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Trend Analysis of Long-Term Rainfall Data for Monsoon Season of Kharun Catchment

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Abstract

This research paper investigates the trends in monsoon season rainfall over a 31-year period (1990–2021) using the non-parametric Mann–Kendall test. A range of statistical methods were utilized to analyze the rainfall data, providing valuable insights into its temporal patterns and trends. The correlation coefficient, measured by Kendall's Tau, exhibited a minimal positive correlation of 0.004 between years and their corresponding rainfall, quantities. This implies a slight tendency for increased rainfall with the passage of time. The Mann–Kendall statistic (S) yielded a value of 2 from a two-tailed test, accompanied by a p-value of 0.98 revealing that there is no statistically significant trend in the rainfall data. This implies that the observed fluctuations in monsoon rainfall over the 31-year span are more likely attributable to natural variability rather than a consistent upward or downward trajectory. Moreover, employing an alpha level of 0.050, the Sens's slope (Q) of 0.119 demonstrated a marginal positive slope, indicating a minor rise in rainfall over time. However, this trend lacks the strength required for statistical significance. The Z value of 1.98 further reinforces the insignificance of the observed trend, aligning with the null hypothesis of no trend.

Keywords: Trend analysis, Mann–Kendall test, Sen's slope estimator, rainfall

INTRODUCTION

India's food security, energy security, and agricultural sustainability are fundamentally reliant on the timely availability of adequate water resources and a stable climate. The extent of water availability for various uses [1], such as agriculture, domestic consumption, and hydroelectric power generation, is predominantly determined by the amount and distribution of rainfall. However, global climate change has introduced variability in long-term rainfall patterns, potentially impacting water availability and exacerbating risks such as droughts and floods. A significant portion of India's freshwater resources depends on the southwest (SW) monsoon, which accounts for nearly 80% of the country's annual rainfall. Changes in the SW monsoon due to climate variability are anticipated to have profound implications for agricultural productivity, water resource management, and overall economic stability in the Indian subcontinent [2]. Despite receiving substantial rainfall during the monsoon months (June–September), many parts of the country face acute water scarcity during the non-monsoon periods. This seasonal imbalance underscores the critical role of large storage reservoirs, which are vital for redistributing water to meet diverse regional demands. However, the reliance on traditional assumptions, such as climate stationarity, poses significant challenges to long-term water resource planning and infrastructure development.

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The design of hydro-infrastructure has historically assumed that climatic conditions remain relatively constant over time, an approach that is increasingly being questioned in the face of climate variability. Rainfall and temperature, as key physical parameters of climate, have a direct and significant impact on the environmental and agricultural conditions of any region. Studies [3, 4] have demonstrated the influence of these variables on agricultural productivity. To evaluate trends in meteorological data, statistical tools like the Mann-Kendall (MK) test are employed. The MK test compares the null hypothesis, which assumes no trend, with the alternative hypothesis, which suggests the presence of a trend in the data. Complementing this, the Sen’s slope estimator provides a robust method to quantify the rate of change over time [5]. Against this backdrop, the current study was undertaken to investigate trends in two critical climatic variables—rainfall and temperature. This analysis provides valuable insights into the changing dynamics of these parameters and their potential implications for water resource management and agricultural sustainability in India [6].

MATERIALS AND METHODS

Study Area

The Kharun catchment forms a part of the Seonath sub-basin within the renowned Mahanadi River basin in Chhattisgarh [7]. It encompasses all or parts of 15 blocks across 6 districts, including Balod, Dhamtari, Durg, and Raipur, covering an area of approximately 4118 km^2. Geographically, the catchment lies between latitudes 20°52'30"N to 21°54'36"N and longitudes 81°27'18"E to 82°06'18" E (Figure 1). The Kharun River originates from Petechua in the southeastern region of Balod district and traverses 164 km before merging with the Seonath River near Somnath in Raipur district. Geologically [8] the area is associated with the Chandrapur Group, Gunderdihi, and Churmuri formations, characterized by lithologies such as shale, sandstone, siltstone, and limestone. The data for this study were converted into monthly datasets for analysis.

Data Acquisition

Daily rainfall and temperature records for the Kharun catchment, covering the period from 1990 to 2022, were sourced from the Central Water Commission (CWC), Bhubaneswar. This comprehensive dataset provided a detailed and consistent record of meteorological variables, crucial for analyzing long-term trends and patterns [9].

