Rainfall and Temperature Trend Analysis using Mann-Kendall and Sen's Slope Estimator Test in Kharun Watershed, Chhattisgarh, India

ABSTRACT:

Temperature and rainfall are important meteorological variables in connection with changes in the climate. Analyzing rainfall temperature changes is a necessary first step in determining how climate change will affect us. Evaluating how climate change would affect the accessibility of water and the environment. The main focus of the current study is on the shifting patterns of rainfall and temperature in the Kharun Watershed, Chhattisgarh. The Mann-Kendall (MK) test and Sen's slope (SS) method are used in this study to examine trends in seasonal and yearly rainfall, and minimum and maximum temperatures (Tmin and Tmax). The research area contained five stations measuring temperature and rainfall. Three seasons—kharif, rabi, and zaid were taken into consideration for the seasonal and yearly trend study. The results of the trend test for precipitation showed an overall upward trend for all five stations (Pindrawan, Raipur, Patan, Dhamtari, and Gurur) and every season. The yearly trend of precipitation likewise exhibits an upward trend throughout the year. Except the Kharif season at Pindrawan, Raipur, and Patan stations, the minimum temperature for all five stations indicates declining trends for all seasons. In all five stations, the annual trend of the minimum temperature over the 35 years had exhibited a downward trend. All five stations' maximum temperatures exhibit rising patterns throughout the year. In all five stations, the annual trend of maximum temperature over the 35 years showed an upward trend.

Keywords: Trend analysis; Mann–Kendall test; Sen's slope estimator, Rainfall, Maximum temperature and Minimum temperature.

INTRODUCTION

As the mother of major external factors, climate change has led to extreme weather events such as temperature fluctuations, humidity changes, and heavy rainfall, resulting in

huge economic losses (Xia *et al*., 2012). Variations in the hydrological cycle have become a challenge that has affected society and the environment (Chowdhury and Beecham, 2010).

The rainfall and temperatures (Singh *et al.*, 2013) are the most important fundamental physical parameters of the climate as these parameters determine the environmental condition of the particular region which affects agricultural productivity (Modarres and da Silva, 2007; Kumar and Gautam, 2014). Agriculture and other related sectors, food security and energy security of any region are crucially dependent on the timely availability of adequate amounts of water and a conducive climate. The rainfall received in an area is an important factor in determining the amount of water available to meet various demands such as agricultural, industrial, and domestic water supply and hydroelectric power generation. The pattern and amount of rainfall (Gajbhiye *et al.*, 2016) are among the most vital factors that affect agricultural production and agriculture is dominant to India's economy and the livelihood of its people (Kumar and Gautam, 2014). In India, despite recent progress in industrialization, the soundness of the economy is significantly dependent upon the gross production of agricultural commodities and agriculture is the mainstay of millions of teeming population with crops predominantly dependent upon natural rainfall.

The Mann-Kendall (MK) test (Kendall, 1975; Mann, 1945) was applied to evaluate the trends in rainfall, Tmax, and Tmin. It's a non-parametric test that doesn't require the data to be normally distributed to perform (Tabari *et al*., 2011). The MK test is based on the null hypothesis (H0), which states that there is no trend—the data are independent and randomly ordered—and is checked against the alternative hypothesis (Ha), which states that there is a trend (Verma *et al*., 2022). The actual slope (change per unit time) was predicted using Sen's slope (SS) estimator (Sen, 1968) (Jain and Kumar, 2012). The current study was carried out to ascertain the trend of the two most important climatic variables, rainfall and temperature, based on the aforementioned problems. A trend assessment of the seasonal and annual

rainfall and temperature in the given river basin will be beneficial for water management in the watershed.

XLSTAT has become one of the most widely used statistical software. It uses Excel to input data and display results, while the computations are handled by independent software components. XLSTAT is a user-friendly and extremely efficient statistical and multivariate data analysis program mainly to its use of Excel as an interface. The computations are of the same high quality as those produced by traditional scientific statistical analysis software (Panda and Sahu, 2019).

