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Trend analysis by Mann-Kendall test for precipitation and temperature for thirteen districts of Uttarakhand

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ABSTRACT

The present study is mainly concerned with the changing trends of rainfall and temperature of all the thirteen districts of the state Uttarakhand. The state lies on the southern slope of the Himalayan range and the climate and vegetation vary greatly with elevation, from the glaciers at the highest elevations to subtropical forests at lower elevations. In the present study, we have tried to analyze the most important climatic variables precipitation and temperature, for analyzing the trend in the area. For this, daily rainfall data of 41 years from 1971 to 2011 and minimum and maximum temperature data of 37 years from 1971 to 2007 has been processed in the study to find out the monthly variability of rainfall and temperature for which Mann-Kendall (MK) Test has been used together with the Sen's Slope Estimator for the determination of trend and slope magnitude. Monthly precipitation and temperature trend has been identified here to achieve the objective which has been shown by 41and 37 years of data. There are increasing trends of precipitation and temperature in some months and decreasing trends in some other months for all the thirteen districts of Uttarakhand obtained from these statistical tests suggesting overall insignificant changes in the area.

Keywords : Rainfall, Trends, Mann-Kendall trend test, Sen's Slope estimator.

Quantitative estimation of the spatial distribution of rainfall and temperature is required for various purposes like water resource management, hydrological modeling, flood forecasting, climate change studies, water balance computations, soil moisture modeling for crop production, irrigation scheduling etc. One of the most significant consequences of global warming due to increase in greenhouse gases would be an uncertainty of the rainfall distribution and temperature variation both spatially and temporally. In the context of climate change, it is pertinent to ascertain whether the change is evident in Indian context also. In India rainfall plays a major role in determining the economy of the country and knowledge regarding its trends helps us in the economic development, disaster management, hydrological planning of the country. Simulation of GCMs, forced with increasing atmospheric concentrations of greenhouse gases, indicates an increase in extreme daily rainfall events on a global (Meehl *et al.*, 2000, Dubey *et al.* 2012) and decrease in overall rainfall at regional scale.

For this purpose Mann–Kendall trend test (Mann, 1945) and (Kendall, 1976) which is one of the widely used (Basistha *et al*, 2009; Oguntunde *et al*, 2011) non-parametric tests to detect significant trends in time series is used in the present study. The Mann-Kendall trend test, being a function of the ranks of the observations rather than their actual values, is not affected by the actual distribution of the data and is less sensitive to outliers. The decrease in precipitation amount in the last two decades (1965-80) over the Himalayan region was reported by (Basistha *et al* (2009). The frequency of extreme rainfall events over India and significant inter-annual and inter-decadal variations in addition to a statistically significant long term trend of 6% per decade is reported by Rajeevan *et al* (2008). Uttarakhand is one of the hilly states in the Indian Himalayas. The population of the state, primarily depends on agriculture for livelihood; about 70% of the population are engaged in agriculture. More than 55.0% of the cultivated land in the State are rain fed and rainfall is the most important agro climatic variable that decides crop yields of a year. Therefore, the need for continuous rainfall studies is to be emphasized for the purpose of long-term water resources planning and management. The main objective of these analyses was to examine variability and trends in precipitation and minimum-maximum temperature for the period 1971-2011 and 1971-2007 in Uttarakhand state.

MATERIAL AND METHODS

Study area

Uttarakhand is one of the hilly states of India. It lies in the Northern part of India between the latitudes 28°43'-31°27'N and longitudes 77°34'- 81°02'E having a maximum dimension of east - west 310 km and 255 km north - south covering an area of 53,484 km^2 with the elevation ranging from 210 to 7817 meters. The state has two distinct climatic regions: the predominant hilly terrain and the small plain region. Broadly the state constitutes of 13 districts, average of rainfall and temperature in each district has been presented in table 1. Basic statistics related to rainfall like, mean, standard deviation (SD), coefficient of variation and the percentage contribution to annual were computed for monthly and season-wise viz., Pre-monsoon (March–May), Monsoon (June–September), Post-monsoon (October–November) and Winter (December–February). Further a linear tend was added as parametric test. Non parametric Mann-Kendall test was also performed by the Sen's slope estimation method.

