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Study of Precipitation Trends and Variability in the Mahi River Basin and Implications for Climate Change and Water Resources

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ABSTRACT

This study analyzes average annual precipitation data from 19 districts between 1985 and 2022, revealing distinct patterns of variability and significant trends in rainfall distribution. Inter-annual fluctuations, including extreme precipitation events and dry spells, suggest the influence of climatic factors such as monsoon variations, El Niño or La Niña events, and regional environmental changes. Regions like Bharuch show anomalous peaks in rainfall, potentially linked to climate change, deforestation, or urbanization. Statistical analysis, using the Mann-Kendall test and Sen's slope estimator, confirms a statistically significant upward trend in precipitation during the study period. The Mann-Kendall test produces a Kendall's Tau value of 0.349 and a p-value of 0.002, indicating a moderate positive correlation and a significant trend in average precipitation. Sen's slope analysis shows a positive slope of 0.372, indicating an average increase of 0.372 mm precipitation per year. The 95% confidence intervals for the slope and intercept confirm the reliability of the observed trends. Time series analysis illustrates precipitation fluctuations, with peaks during the monsoon season and dry years reflecting natural variability, but the general upward trend suggests broader climatic shifts. These findings have important implications for water resource management, agricultural planning, and climate change adaptation. As precipitation patterns become more variable, adaptive management strategies will be necessary to address the challenges posed by changing rainfall patterns. In conclusion, the study confirms a statistically significant upward trend in precipitation over the past 38 years, offering insights into regional climate change impacts on hydrology and highlighting the need for ongoing monitoring and adaptive strategies.

Keywords: Precipitation trends, Mann-Kendall test, Climate variability, Rainfall distribution, Climate change adaptation

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INTRODUCTION

Globally, water resources have emerged as a critical concern for the planning and development of projects aimed at promoting sustainable agricultural practices, ensuring efficient water resource management, and implementing effective flood and erosion control strategies. Precipitation, as a primary source of freshwater, plays a vital role in sustaining life and supporting various sectors, including agriculture, industrial activities, and domestic water supply. The temporal distribution, frequency, and magnitude of precipitation in a given region are essential to meet the diverse demands placed on water resources. Agriculture, in particular, is heavily dependent on precipitation patterns, as the quantity and distribution of rainfall directly impact crop yields and overall food production.

Recent shifts in rainfall trends, which are intricately linked to climate change, have raised concerns about future water availability. According to the Intergovernmental Panel on Climate Change (IPCC) 2007 report, global surface temperatures have increased at a rate of 0.74 ± 0.18°C over the period from 1906 to 2005, with significant implications for freshwater resources. This warming trend is expected to result in reduced freshwater availability in the future, with projections indicating that by the middle of the 21st century, average annual runoff and available water resources could decrease by 10 to 30%. These changing precipitation trends—manifested as either increasing or decreasing rainfall over time—are a dominant factor in the broader climate variations being observed today.

In addition to natural climatic variations, human activities have contributed significantly to alter rainfall patterns. Land-use changes, particularly those driven by agricultural expansion and irrigation practices, are key contributors to these shifts. As a result, the effects of climate change and changing rainfall patterns have far-reaching consequences,

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influencing water resource management, agricultural productivity, and disaster management strategies. The interplay of these factors highlights the importance of understanding and addressing climate change in the context of water and land management.

A comprehensive analysis of rainfall distribution, variability, and trends is crucial for effective water resource management, flood control, and the design of hydraulic structures (Yue and Wang, 2004; Hui-Mean et al., 2018). Chiew and McMahon (1993) emphasize that understanding precipitation trends is vital for predicting future rainfall patterns. Long-term data analysis is indispensable for forecasting future rainfall tendencies, which is essential for water management, especially in the context of climate variability and population growth (Zolina et al., 2010; Kyoung et al., 2011). The World Meteorological Organization (WMO) highlights the importance of data quality, period, and record length for accurate trend analysis.

Global research on rainfall distribution, variability, and trends has garnered significant attention, with numerous studies focusing on the impacts of climate change on precipitation patterns (Gocic et al., 2013; Kamruzzaman et al., 2016). One of the primary consequences of global warming is the alteration in the intensity of annual rainfall, temperature, and evaporation patterns (Santos and de Morais, 2013; Xu et al., 2017). While global rainfall demonstrates an overall positive trend, precipitation patterns at regional and continental levels exhibit heterogeneous results, with some areas experiencing an increase in rainfall and others a decrease (Dore et al., 2005). For instance, significant increases in rainfall have been reported in Africa (Maidment et al., 2015), and Wang et al. (2008) observed a positive trend in rainfall over East Asia. Conversely, South Asia has experienced a decline in precipitation since the 1950s (Turner et al., 2012), and Liu et al. (2008) noted changing precipitation trends in the Yellow river basin from 1961 to 2006.

