**Trend Analysis of Rainfall in Ken Basin & Betwa Basin**

**Abstract**

Understanding long-term rainfall trends is essential for sustainable water resource management, particularly in climate-sensitive regions such as the Ken Basin and Betwa Basin. This study analyzes annual rainfall patterns over the period 1951–2022 for Ken Basin and Betwa Basin. Rainfall was analyzed at 66 grid points and 90 grid points across the Ken Basin and Betwa Basin using the Mann-Kendall trend test and Sen’s slope estimator to detect increasing or decreasing trends and the rate of change. The results indicate a decreasing trend in annual rainfall for both the Ken Basin and the Betwa Basin. In the Ken Basin, the total change in rainfall ranged between -413.71 mm to 235.81 mm, whereas the Betwa Basin exhibited a significant decline ranging between -488.62 mm to 193.75 mm. These decreasing trends suggest a potential reduction in groundwater recharge, surface runoff, and streamflow, which could have serious implications for water availability and agriculture. This research highlights the importance of local climate assessments to support better planning and policy-making in the face of changing weather patterns.

**Keywords:** Rainfall trends, Ken Basin, Betwa Basin, Mann-Kendall, Sen’s slope

1. **INTRODUCTION**

The average global temperature has increased by about 1.1°C since pre-industrial times, according to recent studies (1). The rising concentration of greenhouse gases in the atmosphere, which is directly related to human activities such as fossil fuel combustion, industrial operations, and land use changes, is principally responsible for this warming trend. The increasing global concern over climate change has intensified the focus on long-term variability in key climatic parameters, particularly rainfall and temperature (28). These factors directly affect agriculture, water availability, energy production, and ecosystem sustainability and are essential in determining regional environmental conditions. The studies on climate change generally aim to identify and analyze trends in these metrics through the use of strong statistical techniques that assess mean values as well as variability over long time periods (2, 5). The ability to identify changes in climate patterns that are directly related to the increasing frequency of extreme weather events, like floods and droughts, has greatly improved with the development of analytical techniques and the growing availability of comprehensive climate datasets. Over the past century, global warming has led to observable changes in both temperature and precipitation patterns, resulting in significant disruptions to the hydrological cycle, streamflow dynamics, and water demand patterns, especially in agriculture (6, 23). Additionally, rapid urbanization and land-use transformations have altered natural hydrological processes, including runoff generation and groundwater recharge, further exacerbating the strain on water resources (17, 21, 27). These developments underscore the need for rigorous, region-specific assessments of rainfall variability to support climate-resilient water and agricultural management strategies. Rainfall is the main source of fresh water for the majority of terrestrial ecosystems and is necessary for hydropower production, domestic and industrial water needs, and agricultural productivity. About 80% of India's annual rainfall falls during the southwest (SW) monsoon, making it a particularly important season (22). Most of this rain is limited to the monsoon season, which usually lasts from June to September. Due to the country's heavy reliance on one season for most water resources, it is particularly susceptible to changes in the monsoon's onset, duration, and intensity (13). In the non-monsoon months, when water shortages are common, such variations can have negative impacts on crop cycles, irrigation planning, water storage systems, and general socioeconomic stability (29).

Several studies have investigated climatic trends to inform policy and planning for future climate scenarios (4, 7, 9, 10, 11, 12, 16, 20, 29). To comprehend the climate change affects on water availability, extreme weather events, and ecosystem stability, trend analysis of precipitation data is essential. Trend analysis considers both the magnitude of the trend and its statistical significance. The trend detection analyses for various hydrologic and climatic variables are often determined using parametric tests or nonparametric methods (24, 26). Among the various statistical tools used for trend analysis, non-parametric methods such as the Mann-Kendall (MK) test and Sen’s slope estimator are widely recognized for their effectiveness in analyzing hydrological and meteorological time-series data. These methods are especially useful because they are adaptability to outliers and datasets that are not normally distributed (8, 14, 26). The MK test evaluates the presence of statistically significant monotonic trends, and the Sen’s slope estimator determines the magnitude of those trends by calculating the median of all pairwise slopes (19). When combined, these methods provide an effective analytical framework for evaluating the temporal and spatial variability of rainfall patterns.