The rainfall data captured daily precipitation levels, while the temperature records included maximum and minimum daily temperatures, offering insights into the diurnal and seasonal variations over the 32-year period [10]. The CWC, known for its rigorous data collection and quality control protocols, ensured that the dataset was reliable and suitable for advanced hydrological and climatological analyses. These data were integral to the study, enabling the evaluation of critical climatic trends such as changes in seasonal rainfall distribution, temperature variations, and their potential implications on hydrological cycles, agricultural productivity, and water resource management within the Kharun catchment. By leveraging this robust dataset, the study aimed to provide a nuanced understanding of how climatic factors have evolved over the decades in the context of broader regional and global climate variability [11].

Analysis of Data

Rainfall

The MK test is a widely recognized non-parametric statistical method employed for detecting trends in climatological and hydrological time series data. Originally introduced by Mann in 1945, the method gained further prominence through its application to environmental time series analysis, becoming a standard tool for trend detection in various fields. The MK test offers several advantages that make it particularly suitable for analyzing environmental data.

One significant advantage is its non-parametric nature, which eliminates the requirement for the data to follow a normal distribution. This flexibility allows the test to be applied across a broad range of

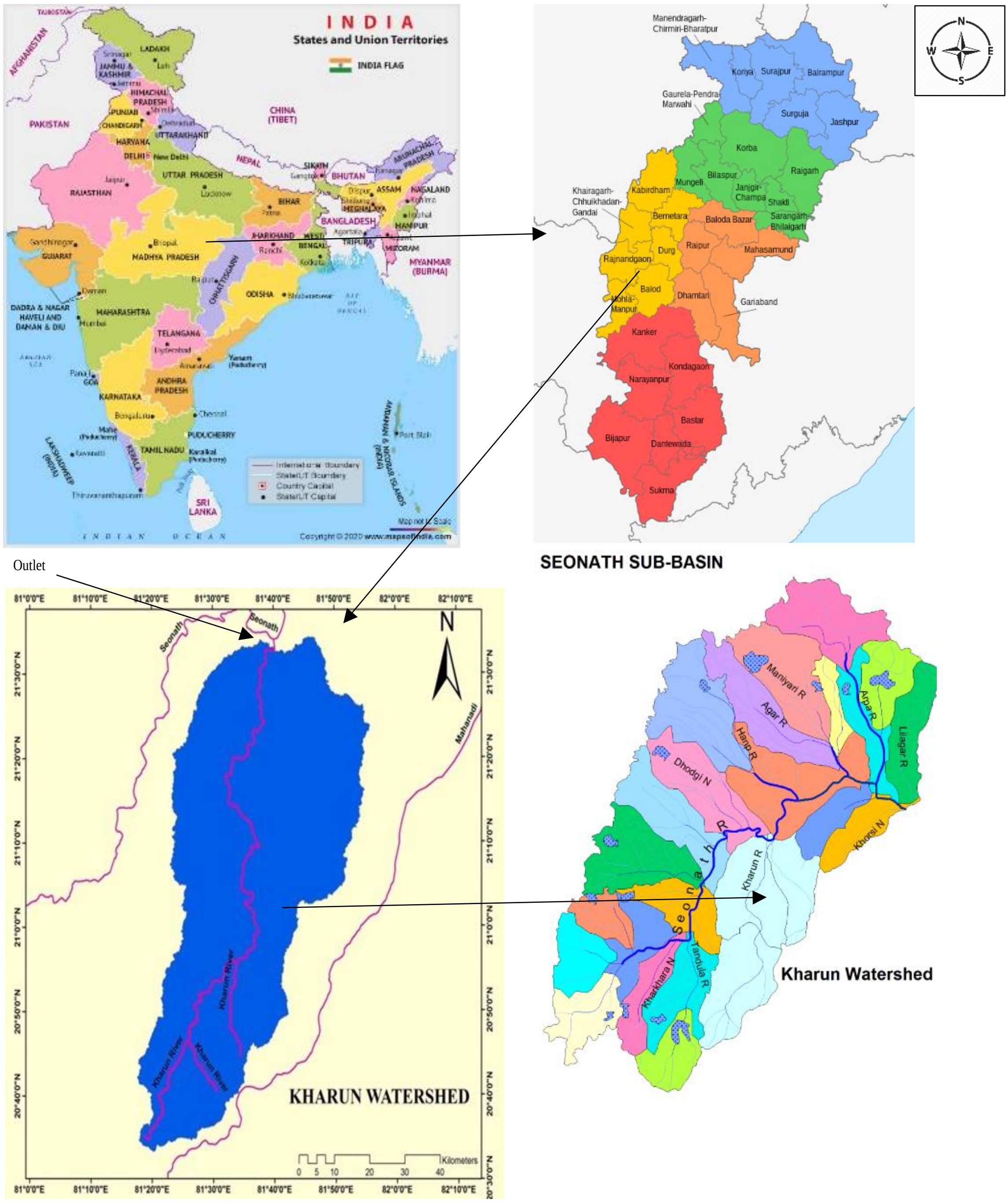

Figure 1. Location map of study area.

