



Climatic variability over the 20th century and future drift during wheat (*Triticum aestivum*) growing period in Uttarakhand region, India

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ABSTRACT

An effort was made to analyze the spatial and temporal variability of rainfall and temperature in 13 districts of the Uttarakhand, India over the period of 102 years (1901–2002). The main focus was to examine the rainfall variability and its future response during wheat crop period (November–April). Mann–Kendall test and Sen's slope estimator test used to detect monotonic trend direction and magnitude of change over time on annual and seasonal basis. The Pettit–Mann–Whitney test applied to detect the change points over the century. Mean annual precipitation varied from 821 mm (in Haridwar) to 1244 mm (in Pithoragarh) whereas it was 75 mm (in Udham Singh Nagar) to 178 mm (in Pithoragarh) during wheat growing period. During the wheat crop period, annual precipitation decrease was noticed in Udham Singh Nagar (-37.1%) which was maximum. Maximum decrease in minimum and maximum temperature during wheat growing period and annual period was observed for Uttarkashi district which was -39.4%, -28% and -25.1%, -21.1%, respectively. Similarly, Champawat was second after Udham Singh Nagar having highest temperature in both the periods. The most affected year of change was 1978 and 1940 in annual precipitation and maximum, minimum temperature, but during wheat growing period it was observed in 1945 and 1978, respectively. Mann Kendall trend test shows decrease in precipitation for all the stations during wheat growing period and annual period. In case of annual minimum temperature, average change was 0.004°C, though during wheat crop period it was 0.009 °C/year.

Key words: Change point, Climate change, Gamma distribution, MK trend, Wheat crop period

Climate influences plant life in many ways and can inhibit, stimulate, alter or modify crop performance. Its components, viz. temperature, solar radiation, rainfall, relative humidity and wind velocity, independently or in combination influence crop growth and productivity. Production of wheat is normally limited by rainfall and temperature (Hatfield and Prueger 2015). For wheat (*Triticum aestivum* L.) as an example, the general optimum growing temperature is about 23°C. With rising temperatures, some winter growth could increase but this may be offset if rainfall is less. Lower or higher temperatures will reduce crop growth and development; however, the largest impact is usually from rainfall and subsequent soil water levels. Less rain in areas where rainfall levels are low will reduce yields. In areas where there is excess rainfall, expected reductions may increase yields on land that is not well

drained such as valley floors because water logging will be reduced. Extreme climatic events and greater seasonal variability, predicted to become more frequent with climate change, will also affect the yield.

Changes in climate over the Indian region, particularly during the WCP, would have a significant impact on Wheat production and overall economy of the country. Numerous studies have been conducted across the globe to understand the trend of precipitation and temperature. Decreasing trends in annual mean precipitation are observed across the globe; Pakistan, Northeastern Asia, Bangladesh and Northern China studied by Farooqi (2005), Savelieva *et al.* (2000), Shahid (2011), Zhai and Pan (2003), respectively. Guhathakurta and Rajeevan (2008) had reported the significant decreasing trend in the three sub-divisions (Jharkhand, Chhattisgarh and Kerala) and significant increasing trend in eight subdivisions (Gangetic West Bengal, West Uttar Pradesh, Jammu and Kashmir, Konkan and Goa, Madhya Maharashtra subdivision, Coastal AP and North Interior Karnataka) in monsoon precipitation during the period of 1901–2003. Lobell *et al.* (2013) analyzed the satellite measurements of wheat growth in northern India to estimate the effect of extreme heat above 34°C. There are various parametric and nonparametric tests that were used for identifying trends in hydro-meteorological

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time series. However, from recent studies it is found that nonparametric tests are mostly used for non-normally distributed and censored data, including missing values, which are frequently encountered in hydrological time series. Among those, rank based non-parametric Mann–Kendall (MK) (Kendall 1975, Mann 1945) test is one of the popular methods for trend analysis. Hamed and Ramachandra Rao (1998) proposed a modified MK (MMK) test for auto-correlated data to eliminate the effect of serial dependence, by modifying the variance of MK test statistic. They compared the power of MMK test with original MK test using 500 samples of independent data each of size 60 and found that power of MMK test is comparable to the original MK test. Further, they reported that there is no loss of power when MMK is applied on auto-correlated data. Another different method proposed by von Storch (1995) called pre whitening (PW) to eliminate the effect of autocorrelation. The essence of the PW procedure is to remove the serial correlation assuming a lag-one autoregressive model, and then apply the MK test to the serially independent residuals. Von Storch (1995) and Yue *et al.* (2002) reported that PW effectively decreases the probability of rejecting the null hypothesis in the MK test. Matalas and Sankarasubramanian (2003) applied the PW procedure to reduce the influence of serial correlation on the MK test and found that PW effectively decreases the probability of rejecting the null hypothesis in the MK test. Yue and Wang (2004) stated that pre whitening is not suitable for eliminating the effect of serial correlation on the MK test when trend exists in a time series because pre whitening will remove a portion (equal to the lag-one autocorrelation coefficient) of trend and hence reduces the probability of rejecting the null hypothesis when it is false. Further, they concluded that the effect of the serial correlation on the rejection rate of the null hypothesis is not significant for large sample sizes (>70) and large magnitudes of trend (>0.005), in which case it is better to use the MK test on the original data rather than after pre whitening. Furthermore, the same conclusion has been made by Bayazit and Önoğuz (2007).

Past studies conducted were focused at the level of meteorological subdivisions. However, major objective of the present study was to investigate the climate trends at district level especially during wheat crop period. Therefore, this is a more precise study as compared to the study conducted by Joshi and Pandey (2011) in India. This study provides a broad overview of climate trend, rate of change in temperature and precipitation during WCP at the district level and may help managers and agricultural planners. Therefore, the aim of this study was to investigate the spatial and temporal variability of rainfall and temperature of the Uttarakhand region of India.

