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

ABSTRACT

Rainfall and temperature are critical meteorological variables for understanding climate change and its potential impacts on water resources. 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. 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 [1]. The variability in the hydrological cycle presents a critical challenge, impacting both societal and environmental systems [2]. Rainfall and temperature [3] are the fundamental climatic parameters that shape the environmental conditions of a region, which, in turn, significantly influence agricultural productivity [4,5]. 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 [6] are key factors influencing agricultural output, and agriculture remains central to India's economy and the livelihoods of its population [5]. 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 Mann-Kendall (MK) test [7] 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 [8]. 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 [9,10]. 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 [11].

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.

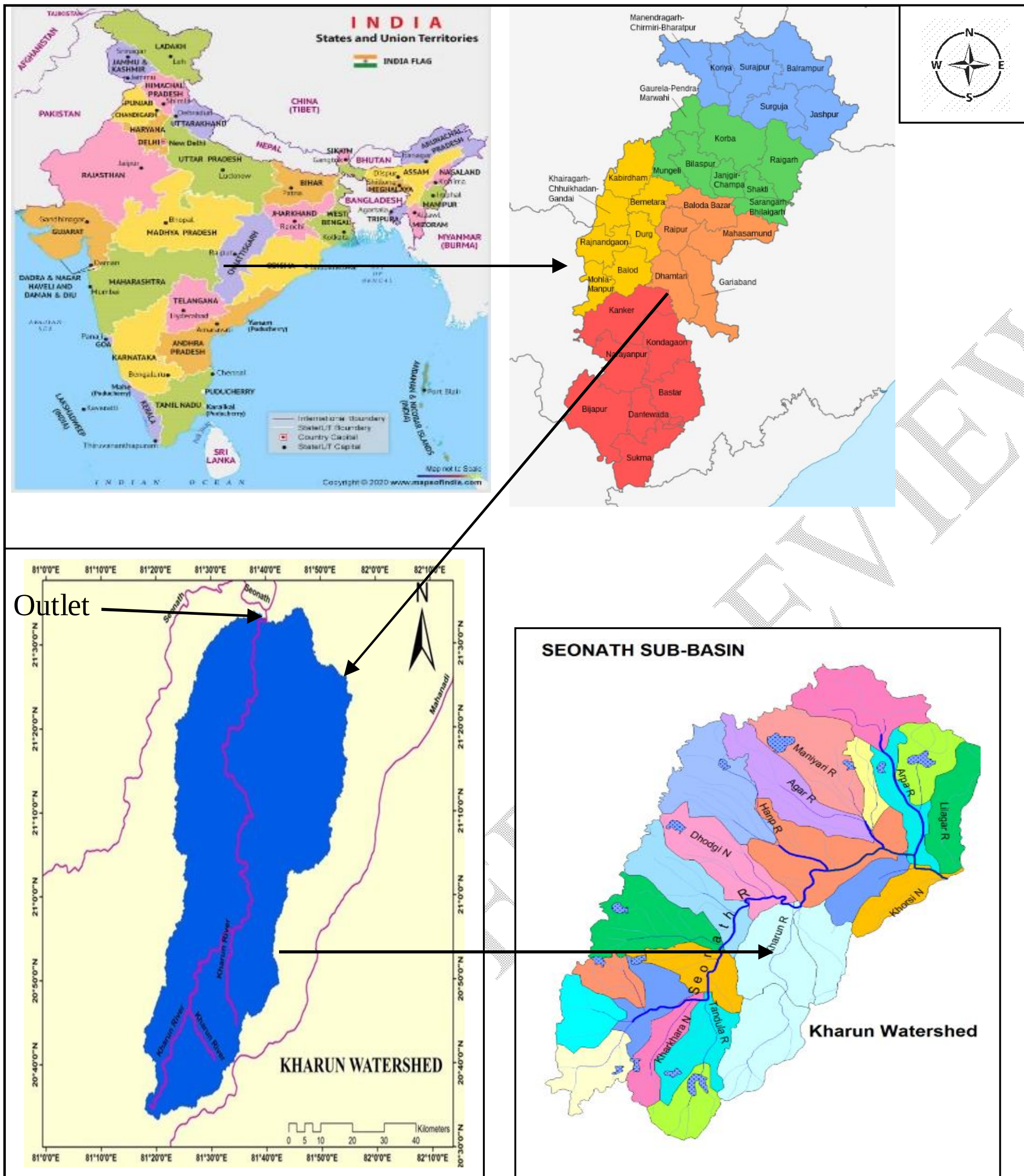

Fig.1. Location map of study area

2.2 Data Acquisition

Daily rainfall and temperature data for the Kharun watershed, spanning the period from 1971 to 2022, were obtained from theIndia 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 [12,13].

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

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 nonparametric 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:

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

$$Sgn(xj - xi) = \begin{cases} +1, & if\ xj - xi > 0 \\ 0, & if\ xj - xi = 0 \\ -1, & if\ xj - xi < 0 \end{cases} \quad (2)$$

$$Var(s) = \frac{1}{8}[n(n-1)(2n+5) - \sum_{p=1}^{4} t_p(t_p - 1)(2t_p + 5)] \quad (3)$$

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

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

Where, S= Mann-Kendall statistic,

X_j= successive data values in the years j, X_i= successive data values in the years i,

n = number of data points recorded,

β= sen slope value.