MATERIALS AND METHODS

Overview of the Study Area

The Kharun watershed is a portion of the Seonath sub-basin of Chhattisgarh's well-known Mahanadi river basin. The Kharun watershed is entirely or partially covered by fifteen blocks distributed over six districts, including Balod, Dhamtari, Durg, and Raipur. Based on reports, the watershed's total area is 4118. The Kharun watershed is located between the latitudes of $20^0$52' 30" N to $21^0$54' 36" N and longitudes of $81^0$27' 18" E to $82^0$06' 18" E. In the southeast of the Balod district, Petechua is the point of origin of the Kharun, which flows 164 kilometres until joining the Seonath river close to Somnath in the Raipur district (Sinha, 2011). It has the geology of Chandrapur Group-Gunderdihi, and Churmuri with the lithology of shale, sandstone, siltstone and limestone (Kumar *et al*. 2017).

Data Acquisition

From 1987 to 2021, the Kharun Watershed's daily rainfall and temperature data were gathered from the Water Resource Department (WRD) in Raipur, (C.G.). Figure 2 shows where the Rainfall Gauging station is located.

ANALYSIS OF DATA

Rainfall and temperature data

From WRD Raipur (C.G.), the daily rainfall and temperature data of various rain gauge (RG) stations in the Kharun watershed were gathered. By using the geographic location of each rain gauge station in the ArcGIS environment, a thematic map displaying the locations of the rain gauge stations in the research region was created (Fig. 1). Data of temperature and precipitation were organized for processing. Then, daily rainfall and temperature data were processed and turned into monthly and seasonal data.