MATERIALS AND METHODS

Uttarakhand lies on the southern slopes of the central, western Himalaya. It extends roughly from Lat. 28°N to 31°N and Long. 77°E to 81°E and borders the Tibet

Autonomous Region on the north, Nepal on the east, and the Indian states of Uttar Pradesh to the south, Haryana to the west and Himachal Pradesh to the northwest. Its elevation ranges from 300 m to 3,600 m spanning the Great, Middle and Sub-Himalaya. The climate of Uttarakhand is sharply demarcated in case of its two distinct divisions: the predominant hilly terrain and the smaller plain region. The type of climate that is mainly to be found in the plains closely resembles the corresponding state in the Gangetic plain. Summers are exceedingly hot with temperatures crossing the 40°C mark and considerable humidity. Winters can be chilly with temperatures going below 5°C at times. The climate in the northern part of Uttarakhand is typically Himalayan.

The state comprised 13 districts covering 53483 sq. km area, where as much as 88% of the area, is mountainous and over 64% is forested.

People of the state practice subsistence farming system. Wheat is the major crop of the state grown during *rabi* season (November to April).

Monthly temperature and precipitation data of all the 13 stations from the periods 1901–2002 was downloaded from India Water Portal (<http://www.indiawaterportal.org/metdata>). The dataset is frequently used by various researchers for other regions of India (Chattopadhyay and Chattopadhyay 2010, Duhan and Pandey 2013). First step is quality control of data before analysis of rainfall series because incorrect value has bad impact on their trends. Outliers play a key role in parametric tests and in assessing the magnitude of the possible changes by computing means and linear regression. In order to identify the outliers, long term series data was plotted on scatter plot. After visual observation of outliers, the suspected values were estimated using normal ratio method (Chow *et al.* 1988). As such no missing value in the data set was noticed. For each station, monthly values were summed during WCP (November–April) to obtain annual and seasonal values.

When the series of data is having positive autocorrelation, the possibility for a series being observed may have trend more but this may not be always true. Similarly, a series of data having negative autocorrelation then there is possibility for a series being observed having trend is less. Presence of positive or negative autocorrelation affects the detection of trend in a series (Hamed and Ramachandra Rao 1998). In this case exact trend of the data is not detected. The coefficient of autocorrelation ρ_k of a discrete time series for lag k is projected as:

$$\rho_k = \frac{\sum_{t=1}^{n-k} (x_t - \bar{x}_t) (x_{t+k} - \bar{x}_{t+k})}{\sqrt{\sum_{t=1}^{n-k} (x_t - \bar{x}_t)^2 \times \sum_{t=1}^{n-1} (x_{t+k} - \bar{x}_{t+k})^2}} \quad (1)$$

where, ρ_k , coefficient of autocorrelation; \bar{x}_t , sample mean and x_t , are sample variance of the first $(n - k)$ terms respectively, and \bar{x}_{t+k} and (x_{t+k}) are the sample mean and sample variance of the last $(n - k)$ terms respectively. Further, the hypothesis of serial independence is tested

by Anderson (1954) the lag₁ autocorrelation coefficient as $H_0: \rho_1 = 0$ against $H_1: |\rho_1| > 0$ using

$$t = |\rho_1| \sqrt{\frac{n-2}{1-\rho_1^2}} \tag{2}$$

where, the t test statistic has a Student's t -distribution with $(n-2)$ degrees of freedom. If $|t| \geq t_{\alpha/2}$, then the null hypothesis about serial independence is rejected at the significance level α .

Mann Kendal Test (Mavromatis and Santhis 2011)

Mann Kendal statistics (S) is defined as follows:

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^N \text{sgn}(x_j - x_i) \tag{3}$$

where N is the number of data points. Assuming $(x_j - x_i) = \theta$, the value of $\text{sgn}(\theta)$ is computed as follows:

$$\text{sgn}(\theta) = \begin{cases} 1 & \text{if } \theta > 0 \\ 0 & \text{if } \theta = 0 \\ -1 & \text{if } \theta < 0 \end{cases} \tag{4}$$

It has been documented that when $n \geq 8$, the statistic S is normally distributed with the mean.

$$E(S) = 0 \tag{5}$$

The variance is written as-

$$\delta(S) = \frac{N(N-1)(2N+5) - \sum_{i=1}^m (t_i-1)(2t_i+5)}{18} \tag{6}$$

where, N is the number of ties group and t_i the number of data points in the t_{ih} tied group. Then Z -statistics computed as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases} \tag{7}$$

Here Z follows standard normal distribution. A positive value of Z indicates upward trend and negative value indicates downward trend. A significance value α is utilized for testing either an upward or downward trend in a two sided test. If the Z value is greater than $Z_{\alpha/2}$, then null hypothesis (H_0) is rejected at α level of significance.

The slope of n pairs of data points was estimated using the Theil-Sen's estimator (Sen 1968, Theil 1992) which is given by the following relation:

$$\beta = \text{Median} \frac{x_j - x_i}{j - i} \text{ for all } i \leq j \tag{8}$$

In which $1 < j < i < n$ and β is the robust estimate of the trend magnitude. A positive value of β indicates an 'upward trend', while a negative value of β indicates a 'downward trend' (Zhang *et al.* 2008).