The Ken Basin and Betwa Basin, located in central India, is a region of both ecological and historical significance. The region is still underdeveloped despite its potential because of poor infrastructure for water resources, economic constraints, and environmental deterioration. Due to limited, unevenly distributed, and frequently unpredictable rainfall, the region is vulnerable to droughts and agricultural instability. Furthermore, the ability to effectively manage its natural resources has been further limited by the severe land degradation caused by massive deforestation for subsistence purposes of marginalised groups. These socio environmental challenges emphasise the importance of understanding regional rainfall patterns in order to develop adaptable and long-lasting management plans. This study examines annual rainfall trends in the Ken Basin and Betwa Basin using the Mann-Kendall test and Sen's slope estimator.

**2. MATERIALS AND METHODS**

**2.1 Study Area**

This study focused on the Ken and Betwa Basins, located in the Bundelkhand region of central India, as shown in Figure 1.

**Ken Basin**

The Ken basin covers approximately 28,573.68 square kilometers, spanning latitudes 23°08′03″ N to 25°53′15″ N and longitudes 78°30′57″ E to 80°37′53″ E. The river originates near Ahirgawan village, located on the northwestern slopes of the Kaimur Hills in the Katni district of Madhya Pradesh, at an elevation of about 550 meters above mean sea level. It flows for nearly 427 kilometers through Madhya Pradesh and Uttar Pradesh before joining the Yamuna River near Chilla village in the Banda district of Uttar Pradesh, where its elevation is approximately 95 meters.

**Betwa Basin**

The Betwa Basin, located between longitudes 77°10ʹ and 80°20ʹ E and latitudes 22°54ʹ and 26°05ʹ N, covers an area of 43500 km². The elevation of the basin ranges between 106 to 706 meters above mean sea level. The Betwa River originates near Barkhera village in the Raisen district of Madhya Pradesh and flows into the Yamuna River near Hamirpur in Uttar Pradesh. The total length of the Betwa River from its source to its confluence is 590 kilometers, with 232 kilometers in Madhya Pradesh and the remaining 358 kilometers in Uttar Pradesh.

|  |
| --- |
| **Studyrea.jpg** |

**Figure 1: Location of study area**

**2.2 Data used**

The daily rainfall data for the period 1951 to 2022 were collected from the Indian Meteorological Department (IMD). In this study, 66 and 90 grid points (latitude and longitude) corresponding to various locations within the Ken Basin and Betwa Basin were selected to ensure comprehensive coverage of the region. The locations of considered grid points are presented in Figure 1.

## 2.3 Mann Kendall Test

The Mann-Kendall (MK) test is a non-parametric statistical method used to identify trends in a time-series dataset without requiring the data to conform to a particular distribution. In this approach, a dataset with ‘n’ observations is analyzed by comparing each data point with subsequent ones, forming two subsets: Ti​ and Tj​, where i=1 to n−1 and j=i+1 to n. If a later observation Tj​ is greater than an earlier one Ti​, the statistic S is increased by 1. If the later value is smaller, S is decreased by 1. The overall test statistic S is the sum of these comparisons, reflecting the cumulative trend in the data (3).

The Mann-Kendall S Statistic is computed as

 (3.1)

 (3.2)

In the context of the Mann-Kendall test, the observations for distinct time intervals, represented as yj and yi, where j > i, hold significant importance. For small sample sizes (n < 10), the absolute value of ∣S∣ is compared directly to the critical values from the Mann-Kendall distribution. If ∣S∣ exceeds the critical threshold Sα/2​, the null hypothesis H0​ (no trend) is rejected in favor of the alternative hypothesis Ha​ (presence of a trend). A positive S value suggests an increasing trend, while a negative S indicates a decreasing trend (13, 25).