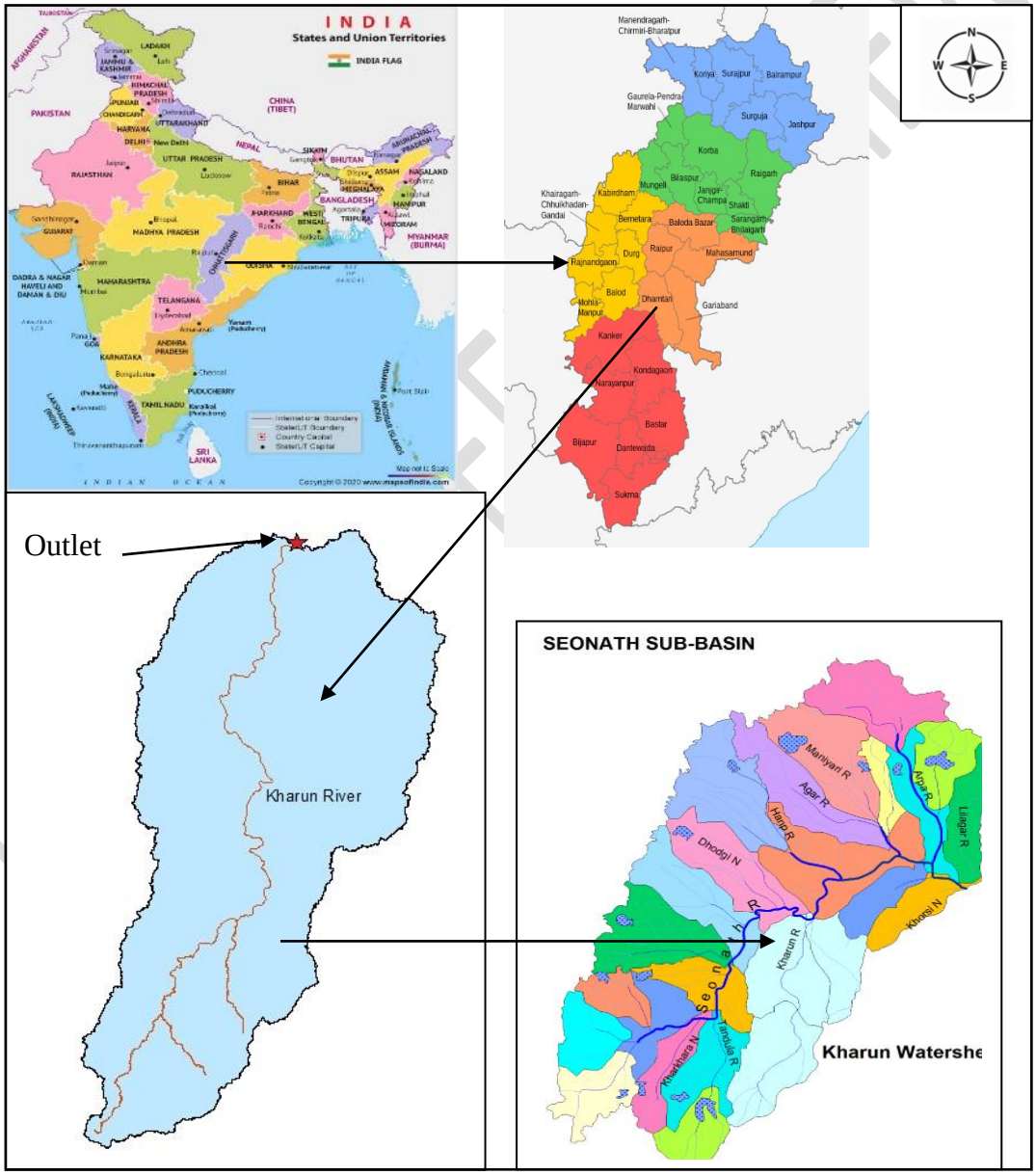

Fig. 1. Study area's location on map.

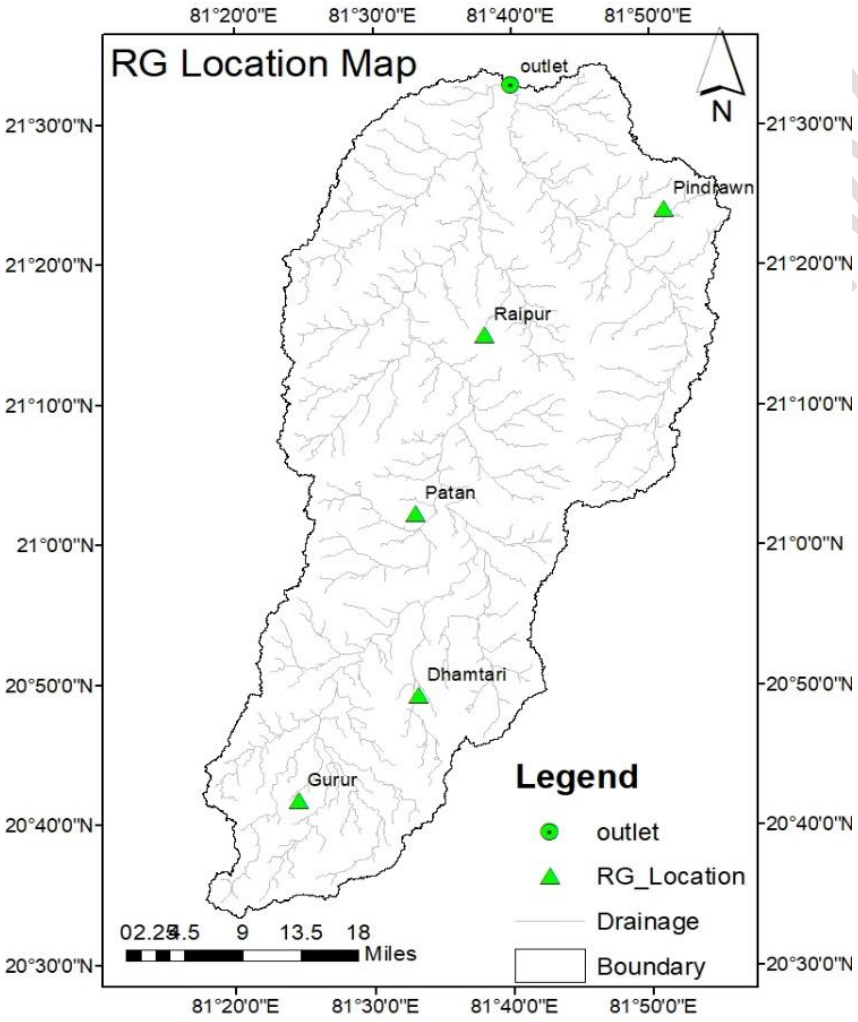

Fig. 2: Location of various recording stations of the Kharun watershed

TREND ANALYSIS

Trend analysis is method of time series data (information in sequence over time) analysis involving the comparison of the same item (such as monthly rainfall data) over a significantly long period to detect general pattern of a relationship between associated factors or variables and project the future direction of this pattern. The statistical significance of the

trend was assessed using the Man-Kendall test, and its magnitude was assessed using the non-parametric Sen's estimator approach.