Consider a time series (X_1, X_2, \dots, X_n) with a length n . Let t be the time of the most likely change point. Two samples, (X_1, X_2, \dots, X_t) and ($X_{t+1}, X_{t+2}, \dots, X_n$) can then

be derived by dividing the time series at time t . An index, U_t , is derived by:

$$U_t = \sum_{i=1}^t \sum_{j=t+1}^n \text{sgn}(X_i - X_j) \tag{9}$$

where,

$$\text{sgn}(X_j - X_i) = \begin{cases} 1 & \text{if } (X_j - X_i) > 0 \\ 0 & \text{if } (X_j - X_i) = 0 \\ -1 & \text{if } (X_j - X_i) < 0 \end{cases} \tag{10}$$

A plot of U_t against t for a time series with no change point would result in a continually increasing value of $|U_t|$. However, if there is a change point (even a local change point), then $|U_t|$ would increase up to the change point and then begin to decrease. The most significant change point t can be identified as the point where the value of $|U_t|$ is maximum.

The approximated significance probability $p(t)$ for a change point (Pettitt 1979) is given as:

$$p = 1 - \exp\left[\frac{-6K_r^2}{n^3 + n^2}\right] \tag{11}$$

The change point is statistically significant at time t with a significance level of α when probability $p(t)$ exceeds $(1-\alpha)$.

Universal Kriging method was found to be the best suitable method suggested by Wagesho *et al.* (2013) for interpolation of rainfall in undulated topographic region. Therefore, the spatial variability of rainfall was interpolated using Kriging method in Arc GIG 9.3 platform.

RESULTS AND DISCUSSION

General condition

Data of rainfall, minimum and maximum temperature during annual and WCP for different districts of Uttarakhand are presented in Table 1. Data revealed that the average annual rainfall of Uttarakhand during the 20th century was 1069 mm which varies from 821 mm (Haridwar) to 1244 mm (Pithoragarh). During WCP, the average rainfall was 120 mm varies from 75.7 (Udham Singh Nagar) to 178.3 mm (Pithoragarh). District situated on higher elevation, *viz.* Almora, Bageshwar, Chamoli, Champawat, Dehradun, Garhwal, Haridwar, Nainital, Pithauragarh and Rudra Prayag having higher rainfall as compared to the district of plains. Higher altitudes receive more rainfall because as the moist air is forced up the side of a mountain to a higher altitude the moist air cools and sooner or later reaches at dew point or the point at which the air is completely saturated and if pushed up even higher, the moisture in the air will fall out of the clouds (Gautam *et al.* 2013). Annual minimum and maximum temperature in the state was 15.3°C and 27.5°C respectively which varies from 11.0 to 18.2 and 21.7 to 31.7°C in Uttarkashi, Udham Singh Nagar district respectively. During WCP, the average minimum and maximum temperature was 9.6 °C and 23.4 °C which vary from 5.8 to 12.2 and 17.6 to 27.2 °C in Uttarkashi, Udham Singh Nagar district respectively.

Table 1 Annual and WCP rainfall, minimum and maximum temperature (°C) of Uttarakhand districts during the period 1901-2002 (A=Annual average and Percent Change from normal of Uttarakhand)

Place	Rainfall (mm)				Minimum temperature (°C)				Maximum temperature (°C)			
	A	% Change	WCP	% Change	A	% Change	WCP	% Change	A	% Change	WCP	% Change
Almora	1132.4	5.9	104.4	-13.2	17.2	12.3	11.3	17.8	29.9	8.7	25.9	10.3
Bageshwar	1220.7	14.2	142.0	18.0	14.6	-4.6	9.3	-3.8	26.3	-4.2	22.5	-3.9
Chamoli	1131.3	5.8	164.2	36.5	11.3	-26.2	6.3	-34.1	22.0	-20.0	18.2	-22.4
Champawat	1240.6	16.0	95.5	-20.7	18.1	18.3	12.2	26.9	31.0	12.7	27.1	15.5
Dehradun	894.1	-16.4	104.5	-13.2	17.0	11.4	10.8	11.9	30.4	10.4	25.8	10.1
Garhwal	995.0	-6.9	96.3	-19.9	17.1	11.8	11.0	14.7	30.1	9.5	25.9	10.4
Haridwar	821.1	-23.2	85.1	-29.3	17.6	15.0	11.3	17.3	30.8	11.9	26.3	12.3
Nainital	1071.9	0.3	83.8	-30.4	18.1	18.0	12.1	25.3	31.0	12.8	27.0	15.3
Pithauragarh	1244.5	16.4	178.3	48.1	11.0	-27.9	6.0	-37.9	22.3	-18.8	18.6	-20.9
Rudra Prayag	1110.4	3.9	159.9	32.9	11.9	-22.5	6.9	-27.8	22.3	-19.0	18.5	-21.0
Tihriharwal	1021.7	-4.4	119.3	-0.8	15.8	3.5	9.9	3.2	28.5	3.6	24.2	3.2
Udham Singh Nagar	1004.7	-6.0	75.7	-37.1	18.2	18.8	12.2	25.9	31.3	13.6	27.2	16.2
Uttarkashi	1009.8	-5.5	155.3	29.1	11.0	-28.0	5.8	-39.4	21.7	-21.1	17.6	-25.1
Uttarakhand	1069.1	0	120.3	0	15.3	0	9.6	0	27.5	0	23.4	0
Max.	1244.5	16.4	178.3	48.1	18.2	18.8	12.2	26.9	31.3	13.6	27.2	16.2
Min.	821.1	-23.2	75.7	-37.1	11.0	-28.0	5.8	-39.4	21.7	-21.1	17.6	-25.1

Trend of weather

Before applying the MK test, all the series were tested for serial correlation using Lag-1 autocorrelation (Anderson 1954) at 1%, 5% and 10% significance level to eliminate the effect of serial correlation. All the series were found serially independent and MK test was directly applied to original data series to detect the trend using the two-sided hypothesis

