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Trend and Change Point Analysis on Key Climatic Variables in Dehradun District, India

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SUMMARY

This study investigates long-term variations in key climatic variables, including maximum, minimum, and mean temperatures $(T_{max}, T_{min}, T_{mean})$, sunshine hours, humidity ($H_{7.19}$ *and* $H_{14.19}$), wind velocity, evaporation, rainy days, rainfall in Dehradun district of India over the period from 1931 to 2015. Trend analysis was performed on monthly, seasonal, and annual scales. Result shows that $H_{7.19}$ shows the highest number of change points and significant trends across the time series, while $H_{14.19}$ displays no change point and exhibits a trend only in August. Overall, most time series are found to be homogeneous, indicating the absence of significant change points. Notably, T_{min} and T_{mean} show a statistically significant change point in the year 1959. Annual time series for $H_{14.19}$, wind velocity, evaporation, rainy days, and rainfall were also found to be homogeneous. The study includes graphical representations to illustrate observed trends and change points.

Keywords: Climate change, climate change variables, change point detection, trend analysis.

1. INTRODUCTION

Climate change is one of the most pressing global challenges, affecting nearly every region across the world. Beyond being an environmental concern, it has significant socio-economic implications, particularly for developing countries like India. According to a report by the Overseas Development Institute, India could experience an annual GDP loss of 3–10% by 2100 and a 3.5% rise in its poverty rate by 2040 due to the impacts of climate change (Picciariello *et al.* (2021)). The costs of climate change in India: A review of the climate-related risks facing India, and their economic and social costs. Overseas Development Institute.

Industrialization has been a major driver of climate change, leading to rising global temperatures, increased greenhouse gas emissions, and altered precipitation patterns, as reported by the Intergovernmental Panel on Climate Change (IPCC). Human activities, especially during the eras of rapid urbanization and industrial growth have played a significant role in accelerating these changes.

Several researchers have previously examined climate variability using statistical methods. Choudhary *et al.* (2009) analyzed temperature variations in Bikaner from 1951 to 2008 using linear regression. Jhajharia *et al.* (2011) applied the Mann-Kendall test and Penman-Monteith method to study evapotranspiration trends in Northeast India, finding significant decreases over the past two decades. Feng and Qian (2004) applied quality control techniques to Chinese meteorological data from 1951–2000 to correct for inhomogeneities. Singh *et al.* (2013) analyzed temperature trends in Dehradun using a moving average approach and found consistent

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upward trends in annual maximum, minimum, and mean temperatures.

Jaiswal *et al.* (2015) assessed monthly, seasonal, and annual trends in climatic variables in Raipur and discussed implications for water availability, irrigation, and crop yield. Conte *et al.* (2019) applied the Bootstrap Pettitt test to hydroclimatological data in Brazil, while Wijngaard *et al.* (2003) evaluated the homogeneity of European daily surface temperature and precipitation series from 1901 to 1999.

Rapid environmental and climatic changes have significantly altered temporal patterns of key hydro-meteorological variables, particularly in ecologically sensitive and rapidly urbanizing regions. Identifying such temporal shifts is essential for understanding sustainable planning and management decisions in the areas of Western Himalaya. Despite the availability of long-term time-series data, limited studies have systematically examined structural changes using statistically robust change point detection techniques at multiple temporal scales in such areas. Furthermore, existing studies in the study region have largely focused on trend analysis, often overlooking abrupt regime shifts that may have critical implications for environmental management and policy formulation. In this context, the present study is motivated by the need to detect and interpret significant change points in the time series, thereby providing deeper insights into temporal variability and potential drivers of change. The findings are expected to contribute to evidence-based decision-making and support region-specific planning aligned with sustainable development goals.