When the dataset includes 10 or more observations, the test statistic S is approximated by a normal distribution with:

E(S) =0

 (3.3)

Here, ti denotes the number of tied ranks. Tied values identical observations are accounted for in the variance calculation, as they can influence the outcome of the trend analysis. The standardized test statistic Zs​is then derived as follows:



(3.4)

The significance of the trend is determined by comparing ∣Zs​∣ to the critical value Zα/2​, which corresponds to the selected significance level. If ∣Zs​∣ exceeds this value, the trend is considered statistically significant (15).

**2.4 Sen’s Slope Estimator**

To quantify the magnitude of a linear trend, Sen’s Slope Estimator (26) is employed. It is a robust, non-parametric method that calculates the true slope of a time series. The linear trend is expressed as:

f(t)= Qt+B (3.5)

Where Q represents the slope and B is a constant. The slope Q is estimated by computing the slopes between all possible pairs of data points using the formula:

, *i=1, 2……………..N, j>1* (3.6)

Given n observations, the total number of slope estimates is N = n (n-1) /2. The Sen’s slope Q is then taken as the median of these N values, making the method resistant to the influence of outliers and suitable for skewed data distributions. The N values of *Qi* are ranked from the smallest to the largest and the Sen’s estimator is



(3.7)

For this study, both the Mann-Kendall test and Sen’s Slope Estimator were applied to analyze annual rainfall trends within the Ken Basin and Betwa Basin. The MK test was conducted at a 1%, 5% and 10% significance level, ensuring statistically reliable results. This combined approach offers a comprehensive and rigorous analysis of rainfall variability, enabling the identification of significant climatic shifts across different timescales and regions.

**3. RESULTS & DISCUSSION**

The rainfall trends were analyzed for 66 grid points for Ken Basin and 90 grid points for Betwa Basin. The annual rainfall data for 1951 to 2022 were considered for this analysis. Mann-Kendall z value, significance level of the trend and Sen’s Slope are presented in Table 1 and 2 for Ken basin and Betwa Basin. The Ken Basin exhibited a **decreasing trend** across the basin. The statistically significant decrease in rainfall observed predominantly with grid points showing at **1%, 5%, and 10%** significance **levels.** The total change in annual rainfall of Ken basin ranges between **−413.71 mm** to **235.81 mm during 1951 to 2020.** Similarly, the Betwa Basin exhibited a **decreasing trend** in annual rainfall. The statistically significant decreasing trends are widely distributed with grid points falling under 1%**, 5%, and 10% significance levels.** The total change in annual rainfall of the Betwa basin ranges between **−488.62 mm to 193.75 mm.** The spatial distribution map of annual rainfall trend analysis over the Ken Basin and Betwa Basins is shown in **Figure 2**.