datasets, including those with non-linear or skewed distributions [12]. Another important feature is its low sensitivity to abrupt interruptions or outliers in the time series. This robustness makes the test particularly useful for analyzing heterogeneous datasets, where sudden changes or anomalies are common. The MK test operates by formulating two hypotheses. The null hypothesis (H_0) asserts that no trend exists in the data, implying that the observed values are independent and randomly distributed over time. In contrast, the alternative hypothesis (H_1) suggests the presence of a monotonic trend, either increasing or decreasing. The test evaluates the likelihood of the alternative hypothesis by comparing it against the null hypothesis. Through its reliability and adaptability, the MK test has become a cornerstone in the statistical analysis of long-term environmental data, aiding researchers in understanding and interpreting trends in critical variables such as temperature, rainfall, and streamflow.

The MK statistic is calculated as follows:

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

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

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

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

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 pth 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| > Z1 – α/2, then H_0 is rejected.

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.

$$\beta = \text{median}\,\frac{Xj - Xk}{j-k} \ldots \forall \ldots k < j \quad (5)$$

where xj and xk are the consecutive data values of series in the year’s j and k, in this equation, Xj and Xk represent data values at time j and k, respectively.

RESULTS AND DISCUSSION

Analysis of Long-Term Meteorological Data

This study aimed to evaluate long-term trends in meteorological variables, specifically focusing on rainfall, to understand their seasonal and annual variations over time. To achieve this, the MK trend test, a widely used non-parametric statistical method, was employed. This approach is well-suited for climatological and hydrological studies as it effectively identifies monotonic trends without requiring data to adhere to a normal distribution.

The analysis was conducted using a 32-year dataset spanning from 1990 to 2022. Rainfall data were sourced from the Pathridih station, strategically located within the Kharun catchment area, a region of significant hydrological and agricultural importance. This station provided consistent and high-quality records, ensuring the reliability of the trend analysis. Seasonal and annual rainfall trends were examined systematically, allowing for a comprehensive understanding of the temporal variations in precipitation patterns. The results were presented in a structured manner, highlighting key observations and trends

Table 1. Result of Mann–Kendall test for rainfall data.

Station name	Season	Kendall's Tau	Mann-Kendall statistic (S)	Var (S)	*p* value (two-tailed test)	Alpha	Sens's slope (Q)	Z
Pathridih	Monsoon	0.004	2	3802.6	0.987	0.050	0.119	1.98

derived from the data (Table 1). Seasonal patterns, including variations during the monsoon and non-monsoon periods, were identified and analyzed to assess their implications for water resource management, agricultural planning, and adaptation strategies in the face of climate variability.

The findings of this study contribute valuable insights into the long-term dynamics of rainfall in the Kharun catchment, serving as a critical resource for researchers, policymakers, and stakeholders engaged in sustainable water resource management and climate adaptation efforts.

CONCLUSIONS

The MK test was employed to analyze the trend of rainfall over a 32-year period (1990–2022) during the monsoon season. Various statistical indicators provided insights into the patterns and variability of monsoon rainfall in the Kharun catchment area. The Z-statistic from the MK test indicated the nature of the trend over time. The test revealed that the monsoon rainfall data did not exhibit any statistically significant trend during the study period. Specifically, Kendall's Tau, a measure of correlation, yielded a low coefficient of 0.004, suggesting a slight positive correlation between years and rainfall amounts. This result indicates a minor tendency for rainfall to increase over time, but the correlation is too weak to be conclusive.

The MK statistic (S) value of 2, combined with a *p*-value of 0.98 (from a two-tailed test), further supports the absence of a statistically significant trend. These findings imply that the observed variations in monsoon rainfall are likely attributable to natural variability rather than a systematic increase or decrease over the 32-year period. Additionally, Sen's slope (Q), calculated as 0.119, suggests a small positive slope in the data, indicating a slight upward trend in rainfall amounts over time. However, this slope is not statistically significant, meaning the observed increase is not robust enough to reject the null hypothesis of no trend. The Z-value of 1.98 confirms this result, as it falls within the range of the confidence interval that supports the null hypothesis at an alpha level of 0.05. Consequently, while there is a slight indication of increasing rainfall, the trend is weak and statistically insignificant.

In summary, the analysis of monsoon rainfall data over the 32-year period revealed no strong or statistically significant trends. The minor positive slope observed is insufficient to suggest a meaningful or consistent increase in monsoon rainfall. These findings underscore the role of natural variability in shaping rainfall patterns and suggest that there has been no substantial change in monsoon precipitation in the Kharun catchment area during the study period.

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