The present study investigates temporal variations in key climatic variables viz. maximum temperature (T_{max} in ^{0}C), minimum temperature (T_{min}, in ^{0}C), mean temperature (T_{mean}, in ^{0}C), Sunshine hours (in hours), humidity (in %), wind velocity (in km/hr), Evaporation (in mm/day), Rainy days (in days), Rainfall (in mm) of Dehradun district of India over a period of time has been performed. Maximum and minimum temperatures for the previous 24 hours are nominally recorded at 9 AM local clock time. Minimum temperature is recorded against the day of observation, and the maximum temperature against the previous day. Average of the maximum temperature and minimum temperature is mean temperature. The average number of hours in a day when sun shines brightly is calculated as sunshine hours. The humidity is measured in percentages and it is recorded at two-time scale one is at 7.19 hours ($H_{7.19}$) and other is at 14.19 hours ($H_{14.19}$). The wind speed measured at 2 meter above ground level. The normal unit of wind speed is the knot (nautical mile per hour). Here in this data set wind velocity got measured in km/hr.

For trend analysis, this study uses three statistical tests: Linear Regression, the Mann-Kendall (MK) test (Mann, 1945; Kendall, 1975), and Spearman's Rho test. To assess homogeneity and detect change points in the time series, three tests are employed: the Standard Normal Homogeneity Test (SNHT) for a single break (Alexandersson, 1986), the Buishand Range Test (Buishand, 1982), and the Pettitt Test (Pettitt, 1979).

2. MATERIAL AND METHODS

2.1 Study Area and Data Source

Dehradun, located in Uttarakhand, India, lies in a valley at the foothills of the Himalayas between latitudes 30°01' N and 31°02' N, and longitudes 77°34' E and 78°18' E. The district is surrounded by rivers, forests, and the Himalayan ranges to the north. The city features a unique topographical setting, with high hills to the east and north and the Shivalik ranges to the south.

The monthly climatic data from 1931 to 2015 was obtained from Forest Research Institute, Dehradun. The data of $T_{max}, T_{min}, T_{mean}$, rainy days and rainfall data is available from 1931 to 2015, sunshine hours from 1967 to 2015, $H_{7.19}$ from 1933 to 2015, $H_{14.19}$ from 1967 to 2015, wind velocity from 1967 to 2015. The data of evaporation was not available for 8 years from 1995 to 2002. Month-wise descriptive statistics of the climatic variables are presented in Table 1.

2.2 Trend Analysis

Trends in the meteorological data were assessed using Linear Regression, the Mann-Kendall test, and Spearman's Rho test. Trend analysis was conducted on annual and seasonal scales. Four seasons were defined as follows: Winter (January–February), Pre-monsoon (March–June), Monsoon (July–September), and Post-monsoon (October–December).

Table 1. Average value of a various climatic variables in Dehradun (Uttarakhand), India

Time Scale	T_{max} (^{0}C)	T_{min} (^{0}C)	T_{mean} (^{0}C)	Sunshine hours (hours)	$H_{7.19}$ (%)	$H_{14.19}$ (%)	Wind Velocity (km/hr)	Evaporation (mm/day)	Rainy days	Rainfall (mm)
Jan	19.3	4.4	11.3	6.6	87	48	2.0	1.3	3	50.1
Feb	21.5	6.3	13.7	7.3	84	46	2.5	2.0	3	56.2
March	26.5	9.9	18.0	8.1	76	41	3.0	3.3	3	46.4
April	32.2	13.7	23.1	9.3	62	33	3.2	5.3	1	22.6
May	35.7	18.0	26.2	9.5	56	31	3.4	6.6	3	45.3
Jun	34.8	21.6	27.3	7.4	69	51	3.1	5.2	8	207.1
Jul	30.5	22.8	26.1	4.5	89	75	2.4	2.5	19	601.3
Aug	29.9	22.4	25.5	4.4	91	76	2.2	2.1	20	636.9
Sept	29.9	20.2	24.4	6.7	88	68	2.2	2.6	11	280.9
Oct	28.7	13.8	20.8	8.7	82	52	1.9	2.7	2	47.7
Nov	25.0	8.1	16.1	8.2	83	46	1.7	1.8	0	7.1
Dec	21.2	4.8	12.4	7.1	87	46	1.7	1.3	1	19.9

2.2.1 Linear Regression Test

Linear Regression $y = mx + c$ is used to estimate the trend of the variables to test the hypothesis H_0: There exists no trend, against H_1: There exists trend in climatic variables. Results were evaluated based on p-values.

