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Trend Analysis of Rainfall and Temperature in the Kharun Watershed: Implications for Climate and Water Management

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Rainfall and temperature are critical meteorological variables for understanding climate change and its potential impacts on water resources. Rainfall and Temperature are the most important for climatic parameters. The result of this study will help to take necessary steps and measures for agricultural production. This study focuses on analyzing rainfall and temperature trends in the Kharun watershed, Chhattisgarh, using the Mann-Kendall (MK) test and Sen's slope (SS) estimator.

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The analysis covers seasonal (summer, winter, and monsoon) and annual trends across key stations. Results for precipitation trends reveal mixed outcomes. At Dhamtari, a significant increasing trend in summer rainfall (z = 3.21, p < 0.01, Sen's slope = 0.77) was observed, though the annual trend remains insignificant. In Patharidih, summer rainfall also shows a significant upward trend (z = 2.04, p = 0.04), while Raipur exhibits a significant decline in both annual and summer precipitation (z = -1.04, p = 0.03, Sen's slope = -0.27). Temperature trends indicate no significant changes in maximum temperature across most stations, though slight positive trends are observed in summer and monsoon seasons. However, minimum temperature trends show a significant decline during winter at Dhamtari and Raipur (z = -2.12, Sen's slope = -0.04). These findings highlight localized seasonal variability in rainfall and temperature, underlining potential challenges for water resource management and climate adaptation in the region.

Keywords: Trend analysis; mann–kendall test; sen's slope estimator; rainfall; maximum temperature; minimum temperature; kharun.

1. INTRODUCTION

Climate change, as one of the primary external forces, has triggered extreme weather phenomena such as temperature fluctuations, shifts in humidity, and intense rainfall, leading to substantial economic losses (Chowdhury and Beecham 2010). The variability in the hydrological cycle presents a critical challenge, impacting both societal and environmental systems (Gajbhiye et al. 2016). Rainfall and temperature (Jain & Kumar 2012) are the fundamental climatic parameters that shape the environmental conditions of a region, which, in turn, significantly influence agricultural productivity (Kendall 1975, Kumar et al. 2014). Agriculture, along with other interrelated sectors like food and energy security, is heavily dependent on the timely availability of sufficient water and favorable climatic conditions. The amount of rainfall a region receives plays a pivotal role in determining the water supply needed for various purposes, including agriculture, industry, domestic use, and hydroelectric power generation. Both the distribution and quantity of rainfall (Kundan et al. 2020) are key factors influencing agricultural output, and agriculture remains central to India's economy and the livelihoods of its population (Kumar et al. 2014). Despite recent industrial advancements, India's economic stability is largely tied to the overall agricultural production, with a vast portion of the population relying on rainfall-dependent crops for sustenance.

The trends of rainfall and temperature in the Kharun watershed, a critical region in India. The use of the Mann-Kendall test and Sen's slope estimator provides a robust statistical approach to understanding long-term climatic changes, which are essential for developing water management strategies and climate adaptation measures. Furthermore, the localized seasonal variability identified in this study can help inform regional policy decisions related to agriculture and water resource planning.

The Mann-Kendall (MK) test (Mann 1945) was employed to identify trends in rainfall, maximum temperature (Tmax), and minimum temperature (Tmin). This non-parametric test does not require the data to follow a normal distribution Modarres & da Silva 2007). It tests the null hypothesis (H0), which posits no trend and assumes the data are independent and randomly ordered, against the alternative hypothesis (Ha), which suggests the presence of a trend (Verma et al., 2022). The actual rate of change over time was estimated using Sen's slope (SS) method (Panda & Sahu 2019 and Sen 1968). The present study aimed to examine the trends of two critical climatic variables—rainfall and temperature—in response to the challenges. Analyzing the seasonal and annual trends of rainfall and temperature within the specified river basin is essential for enhancing water management strategies in the watershed.

XLSTAT has emerged as a widely used statistical software, integrating data input and output through Excel while performing calculations via independent software components. It is recognized for its user-friendly interface and high efficiency in statistical and multivariate data analysis, offering the same level of precision as traditional scientific statistical software (Singh et al. 2013).