In regions such as Trinidad and Tobago, Perera et al. (2020) observed no significant increasing or decreasing trends in monthly rainfall from 1981 to 2017. Similarly, Thapliyal and Kulshreshtha (1991) reported that India's average annual rainfall (AAR) did not exhibit a clear trend from 1875 to 1989. However, Sinha et al., (2000) noted that certain regions of India experienced increased rainfall during the southwest monsoon from 1901 to 1990. Sharma et al. (2000) identified an increasing trend in annual rainfall over the Himalayan region between 1943 and 1993. Goswami et al. (2006) observed a significant increase in extreme precipitation events in central India from 1951 to 2000.

Conversely, Singh et al. (2008) reported higher variability and a decreasing trend in rainfall across central India's river basins from 1901 to 2000, with a decline of 2% to 19% in annual rainfall. A comparative rainfall trend analysis demonstrated that the Ganga basin maintained stable rainfall from 1871 to 1994, in contrast to the Brahmaputra and Meghna basins, which experienced greater fluctuations (Mirza et al., 1998). Kumar and Jain (2011) observed that 15 out of 22 river basins in India exhibited a decreasing trend in rainy days and annual precipitation from 1951 to 2004. Recent investigations in the Narmada Basin also reported declining trends in average annual rainfall (AAR) from 1901 to 2002 (Pandey and Khare, 2018). Similarly, Sharma et al. (2018) identified a decreasing trend in total annual rainfall over the upper Tapi Basin from 1944 to 2013.

Trend analysis is an essential tool for identifying future fluctuations in hydrometeorological variables, aiding in risk management, flood and drought monitoring, and water resource planning and design (Dinpashoh et al., 2014). Numerous studies globally and in India have utilized widely accepted trend analysis techniques such as the Mann-Kendall (MK) test, Sen's slope (SS), and innovative trend analysis (ITA) to assess hydrological and meteorological trends (Jeet et al., 2024). However, the MK test has limitations, particularly when autocorrelation or periodicities are present in the data. Despite this, the MK test remains a widely used method for trend analysis in hydrometeorology because it does not require data to be normally distributed and is not dependent on the length of the time series (Kamal et al., 2018). Analyzing spatiotemporal rainfall trends is vital for managing flood and drought risks, as well as addressing crop failures in agricultural regions like India, where the economy heavily relies on agriculture (Maity et al., 2007).

The analysis of precipitation trends, patterns, and distribution is essential for comprehending rainfall dynamics, whether utilizing data from rain gauge stations or satellite-gridded datasets. In India, this type of analysis plays a crucial role, particularly for agriculture in rain-fed regions (Varikoden et al., 2019). As elucidated by Patakamuri et al. (2020) and Singh et al. (2021), investigating rainfall variability and distribution is of paramount importance in regions that rely heavily on rainfall for agricultural productivity. Fluctuations in climatic extremes, such as abrupt shifts in rainfall patterns, frequently result in devastating flood and drought events that can disrupt food production, water availability, and overall agricultural sustainability (Pawar et al., 2023). However, the impact of such extreme events can vary significantly across different regions and timeframes, as observed by Zampieri et al. (2017), with certain areas more susceptible to severe impacts due to local climatic and geographic factors.

In northwestern India, the Mahi river serves as a critical source of both surface and groundwater, supporting agriculture, industry, and human populations. The river is susceptible to flash floods, particularly during intense precipitation events triggered by low-pressure systems (LPSs), which can rapidly escalate into severe meteorological phenomena. Despite the significance of the Mahi river in sustaining the region's water supply, there has been limited research on the precipitation patterns, variability, and trends within the Mahi basin. Previous studies have explored these topics (Sharma et al., 2022); however, none have utilized long-term precipitation data to provide a comprehensive analysis.

This study aims to address this research gap by examining the precipitation variability, distribution, and trends in the Mahi basin, utilizing a long-term dataset spanning from 1901 to 2012. By incorporating a robust, multi-decadal dataset, this research seeks to provide valuable insights into how precipitation patterns have changed over time, how they have impacted local water resources, and how future trends might affect the region's agricultural and water management strategies. The findings of this study will contribute to a better understanding of the temporal shifts in precipitation, informing more effective management of water resources in this critical region of India.

