. In addition, the homogeneity of winter temperature has shattered in the year of 1959 for t_{max} , 1988 for t_{min} and 1952 for t_{mean} . However, at the six sites, the total figures of statistically significant values were greater than the total figures of non-significant values on a seasonal and monthly timescale. This increasing winter temperature trend in this agricultural based region would need higher crop water requirement due to high evapotranspiration rates. Hence, there would further intensify the gap between water requisite and supply in the commitment. The impact of higher temperature in the Rabi crop production and productivity is, however, to be settled down in the region, but certainly, an increase in the demand for water would further amplify the water stress. Keeping in view these factors, keen agriculture strategies are required especially

for Rabi crops to make tropical agriculture more durable to climate change.

Acknowledgements The authors are grateful to the India Water Portal for providing free download of various dataset used in the analysis. Also, the authors would like to thank anonymous reviewers and editor for their helpful comments on the previous version of the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This paper does not contain any studies with human participants performed by any of the authors. This paper does not contain any studies with animals performed by any of the authors.

References

- Barry, R. G., & Chorley, R. J. (2010). *Atmosphere, weather and climate*. London: Routledge.
- Singh, S. (2016). *Climatology*. Allahabad: Pravalika Publication.
- Khan, A., Chatterjee, S., & Bisai, D. (2017). Air temperature variability and trend analysis by non-parametric test for Kolkata observatory, West Bengal, India. *Indian Journal of Geo Marine Sciences*, 46(5), 966–971.
- Jaswal, A. K. (2010). Recent winter warming over India-spatial and temporal characteristics of monthly maximum and minimum Temperature trends for January to march. *Mausam*, 61(2), 163–174.
- Raha, G. N., Bhattacharjee, K., Das, M., Dutta, M., & Bandyopadhyay, S. (2014). Statistical study of surface temperature and rainfall over four stations in north Bengal. *Mausam*, 62(2), 179–184.
- Hunter, D. E., Schwartz, S. E., Wagener, R., & Benkovitz, C. M. (1993). Seasonal, latitudinal, and secular variations in temperature trend: Evidence for influence of anthropogenic sulfate. *Geophysical Research Letters*, 20, 2455–2458.
- Dammo, M. N., Ibn Abubakar, B. S. U., & Sangodoyin, A. Y. (2015). Trend and change analysis of monthly and seasonal temperature series over North-eastern Nigeria. *Journal of Geography, Environment and Earth Science International*, 3(2), 1–8.
- Pramanik, S. K., & Jagannathan, P. (1954). Climate change in India (II)-temperature. *Indian Journal of Meteorology & Geophysics*, 5(1), 29–47.
- Hingane, L. S., Rupa Kumar, K., & Ramana Murty, Bh. V. (1985). Long-term trends of surface air temperature in India. *Journal of Climatology*, 5, 521–528.
- Arora, M., Goel, N. K., & Singh, P. (2005). Evaluation of temperature trends over India. *Hydrological Sciences Journal*, 50(1), 81–93.
- Dash, S. K., Jenamani, R. K., Kalsi, S. R., & Panda, S. K. (2007). Some evidence of climate change in twentieth-century India. *Climatic Change*, 85, 299–321.
- Mandal, S., Choudhury, B. U., Mandal, M., & Bej, S. (2013). Trend analysis of weather variables in Sagar Island, West Bengal, India: a long-term perspective (1982–2010). *Current Science*, 105(7), 947–953.
- Jain, S. K., Kumar, V., & Saharia, M. (2012). Analysis of rainfall and temperature trends in northeast India. *International Journal of Climatology*, 5, 5. <https://doi.org/10.1002/joc.3483>.
- Oza, M., & Kishtawal, C. M. (2014). Trends in rainfall and temperature patterns over northeast India. *Earth Science, India*, 7(4), 90–105.
- Tomar, C. S., Saha, D., Das, S., Saw, S., Bist, S., & Gupta, M. K. (2017). Analysis of temperature variability and trends over Tripura. *Mausam*, 68(1), 149–160.