The present study on rainfall and temperature trend analysis in the Kharun watershed holds significant importance for optimizing water resource management within the basin. The findings contribute to a deeper understanding of localized climate change impacts, enabling the prediction of future hydrometeorological patterns. Additionally, these insights are crucial for improving water management strategies, facilitating better planning and adaptation measures in response to evolving climatic conditions.

2. MATERIALS AND METHODS

2.1 Overview of the Study Area

The Kharun watershed is a part of the Seonath sub-basin, situated within the renowned Mahanadi River basin in Chhattisgarh. It spans across fifteen administrative blocks, either fully or partially, and covers six districts: Balod, Dhamtari, Durg, and Raipur. The total area of the watershed is reported to be 4,118 square kilometers. Geographically, the Kharun watershed lies between latitudes 20°52'30'' N and 21°54'36'' N, and longitudes 81°27'18'' E and 82°06'18'' E. The Kharun originates near Petechua, located in the southeastern part of the Balod district, and flows for approximately 164 kilometers before merging with the Seonath river near Somnath in Raipur district (Sinha, 2011). The watershed features the geology of the Chandrapur Group—comprising Gunderdihi and Churmuri formations, with lithology dominated by shale.

2.2 Data Acquisition

Daily rainfall and temperature data for the Kharun watershed, spanning the period from 1971 to 2021, were obtained from the India Meteorological Department Pune, Maharashtra . These data include records from multiple rain gauge stations located throughout the watershed. The locations of these stations are depicted in Fig. 1.

2.3 Data Analysis

2.3.1 Rainfall and temperature data processing

Daily rainfall and temperature records for the Kharun watershed were collected from various rain gauge (RG) stations through India Meteorological Department Pune, Maharashtra website. The geographical coordinates of each station were utilized within an ArcGIS environment to generate a thematic map. Once organized, the daily data on precipitation and temperature were processed for analysis. This involved aggregating the daily values into monthly and seasonal datasets for more effective interpretation and trend analysis (Tabari et al. 2011 and Xia et al. 2012).

2.4 Trend Analysis

Trend analysis is a technique used in time series data evaluation, where data points—such as monthly or seasonal rainfall records—are compared over an extended period to identify and assess long-term patterns or relationships between variables. This approach helps in understanding the general behavior of these variables over time and provides a basis for predicting future trends. In this study, the Mann-Kendall test was applied to assess the statistical significance of trends in the rainfall and temperature data. This non-parametric test is widely used for detecting trends in climatological and hydrological time series data. Additionally, the magnitude of the observed trends was quantified using Sen's slope estimator, which is a non-parametric method for calculating the slope of a trend over time. These analyses offer insights into long-term climatic variability and its potential future trajectory in the Kharun watershed.

2.4.1 Mann–kendall test

The Mann-Kendall trend test (Mann, 1945; Kendall, 1975) was utilised for every independent weather parameter (highest and lowest temperatures as well as rainfall) were statistically investigated in two stages. A non-parametric method for discovering trends in time series is the Man-Kendall test. Instead of comparing the actual values of the data, this test compares the relative magnitudes of the data. This test has the advantage of not requiring data to validate a certain distribution. Kendall provides a description of the normal approximation test technique. The non-parametric Mann-Kendall test is used in the first instance, and the non-parametric Sen's estimate of slope. Sen's slope, which was used to determine an existing trend's, real slope was used to assess whether the trend was rising or decreasing using normalised test statistics (Z). The trend is increasing when Z is positive and declining when Z is negative. The yearly rate and direction of change are shown by the trend's slope.