2.2.2 Mann-Kendall (MK) Test

The non-parametric Mann-Kendall (MK) test (Mann, 1945; Kendall, 1975) was employed to detect monotonic trends in temporal data. This test is widely used for environmental, climate, and hydrogeological datasets because it assesses whether values consistently increase or decrease over time.

The MK statistic SSS is calculated as:

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sgn\ (x_j - x_i)$$

where n is the number of observations and x_j is the j^{th} observation and sgn (θ) is the sign function which can be defined as

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

Under the assumption that data are independent and identically distributed, the mean and variance of the S statistic are given by (Kendall, 1975)

$$\text{E}(S) = 0$$

$$\text{V}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i (t_i - 1)(2t_i + 5)}{18}$$

where m is the number of groups of tied ranks, each with tied observations. The original MK statistic, designated by Z, can be computed as

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & S > 0 \\ 0 & S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} & S < 0 \end{cases}$$

If $-Z_{1-\alpha/2} \le Z \le Z_{1-\alpha/2}$ then the null hypothesis of no trend can be accepted at a significance level of α. Otherwise, the null hypothesis can be rejected at the same level α.

2.2.3 Spearman's Rho Test

Spearman's rho can be used to test the significance of trends by comparing the ranks of the values of series X with their time order. In this test, the difference between order and rank (d_i) for all observations x_1, x_2, x_2, ……, x_n can be used to compute Spearman's ρ, variance $Var(\rho)$ and test statistic (Z) as follows:

$$\rho = 1 - \frac{6\sum d_i^2}{n(n-1)};\ Var(\rho) = \frac{1}{(n-1)};\ Z = \frac{\rho}{\sqrt{Var(\rho)}}$$

2.3 Change Point Detection

The change point detection tests *viz* Pettitt's test, von Neumann ratio test, Buishand's Range test and Standard Normal Homogeneity test to assess the significant change occurred in various variables of the climate change data has been used.

2.3.1 Pettitt's Test

The Pettitt test (Pettitt 1979) is a rank-based nonparametric statistical test used to detect change points present in a data series. Consider a sequence of random variables X_1, X_2, . . ., X_T with change point at time τ, which is divided in two sets with distinct distributions functions: F_1 (X_t), t = 1, 2, . . ., τ, and F_1 (X_t), $t = \tau + 1, \ldots, T$.

The hypothesis is

H_0: if $F_1(X)=F_2(X)$, i.e., there is no change point

H_1: if $F_1(X)\neq F_2(X)$, i.e., there is change point

To detect the change point, the test uses the statistic $U_{t,T}$, similar to the Mann-Whitney test statistic:

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

Where,

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

The most probable change point τ will be the one that satisfies the following equation:

$$K_\tau = U_{t,T} = max\left|U_{t,T}\right|,\ 1 \le t < T$$

Based on asymptotic arguments about the test statistic, Pettitt (1979) defines the following approximate p value of the test: if the p-value is less than the level of significance, reject the null hypothesis and if the p-value is greater than the level of significance, fail to reject the null hypothesis.

2.3.2 Buishand's Range Test

Let X denote a normal random variate, then the following model with a single shift (change-point) can be proposed:

$$x_i = \begin{cases} \mu + \epsilon_i & i=1,\ldots\ldots,m \\ \mu + \Delta + \epsilon_i & i=m+1,\ldots.,n \end{cases}$$

$\epsilon \approx N(0,\sigma)$. The null hypothesis are:

H_0: if $\Delta = 0$, there is no change point

H_1: if $\Delta \neq 0$, there is change point

In the Buishand range test (Buishand, 1982), the rescaled adjusted partial sums are calculated as

$$S_k = \sum_{i=1}^{k}\left(x_i - \hat{x}\right)\ (1 \le i < n)$$

The test statistic is calculated as:

$$Rb = \frac{MaxS_k - MinS_k}{\sigma}$$

the p-value is estimated with a Monte Carlo simulation using *m* replicates.