(Fu *et al.* 2009) at 1%, 5% and 10% significant level. The results of MK trend (Z) and Sen's slope (β) of rainfall, minimum and maximum temperature over all 13 districts of the Uttarakhand is presented in Table 2. Annual precipitation showed negative trend on over different particular district. The trend is significant for Almora, Bageshwar, Champawat and Pithoragarh district. Average change during the study

Table 2 Mann Kendall Trend test (Z) and Sen's slope (β) for different district of Uttarakhand

Place	Annual period						Wheat period (November -April)					
	Rainfall (mm)		Max temp. (°C)		Min temp. (°C)		Rainfall (mm)		Max temp (°C)		Min temp (°C)	
	Z	β	Z	β	Z	β	Z	β	Z	β	Z	β
Almora	-1.90	-1.822	1.42	0.003	1.80	0.003	-0.45	-0.065	3.15	0.009	3.48	0.009
Bageshwar	-2.08	-2.026	1.93	0.004	2.29	0.004	-0.41	-0.080	3.48	0.010	3.79	0.010
Chamoli	-1.50	-1.404	2.31	0.004	2.49	0.005	-0.34	-0.063	3.84	0.010	3.96	0.010
Champawat	-2.34	-2.269	1.68	0.003	2.13	0.004	-0.35	-0.048	3.32	0.009	3.72	0.009
Dehradun	-1.31	-11.524	1.57	0.003	1.85	0.003	-2.01	-2.782	3.61	0.009	3.97	0.009
Garhwal	-1.46	-11.396	1.48	0.003	1.63	0.003	-1.81	-2.363	3.24	0.009	3.62	0.009
Haridwar	-1.51	-11.371	1.50	0.002	1.78	0.003	-1.96	-2.446	3.60	0.009	4.17	0.009
Nainital	-1.51	-13.344	1.29	0.003	1.78	0.003	-1.71	-1.999	3.19	0.009	3.57	0.009
Pithauragarh	-1.86	-19.373	2.71	0.005	2.82	0.005	-1.71	-3.718	4.01	0.011	4.31	0.011
Rudra Prayag	-1.22	-12.398	2.17	0.004	2.44	0.005	-1.51	-3.777	3.77	0.010	3.87	0.010
Tihriharwal	-1.51	-10.634	1.77	0.003	1.92	0.004	-1.61	-2.525	3.50	0.009	3.76	0.009
Udham Singh Nagar	-1.36	-11.726	1.49	0.003	1.90	0.003	-2.01	-1.647	3.48	0.009	3.78	0.009
Uttarkashi	-1.17	-10.248	2.33	0.004	2.59	0.005	-1.56	-2.991	4.04	0.010	4.11	0.010

(Values in bold letters indicates the trend is significant at 95% level of confidence)

period was 9.27 mm/year. Magnitude of trend (slope) in different districts of Uttarakhand varied from -1.40 to -19.37 mm/year. Annual maximum temperature showed increasing trend over entire state. Mann Kendal trend test showed that the value is significant for Bageshwar, Chamoli, Champawat, Dehradun, Garhwal, Haridwar, Nainital, Pithauragarh, Rudra Prayag, Tihriharwal, Udham Singh Nagar and Uttarkashi district. The change varied from 0.002°C (Haridwar) to 0.005 °C/year (Pithoragarh). Annual minimum temperature posed significantly increasing trend for entire state except Garhwal district, the change varied from 0.003-0.005 °C/year. Similar trend in precipitation and temperature over Indian continent was reported by Jain and Kumar (2012), Pramanik and Jagannathan (1954).

Trend of precipitation during WCP have a decline curve over entire state. It was statistically significant for entire plain regions of the state, i.e. Dehradun, Garhwal, Haridwar, Nainital and Udham Singh Nagar district. Change in rainfall (β) showed variation from -0.048 (Champawat) to -3.77 mm/year (Rudraprayag). The trend of maximum and minimum temperature during WCP was highly significant (at 99% probability) for different districts. The magnitude of change during WCP was double as compared to annual temperature and changes were observed from 0.009-0.011 °C/year. Temperature (T) is one of the major environment factors affecting the growth, development and yield of wheat crop especially the rate of development. Temperature rise obviously shortened wheat growing season (Dubey *et al.* 2014). Warming increased the number of tillers/m² and kernel weight, but tended to decrease the number of spikes/m². Winter wheat might adjust its growth (shortened vegetative period to maintain reproductive period) to partly compensate for the negative effects from global warming in this temperate irrigated cropland (Ludwig and Asseng 2010). Linear trend of precipitation, minimum and maximum temperature during entire growing period has been presented in Table 3.

MW Pettitt's test (Change point detection)

Average change point in annual and WCP precipitation and temperature over different districts has been presented

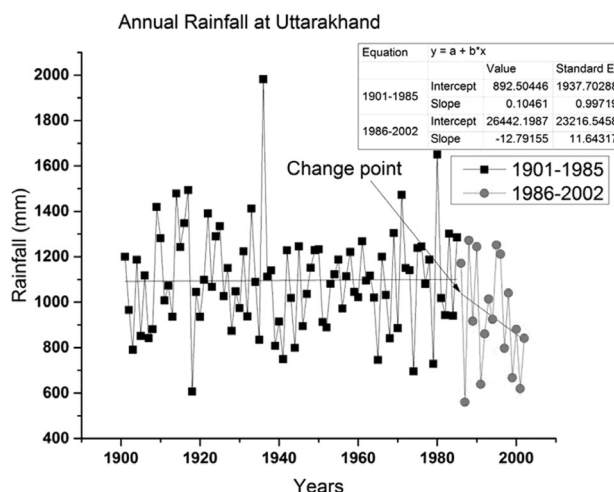


Fig 1 Pattern of annual rainfall at Uttarakhand from 1901-1985 (before change) and 1986-2002 (after change), Source: Indian Metrological Department.

in Table 4. Majority of district show the year 1986 as change point therefore on the basis of mode the year 1986 considered as changing point (Fig 1). The values are significant for the district of plains, i.e. Dehradun, Garhwal and Haridwar. Changing point for the annual minimum and maximum temperature was year 1940 which was detected using mode analysis. Change in precipitation during WCP was observed in 1978. Out of 13 districts, 8 districts had significant change point in 1978 therefore the same was considered as changing point for the entire state. Change in temperature during WCP was noticed from 1945 over the entire state, thus it may be considered as the change point.