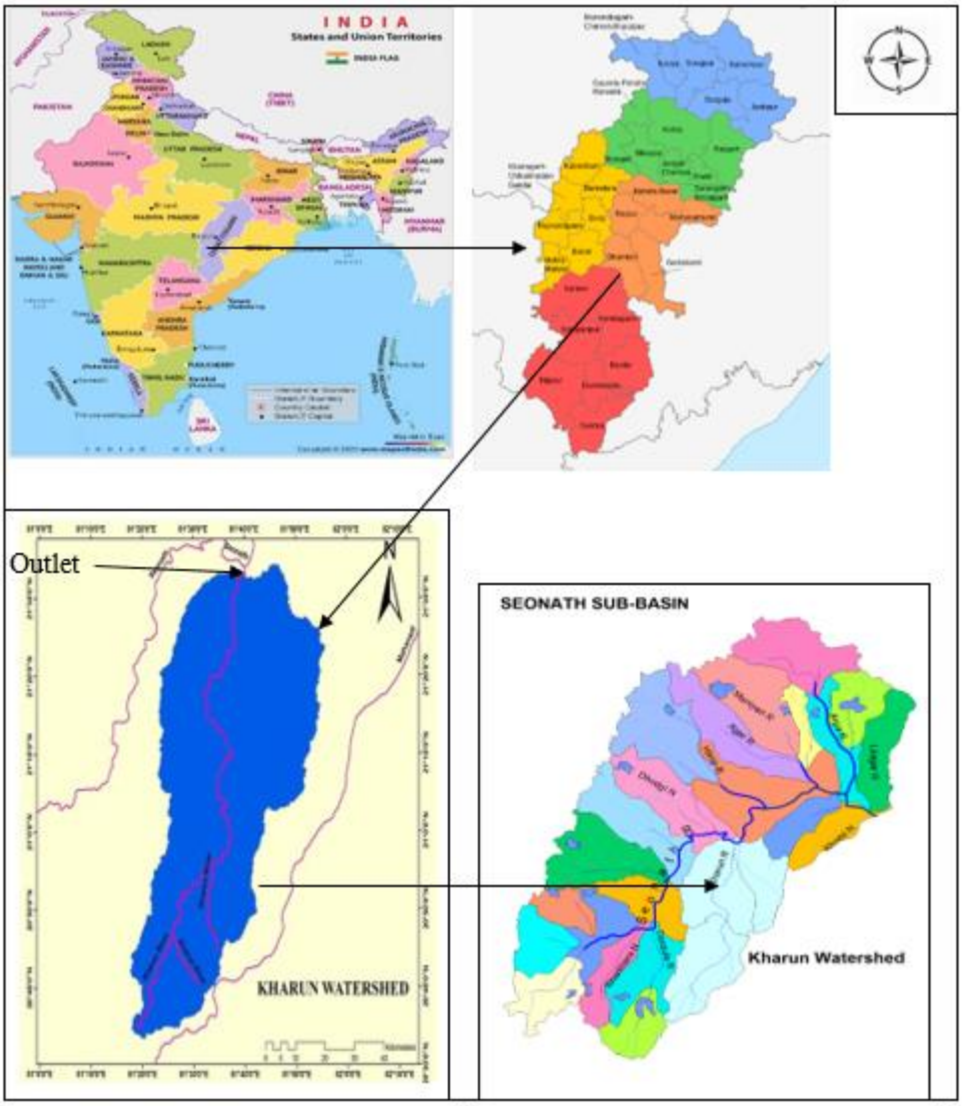

Fig. 1. Location map of study area

This approach looks for trends in the time series data. The test is non-parametric and removes outliers. The values of the n time series (X1, X2, X3,...Xn) are substituted by their respective ranks (R1, R2, R3,... Rn) (with the lowest ranking starting at 1 and going up to n).

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

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

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

$$Z = \begin{cases} \frac{s-1}{\sqrt{Var(s)}}, \text{if } S > 0 \\ 0 \ldots\ldots\ldots, \text{if } S = 0 \\ \frac{s+1}{\sqrt{Var(s)}}, \text{if } S < 0 \end{cases} \quad (4)$$

The statistical parameters are: Xi and Xj successive data values in the years i and j, n is the number of recorded data, tp is the number of ties for the pth value, and q is the number of tied values. Positive Z values indicate rising trend values, whereas negative Z values indicate decreasing trend values for the associated time series. In the two-tailed test, Ho represents the null hypothesis and H1 represents the alternate hypothesis. Ho is rejected if there is no trend in the series.

2.4.2 Sen's slope estimator

A positive value of S indicates an increasing trend, and a negative value indicates a decreasing trend. However, it is necessary to perform the statistical analysis for the significance of the trend.