2.3.3 Standard Normal Homogeneity Test (SNHT)

The SNHT is a statistical method used for detecting changes in the mean of a time series. It is commonly used in climatology and hydrology to detect changes in temperature, evaporation and other climate variables. The test statistic (T_k) is used to compare the mean of first *n* observations with the mean of the remaining $(n-k)$ observations with n data points (Stepanek *et al.* 2009; Vezzoli *et al.* 2012).

$$T_k = kZ_1^2 + (n-k)Z_2^2$$

Where, $Z_1 = \frac{1}{k}\sum_{i=1}^{k}\frac{\left(x_i - \overline{x}\right)}{\sigma_x}$ and

$$Z_2 = \frac{1}{n-k}\sum_{i=k+1}^{n}\frac{\left(x_i - \overline{x}\right)}{\sigma_x}$$

where, x and σ_x are the mean and standard deviation of the series.

3. RESULT AND DISCUSSION

The trend analysis of all climatic variables was performed using three methods: Linear Regression, Mann-Kendall Test, and Spearman's Rho Test. The presence of a trend for T_{max} based on these methods is shown in Table 2. A time series is considered to exhibit a trend ("Yes") if at least two of the three methods indicate a trend; otherwise, it is considered to have no trend ("No"). The overall presence of trend across monthly, seasonal, and annual scales, based on the combined results of the three methods, is summarized in the last column of Table 2. Similar analyses were conducted for other climatic variables, and their summarized results are presented in Table 3.

Table 2. Presence of trend in T_{max} at monthly, seasonally and annually scale

Period	Linear Regression	MK Test	Spearman's Rho Test	Presence of trend
Jan	Yes	Yes	Yes	Yes
Feb	Yes	Yes	Yes	Yes
Mar	No	No	No	No
Apr	No	No	No	No
May	No	Yes	Yes	Yes
Jun	Yes	Yes	Yes	Yes
Jul	No	No	No	No
Aug	Yes	Yes	Yes	Yes
Sept	Yes	Yes	Yes	Yes
Oct	Yes	Yes	Yes	Yes
Nov	Yes	Yes	Yes	Yes
Dec	Yes	Yes	Yes	Yes
Winter	Yes	Yes	Yes	Yes
Pre-monsoon	Yes	Yes	Yes	Yes
Monsoon	Yes	Yes	Yes	Yes
Post-monsoon	Yes	Yes	Yes	Yes
Annual	Yes	Yes	Yes	Yes

From Table 3, it is observed that in T_{max}, except March, April and July all the other months, seasons and years have the trend present. T_{min} have no trend in March, July, August, September, October, November and in Monsoon. This shows that T_{max} have more variations in comparison of T_{min}. Thereafter, the trend is present for T_{mean} for the month of May, June, August, October and two seasons pre and post monsoons. Similarly, sunshine Hrs shows the trend for all the seasons, years and months excepts for the months of April and June. $H_{7.19}$ have trend in all the series of monthly, seasonal and annual. The case is reverse in case of $H_{14.19}$ for which the trend is shown for only one month i.e., August. The wind velocity shows the trend for April, May, October, November, December, pre-monsoon, Post-monsoon and annual only. Rainy days have trend in May and Pre-monsoon and the trend for rainfall is observed for monsoon season only. The representation of data for one trend month/season of each climatic variable is shown is given in Figure 1. Thereafter, the trend is present for meanT for the month of May, June, August, October and two seasons pre and post monsoons. Similarly, sunshine Hrs shows the trend for all the seasons, years and months excepts for the months of March, April and June.