Probable rainfall and temperature in the state during last century

Probability of precipitation and temperature during annual and WCP were plotted using lognormal curve and depicted in Fig 2. Probability of annual rainfall in the state varied from 1000 to 1200 mm. Probability lesser than 10% was expected for rainfall more than 1500 and below 800 mm, though the highest probability of precipitation during

Table 3 Linear trend of weather parameters during WCP.

Month	Precipitation (mm)	Min. Temperature (°C)	Max. Temperature (°C)
November	y = 0.001x + 5.648 R ² = 0.002	y = 0.009x + 9.830 R ² = 0.082	y = 0.010x + 24.08 R ² = 0.082
December	y = -0.018x + 12.56 R ² = 0.001	y = 0.012x + 5.739 R ² = 0.109	y = 0.011x + 19.32 R ² = 0.079
January	y = -0.075x + 33.17 R ² = 0.010	y = 0.006x + 4.726 R ² = 0.018	y = 0.005x + 17.62 R ² = 0.011
February	y = -0.016x + 31.00 R ² = 0.007	y = 0.016x + 6.325 R ² = 0.112	y = 0.017x + 19.53 R ² = 0.100
March	y = 0.071x + 20.97 R ² = 0.012	y = 0.011x + 11.04 R ² = 0.041	y = 0.010x + 25.37 R ² = 0.031
April	y = -0.005x + 19.25 R ² = 0.007	y = 0.009x + 16.66 R ² = 0.031	y = 0.008x + 31.47 R ² = 0.025

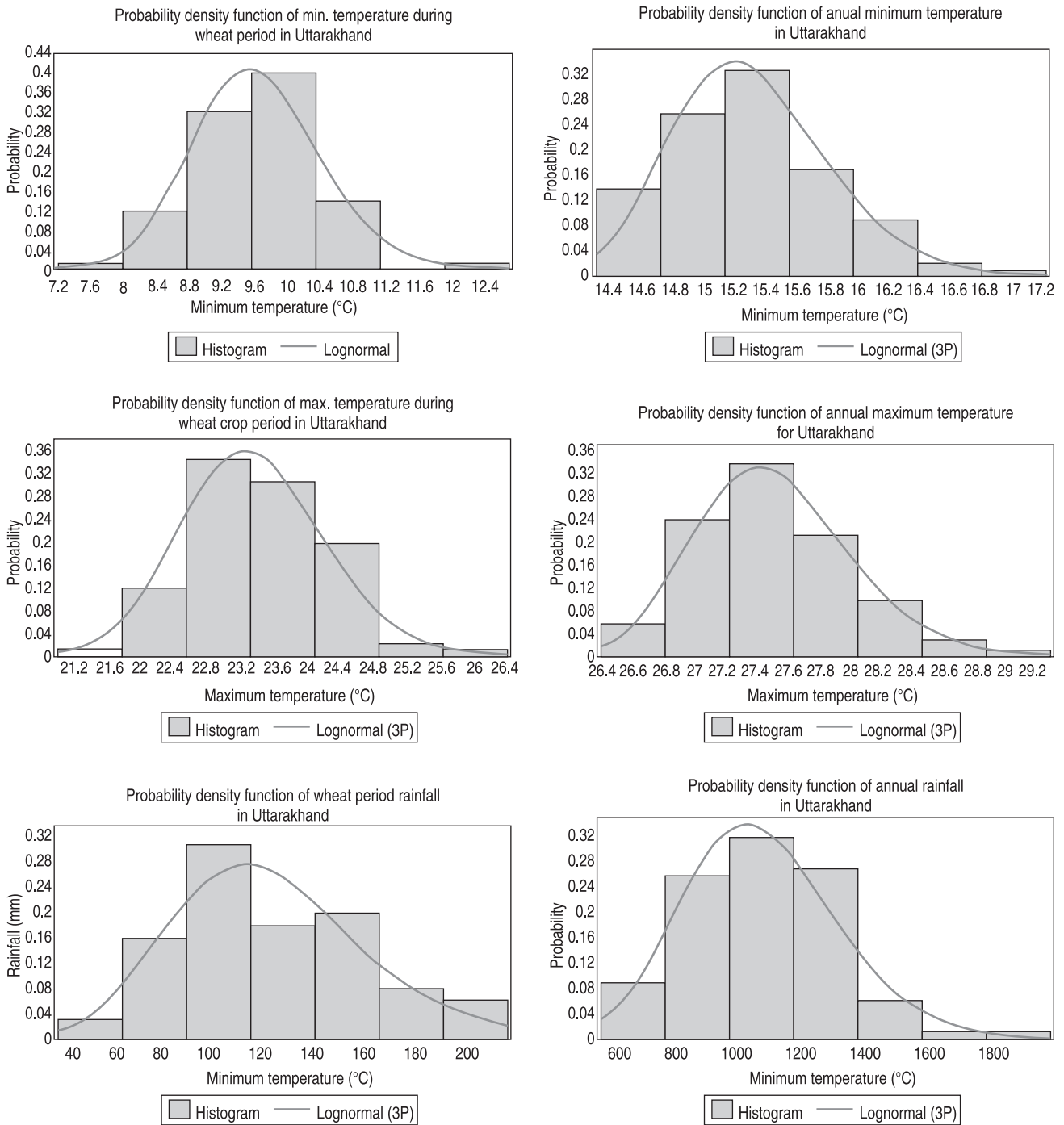


Fig 2 Probability density function and log normal distribution fitting of minimum, maximum temperature (°C) and rainfall (mm) during wheat growth period (Nov.-Apr.) and annual basis from the period 1901-2002. Source: Indian Metrological Department