Data used

Data for each station was collected from the All India Co ordinate Research Project on Agrometeorology under section of NICRA govern by the Indian government. The dataset was frequently used in analysis of trend (Pranuthi *et al.*, 2014). Rainfall for entire station available for the period of 1971-2011 (41 years) while minimum and maximum temperature available for the period 1971-2007 (37 years).

Non-Parametric test

Non-parametric statistics are usually much less affected by the presence of outliers and other forms of non-normality (Lanzante, 1996) and represent a measure of monotonic linear dependence (Davis 1986; Rossi et al., 1992). The most frequently used non-parametric test for identifying trends in hydrologic variables is the Mann-Kendall (MK) test. The statistical significance trend detected using a non-parametric model such as the Mann-Kendall (MK) test can be complemented with Sen's slope estimation to determine the magnitude of the trend.

Mann-Kendall test

This method tests whether there is a trend in the time series data. It is a non-parametric test and it eliminates the outliers. The n time series values ($X_1, X_2, X_3, \ldots, X_n$) are replaced by their relative ranks ($R_1, R_2, R_3, \ldots, R_n$) (starting at 1 for the lowest up to n).

The Sen's slope S is:

$$S = \sum_{i=1}^{n} \left\{ \sum_{j=i+1}^{n} \text{sgn}\,(R_i - R_j) \right\} \quad \ldots\ldots(1)$$

Where,

sgn (x) = 1 for x > 0

sgn (x) = 0 for x = 0

sgn (x) = -1 for x < 0

If the null hypothesis Ho is true, then S is approximately normally distributed with:

$\mu = 0$

$$\delta = n\frac{(n-1)\,(2n+5)}{18} \quad \ldots\ldots(2)$$

The Mann Kendall z-statistic is written as

$$Z = \frac{|S|}{\sigma^{0.5}} \quad \ldots\ldots(3)$$

A positive value of S indicates that there is an increasing trend and vice versa. The critical test statistic values for various significance levels for observations are 1.645, 1.97 and 2.57 at 90, 95 and 99 % probability levels. These tests are applied to the precipitation and temperature data to detect the trends and to quantify the change both spatially and temporally.

Theil–Sen's estimator

The slope of n pairs of data points was estimated using the Theil–Sen's estimator (Theil, 1950 and Sen, 1968) which is given by the following relation:

$$\beta = Median\ \frac{x_j - x_i}{j - i}\ \ forall\ i \leq j \quad \ldots\ldots (4)$$

In which 1<j<i<n and â is the robust estimate of the trend magnitude. A positive value of â indicates an 'upward trend', while a negative value of â indicates a 'downward trend' (Xu et al., 2010).

RESULTS AND DISCUSSION

Data pertaining to trend and slope of rainfall and temperature in all 13 districts of Uttarakhand has been

Table1: Details of climate and coordinates of study districts

Places	Latitude	Longitude	Altitude(m)	Max T (^{0}C)	Min T (^{0}C)	Rain (mm)
Almora	29.59 N	79.65 E	1646	26.6	14.8	1305
Bageshwar	29.85 N	79.77 E	960	26.3	14.7	1115
Chamoli	30.42 N	79.33 E	1293	25.2	14.0	1397
Champawat	29.33 N	80.10 E	1615	27.8	15.8	1157
Dehradun	30.31 N	78.02 E	435	26.2	14.5	1812
Haridwar	77.98 N	29.88 E	249.7	27.5	15.5	1437
Nainital	79.44 N	29.35 E	2084	26.6	14.8	1292
Pauri Garhwal	78.69 N	29.94 E	1814	26.1	14.6	1297
Pithoragarh	80.35 N	30.10 E	1514	27.0	15.3	2013
Rudraprayag	79.09 N	30.60 E	895	25.2	14.0	1274
Tehri Garhwal	30.38 N	78.48 E	1750	25.1	14.0	1532
Udhamsingh Nagar	28.98 N	79.40 E	550	28.2	16.1	1174
Uttarkashi	30.73 N	78.45 E	1158	24.8	13.4	1236

calculated and result on seasonal and annual basis were presented as under:

Rainfall (mm)

Pre-monsoon season : The pre-monsoon has a decreasing trend of rainfall (Table 1&2) in most of the districts of Uttarakhand except for Dehradun (slope 5), Udhamsingh Nagar (slope 10) which have increasing trend and in Haridwar and Rudraprayag where exceptionally different trend was observed by 90% significant increasing trend (slope 39) and 90% significant decreasing trend (slope -90) over the past 41 years.

Monsoon season : The monsoon season has shown an increasing trend (Table 1&2) in most of the districts over Uttarakhand. But there were some exceptions also like Bageshwar (slope -2) and Champawat (slope -10) which showed decreased trend. And it is important to report that Haridwar (slope 317) and Uttarkashi (slope 330) had 95% significant increase and Dehradun has shown an exceptional 99% significant increase (slope 643) over the last 41 years.

Post-monsoon season : In the post monsoon season over the past 41 years the trend (Table 1&2) in precipitation in all the 13 districts of Uttarakhand has shown a decreasing trend, wherein the three districts Chamoli (slope -22), Rudraprayag (slope -26) and Uttarkashi (slope -23) showed 90% significant decrease in trend and Bageshwar (slope -31) and Champawat (slope -55) showed 95% significant decrease.

Winter season : In winter season among 13 districts of Uttarakhand 6 (Almora, Dehradun, Haridwar, Nainital, Pauri-Garhwal and Pithoragarh) had shown increasing trend and the rest seven showed decreasing trend (Table 1&2) with Chamoli (slope -104), Rudraprayag (slope -94) and Uttarkashi (slope -88) showing 95% significance and Tehri-Garhwal (slope -55) showed 90% significant decreasing trend over the 41 years time period.

Annual : The annual trend of rainfall throughout the 41 years time period in various districts of Uttarakhand had shown increasing trend (Table 1&2) in Almora (slope 109) , Bageshwar (slope 11) , Nainital (slope 112) , Pauri-Garhwal (slope 152), Pithoragarh (slope 152), Udhamsingh Nagar (slope 212) and Uttarkashi (slope 77) increasing trend with Dehradun, Haridwar showing 90% significant increasing trend and the remaining Chamoli (slope -133), Champawat (slope -179), Rudraprayag (slope -98) and Tehri-Garhwal (slope -88) decreasing trend in precipitation.

Maximum and minimum temperatures (^{0}C)

Pre-monsoon season : In the pre-monsoon season the trend for maximum temperature (Table 3&4) was decreased in 10 districts out of 13 districts of Uttarakhand where as in Dehradun, Haridwar and Uttarkashi it was increasing. But

Table 2: Mann Kendall trend statistics (Z) precipitation

Places	Alm ora	Bagesh war	Cha moli	Champ awat	Dehra dun	Harid war	Nain ital	Pauri-Garhwal	Pithora garh	Rudrapr ayag	Tehri-Garhwal	Udhamsingh Nagar	Uttark ashi
Annual	↑	↑	↓	↓	↑*	↑*	↑	↑	↑	↓	↓	↑	↑
pre-monsoon (Mar-May)	↓	↓	↓	↓	↑	↑+	↓	↓	↓	↓+	↓	↑	↓
Monsoon (June-Sept)	↑	↓	↑	↓	↑**	↑*	↑	↑	↑	↑	↑	↑	↑*
post-monsoon (Oct-Nov)	↓	↓*	↓+	↓*	↓	↓	↓	↓	↓	↓+	↓	↓	↓+
Winter (Dec-Feb)	↑	↓	↓*	↓	↑	↑	↑	↑	↑	↓*	↓+	↓	↓*