Table 3. Trend availability among the climatic variables of Dehradun District

Period	T_{max} (^{0}C)	T_{min} (^{0}C)	T_{mean} (^{0}C)	Sunshine hours	$H_{7.19}$ (%)	$H_{14.19}$ (%)	Wind Velocity (km/hr)	Evaporation (mm/day)	Rainy days	Rainfall (mm)
Jan	Yes	Yes	No	Yes	Yes	No	No	No	No	No
Feb	Yes	Yes	No	Yes	Yes	No	No	No	No	No
Mar	No	No	No	No	Yes	No	No	No	No	No
Apr	No	Yes	No	No	Yes	No	Yes	Yes	No	No
May	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No
Jun	Yes	Yes	Yes	No	Yes	No	No	No	No	No
Jul	No	No	No	Yes	Yes	No	No	Yes	No	No
Aug	Yes	No	Yes	Yes	Yes	Yes	No	Yes	No	No
Sept	Yes	No	No	Yes	Yes	No	No	No	No	No
Oct	Yes	No	Yes	Yes	Yes	No	Yes	No	No	No
Nov	Yes	No	No	Yes	Yes	No	Yes	Yes	No	No
Dec	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	No
Winter	Yes	Yes	No	Yes	Yes	No	No	No	No	No
Pre-monsoon	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No
Monsoon	Yes	No	No	Yes	Yes	No	No	Yes	No	Yes
Post-monsoon	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No
Annual	Yes	Yes	No	Yes	Yes	No	Yes	No	No	No

