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Recent Precipitation Trends in Six Districts of the Ken River Basin of Bundelkhand Region, India

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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

The future development and sustainable management of water resources will be greatly influenced by the trend analysis of precipitation. This paper focuses on the analysis of rainfall trends in the Bundelkhand region, particularly in six districts covering the Ken basin. Mann-Kendall test was employed to identify potential trends, and the Sen's slope estimator was utilized to quantify the magnitude of change during 1990 to 2020. Given that a significant portion of rainfall occurs during the southwest monsoon season, the study included both seasonal (monsoon) and annual analyses. The findings indicated a decreasing trend in precipitation for both the monsoon season and the

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annual scale, although many districts exhibited insignificant trends. The outcomes of this study offer valuable insights for agriculture, related sectors, and contribute to the food and energy security considerations for the six districts in the Bundelkhand region and regions with similar physiography.

Keywords: Trend analysis; Mann-Kendall test; rainfall.

1. INTRODUCTION

In climate change detection studies, the primary focus is on analyzing long-term shifts in climatic variables, which involves statistically describing mean and variability over temporal spans [1,2]. The investigation into historical and contemporary climate change has attracted considerable attention due to advancements in datasets and sophisticated global data analyses. Global climate shifts have the potential to influence long-term rainfall patterns, posing risks of heightened droughts and floods. Fundamental physical parameters, such as rainfall and temperatures, are pivotal in determining the environmental conditions of a specific region, significantly affecting agricultural productivity. Agriculture and related sectors, along with the food and energy security of any region, depend on the timely availability of sufficient water and favorable climatic conditions [3].

Despite recent industrialization, India's economic stability heavily relies on substantial agricultural production. Agriculture is the primary livelihood source for millions, mainly dependent on natural rainfall. The southwest (SW) monsoon contributes around 80% of the total precipitation in India. Alterations in the SW monsoon's pattern can profoundly impact agricultural production, water resource management, and the overall economy.

Numerous studies have examined climatic variables in India, aiding in constructing future climate scenarios [4-8]. Trend analyses of precipitation are valuable for understanding the impact of climate change on water resources. Anticipated changes in precipitation intensity and frequency, along with higher temperatures, may lead to altered runoff and water availability in various regions.

The analysis of precipitation trends is crucial for sustainable water planning and utilization, providing insights into challenges related to floods, droughts, and water availability for diverse purposes. Non-parametric trend tests are widely employed for their adaptability to independent data and accommodation of outliers.

The Ken basin region, while holding historical significance, remains significantly underdeveloped, primarily due to the ineffective administration of irrigation facilities within the basin. The geological characteristics of the area, coupled with economic constraints among the local population, prevent cultivators from independently establishing essential water sources like tube wells, shallow wells, or tanks. Rainfall in the region is scarce, unpredictable, and unevenly spread, making the area susceptible to famines and droughts. Ongoing deforestation, driven by the need to fulfill the fuel and fodder demands of the underprivileged population, has led to land degradation, a concern that might intensify in the future. Understanding rainfall trends is crucial for enhancing community resilience and informing strategies for sustainable development in the face of a changing climate. Keeping in view, the Mann-Kendall test and Sens's slope estimator were applied to identify precipitation trends in six districts of Bundelkhand region encompassing Ken basin, to understand the spatio-temporal trends in monsoon season and annual precipitation in the region.

2. MATERIALS AND METHODS

2.1 Study Area

The study area covers Banda, Mahoba, Chattarpur, Panna, Sagar, and Damoh districts in the Bundelkhand Region of Central India, including the Ken basin. Bundelkhand, located south of the Yamuna River, spans northern Uttar Pradesh (UP) and central Madhya Pradesh (MP). The focus is on the Ken River Basin, a key economic factor for Bundelkhand, geographically spanning latitudes 23°07' to 25°54' north and longitudes 78°30' to 80°40' east. Covering districts in MP and UP, the basin is surrounded by the Vindhyan range, the Betwa basin, the free catchment area of the Yamuna River, and the Yamuna River. The basin encompasses 28,692 sq. km, with 24,768 sq. km in MP and 3,924 sq. km in UP (Fig. 1).

2.2 Dataset

The daily rainfall data for the period 1990 to 2020 in six districts covering most of the Ken River basin were collected from Indian Meteorological Department (IMD) website (http://www.imd.gov.in/section/hydro/distrainfall/districtrain.html).