Where, (↑) shows increasing trend; (↓) shows decreasing trend;*** 0.001 level of significance; ** 0.01 level of significance;* 0.05 level of significance; + 0.1 level of significance

Table 3: Sen's Slope (Q) of precipitation (mm)

Month	Alm ora	Bagesh war	Cha moli	Champ awat	Dehra dun	Harid war	Nain ital	Pauri-Garhwal	Pithora garh	Rudrapr ayag	Tehri-Garhwal	Udhamsingh Nagar	Uttark ashi	Aver age
Annual	109	11	-133	-179	567	386	112	152	152	-98	-88	212	77	98
pre-monsoon (Mar-May)	-16	-29	-85	-35	5	39	-15	-7	-7	-90	-95	10	-69	-30
Monsoon (June-Sept)	55	-2	41	-105	643	317	78	216	216	143	149	182	330	174
post-monsoon (Oct-Nov)	-16	-31	-22	-55	-16	-5	-15	-11	-11	-26	-23	-16	-23	-21
Winter (Dec-Feb)	0	-37	-104	-18	0	34	0	6	6	-94	-55	-6	-88	-27

Table 4: Mann Kendall Trend Statistics (Z) of maximum temperature (^{0}C)

Places	Alm ora	Bagesh war	Cha moli	Champ awat	Dehra dun	Harid war	Nain ital	Pauri-Garhwal	Pithora garh	Rudrapr ayag	Tehri-Garhwal	Udhamsingh Nagar	Uttark ashi
Annual	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
pre-monsoon (Mar-May)	↓	↓	↓	↓	↑	↑	↓	↓	↓	↓	↓	↓	↑
Monsoon (June-Sept)	↑	↑	↓	↑	↓	↓	↑	↓	↑	↓	↓	↑	↓
post-monsoon (Oct-Nov)	↓	↑	↓	↑	↓	↓	↓	↓	↑	↓	↓	↑	↓
Winter (Dec-Feb)	↓+	↓	↓	↓+	↓	↓	↓	↓	↓	↓	↓	↓	↓

Where, (↑) shows increasing trends; (↓) shows decreasing trend;* 0.05 level of significance; + 0.1 level of significance

Table 5: Sen's Slope (Q) of maximum temperature (^{0}C)

Month	Alm ora	Bagesh war	Cha moli	Champ awat	Dehra dun	Harid war	Nain ital	Pauri-Garhwal	Pithora garh	Rudrapr ayag	Tehri-Garhwal	Udhamsingh Nagar	Uttark ashi	Aver age
Annual	0	0	0	0	0	0	0	0	0	0	0	0	0	0
pre-monsoon (Mar-May)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Monsoon (June-Sept)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
post-monsoon (Oct-Nov)	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Winter (Dec-Feb)	**-1**	**-1**	0	**-1**	0	**-1**	**-1**	**-1**	**-1**	0	0	**-1**	0	**-1**

Table 6: Mann Kendall trend statistics (Z) of minimum temperature (^{0}C)

Places	Alm ora	Bagesh war	Cha moli	Champ awat	Dehra dun	Harid war	Nain ital	Pauri-Garhwal	Pithora garh	Rudrapr ayag	Tehri-Garhwal	Udhamsingh Nagar	Uttark ashi
Annual	↑***	↑***	↑***	↑***	↑***	↑***	↑***	↑***	↑***	↑***	↑***	↑***	↑***
pre-monsoon (Mar-May)	↑**	↑**	↑**	↑**	↑**	↑**	↑**	↑**	↑**	↑**	↑**	↑**	↑**
Monsoon (June-Sept)	↑***	↑***	↑***	↑**	↑***	↑***	↑***	↑***	↑**	↑***	↑***	↑***	↑***
post-monsoon (Oct-Nov)	↑+	↑*	↑**	↑*	↑*	↑*	↑+	↑*	↑*	↑**	↑**	↑+	↑**
Winter (Dec-Feb)	↑***	↑***	↑***	↑***	↑***	↑***	↑***	↑***	↑***	↑***	↑***	↑***	↑***