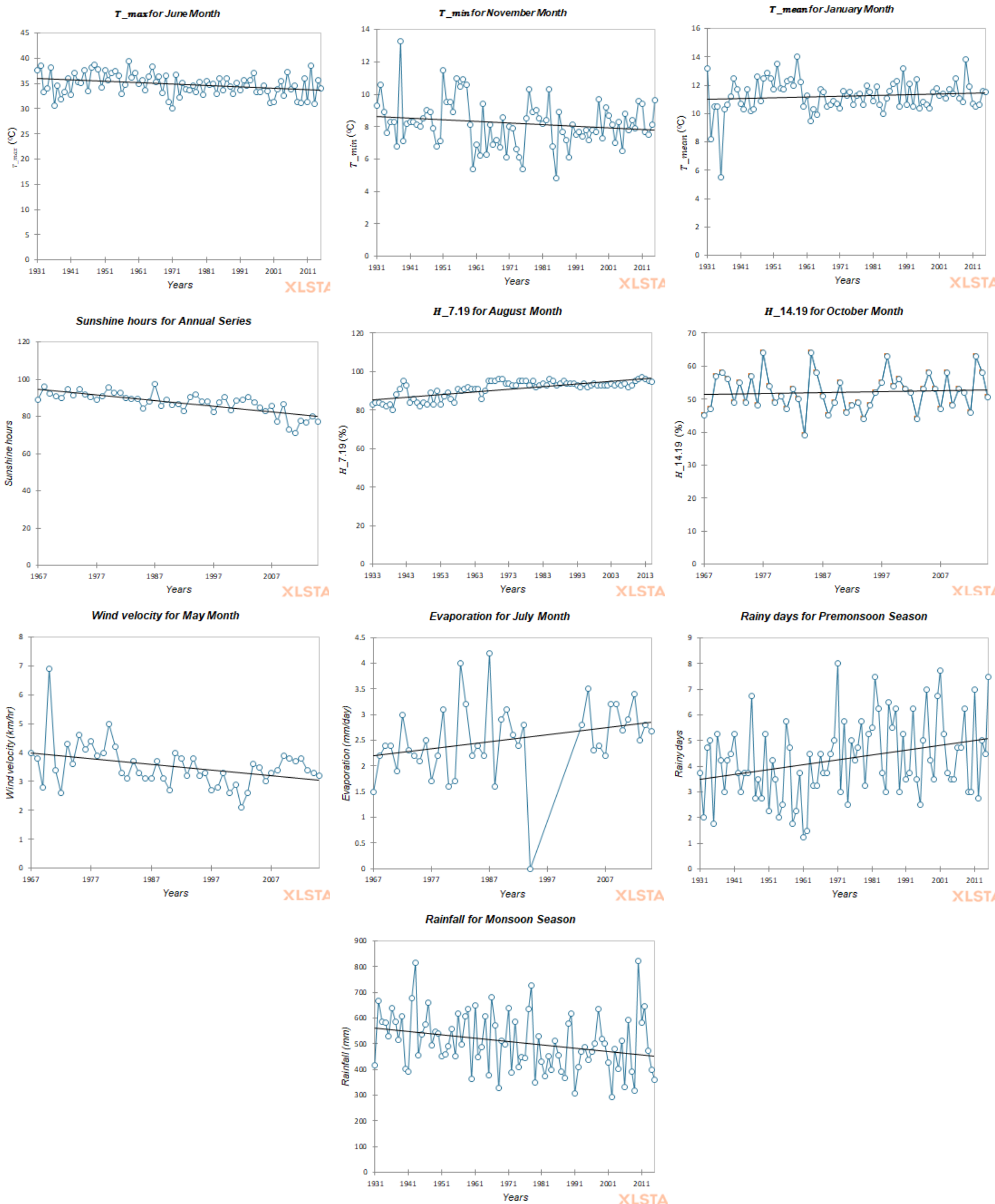

Fig. 1. Representation of trend for each climatic variable

3.1 Change Point Detection Analysis

Change points in the monthly, seasonal, and annual time series were analyzed using Pettitt's test, Buishand's Range test, and the Standard Normal Homogeneity test (SNHT).

Table 4 representing the change point obtained in T_{max} (^{0}C) one of all the climatic variables. Similarly, we obtained for other variables and their final results are shown in Table 5.

We considered two natures whether change point is present or not as given under:

a) Homogeneous (HG) or No change point: A series is considered as homogeneous in nature, if two out of three tests fail to reject null hypothesis at 5% significant level i.e., they have no change point.

b) Change point (CP): A series is considered as change point (CP) or inhomogeneous in nature, if two out of three tests reject null hypothesis at 5%significant level i.e., they have change point.

Table 5 representing final results of the change point of T_{max} (^{0}C), T_{min} (^{0}C), T_{mean} (^{0}C), Sunshine hours, $H_{7.19}$ (%), $H_{14.19}(\%)$, Wind velocity (km/hr), Evaporation (mm/day), Rainy days, Rainfall (mm). T_{max} of August, October, November, December months are indicating a significant change point in 1978 and Monsoon, Post-monsoon are indicating change point in the year 1968, February, March, April, May, September months are in Homogeneous state i.e., there is no change point. T_{min} have significant change point in January, February, May, October, Winter, Pre-monsoon, Post-monsoon, Annual in 1959 and in March, April, November, December has significant change point in 1958. T_{mean} of April, May, Pre-monsoon, Annual have change point in 1959 and June, August, Monsoon and Post-monsoon have diverse change point other series are homogenous. As a conclusion we find that in T_{min} and T_{mean} have a significant change point in the year 1959. In Sunshine hrs there are various change point February, Annual series have change point in 1987 and October, Monsoon have in 1994, in May, July, September, November, Winter. Pre-monsoon, Post-monsoon have nonsignificant change point. $H_{7.19}$ of March have change point in 1967, in winter 1958 and other series have significant change point in the year 1966. $H_{14.19}$ have no change point i.e., it is in homogeneous state. Wind velocity are showing diverse change point in March 1993, April 1984, May 1981,

Table 4. Change point analysis for maximum temperature (T_{max}, ^{0}C)