Here, n is the length of the rainfall data, p is the number of ties for the p^{th} value, and q is the number of tied values. Xi and Xj are the rainfall time series data in chronological sequence. The hydrologic time series data show an upward or downward trend when the Z value is positive or negative, respectively, and no trend when the Z value is zero. If the rainfall time series data exhibit a statistically significant trend and $|Z| > Z_{1-\alpha/2}$, then (H0) is rejected.

2.5 Sen's Slope Estimator

This study employed the Theil-Sen approach (TSA), a widely used technique to measure the major linear trends in time series. Sen's nonparametric technique is employed to determine the actual slope of an established trend. Because of its improved performance even for regularly distributed data and relative insensitivity to extreme values, the TSA is thought to be more resilient than the least-squares approach.

Sen's slope approach is used to evaluate the trend's size. It is followed by figuring out the slope as a measurement change per time change. Compute the slopes of each pair of data values to obtain the slope estimate Q in the equation.

$$\beta = \text{median}\,\frac{X_j - X_k}{j-k} \ldots \forall \ldots k < j \qquad (5)$$

Where,

In this equation, Xj and Xk represent data values at time j and k, respectively.
β is the magnitude of the trend slope of data values.

3. RESULTS AND DISCUSSION

3.1 Long-term Meteorological Data Analysis

In this study, the Mann-Kendall trend test was applied to examine trends in 50 years of time series data (1971–2021) for the meteorological variables of rainfall and temperature at five stations: Raipur, Patan, Dhamtari, and Patharidih. The analysis evaluated the trends in temperature and precipitation across all five stations within the Kharun watershed. The findings, reflecting both seasonal and annual variations, are presented in the following sections.

3.2 Trend Analysis of Precipitation

The Mann-Kendall trend analysis for precipitation across different seasons and stations in the Kharun watershed reveals mixed results. In Dhamtari, while the annual precipitation trend is insignificant ($z = 0.37$, $p = 0.71$), the summer season displays a significant increasing trend ($z = 3.21$, $p < 0.01$), with a Sen's slope of 0.77. A marginally significant positive trend is also observed during the winter season ($z = 1.92$, $p = 0.05$). Conversely, the southwest monsoon (SWM) shows a decreasing trend, though this is statistically insignificant ($z = -0.81$). At Patharidih, the summer season exhibits a significant upward trend ($z = 2.04$, $p = 0.04$) with a Sen's slope of 0.48, but no significant trends are observed annually or in other seasons. In Patan, despite positive trends across all seasons and the annual cycle, none are statistically significant (p-values > 0.05). At Raipur, there is a general decline in annual rainfall ($z = -0.32$, $p = 0.75$), with a significant decreasing trend observed in the summer season ($z = -1.04$, $p = 0.03$), accompanied by a Sen's slope of -0.27. No significant trends are noted for the other seasons.

3.3 Trend Analysis of Maximum Temperature and Minimum Temperature

The trend analysis for maximum temperature (Tmax) across the stations and seasons largely shows insignificant results. At Dhamtari, the winter, summer, and northeast monsoon (NEM) seasons exhibit no statistically significant trends (z-values of 0.26, 0.34, and 0.39, respectively), though slight positive trends are observed during the summer (Sen's slope = 0.006) and southwest monsoon (SWM) (Sen's slope = 0.003). In Patharidih, a marginally positive trend is seen in winter ($z = 0.29$, Sen's slope = 0.002), but no significant changes are noted in the other seasons. Raipur shows no significant temperature variations across any season or annually, with Mann-Kendall z-values hovering around zero. Patan exhibits a positive trend during the winter season (z = 0.62), but it remains statistically insignificant, and other seasonal and annual trends also lack statistical significance, although the summer season shows a minor positive slope (Sen's slope = 0.011).