Mann–Kendall Test

In hydro-climatic time series data, this is a statistical approach for comparing the null hypothesis of no trend with the alternative hypothesis of a monotonic expanding or declining trend. The Mann Kendall non- parametric test is ideal for data series with a monotonic trend(i.e., a trend that is always increasing and never decreasing numerically) and no seasonal or other cycle. This is how M-K statistic is calculated:

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

$$Sgn(x_j - x_i) = \begin{cases} +1, \text{if } x_j - x_i > 0 \\ 0, \text{if } x_j - x_i = 0 \\ -1, \text{if } x_j - x_i < 0 \end{cases} \quad \textbf{2}$$

$$\text{Var}(s) = \frac{1}{18}[n(n-1)(2n+5) - \sum_{p=1} t_p(t_p-1)(2t_p+5)] \quad \textbf{3}$$

$$Z = \begin{cases} \frac{s-1}{\sqrt{\text{Var}(s)}}, \text{if } S > 0 \\ 0 \ldots\ldots\ldots, \text{if } S = 0 \\ \frac{s+1}{\sqrt{\text{Var}(s)}}, \text{if } S < 0 \end{cases}$$

Sen's slope Estimator

The magnitude of the trend is estimated using the Theil-Sen method, a median-based non-parametric slope estimator. Equation 4 provides the formula for computing slope.

$$\beta = \boldsymbol{median}\frac{\mathbf{Xj - Xk}}{\boldsymbol{j-k}} \ldots \forall \ldots \boldsymbol{k < j} \qquad \mathbf{4}$$

where x_j and x_k are the consecutive data values of series in the year's j and k.

β is the magnitude of the trend slope of data values.

RESULTS AND DISCUSSION

LONG-TERM METEOROLOGICAL DATA ANALYSIS

In the current study, the Mann-Kendall trend test was used to analyze trends in 35 years of time series data from 1987 to 2021 for the meteorological variables of rainfall and temperature at the stations Pindrawan, Raipur, Patan, Dhamtari, and Gurur. Data on temperature and precipitation trends in all five stations of the Kharun watershed have been calculated, and the results were presented as follows on a seasonal and annual basis:

Trend analysis of Precipitation

According to the examination of station data on precipitation, the average annual rainfall for the Kharun Watershed was 1252.47 mm. For the period of 1987 to 2021, the Mann-Kendall trend test for precipitation was used. The results of a trend test for precipitation indicate an overall upward trend for all five stations (Pindrawan, Raipur, Patan, Dhamtari, and Gurur). In all five stations, the annual trend of precipitation over the 35-year period has exhibited an upward trend. Table 1 contains the Mann-Kendall test outcomes for precipitation data.

Table 1: Results of the Mann-Kendall Test for Data on Precipitation

Station Name	Season	Kendall's Tau	Mann-Kendall Statistic (S)	Var (S)	p Value (two tailed test)	Alpha	Sens's Slope (Q)	Z
Pindrawan	Kharif	0.220	131	4958	0.065	0.050	10.831	3.75
	Rabi	0.205	109	4465	0.103	0.050	0.000	3.29
	Zaid	0.308	161	4369	0.015	0.050	0.528	3.55
	Annual Statistics	0.261	155	4958	0.028	0.050	11.694	3.89
Raipur	Kharif	0.158	94	4957	0.182	0.050	0.000	1.32
	Rabi	0.247	140	4793	0.043	0.050	0.830	2.01
	Zaid	0.336	192	4833	0.006	0.050	1.217	2.75
	Annual Statistics	0.217	129	4958	0.069	0.050	9.137	1.82
Patan	Kharif	0.340	200	4930	0.004	0.050	20.863	2.83
	Rabi	0.335	156	3701	0.010	0.050	0.000	2.55
	Zaid	0.518	217	3125	0.000	0.050	0.000	3.86
	Annual Statistics	0.395	232	4930	0.001	0.050	27.281	3.29
Dhamtari	Kharif	0.066	39	4958	0.592	0.050	2.267	0.54
	Rabi	0.240	136	4793	0.049	0.050	0.745	1.95
	Zaid	0.280	160	4833	0.021	0.050	1.367	2.29
	Annual Statistics	0.129	77	4958	0.283	0.050	5.974	1.08
Gurur	Kharif	0.035	21	4958	0.778	0.050	2.091	0.28
	Rabi	0.282	127	3524	0.032	0.050	0.000	2.12
	Zaid	0.473	220	3701	0.000	0.050	0.000	3.60
	Annual Statistics	0.082	49	4958	0.499	0.050	4.960	0.68