WCP lies between 80-110 mm, however having the rainfall more than 160 mm and below 60 mm during this period was less than 10%. Similarly, probability of having maximum temperature in the state varied from 27 to 28°C, whereas below 10% probability was observed for more than 28°C and below 26.5°C. Highest probability of temperature during WCP varies from 22.4°C to 23.2°C, whereas having temperature more than 24.8°C and below 22.4°C was less than 10%. Highest probability of having annual minimum temperature in the state varies from 15.1 to 15.6°C, below

10% chance was noticed having temperature more than 16°C. Although the highest probability of temperature during WCP varying from 9.6 to 10.4°C while less than 10% chance of having temperature more than 10.4°C and below 8.8°C during this period.

Spatial variability of rate of change in (β) weather parameters

Spatial distribution of change in weather parameters (rainfall and temperature) for different districts of entire state

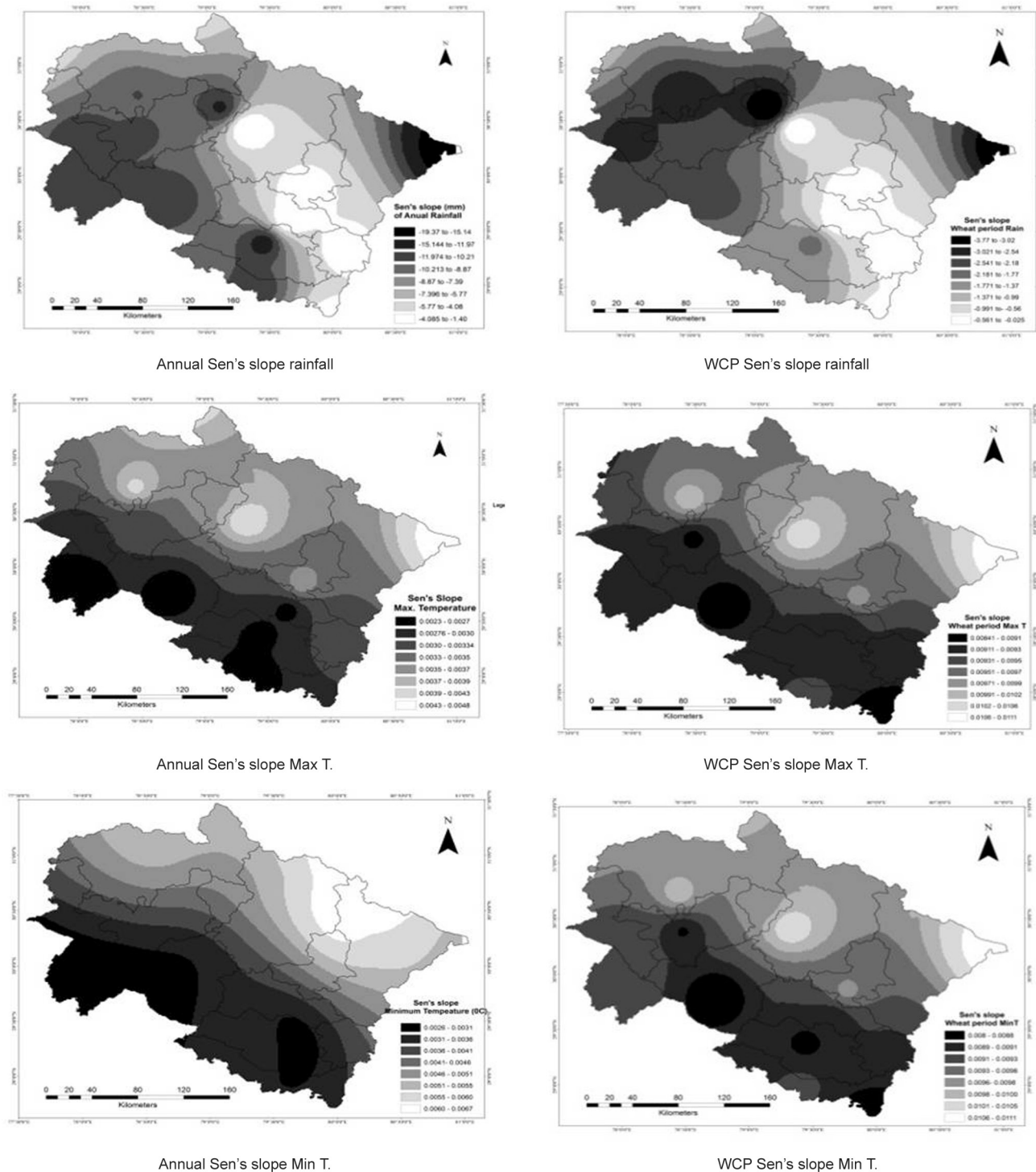


Fig 3 Spatial distribution of rainfall, minimum and maximum temperature during annual and WCP. Source: Indian Metrological Department.

has been interpolated using ArcGIS 9.3. Trend (Z) and rate of change (B) during annual and WCP is illustrated in Fig 3.