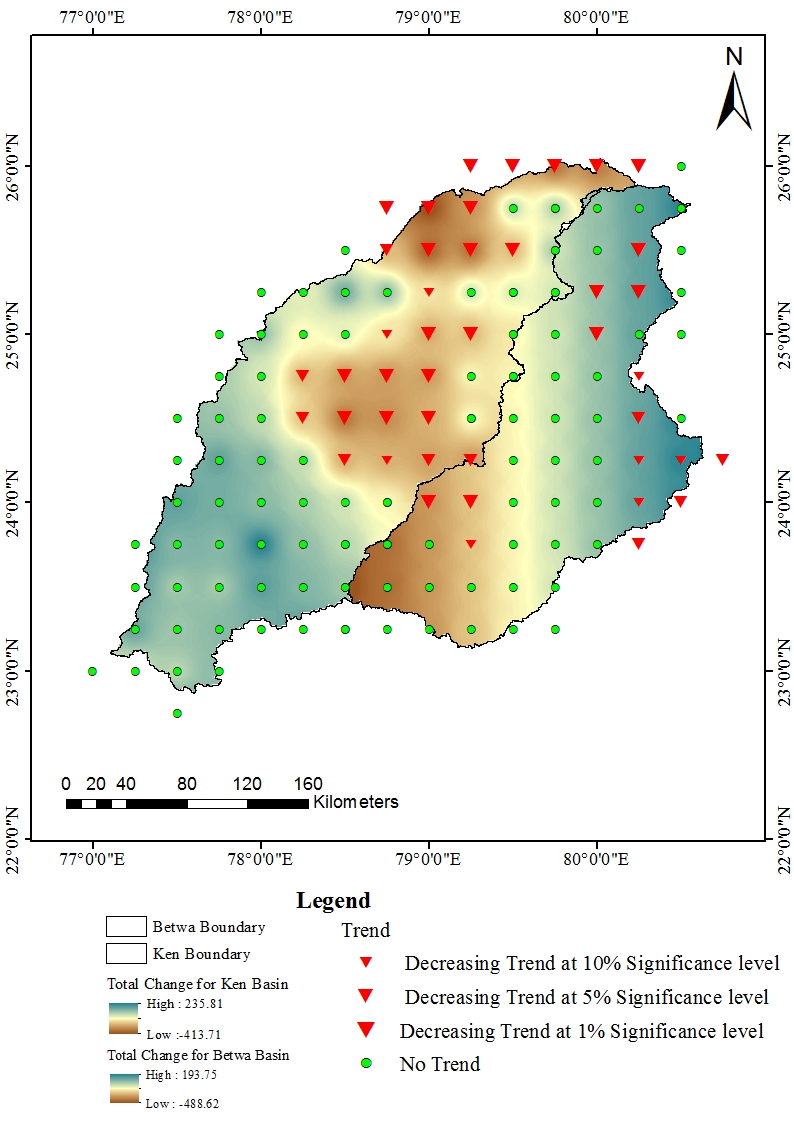
The study observed that annual rainfall in the Ken Basin and Betwa Basin is significantly decreasing. This may result in increased groundwater decrease in groundwater levels, increased groundwater extraction for agricultural irrigation, drought problems, and decreased soil moisture (18, 24). In general, the Betwa Basin appears to be more affected than the Ken Basin by the decrease in rainfall. This indicates that the Betwa Basin is undergoing more abrupt hydrological stress, which may lead to increased unpredictability in streamflow and water availability, along with decrease groundwater recharge and surface runoff. The Betwa Basin is more affected than the Ken Basin because of the magnitude of change, which increases the risk of hydrological shocks. As a result, basin-specific management approaches are essential. The Betwa Basin requires rapid interventions such as micro-irrigation projects, drought-resistant farming systems and infrastructure for localised water conservation. However, the Ken Basin requires improved land use planning, afforestation projects, and integrated watershed development, to mitigate hydroclimatic impacts. These results underline the importance of incorporating rainfall trend data into frameworks for agricultural planning and water governance in order to improve climate resilience in both basins, particularly considering the increasing demands of climate change on regional water systems.