Table 1. Precipitation trend analysis statistics of all the station

Location	Season	Mann-Kendall (z)	Mann-Kendall (p-value)	Sen's Slope
Dhamtari	Annual	0.37	0.71	0.55
	Winter	1.92	0.05	0.29
	Summer	3.21	0	0.77
	SWM	-0.81	0.42	-1.61
	NEM	0.39	0.69	0.1
Patharidih	Annual	0.37	0.71	0.55
	Winter	1.23	0.22	0.16
	Summer	2.04	0.04	0.48
	SWM	0.97	0.33	1.96
	NEM	0.51	0.61	0.26
Patan	Annual	0.37	0.71	0.55
	Winter	1.18	0.24	0.27
	Summer	1.07	0.29	0.29
	SWM	0.09	0.93	0.15
	NEM	-0.35	0.73	-0.16
Raipur	Annual	-0.32	0.75	-0.76
	Winter	0.47	0.64	0.1
	Summer	-1.04	0.3	-0.27
	SWM	0.01	0.99	0.05
	NEM	-0.84	0.4	-0.34

Table 2. Table showing trend analysis statistics of tmax

Station Name	Season	Mann- Kendall Statistic (S)	Z	Sen's Slope (Q)
Dhamtari	Winter	17	0.26	0.01
	Summer	22	0.34	0.006
	SWM	-8	0.11	0.003
	NEM	25	0.39	-0.001
	Annual Statistics	14	0.21	-0.005
Patharidih	Winter	19	0.29	0.002
	Summer	8	0.11	0.005
	SWM	-20	0.31	0.004
	NEM	-13	-0.19	-0.002
	Annual Statistics	-2	-0.02	-0.004
Raipur	Winter	19	0.29	0
	Summer	8	0.11	0.005
	SWM	-20	-0.31	0.004
	NEM	-13	-0.19	-0.002
	Annual Statistics	-2	-0.02	-0.005
Patan	Winter	39	0.62	0
	Summer	-18	-0.28	0.011
	SWM	8	0.11	-0.004
	NEM	-5	-0.06	0.004
	Annual Statistics	6	0.08	-0.001

Table 3. Table showing trend analysis statistics of tmin

Station Name	Season	Mann- Kendall Statistic (S)	Z	Sen's Slope (Q)
Dhamtari	Winter	-138	-2.12	-0.04
	Summer	-46	-0.7	-0.01
	SWM	-4	-0.05	0
	NEM Annual	34	0.51	0.01
	Statistics	-90	-1.38	-0.01
Patharidih	Winter	19	0.29	0
	Summer	8	0.11	0
	SWM	-20	0.31	0
	NEM Annual	-13	-0.19	0
	Statistics	-2	-0.02	0
Raipur	Winter	-138	-2.12	-0.04
	Summer	-46	-0.7	-0.01
	SWM	-4	-0.05	0
	NEM Annual	34	0.51	0.01
	Statistics	-90	-1.38	-0.01
Patan	Winter	39	0.62	0.01
	Summer	-18	-0.28	0
	SWM	8	0.11	0
	NEM Annual	-5	-0.06	0
	Statistics	6	0.08	0

The minimum temperature (Tmin) trend analysis reveals some seasonal variations, though no statistically significant long-term trends are detected overall. At Dhamtari, the winter season shows a significant decreasing trend (z = -2.12, Sen's slope = -0.04), while other seasons, including summer, SWM, and NEM, display insignificant trends with low z-values and minimal Sen's slopes. Similarly, Patharidih shows no statistically significant trends in Tmin across any season or annually, with close-to-zero results for most seasons. At Raipur, a significant declining trend is observed in the winter season (z = -2.12, Sen's slope = -0.04), while the other seasons remain insignificant. Patan shows no significant changes in Tmin across any season or annually, with only a small positive trend in winter (Sen's slope = 0.01), which is not statistically significant.

4. CONCLUSION

The Mann-Kendall test results for the 50-year period (1971–2021) identified significant climatic trends in both rainfall and temperature across the Kharun watershed. For precipitation, statistically significant positive trends were observed in the summer season at Dhamtari and Patharidih stations, while Raipur exhibited a notable declining trend in summer rainfall. In terms of maximum temperature (Tmax), minor positive slopes were detected during the summer season at Dhamtari and Patan, though no significant long-term trends were apparent. Conversely, minimum temperature (Tmin) displayed a significant decreasing trend during the winter season at both Dhamtari and Raipur, with other seasons showing no substantial changes. These results highlight the spatial and seasonal variability of climatic trends within the watershed, offering critical insights for regional climate impact assessments and water resource management strategies.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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