Trend analysis of maximum temperature and minimum temperature

With the exception of the Kharif season at Pindrawan, Raipur, and Patan stations, the minimum temperature for all five stations indicates declining trends for all seasons. Kharif season of Pindrawan, Raipur and Patan station shows increasing trend towards minimum temperature. Dhamtari and Gurur stations had also shown decreasing trend for all season and annually but in Kharif season increasing trend was shown. In all five stations, the annual trend of the minimum temperature over the 35-year period had exhibited a downward trend. Table 2 contains the results of the Mann-Kendall test for the minimum temperature data.

Table 2: Mann-Kendall test results for data on minimum temperatures

Station Name	Season	Kendall's Tau	Mann-Kendall Statistic (S)	Var (S)	p Value (two tailed test)	Alpha	Sens's Slope (Q)	Z
Pindrawan	Kharif	0.049	29	4958	0.693	0.05	0.011	0.40
	Rabi	-0.459	-273	4958	< .0001	0.05	-0.101	-3.86
	Zaid	-0.250	-149	4958	0.035	0.05	-0.056	-2.10
	Annual Statistics	-0.250	-149	4958	0.035	0.05	-0.035	-2.10
Raipur	Kharif	0.049	29	4958	0.693	0.05	0.011	0.40
	Rabi	-0.459	-273	4958	<0.0001	0.05	-0.101	-3.86
	Zaid	-0.250	-149	4958	0.035	0.05	-0.056	-2.10
	Annual Statistics	-0.250	-149	4958	0.035	0.05	-0.035	-2.10
Patan	Kharif	0.042	25	4958	0.735	0.05	0.013	0.34
	Rabi	-0.455	-271	4958	<0.0001	0.05	-0.103	-3.83
	Zaid	-0.250	-149	4958	0.035	0.05	-0.056	-2.10
	Annual Statistics	-0.250	-149	4958	0.035	0.05	-0.035	-2.10
Dhamtari	Kharif	-0.113	-67	4958	0.352	0.05	-0.013	-0.94
	Rabi	-0.382	-227	4958	0.001	0.05	-0.102	-3.21
	Zaid	-0.395	-235	4958	0.001	0.05	-0.090	-3.32
	Annual Statistics	-0.385	-229	4958	0.001	0.05	-0.056	-3.24
Gurur	Kharif	-0.064	-38	4957	0.589	0.05	-0.008	-0.53
	Rabi	-0.333	-198	4957	0.005	0.05	-0.098	-2.80
	Zaid	-0.394	-234	4957	0.001	0.05	-0.090	-3.31
	Annual Statistics	-0.326	-194	4957	0.006	0.05	-0.045	-2.74

The Mann-Kendall test's findings for the minimum and maximum temperatures demonstrate seasonal increases for all five stations. In all stations, the maximum temperature has increased on an annual basis over the previous 35 years. Table 3 contains the Mann-Kendall test outcomes for maximum temperature data. The study area's average temperature was found to range from 5.03 °C to 51.770 °C. It was discovered that the mean minimum and mean maximum temperatures were 17.110C and 38.280C, respectively.

Table 3: Mann-Kendall test results for data on Maximum temperatures

Station Name	Season	Kendall's Tau	Mann-Kendall Statistic (S)	Var (S)	p Value (two tailed test)	Alpha	Sens's Slope (Q)	Z
Pindrawan	Kharif	0.445	265	4958	0.000	0.050	0.118	3.75
	Rabi	0.392	233	4958	0.001	0.050	0.102	3.29
	Zaid	0.422	251	4958	0.000	0.050	0.261	3.55
	Annual Statistics	0.462	275	4958	<0.0001	0.050	0.140	3.89
Raipur	Kharif	0.445	265	4958	0.000	0.050	0.118	3.75
	Rabi	0.392	233	4958	0.001	0.050	0.102	3.29
	Zaid	0.422	251	4958	0.000	0.050	0.261	3.55
	Annual Statistics	0.462	275	4958	<0.0001	0.050	0.140	3.89
Patan	Kharif	0.445	265	4958	0.000	0.050	0.114	3.75
	Rabi	0.378	225	4958	0.001	0.050	0.096	3.18
	Zaid	0.408	243	4958	0.000	0.050	0.246	3.44
	Annual Statistics	0.449	267	4958	<0.0001	0.050	0.137	3.78
Dhamtari	Kharif	0.311	185	4958	0.008	0.050	0.056	2.61
	Rabi	0.203	121	4958	0.089	0.050	0.035	1.70
	Zaid	0.415	247	4958	0.000	0.050	0.233	3.49
	Annual Statistics	0.365	217	4958	0.002	0.050	0.091	3.07
Gurur	Kharif	0.311	185	4958	0.008	0.05	0.055	2.61
	Rabi	0.193	115	4958	0.106	0.05	0.033	1.62
	Zaid	0.405	241	4958	0.000	0.05	0.219	3.41
	Annual Statistics	0.365	217	4958	0.002	0.05	0.080	3.07