**Table 1: Trend of Annual Rainfall for Ken Basin**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Latitude** | **Longitude** | **Zmk** | **Trend** | **Sen’s Slope** |
| 23.25 | 78.5 | 0.6465 | 0 | 1.0633 |
| 23.25 | 78.75 | -0.6952 | 0 | -0.976 |
| 23.25 | 79 | -1.0063 | 0 | -1.5824 |
| 23.25 | 79.25 | -0.9285 | 0 | -1.5396 |
| 23.25 | 79.5 | -0.2576 | 0 | -0.6359 |
| 23.25 | 79.75 | -0.6952 | 0 | -1.3951 |
| 23.5 | 78.5 | 0.0049 | 0 | 0.0272 |
| 23.5 | 78.75 | -0.4715 | 0 | -1.035 |
| 23.5 | 79 | -0.9091 | 0 | -1.7023 |
| 23.5 | 79.25 | -1.4049 | 0 | -2.6811 |
| 23.5 | 79.5 | -0.4764 | 0 | -0.8234 |
| 23.5 | 79.75 | -1.4243 | 0 | -2.6186 |
| 23.75 | 78.5 | -0.2382 | 0 | -0.5574 |
| 23.75 | 78.75 | -1.0354 | 0 | -1.89 |
| 23.75 | 79 | -1.2007 | 0 | -2.2025 |
| 23.75 | 79.25 | -1.8327 | -10 | -3.2877 |
| 23.75 | 79.5 | -1.0841 | 0 | -1.6397 |
| 23.75 | 79.75 | -0.8313 | 0 | -1.5654 |
| 23.75 | 80 | -0.7438 | 0 | -1.4195 |
| 23.75 | 80.25 | -1.9931 | -5 | -3.3143 |
| 24 | 78.75 | -1.0938 | 0 | -2.1035 |
| 24 | 79 | -3.2036 | -1 | -5.746 |
| 24 | 79.25 | -2.873 | -1 | -4.7918 |
| 24 | 79.5 | -1.1132 | 0 | -1.6279 |
| 24 | 79.75 | -0.1313 | 0 | -0.2499 |
| 24 | 80 | -0.8604 | 0 | -1.5322 |
| 24 | 80.25 | -1.7355 | -10 | -2.7224 |
| 24 | 80.5 | -1.9785 | -5 | -3.3551 |
| 24.25 | 79 | -2.2119 | -5 | -4.2706 |
| 24.25 | 79.25 | -2.2313 | -5 | -4.2897 |
| 24.25 | 79.5 | -1.1521 | 0 | -2.0949 |
| 24.25 | 79.75 | -0.5007 | 0 | -1.0776 |
| 24.25 | 80 | -0.5736 | 0 | -0.86 |
| 24.25 | 80.25 | -1.6577 | -10 | -2.7288 |
| 24.25 | 80.5 | -1.8424 | -10 | -3.7901 |
| 24.25 | 80.75 | -1.998 | -5 | -3.2397 |
| 24.5 | 79.25 | -1.0841 | 0 | -1.9213 |
| 24.5 | 79.5 | -1.2105 | 0 | -1.893 |
| 24.5 | 79.75 | -0.8216 | 0 | -1.2898 |
| 24.5 | 80 | -1.1132 | 0 | -2.1833 |
| 24.5 | 80.25 | -2.0758 | -5 | -3.911 |
| 24.5 | 80.5 | -1.0452 | 0 | -1.7169 |
| 24.75 | 79.5 | -1.2299 | 0 | -2.1065 |
| 24.75 | 79.75 | -1.016 | 0 | -1.7979 |
| 24.75 | 80 | -1.298 | 0 | -2.4286 |
| 24.75 | 80.25 | -1.8521 | -10 | -2.9352 |
| 25 | 79.5 | -1.473 | 0 | -2.5201 |
| 25 | 79.75 | 0.3549 | 0 | 0.4635 |
| 25 | 80 | -2.8536 | -1 | -4.9689 |
| 25 | 80.25 | -1.5605 | 0 | -2.4606 |
| 25 | 80.5 | 1.0841 | 0 | 1.741 |
| 25.25 | 79.5 | -0.8216 | 0 | -1.2777 |
| 25.25 | 79.75 | -0.6174 | 0 | -1.0271 |
| 25.25 | 80 | -2.9022 | -1 | -3.5237 |
| 25.25 | 80.25 | -3.3105 | -1 | -5.1821 |
| 25.25 | 80.5 | 1.298 | 0 | 2.1838 |
| 25.5 | 79.75 | -0.1215 | 0 | -0.2116 |
| 25.5 | 80 | -1.0938 | 0 | -1.2785 |
| 25.5 | 80.25 | -2.3383 | -1 | -3.2422 |
| 25.5 | 80.5 | -1.4243 | 0 | -2.0657 |
| 25.75 | 79.75 | -0.2965 | 0 | -0.4254 |
| 25.75 | 80 | -0.3354 | 0 | -0.5647 |
| 25.75 | 80.25 | 1.541 | 0 | 3.2752 |
| 25.75 | 80.5 | 0.0438 | 0 | 0.0595 |
| 26 | 80.25 | -2.3966 | -1 | -4.4374 |
| 26 | 80.5 | -1.3563 | 0 | -1.7881 |