Where, (↑) shows increasing trends; (↓) shows decreasing trend;*** 0.001 level of significance; ** 0.01 level of significance;* 0.05 level of significance; + 0.1 level of significance

Table 7: Sen's Slope (Q) minimum temperature

Month	Alm ora	Bagesh war	Cha moli	Champ awat	Dehra dun	Harid war	Nain ital	Pauri-Garhwal	Pithora garh	Rudrapr ayag	Tehri-Garhwal	Udhamsingh Nagar	Uttark ashi	Aver age
Annual	1	1	1	1	1	1	1	1	1	1	1	1	1	1
pre-monsoon (Mar-May)	1	1	2	1	1	1	1	1	1	2	2	1	2	1
Monsoon (June-Sept)	1	1	1	1	1	1	1	1	1	1	1	1	1	1
post-monsoon (Oct-Nov)	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Winter (Dec-Feb)	1	1	1	1	1	1	1	1	1	1	1	1	1	1

in contrast to the trend of maximum temperature there has been seen a 99% significant increase in minimum temperature (Table 5&6) for all the districts of Uttarakhand. With a slope value of 2 for Chamoli, Rudraprayag, Tehri-Garhwal and Uttarkashi and for rest of districts 1 slope value.

Monsoon season : In the monsoon season the trend for maximum temperature (Table 3&4) has shown a fifty-fifty distribution of increasing and decreasing trend in all the 13 districts of Uttarakhand. As for Almora, Bageshwar, Champawat, Nainital, Pithoragarh and Udhamsingh Nagar it was increasing and for Chamoli, Dehradun, Haridwar, Pauri-Garhwal, Rudraprayag, Tehri-Garhwal and Uttarkashi the trend was decreasing with zero slope value for all stations. Whereas for minimum temperature the trend (Table 5&6) was increased for all the 13 districts of Uttarakhand with various levels of significances as in Almora and Nainital the increase was with a 95 % significance and in Chamoli, Champawat, Dehradun, Haridwar and Pithoragarh the increase was with a 99 % significance and for remaining Bageshwar, Pauri-Garhwal, Rudraprayag, Tehri-Garhwal, Udhamsingh Nagar and Uttarkashi the significance level of 99.9% increase was observed.

Post monsoon season : In the post monsoon season the trend for maximum temperature (Table 3&4) in Uttarakhand for Almora, Chamoli, Dehradun, Haridwar, Nainital, Pauri-Garhwal, Rudraprayag, Tehri-Garhwal and Uttarkashi it was decreasing. And for Bageshwar, Champawat, Pithoragarh and Udhamsingh Nagar the trend was increasing. But for minimum temperature (Table 5&6) scenario is different as for Almora, Nainital and Udhamsingh Nagar it is positively increasing trend. In Bageshwar, Champawat, Dehradun, Haridwar, Pauri-Garhwal and Pithoragarh it was 95% significant increase. And in Chamoli, Rudraprayag, Tehri-Garhwal and Uttarkashi the increase was 99% significant for minimum temperature.

Winter season : The trend for maximum temperature (Table 3&4) in the winter season for all the 13 districts of Uttarakhand was decreasing with Almora (slope -1) and Champawat (slope -1) showing a positive decrease. And for minimum temperature (Table 5&6) the trend was 99.9%, significantly increasing in order for all the 13 districts of Uttarakhand (slope 1).

Annual : The annual trend (Table 3&4) of temperature throughout the year has shown the decreasing trend for all the 13 districts of Uttarakhand for maximum whereas in case of minimum temperature (Table 5&6) the trend showed 99.9% significant increasing trend for all the districts.