In respect to annual rainfall most eastern and southwest parts of the state had lower rate of change while the highest degree of change was observed over central region. Rate of change in rainfall during WCP has definite pattern on higher altitude the rate of change *vice-e-versa* for lower

altitude. Rate of change in annual maximum temperature over different district is more pronounced and higher for hilly districts while less change was observed for district of Tarai region. More or less similar condition for annual temperature has been detected during WCP. The highest change was limited in some patches of hilly districts.

Rate of change for annual minimum temperature in

Table 4 Mann–Whitney–Pettitt test to detect the change point in the data series in different district of Uttarakhand (MWP).

Place	Annual Period						Wheat Period (November–April)					
	Rainfall (mm)		Max temp (°C)		Min temp (°C)		Rainfall (mm)		Max temp (°C)		Min temp (°C)	
	Year	p value	Year	p value	Year	p value	Year	p value	Year	p value	Year	p value
Almora	1973	0.236	1940	0.050	1940	0.017	1915	0.992	1945	0.001	1945	0.001
Bageshwar	1986	0.163	1940	0.017	1940	0.005	1978	0.987	1945	0.000	1945	0.000
Chamoli	1986	0.258	1940	0.004	1940	0.004	1919	0.988	1945	0.000	1951	< 0.0001
Champawat	1973	0.058	1940	0.026	1940	0.012	1915	0.990	1945	0.001	1945	0.000
Dehradun	1990	0.787	1940	0.032	1940	0.010	1978	0.898	1940	0.000	1940	< 0.0001
Garhwal	1986	0.606	1940	0.036	1940	0.015	1978	0.981	1940	0.000	1940	0.000
Haridwar	1947	0.707	1940	0.045	1940	0.010	1978	0.831	1940	0.000	1940	< 0.0001
Nainital	1973	0.142	1940	0.051	1940	0.020	1977	0.989	1940	0.001	1945	0.000
Pithauragarh	1986	0.110	1940	0.002	1940	0.001	1919	0.979	1945	< 0.0001	1951	< 0.0001
Rudra Prayag	1986	0.332	1940	0.006	1940	0.003	1915	0.992	1945	0.000	1951	0.000
Tihriharwal	1986	0.532	1940	0.013	1940	0.009	1978	0.964	1940	0.000	1940	< 0.0001
Udham Singh Nagar	1973	0.295	1940	0.029	1940	0.014	1978	0.977	1940	0.001	1945	< 0.0001
Uttarkashi	1986	0.449	1940	0.002	1940	0.001	1978	0.930	1945	0.000	1945	< 0.0001
Mode	1986		1940		1940		1978		1945		1945	

different districts was similar to maximum temperature up to some extent. The district near the Himalayan hills having highest rate of change as compared to the districts of plains. Change in minimum temperature during WCP was less in plains as compared to hilly regions. Overall rate of change in minimum and maximum temperature during WCP is less in plains which to be considered as the pocket of Wheat for Uttarakhand state (Tripathi *et al.* 2013). The change in rainfall has positive impact on production and productivity (Dubey *et al.* 2012) of wheat crop because the rate of change was quite higher as compared to hilly tract.

An understanding of the spatial and temporal distribution and changing patterns in rainfall and temperature is a basic and important requirement for the planning and management of water resources. Considering the fact an effort has been made to analyze the spatial and temporal variability of rainfall and temperature at 13 districts of the Uttarakhand, India over the period of 102 years (1901–2002) during Wheat Crop Period-(WCP) and annual basis. WCP is considered as a growing season of winter wheat which starts from November and ends in April. Analysis of the data during study period indicates that the annual precipitation in the state varied from 821 mm (at Haridwar) to 1244 mm (at Pithoragarh) whereas it was 75 mm (at Udham Singh Nagar) to 178 mm (at Pithoragarh) during WCP. Maximum decrease in precipitation during WCP and annually was found at Udham Singh Nagar (-37.1%) and Haridwar (-23.2%) district while maximum temperature increase was observed at Pithoragarh district (48.14%). Highest fall in minimum and maximum temperature during WCP and annual period was found at Uttarkashi district which was -39.4, -28 and -25.1, -21.1% respectively. Champawat was second after Udham Singh Nagar that had highest temperature during

both the periods. The most probable year of change was 1978 and 1940 in annual precipitation and maximum, minimum temperature, while during WCP it was 1978 and 1945 respectively. Mann Kendal trend test showed the decrease in precipitation for all the stations during WCP and annual period both. The average change in annual rainfall was -9.2 mm/year varies from -1.4 (at Haridwar) to -19.37 mm/year (Pithoragarh) while during WCP it was -1.89 mm/year varies from -0.048 (Champawat) to -3.77 mm/year (Rudraprayag). The average change in annual maximum temperature was 0.003 °C /year that varies from 0.003 in plains to 0.005 °C /year at hills whereas during WCP it was just double 0.010 °C/ year. In case of annual minimum temperature, average change was 0.004, though during WCP it was 0.009 °C/year. Temperature was more pronounced to increase in hilly tracts as compared to the district of plains. Probability density function plot and gamma distribution fit was employed for rainfall and minimum, maximum temperature to detect the probability. Study clearly indicates that the rate of change in minimum and maximum temperature during WCP is less in plains which to be considered as the pocket of Wheat for Uttarakhand state. The change in rainfall in plain region was quite higher as compared to the hilly tract. Thus, the wheat growing belts of Uttarakhand are not much affected due to change in climate while hilly tract may face the negative impact and may cause serious damage on every assets of life.