Period	Pettitt's Test			Buishand's Test			SNH Test			Final Results	
	p-value	Shift	Year of shift	p-value	Shift	Year of shift	p-value	Shift	Year of shift	Nature	Year of shift
Jan	0.0417	Yes	1964	0.5070	No	-	<0.0001	Yes	1945	CP	1964
Feb	0.0794	No	-	0.8420	No	-	0.0050	Yes	1940	HG	-
Mar	0.4569	No	-	0.4260	No	-	0.3950	No	-	HG	-
Apr	0.0000	Yes	1946	0.5210	No	-	0.8180	No	-	HG	-
May	0.0098	Yes	1962	0.4350	No	-	0.1000	No	-	HG	-
Jun	0.0038	Yes	1967	0.0040	Yes	1969	0.0020	Yes	1967	CP	1967
Jul	0.7303	No	-	0.5210	No	-	0.4790	No	-	HG	-
Aug	0.0054	Yes	1978	0.0040	Yes	1978	0.0080	Yes	1978	CP	1978
Sept	0.0387	Yes	1978	0.3610	No	-	0.0800	No	-	HG	-
Oct	0.0001	Yes	1978	0.0140	Yes	1978	0.0020	Yes	1978	CP	1978
Nov	<0.0001	Yes	1978	0.0050	Yes	1978	<0.0001	Yes	1978	CP	1978
Dec	<0.0001	Yes	1978	0.0040	Yes	1978	<0.0001	Yes	1997	CP	1978
Winter	0.0227	Yes	1950	0.5750	No	-	<0.0001	Yes	1945	CP	1950
Pre-monsoon	0.0301	Yes	1975	0.0160	Yes	1966	0.0590	Yes	1966	CP	1966
Monsoon	0.0047	Yes	1978	0.0660	Yes	1978	0.0110	Yes	1978	CP	1968
Post-monsoon	<0.0001	Yes	1978	<0.0001	Yes	1978	<0.0001	Yes	1978	CP	1968
Annual	0.0338	Yes	1983	0.7160	No	-	0.0020	Yes	1940	CP	1983

Table 5. Final results of change point detection analysis of climatic variables by using Pettitt's Test, Buishand Test and SNHT Test

Period	T_{max} (^{0}C)		T_{min} (^{0}C)		T_{mean} (^{0}C)		Sunshine hours (hours)		$H_{7.19}$ (%)		$H_{14.19}$ (%) (%)		Wind Velocity (km/hr)		Evaporation (mm/day)		Rainy days		Rainfall (mm)	
	Nature	Year of shift	Nature	Year of shift	Nature	Year of shift	Nature	Year of shift	Nature	Year of shift	Nature	Year of shift	Nature	Year of shift	Nature	Year of shift	Nature	Year of shift	Nature	Year of shift
Jan	CP	1964	CP	1959	HG	-	HG	-	CP	1966	HG	-	HG	-	HG	-	HG	-	HG	-
Feb	HG	-	CP	1959	HG	-	CP	1987	CP	1967	HG	-	HG	-	HG	-	HG	-	HG	-
Mar	HG	-	CP	1958	HG	-	HG	-	CP	1966	HG	-	CP	1993	HG	-	HG	-	HG	-
Apr	HG	-	CP	1958	CP	1959	HG	-	CP	1966	HG	-	CP	1984	HG	-	HG	-	HG	-
May	HG	-	CP	1959	CP	1959	CP	1998	CP	1966	HG	-	CP	1981	HG	-	CP	1968	HG	-
Jun	CP	1967	CP	1961	CP	1969	HG	-	CP	1966	HG	-	HG	-	HG	-	CP	1965	HG	-
Jul	HG	-	HG	-	HG	-	CP	2004	CP	1966	HG	-	HG	-	HG	-	HG	-	HG	-
Aug	CP	1978	HG	-	CP	1999	HG	-	CP	1966	HG	-	HG	-	HG	-	HG	-	HG	-
Sept	HG	-	CP	1961	HG	-	CP	1989	CP	1966	HG	-	CP	1982	HG	-	HG	-	HG	-
Oct	CP	1978	CP	1959	HG	-	CP	1994	CP	1966	HG	-	HG	-	HG	-	HG	-	HG	-
Nov	CP	1978	CP	1958	HG	-	CP	1996	CP	1966	HG	-	CP	1982	CP	1988	HG	-	HG	-
Dec	CP	1978	CP	1958	HG	-	HG	-	CP	1966	HG	-	CP	1992	CP	1984	HG	-	HG	-
Winter	CP	1950	CP	1959	HG	-	CP	1989	CP	1958	HG	-	HG	-	HG	-	HG	-	HG	-
Pre-monsoon	CP	1966	CP	1959	CP	1959	CP	1999	CP	1966	HG	-	CP	1984	HG	-	CP	1968	CP	1965
Monsoon	CP	1968	HG	-	CP	2000	CP	1994	CP	1966	HG	-	CP	1983	HG	-	HG	-	CP	1978
Post-monsoon	CP	1968	CP	1959	CP	1997	CP	1984	CP	1966	HG	-	CP	1983	CP	1984	HG	-	HG	-
Annual	CP	1983	CP	1959	CP	1959	CP	1987	CP	1966	HG	-	CP	1984	HG	-	HG	-	HG	-