**Table 2: Trend of Annual Rainfall for Betwa Basin**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Latitude** | **Longitude** | **Zmk** | **Trend** | **Sen’s Slope** |
| 22.75 | 77.5 | 1.2493 | 0 | 2.3459 |
| 23 | 77 | -0.8021 | 0 | -1.7024 |
| 23 | 77.25 | -0.7827 | 0 | -1.5979 |
| 23 | 77.5 | -0.1799 | 0 | -0.5177 |
| 23 | 77.75 | 0.1799 | 0 | 0.4643 |
| 23.25 | 77.25 | 0.6077 | 0 | 1.279 |
| 23.25 | 77.5 | 0.0924 | 0 | 0.0947 |
| 23.25 | 77.75 | 0.2771 | 0 | 0.5257 |
| 23.25 | 78 | 0.6757 | 0 | 1.077 |
| 23.25 | 78.25 | 0.8313 | 0 | 1.6094 |
| 23.25 | 78.5 | 0.6465 | 0 | 1.0633 |
| 23.5 | 77.25 | 0.9868 | 0 | 1.7552 |
| 23.5 | 77.5 | -0.0535 | 0 | -0.1082 |
| 23.5 | 77.75 | -0.0632 | 0 | -0.1519 |
| 23.5 | 78 | 0.8896 | 0 | 1.5939 |
| 23.5 | 78.25 | 0.3451 | 0 | 0.6487 |
| 23.5 | 78.5 | 0.0049 | 0 | 0.0272 |
| 23.75 | 77.25 | 1.4632 | 0 | 2.5477 |
| 23.75 | 77.5 | 0.3743 | 0 | 0.6759 |
| 23.75 | 77.75 | 0.2576 | 0 | 0.5411 |
| 23.75 | 78 | 1.4438 | 0 | 2.691 |
| 23.75 | 78.25 | 0.1118 | 0 | 0.2907 |
| 23.75 | 78.5 | -0.2382 | 0 | -0.5574 |
| 23.75 | 78.75 | -1.0354 | 0 | -1.89 |
| 24 | 77.5 | 0.8507 | 0 | 1.4944 |
| 24 | 77.75 | 0.559 | 0 | 0.939 |
| 24 | 78 | 0.2771 | 0 | 0.4586 |
| 24 | 78.25 | -0.141 | 0 | -0.1983 |
| 24 | 78.5 | -0.4521 | 0 | -0.8531 |
| 24 | 78.75 | -1.0938 | 0 | -2.1035 |
| 24 | 79 | -3.2036 | -1 | -5.746 |
| 24.25 | 77.5 | 0.4813 | 0 | 0.8024 |
| 24.25 | 77.75 | 1.2299 | 0 | 1.4111 |
| 24.25 | 78 | 0.5493 | 0 | 0.6938 |
| 24.25 | 78.25 | -0.384 | 0 | -0.592 |
| 24.25 | 78.5 | -2.2508 | -5 | -3.8202 |
| 24.25 | 78.75 | -1.9105 | -10 | -3.8326 |
| 24.25 | 79 | -2.2119 | -5 | -4.2706 |
| 24.25 | 79.25 | -2.2313 | -5 | -4.2897 |
| 24.5 | 77.5 | -0.0243 | 0 | -0.0662 |
| 24.5 | 77.75 | 0.1118 | 0 | 0.2157 |
| 24.5 | 78 | -0.316 | 0 | -0.6064 |
| 24.5 | 78.25 | -1.998 | -5 | -3.2595 |
| 24.5 | 78.5 | -2.9799 | -1 | -5.3983 |
| 24.5 | 78.75 | -2.7563 | -1 | -4.7575 |
| 24.5 | 79 | -2.4452 | -1 | -3.8426 |
| 24.5 | 79.25 | -1.0841 | 0 | -1.9213 |
| 24.5 | 79.5 | -1.2105 | 0 | -1.893 |
| 24.75 | 77.75 | -0.0535 | 0 | -0.1242 |
| 24.75 | 78 | -0.5785 | 0 | -1.0533 |
| 24.75 | 78.25 | -1.9688 | -5 | -3.6478 |
| 24.75 | 78.5 | -2.8827 | -1 | -4.4348 |
| 24.75 | 78.75 | -2.8049 | -1 | -4.4525 |
| 24.75 | 79 | -2.7758 | -1 | -4.3714 |
| 24.75 | 79.25 | -1.2785 | 0 | -2.1189 |
| 24.75 | 79.5 | -1.2299 | 0 | -2.1065 |
| 25 | 77.75 | 0.7729 | 0 | 1.0761 |
| 25 | 78 | 0.2285 | 0 | 0.2617 |
| 25 | 78.25 | -1.1618 | 0 | -1.9523 |