CONCLUSION

The analysis of precipitation (41years) and minimum-maximum temperature (37 years) variability and detection of trends in the annual, monthly, winter, pre-monsoon, monsoon, post-monsoon seasons have been carried out in 13 districts of Uttarakhand. Pattern of trend as discussed in results leads to the confirmation of climate change in Uttarakhand due to anthropogenic activities of increased population, urbanization, industrialization and deforestation (Dubey et al. 2014a). As the decrease in rainfall in the month of January will affect the Rabi crop specially Wheat and the pre-monsoonal decrease in rainfall and delay in monsoon arrival will affect the Kharif crop production extensively. Similarly the decrease in annual maximum temperature and an increase of 99.9% significance in minimum temperature will be helpful in high altitude regions for the crop production but in the plain areas the effect will be opposite. So the farmers of Uttarakhand have to think about some alternative package of practices, i.e. sowing time, irrigation, harvesting etc. (Dubey et al. 2014b) so that their dependency on monsoon will not affect crop production. New and improved varieties of crops should be applied in the fields to gain sustainable agriculture.

REFERENCES

Basistha A, Arya DS, Goel NK (2009). Analysis of historical changes in rainfall in the Indian Himalayas. *Int. J. Climatol.* 29:555–572.

Davis JC (1986) Statistics and Data Analysis in Geology (second ed). Wiley, New York

Dubey, S. K., Tripathi, S. K. and Pranuthi, G., (2012). Relationship Between NDVI and Rainfall Relationship over India *Intern. J. Water Resou. Environ. Sci.* 1(**4**): 102-108.

Dubey, S. K., Tripathi, S. K., Pranuthi, G., & Yadav, R. (2014a). Impact of projected climate change on wheat varieties in Uttarakhand, India. *J. Agrometeorol.*, *16*(**1**), 26-37.

Dubey, S. K., Tripathi, S. K., Pranuthi, G., & Yadav, R., Maurya, D. and Upreti, Pankaj (2014b). Potential of Agronomy in Mitigating the Challenges of 'Future Food Security. *Trends in Biosci.* 7 (**13**) 1367-1377

Kendall MG (1975) Rank correlation methods. Griffin, London

Lanzante JR (1996). Resistant, robust and non-parametric techniques for the analysis of climate data: Theory and examples, including applications to historical radiosonde station data. *Int. J. Climatol.* **16**:1197–1226

Mann HB (1945) Nonparametric tests against trend. Econometrica. 13:245–259

Meehl et al (2000). Trends in Extreme Weather and Climate Events: Issues Related to Modeling Extremes in Projections of Future Climate Change, *Bulletin American Meteorol. Society*, 81 (3):427-436

Oguntunde, P. G., B. J. Abiodun, O. J. Olukunle, and A. A. Olufayoa (2011). Trends and variability in pan evaporation and other climatic variables at Ibadan, Nigeria, 1973–2008, *Meteorol. Appl.,* doi: 10.1002/ met.281, in press.

Pranuthi, G.,Dubey, S. K., Tripathi, S. K. and Chandniha, S.K. (2014). Trend and Change Point Detection of Precipitation in Urbanizing Districts of Uttarakhand. Indian J. Sci. Techn. (*accepted for September Issue under press*).

Rajeevan M, Bhate J, Jaswal AK (2008). Analysis of variability and trends of extreme rainfall events over India using 104 years of gridded daily rainfall data. *Geophys Res Lett* 35:L18707. doi:10.1029/2008GL035143

Rossi R, Mulla D, Journel A, Franz E (1992). Geostatistical tools for modeling and interpreting ecological spatial dependence. *Ecolo. Mono.,* 62:277–314

Xu Z, Liu Z, Fu G, Chen Y (2010). Trends of major hydro climatic variables in the Tarim River basin during the past 50 years. *J Arid Environ*, 74(2):256–267

Zwiers, F. W., and V. V. Kharin, (1998): Changes in the extremes of the climate simulated by CC GCM2 under CO2 doubling. *J. Climate.*, 11: 2200–2222.

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