CONCLUSION

The Z statistics revealed the trend of the series for 35 years (1987-2021) on an annual and seasonal basis in the non-parametric Mann-Kendall test. The maximum value for the slope of precipitation (20.863 mm/year) trend line was observed in Patan station in the Kharif season, while there is no trend in the lowest value for Patan station. The magnitude of seasonal precipitation data was assessed in seasonal time steps. In terms of annual time steps, Patan station recorded the highest slope of precipitation value (27.281 mm/year) and Guru station recorded the lowest slope of precipitation value (4.96 mm/year). Minimum temperature magnitude data are estimated in annual time steps. Raipur, Pindrawan, and Patan stations had the

highest slope of temperature (-0.035 0C/year) value, while Dhamtari station recorded the lowest slope of temperature (-0.056 0C/year) value. The highest value for the slope of the maximum temperature trend line (0.14 0C/year) was found in Pindrawan and Raipur stations and the lowest value for the slope of the maximum temperature trend line (0.08 0C/year) was found in Gurur station. The magnitude of maximum temperature data was estimated in annual time steps.

REFERENCES

Chowdhury RK, Beecham S 2010. Australian rainfall trends and their relation to the southern oscillation index. Hydrol Process: Int J 24(4):504–514.

Gajbhiye, S., Meshram, C., Singh, S.K., Srivastava, P.K. and Islam, T. 2016. Precipitation trend analysis of Sindh River basin, India, from 102-year record (1901-2002). Atmospheric Science Letters, 17, 71– 77.

Jain, S. K. and Kumar, V. 2012. Trend analysis of rainfall and temperature data for India. Current Science, 102(1).

Kendall, M.G. 1975. Rank Correlation Methods; Griffin: London, UK, 1975.

Kumar R. and Gautam H.R. 2014. Climate change and its impact on agricultural productivity in India. Journal of Climatology and Weather Forecasting, 2, 109. https://doi.org/10.4172/2332-2594.1000109.

Kundan M. Kamble, V.A. Sthool, S.K. Upadhye, J.D. Jadhav, S.V. Bagade and Giri, A.M. 2020. Trend Analysis of Rainfall and Rainy Days using Mann Kendall Method and Sen‟s Slope Estimator in Parola Tehsil of Jalgaon District of Maharashtra (India). Int.J.Curr.Microbiol.App.Sci.9(12):3038-3044.doi: https://doi.org/10.20546/ijcmas.2020.912.360

Mann, H. B. 1945. Non-parametric test against trend. Econometrical 13: 245 – 259.

Modarres R. and da Silva V.P. 2007. Rainfall trends in arid and semi-arid regions of Iran. Journal of Arid Environments, 70, 344– 355.

Panda, A. and Sahu, N. 2019. Trend analysis of seasonal rainfall and temperature pattern in Kalahandi, Bolangir and Koraput districts of Odisha, India. Atmos. Sci Lett., 20: e932.

Sen, P.K. 1968. Estimates of the Regression Coefficient Based on Kendall's Tau. J. Am. Stat. Assoc., 63, 1379–1389.

Singh O., Arya P. and Chaudhary B.S. 2013 On rising temperature trends at Dehradun in Doon valley of Uttarakhand, India. Journal of Earth System Science, 122, 613– 622.

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

Xia XH, Wu Q, Mou XL 2012. Advances in impacts of climate change on surface water quality. Adv Water Resource 23(1):124–133.