2.3 Mann Kendall (MK) Test

The MK test, also known as Kendall's tau test [9] (Kendall, 1975), is a widely used rank-based non-parametric test in hydrological trend detection studies. It employs the test statistic S, defined as follows:

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

where, x_1, x_2, …, x_n represent n data points, where x_j represents the data point at time j.
A substantially high positive S value suggests an upward trend, while a markedly low negative value signifies a downward trend.

$$sgn(x_j - x_i) = \begin{Bmatrix} 1 \ldots if\ (x_j - x_i) > 0 \\ 0 \ldots if\ (x_j - x_i) = 0 \\ -1 \ldots if\ (x_j - x_i) < 0 \end{Bmatrix} \quad (2)$$

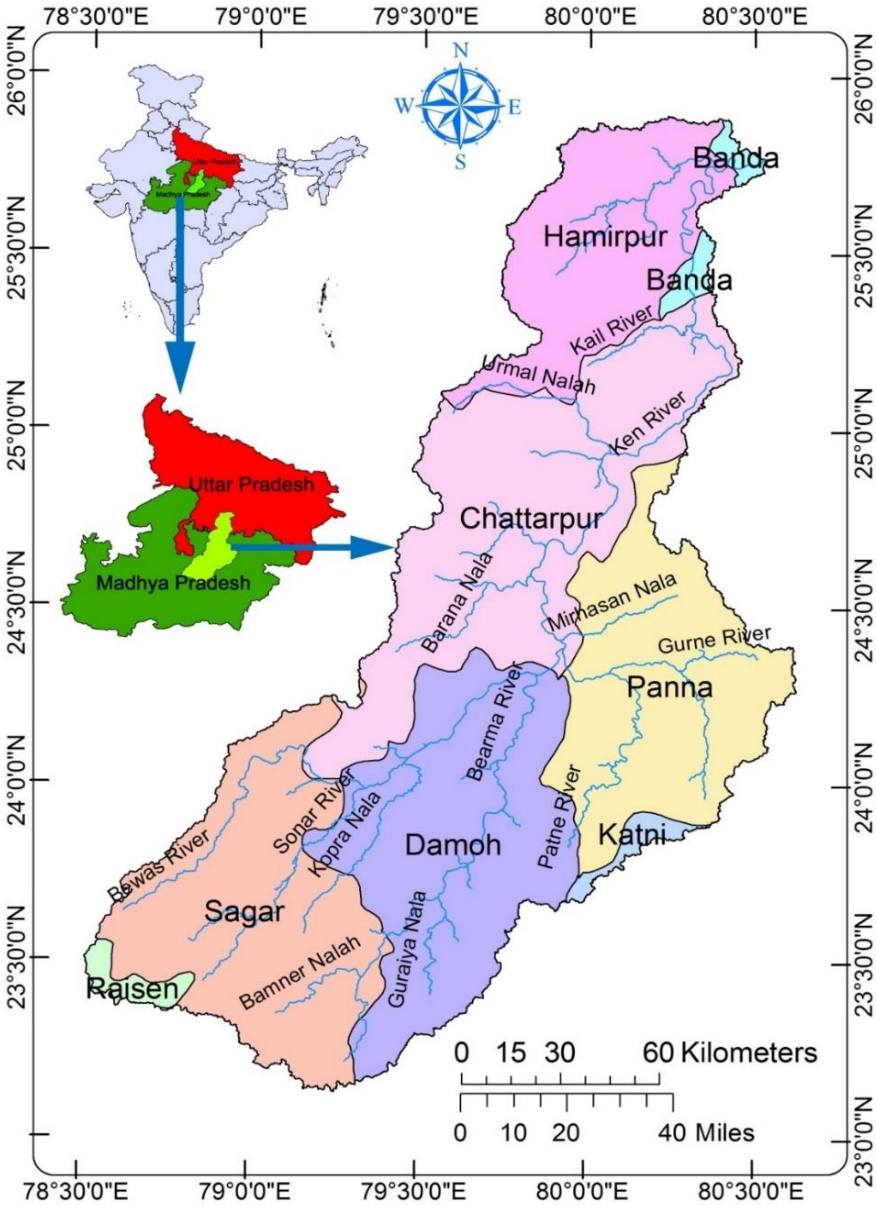

Fig. 1. Location Map of Ken River Basin

It has been documented that when n ≥10, the statistic S is approximately normally distributed with the mean E (S) = 0 and its variance is

$$VAR(S) = \frac{n(n+1)(2n+5) - \sum_{i=1}^{m}(t_i(t_i-1)(2t_i+5)}{18} \quad (3)$$

The standardized test statistic Z is computed by as follows:

$$Z = \begin{Bmatrix} \frac{S-1}{\sqrt{VAR\ (S)}}\ if\ S > 0 \\ 0\ if\ S = 0 \\ \frac{S+1}{\sqrt{VAR\ (S)}}\ if\ S < 0 \end{Bmatrix} \quad (4)$$

The null hypothesis, H0, meaning that no significant trend is present, is accepted if the test statistic Z is not statistically significant, i.e., –$Z_{\alpha/2}$<Z <$Z_{\alpha/2}$, where $Z_{\alpha/2}$ is the standard normal deviate. In this study, 5 % significance level was considered.