Fig. 2. Representation of change points for the climatic variables

September 1982, Nov 1982, Dec 1992, Pre-monsoon and Annual have change point in 1984, Monsoon and Post-monsoon in 1983, other series are in homogeneous state. Evaporation has same change point in December and Post-monsoon in 1984, November have change point in 1988 other have no change point. Rainy days have significant change point in May and Pre-monsoon in 1968, in June 1965 is a change point. Rainfall have change point in Pre-monsoon and Monsoon season in 1965 and 1978 respectively other have no change point i.e., they are in homogenous state. The results of change point analysis indicating that most of the series are homogeneous in nature i.e., there is no change point.

The methods chosen in this study are based on the standard assumptions of the adopted statistical tests. Time-series data may exhibit autocorrelation; the analysis was performed based on these assumptions. Further improvement could be achieved by incorporating additional explanatory variables such as forest density, canopy cover, and related environmental factors; however, due to limited data available, the study has further scope for future research.

4. CONCLUSION

This study provides a comprehensive analysis of long-term variations in key climatic variables over the past 84 years in Dehradun, examining trends on annual and seasonal scales. Using multiple statistical approaches-Linear Regression, Mann-Kendall, and Spearman's Rho tests for trend detection, alongside Pettitt's, Buishand's, and Standard Normal Homogeneity tests for change point analysis-we identified significant patterns and shifts in climate variables.

The relative humidity at 7:19AM ($H_{7.19}$) consistently exhibited significant trends and change points across all series, with a major change point detected around 1966. In contrast, relative humidity at 2:19 PM ($H_{14.19}$) showed a trend only in August and remained largely homogeneous without any detected change points. Minimum temperature (T_{min}) and mean temperature (T_{mean}) both showed significant change points around 1959. Sunshine hours demonstrated trends in nearly all series, particularly in April and June, along with multiple change points. Variables such as evaporation, rainy days, and rainfall exhibited fewer change points overall. Notably, rainy days increased during the pre-monsoon season but decreased during the monsoon, while rainfall trends remained marginal, which could impact agricultural productivity given that approximately 60% of irrigation in India relies on rainfall.

Our comparative analysis revealed that the Mann-Kendall and Spearman's Rho tests yield largely consistent trend detection results. Moreover, change point analysis suggests that most climatic time series are homogeneous, indicating stability in many variables over time.

The insights gained from this study are vital for formulating targeted climate adaptation and mitigation strategies in Dehradun, and have broader implications for regional and global climate policy. These findings support ongoing efforts under international frameworks such as the Intergovernmental Panel on Climate Change (IPCC), the United Nations Framework Convention on Climate Change (UNFCCC), and the pursuit of the United Nations Sustainable Development Goals (SDGs). SDG 13 (Climate Action), particularly Targets 13.1 and 13.3, will benefit from the present study, as trend and change point analysis helps in identifying climatic shifts, extremes, and regime changes in temperature and rainfall. Early detection of such changes supports climate adaptation planning, disaster risk reduction, and the enhancement of climate resilience at the district level. The study is also expected to strengthen climate awareness and promote evidence-based decision-making at the national scale in general, and for the western Himalayan region in particular.

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