REFERENCES

- Anderson R L. 1954. The problem of autocorrelation in regression analysis. *Journal of the American Statistical Association* **49**: 113–29.
- Bayazit M and Önöz B. 2007. To prewhiten or not to prewhiten in trend analysis? *Hydrological Sciences Journal* **52**: 611–24.
- Chattopadhyay S and Chattopadhyay G. 2010. Univariate modelling

- of summer-monsoon rainfall time series: comparison between ARIMA and ARNN. *Comptes Rendus Geoscience* **342**: 100–7.
- Chow V T, Maidment D R and Mays L W. 1988. *Applied Hydrology*. Mc Graw Hill Book Company.
- Dubey S, Pranuthi G and Tripathi S. 2012. Relationship between NDVI and rainfall relationship over India. *International Journal of Water Resources and Environmental Sciences* **4**: 102–8.
- Dubey S K, Tripathi S K, Pranuthi G and Reshu Y. 2014. Impact of projected climate change on wheat varieties in Uttarakhand, India. *Journal of Agrometeorology* **16**: 26–37.
- Duhan D and Pandey A. 2013. Statistical analysis of long term spatial and temporal trends of precipitation during 1901–2002 at Madhya Pradesh, India. *Atmospheric Research* **122**: 136–49.
- Farooqi A B, Khan A H and Mir H. 2005. Climate change perspective in Pakistan. *Pakistan Journal of Meteorology* **2**.
- Fu G, Charles S P Yu J and Liu C. 2009. Decadal climatic variability, trends, and future scenarios for the North China Plain. *Journal of Climate* **22**: 2111–23.
- Gautam R, Hsu N C, Eck T F, Holben B N, Janjai S, Jantarach T Tsay S C and Lau W K. 2013. Characterization of aerosols over the Indochina peninsula from satellite-surface observations during biomass burning pre-monsoon season. *Atmospheric Environment* **78**: 51–9.
- Guhathakurta P and Rajeevan M. 2008. Trends in the rainfall pattern over India. *International Journal of Climatology* **28**: 1453–69.
- Hamed K H and Ramachandra Rao A. 1998. A modified Mann-Kendall trend test for autocorrelated data. *Journal of Hydrology* **204**: 182–96.
- Hatfield J L and Prueger J H. 2015. Temperature extremes: effect on plant growth and development. *Weather Climate Extremes* **10**: 4–10.
- Jain S K and Kumar V. 2012. Trend analysis of rainfall and temperature data for India. *Current Science (Bangalore)* **102**: 37–49.
- Joshi M K and Pandey A. 2011. Trend and spectral analysis of rainfall over India during 1901–2000. *Journal of Geophysical Research: Atmospheres (1984–2012)* **116**.
- Kendall M. 1975. "Multivariate analysis," Charles Griffin.
- Lobell D B, Ortiz-Monasterio J I, Sibley A M and Sohu V. 2013. Satellite detection of earlier wheat sowing in India and implications for yield trends. *Agricultural Systems* **115**: 137–43.
- Ludwig F and Asseng S. 2010. Potential benefits of early vigor and changes in phenology in wheat to adapt to warmer and drier climates. *Agricultural Systems* **103**: 127–36.
- Mann H B. 1945. Nonparametric tests against trend. *Econometrica: Journal of the Econometric Society*: 245–59.
- Matalas N C and Sankarasubramanian A. 2003. Effect of persistence on trend detection via regression. *Water Resources Research* p 9.
- Mavromatis T and Stathis D. 2011. Response of the water balance in Greece to temperature and precipitation trends. *Theoretical and Applied Climatology* **104**: 13–24.
- Ortiz R, Sayre K, Govaerts B, Gupta R, Subbarao G V, Ban T, Hodson D, Dixon J, Ortiz-Monasterio I and Reynolds M. 2008. Climate change: can wheat beat the heat? *Agriculture Ecosystem Environment* **126**(2): 46–58.
- Pettitt A. 1979. A non-parametric approach to the change-point problem. *Applied Statistics* 126–35.
- Pramanik S and Jagannathan P. 1954. Climatic changes in India, II Temperature. *Indian Journal of Meteorology Geophysics* **5**: 29.
- Savelieva N, Semiletov I, Vasilevskaya L and Pugach S. 2000. A climate shift in seasonal values of meteorological and hydrological parameters for Northeastern Asia. *Progress in Oceanography* **47**: 279–97.
- Sen P K. 1968. Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association* **63**: 1379–89.
- Shahid S. 2011. Trends in extreme rainfall events of Bangladesh. *Theoretical and Applied Climatology* **104**: 489–99.
- Theil H. 1992. A rank-invariant method of linear and polynomial regression analysis. (In) *Henri Theil's Contributions to Economics and Econometrics*, pp 345–81. Springer.
- Tripathi S, Pranuthi G, Dubey S, Kumar G and Mfwango L. 2013. Characterization of climate and crop productivity using DSSAT for SW Uttarakhand, India.
- von Storch H. 1995. Inconsistencies at the interface of climate impact studies and global climate research. *Meteorologische Zeitschrift* **4**: 72–80.
- Wagesho N, Goel N K and Jain M K. 2013. Temporal and spatial variability of annual and seasonal rainfall over Ethiopia. *Hydrological Sciences Journal* **58**(2): 354–73.
- Yue S, Pilon P and Cavadias G. 2002. Power of the Mann-Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. *Journal of Hydrology* **259**: 254–71.
- Yue S and Wang C. 2004. The Mann-Kendall test modified by effective sample size to detect trend in serially correlated hydrological series. *Water Resources Management* **18**: 201–18.
- Zhai P and Pan X. 2003. Change in extreme temperature and precipitation over northern China during the second half of the 20th century. *Acta Geographica Sinica* **58**: 1–10.
- Zhang Q, Xu C Y, Zhang Z, Chen Y D, Liu C and Lin H. 2008. Spatial and temporal variability of precipitation maxima during 1960–2005 in the Yangtze River basin and possible association with large-scale circulation. *Journal of Hydrology* **353**: 215–27.