2.4 Sen Slope

The Thiel-Sen Approach is employed to estimate the slope of the lines fitted to climatic data time series, offering insights into changes that have transpired at a specific location over an extended duration. This method is preferred over linear regression due to its ability to mitigate the impact of outliers on the slope, as outlined by Hirsch et al. [10].

$$\beta = Median\left[\frac{X_j - X_i}{j-i}\right] Foralli < j \quad (5)$$

where X_j and X_i are data values at times j and i (i>j), respectively.

3. RESULTS AND DISCUSSION

3.1 Trend of Monsoon Season Rainfall During 1990-2020

To explore the Monsoon season rainfall trend, the MK Test was employed, and the outcomes are presented in Table 1.

Upon close examination, it becomes apparent that a prevailing downward trajectory characterizes the rainfall pattern across all districts, with the notable exception of Banda and Damoh districts. In these latter districts, a non-significant increase in rainfall was discerned. Delving deeper into the specifics, the districts of Mahoba, Panna, and Sagar prominently showcase a discernible and statistically significant decline in rainfall trends. The comprehensive evaluation of the Ken basin further underscores this prevailing trend of substantial decrease. Noteworthy are the calculated slopes of these trends, ranging from a modest 0.43 mm/season in Banda district to a more substantial 12.07 mm/season in Sagar district. These gradient values illuminate the rate at which the Monsoon season rainfall is either receding or expanding across these districts, providing valuable insights into the evolving climatic conditions in the bundelkhand region.

3.2 Trend of Annual Rainfall During 1990-2020

To comprehensively investigate the annual rainfall patterns, the Mann-Kendall (MK) Test was employed, and the detailed outcomes are provided in Table 2. A comprehensive examination across all districts within the study area revealed a downward trend in annual rainfall, with the noteworthy exception of Banda district, where an insignificantly increasing trend was identified.

The results highlight the critical significance of precise trend analysis to unravel the distinct variations in annual rainfall across the bundelkhand region. Significantly, the findings indicate that both Panna district and the broader Ken basin experienced a substantial and statistically significant decreasing trend in annual rainfall at a 5% significance level.

Table 1. Mann-Kendall test statistics for Monsoon Season during 1990-2020

District	Z-Value	Trend	Sen's slope (mm/season)
Banda	0.07	Non-significant Increasing	0.43
Mahoba	-1.75	Significant Decreasing Trend	-10.9
Chattarpur	-1.19	Non-significant Decreasing	-9.10
Panna	-2.14	Significant Decreasing Trend	-13.6
Sagar	-1.65	Significant Decreasing Trend	-12.07
Damoh	0.75	Non-significant Increasing	-7.3
Whole Ken basin	-1.97	Significant Decreasing Trend	-10.24

Table 2. Annual Rainfall Mann-Kendall Trend test Statistics

District	Z-Value	Trend	Sen's slope (mm/ year)
Banda	0.13	Non-significant Increasing	0.24
Mahoba	-1.63	Non-significant Decreasing	-9.77
Chattarpur	-1.05	Non-significant Decreasing	-8.92
Panna	-1.90	Significant Decreasing Trend	-11.47
Sagar	-0.99	Non-significant Decreasing	-7.95
Damoh	-0.75	Non-significant Decreasing	-6.36
Whole basin	-2.01	Significant Decreasing Trend	-9.74

This underscores a noteworthy environmental shift with implications for water resource management, agricultural practices, and ecological stability in these regions. The variability in the slope of the observed trend, ranging from 0.24 mm/year in Banda to 11.47 mm/year in Panna, highlights the diverse magnitudes of change in annual rainfall trends across the studied districts. This detailed analysis serves to underscore the critical importance of employing robust statistical methodologies in trend detection, given the complex interplay of factors influencing precipitation trends. The results presented herein not only contribute to the scientific understanding of hydrological shifts in the Bundelkhand region but also bear significant implications for informed decision-making. These findings, characterized by a collective decrease in precipitation trends across the region, have far-reaching implications for sustainable resource management. The intricate relationship between climate dynamics and water availability underscores the need for proactive measures in response to these changing patterns. This information is invaluable for policymakers, environmental scientists, and stakeholders who are actively involved in formulating strategies for sustainable resource management, particularly in the face of evolving and unpredictable climate patterns. As such, this study becomes an indispensable resource for those navigating the complex intersection of environmental science and policy implementation [11].

4. CONCLUSION

The exhaustive examination of rainfall trends conducted across the water-scarce Bundelkhand region, specifically within the confines of the Ken basin, spanning the considerable time frame from 1990 to 2020, has brought to the forefront a prevailing and concerning trend of decreasing precipitation. This discernible decrease extends its impact over both annual and seasonal scales, painting a complex picture of the region's hydrological behavior over the studied period. A noteworthy observation in this multifaceted analysis is the considerable variation in trend slopes among the diverse districts that constitute the Bundelkhand region. This diversity in precipitation trends underscores the nuanced and localized nature of the environmental shifts taking place within the broader geographical context. The identification of these variations is crucial for a more granular understanding of the intricate dynamics governing annual rainfall patterns.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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