- Kumar, K., Mishra, N., & Gupta, S. (2014). Trend analysis of temperature by Mann–Kendall test in the high altitude regions of Uttarakhand, India. *Asian Academic Research Journal of Multidisciplinary*, 1(18), 387–399.
- Chen, H., Guo, S., Xu, C. Y., & Singh, V. P. (2007). Historical temporal trends of hydro-climatic variables and run-off response to climate variability and their relevance in water resource management in the Hanjiang Basin. *Journal of Hydrology*, 344, 171–184.
- Suhaila, J., Jemain, A. A., Hamdan, M. F., & Zin, W. Z. W. (2011). Comparing rainfall patterns between regions in Peninsular Malaysia via a functional data analysis technique. *Journal of Hydrology*, 411(3), 197–206. <https://doi.org/10.1016/j.jhydrol.2011.09.043>.
- Firat, M., Dikbas, F., Koc, A. C., & Gungor, M. (2012). Analysis of temperature series: estimation of missing data and homogeneity test. *Meteorological Applications*, 19, 397–406. <https://doi.org/10.1002/met.271>.
- Omar, M. A., Mahmood, A. S., Cagatay, B., & Nermin, S. (2017). Homogeneity analysis of precipitation series in North Iraq. *IOSR Journal of Applied Geology and Geophysics*, 5(3), 57–63.
- Akinsanola, A. A., & Ogunjobi, K. O. (2015). Recent homogeneity analysis and long-term spatio-temporal rainfall trends in Nigeria. *Theoretical and Applied Climatology*, 128, 275. <https://doi.org/10.1007/s00704-015-1701-x>.
- Easterling, D. R., & Peterson, T. C. (1995). A new method for detecting undocumented discontinuities in climatological time series. *International Journal of Climatology*, 15, 369–377.
- Mann, H. B. (1945). Non parametric tests against trend. *Econometrica*, 13, 245–259.
- Kendall, M. G. (1975). *Rank correlation methods*. London: Griffin.
- Odoulami, R. C., & Akinsanola, A. A. (2017). Recent assessment of West African summer monsoon daily rainfall trends. *Weather*, 5, 5. <https://doi.org/10.1002/wea.2965>.
- Das, J., & Bhattacharya, S. K. (2018). Trend analysis of long-term climatic parameters in Dinhat of Koch Bihar district, West Bengal. *Spatial Information Research*, 5, 1–10. <https://doi.org/10.1007/s41324-018-0173-3>.
- Pearson, E. S., & Hartley, H. O. (1966). *Biometrika tables for statisticians* (3rd ed., Vol. 1). London: Cambridge University Press.
- Wijngaard, J. B., Klein Tank, A. M. G., & Konnen, G. P. (2003). Homogeneity of 20th century European daily temperature and precipitation series. *International Journal of Climatology*, 23, 679–692.
- Buishand, T. A. (1982). Some methods for testing the homogeneity of rainfall records. *Journal of Hydrology*, 58, 11–27.
- Pettitt, A. N. (1979). A non-parametric approach to the change-point detection. *Applied Statistics*, 28, 126–135.
- Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association*, 63, 1379–1389.
- Gilbert, R. O. (1987). *Statistical methods for environmental pollution monitoring*. Hoboken: Wiley.
- Jangra, S., & Singh, M. (2011). Analysis of rainfall and temperatures for climatic trend in Kullu valley. *Mausam*, 62(1), 77–84.
- Jain, S. K., & Kumar, V. (2012). Trend analysis of rainfall and temperature data for India. *Current Science*, 102(1), 37–49.

35. Warwade, P., Sharma, N., Ahrens, B., & Pandey, A. (2015). Characterization and analysis of the trend of climate variable (Temperatures) for the North-Eastern region of the India. *International Journal of Recent Scientific Research*, 6(4), 3618–3624.
36. Shrestha, A. B., Wake, C. P., Mayewski, P. A., & Dibb, J. E. (1999). Maximum temperature trends in the Himalaya and its vicinity: an analysis based on temperature records from Nepal for the period 1971–94. *Journal of Climate*, 12(9), 2775–2786.
37. Domroes, M., & El-Tantawi, A. (2005). Recent temporal and spatial temperature changes in Egypt. *International Journal of Climatology*, 25(1), 51–63.
38. Gbode, I. E., Akinsanola, A. A., & Ajayi, V. O. (2015). Recent changes of some observed climate extreme events in Kano. *International Journal of Atmospheric Sciences*. Article ID 298046. <http://dx.doi.org/10.1155/2015/298046>.
39. Jacob, D., & Walland, D. (2016). Variability and long-term change in Australian temperature and precipitation extremes. *Weather and Climate Extremes*, 14, 36–55.