| 25 | 78.5 | -1.0452 | 0 | -1.3884 |
| 25 | 78.75 | -1.6966 | -10 | -2.4916 |
| 25 | 79 | -2.7077 | -1 | -3.9803 |
| 25 | 79.25 | -2.3577 | -1 | -3.5881 |
| 25 | 79.5 | -1.473 | 0 | -2.5201 |
| 25.25 | 78 | -1.0063 | 0 | -1.3481 |
| 25.25 | 78.25 | -1.0063 | 0 | -1.3656 |
| 25.25 | 78.5 | 0.5882 | 0 | 1.0068 |
| 25.25 | 78.75 | 0.141 | 0 | 0.2621 |
| 25.25 | 79 | -1.6577 | -10 | -2.4706 |
| 25.25 | 79.25 | -0.8118 | 0 | -1.0117 |
| 25.25 | 79.5 | -0.8216 | 0 | -1.2777 |
| 25.25 | 79.75 | -0.6174 | 0 | -1.0271 |
| 25.5 | 78.5 | -0.8118 | 0 | -1.1257 |
| 25.5 | 78.75 | -2.2216 | -5 | -3.5425 |
| 25.5 | 79 | -3.8841 | -1 | -6.0286 |
| 25.5 | 79.25 | -4.0105 | -1 | -5.5349 |
| 25.5 | 79.5 | -2.7855 | -1 | -3.5425 |
| 25.5 | 79.75 | -0.1215 | 0 | -0.2116 |
| 25.75 | 78.75 | -4.0883 | -1 | -6.7864 |
| 25.75 | 79 | -4.4675 | -1 | -6.7125 |
| 25.75 | 79.25 | -4.1953 | -1 | -4.501 |
| 25.75 | 79.5 | -0.5104 | 0 | -0.7069 |
| 25.75 | 79.75 | -0.2965 | 0 | -0.4254 |
| 25.75 | 80 | -0.3354 | 0 | -0.5647 |
| 25.75 | 80.25 | 1.541 | 0 | 3.2752 |
| 26 | 79.25 | -3.5925 | -1 | -5.8008 |
| 26 | 79.5 | -3.3202 | -1 | -4.4991 |
| 26 | 79.75 | -4.0203 | -1 | -5.3603 |
| 26 | 80 | -3.3786 | -1 | -5.1992 |
| 26 | 80.25 | -2.3966 | -1 | -4.4374 |



**Figure 2: Spatial distribution map of annual rainfall trend analysis during 1951-2022**

## ****4. CONCLUSION****

This study examined long-term rainfall trends in the Ken Basin and Betwa Basin from 1951 to 2022. The analysis showed that a decreasing trend in annual rainfall for both Ken Basin and Betwa Basin. However, the decrease was more significant in Betwa Basin, where total change ranged from -488.62 mm to 193.75 mm, whereas in Ken Basin, it ranged from

-413.71 mm to 235.81 mm. This indicates that the Betwa Basin is experiencing more severe hydrological stress which may result in decreased groundwater recharge, decreased surface runoff, and increased streamflow variability. The results show the importance of involving trend analysis of rainfall into water resource management plan, particularly in relation to inter-basin water transfer projects such as Ken–Betwa Link. The future planning should prioritize basin-specific methods to ensure sustainable water use across regions, enhancing climate resilience particularly considering the increasing demands of climate change on regional water systems.

**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 the writing or editing of this manuscript.

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