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

Theil-Sen method, a median-based non-parametric slope estimator, is used to determine the magnitude of the trend. The computation of slope is given by Equation 4.

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

Where,

xj and xk 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.

3. RESULTSANDDISCUSSION

3.1 Long-term Meteorological Data Analysis

In this study, the Mann-Kendall trend test was applied to examine trends in 35 years of time series data (1987–2021) for the meteorological variables of rainfall and temperature at five stations: Raipur, Patan, Dhamtari, andPatharidih. 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 trends. At Dhamtari, the annual trend is insignificant with a z-value of 0.37 and a p-value of 0.71. However, a significant increasing trend is observed in the summer season (z = 3.21, $p < 0.01$) with a Sen’s slope of 0.77, while the winter season shows a positive trend at a marginally significant level (z = 1.92, p = 0.05). The southwest monsoon (SWM) indicates a decreasing trend, although not significant, with a z-value of -0.81.In Patharidih, the summer season exhibits a significant increasing trend (z = 2.04, p = 0.04) with a Sen’s slope of 0.48, while the annual and other seasonal trends remain insignificant.At Patan, while all seasons and the annual trend are positive, none show statistical significance, as evidenced by p-values greater than 0.05.Raipur shows an overall declining trend in the annual rainfall (z = -0.32, p = 0.75) and a significant decreasing trend in the summer season (z = -1.04, p = 0.03) with a Sen’s slope of -0.27. Other seasons show no significant trends

3.3 Trend Analysis of Maximum Temperature and Minimum Temperature

The Mann-Kendall trend analysis for maximum temperature (Tmax) across the different stations and seasons shows mostly insignificant trends. At Dhamtari, the winter, summer, and northeast monsoon (NEM) seasons show no statistically significant trend with z-values of 0.26, 0.34, and 0.39, respectively. However, slight positive trends are observed in the summer (Sen's slope = 0.006) and southwest monsoon (SWM) (Sen's slope = 0.003).At Patharidih, a marginally positive trend is observed in winter (z = 0.29, Sen's slope = 0.002) but no significant trend is found in other seasons. For the summer and annual temperature trends, the Sen's slopes indicate small positive or negative changes, but they are statistically insignificant.In Raipur, all seasons, including the annual trend, show no significant temperature variation. The Mann-Kendall z-values hover around zero, indicating no considerable trends in maximum temperature over time.At Patan, the winter season shows a positive z-value of 0.62, but no significant trend in Tmax. Similarly, other seasons and annual trends exhibit minimal statistical significance, though the summer trend has a small positive slope (Sen’s slope = 0.011).

The Mann-Kendall trend analysis for minimum temperature (Tmin) reveals some seasonal variations across the stations, but overall, no statistically significant long-term trends were detected.At Dhamtari, the winter season shows a negative trend with a z-value of -2.12, which is statistically significant, indicating a decreasing trend in Tmin (Sen’s slope = -0.04). For the summer, southwest monsoon (SWM), and northeast monsoon (NEM) seasons, the trends are statistically insignificant, with very low z-values and minimal Sen's slopes.In Patharidih, all seasonal and annual trends exhibit statistically insignificant results. The winter season has a positive z-value of 0.29, while the other seasons show close-to-zero results, indicating a stable Tmin over the years.At Raipur, similar to Dhamtari, the winter season shows a significant decreasing trend with a z-value of -2.12 and a Sen’s slope of -0.04, highlighting a drop in Tmin over the years. However, for the other seasons and the annual trend, the results are insignificant, with very low z-values and Sen's slopes close to zero.At Patan, none of the seasonal or annual trends show any significant changes in Tmin. The winter season shows a small positive trend (Sen’s slope = 0.01), but it is not statistically significant.

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

Table2Table 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	34	0.51	0.01
	Annual Statistics	-90	-1.38	-0.01
Patharidih	Winter	19	0.29	0
	Summer	8	0.11	0
	SWM	-20	0.31	0
	NEM	-13	-0.19	0
	Annual Statistics	-2	-0.02	0
Raipur	Winter	-138	-2.12	-0.04
	Summer	-46	-0.7	-0.01
	SWM	-4	-0.05	0
	NEM	34	0.51	0.01
	Annual Statistics	-90	-1.38	-0.01
Patan	Winter	39	0.62	0.01
	Summer	-18	-0.28	0
	SWM	8	0.11	0
	NEM	-5	-0.06	0
	Annual Statistics	6	0.08	0

4. CONCLUSION

The Mann-Kendall test results for the 35-year period (1987–2021) revealed notable trends in rainfall and temperature across the Kharun watershed. For precipitation, significant positive trends were observed in the summer season at Dhamtari and Patharidih stations, while Raipur displayed a decreasing summer rainfall trend. The Tmax trends showed minor positive slopes during the summer season at Dhamtari and Patan, but overall, no significant long-term trends were observed. In contrast, the Tmin exhibited a significant decreasing trend during winter at Dhamtari and Raipur, while other seasons remained stable. These findings underscore the spatial and seasonal variability in climatic trends across the watershed.

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