MATERIALS AND METHODS

Study Area

The Mahi river basin encompasses the states of Madhya Pradesh, Rajasthan, and Gujarat, having a total area of 34,842 square kilometers, with a maximum length of approximately 330 km and a width of approximately 250 km. It is situated between longitudes 72°21' and 75°19' east and latitudes 21°46' and 24°30' north. The basin is delineated by the Aravalli hills to the north and northwest, the Malwa Plateau to the east, the Vindhya range to the south, and the Gulf of Khambhat to the west. The Mahi River, one of India's significant west-flowing interstate rivers, originates from the northern slopes of the Vindhyas at an elevation of 500 m, near the village of Bhopawar in the Sardarpur tehsil of Dhar district, Madhya Pradesh. The river extends 330 km, with the Som river as its primary tributary joining from the right, and the Anas and Panam rivers entering from the left, ultimately discharging into the Arabian Sea through the Gulf of Khambhat. Agricultural land constitutes 63.63% of the basin, while water bodies account for 4.34%. Figure 1 illustrates the study area, highlighting the Mahi Basin and its network of hydrological observation stations. These stations serve a crucial function in monitoring various hydrological parameters, including river flow and precipitation. The spatial distribution of these observation points is essential for comprehending the basin's hydrological dynamics, facilitating effective water resource management, flood control, and environmental monitoring in the region.

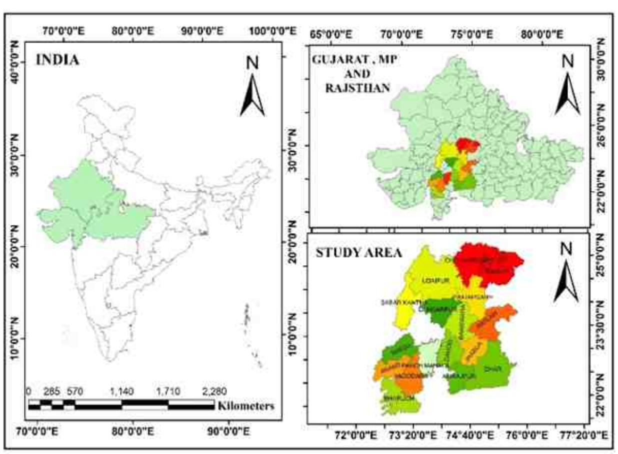

Fig. 1: Study Area (Mahi Basin with hydrological observation stations)

Mann–Kendall (MK) Test

The Mann–Kendall test was used to identify the significant rainfall trends over the Mahi basin. (Mann, 1945; Kendall,1975)

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(X_j - X_k)$$

(1) Where, X_j and X_k are the data points for rainfall, n is the length of data j and k (k > j) respectively, and sgn $(X_j - X_k)$ is sign function as follows:

$$sgn(\propto_j - \propto_i) = \begin{cases} +1, if\ (X_j - X_k) > 0 \\ 0, if\ (X_j - X_k) = 0 \\ -1, if\ (X_j - X_k) < 0 \end{cases}$$

(2) S approximates a normal distribution with a mean of 0 when n is equal to 10. The variance can be found as given in Equation (4):

$$Var(S) = \frac{1}{18}[n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)$$

(3) where t and $\sum_t$ are the extent of any given tie indicates and the summation of all ties. The value of Zc is computed using Equation (5):

$$Z = \begin{cases} \frac{S-1}{VAR(S)1/2}, S > 0 \\ 0, S = 0 \\ \frac{S+1}{VAR(S)1/2}, S < 0 \end{cases}$$

(4) where Z is the standard normal variate; an increasing (or decreasing) trend can be identified based on the positive (negative) values of Z. A noteworthy trend is observed, and the null hypothesis is rejected when |Z| > Z1 ⊚ _/2. All the outcomes were confirmed at _ = 0.05 (Z = _1.96) and _ = 0.10 (Z = _1.66) significance level

Sen's Slope (SS)

The Sen's slope method was applied to study the magnitude of rainfall change by using the following equations (Sen, 1968):

$$Q_i = \frac{Y_j - Y_k}{j-k}, i = 1,2,3 \ldots \ldots \ldots \ldots \ldots \ldots \ldots N$$

(5) where Yj and Yk are values in a series at time j and k (j > k), respectively. Qi is Sen's estimator of slope. If there is a single datum in each time period, then N = n[n-1]/2, where n is the number of time periods. However, if the number of values in every year are many, then N < n[n-1]/2, where n is total number of observations. First, N values were ordered from the minimum to maximum. Then, the median of slope Type equation here. is calculated as follows:

$$\beta = \begin{cases} \frac{Q_n+1}{2}, & if\ N\ is\ odd \\ \frac{1}{2}\left(\frac{Q_n}{2} + \frac{Q_n+2}{2}\right), & if\ I\ is\ even \end{cases}$$

RESULT AND DISCUSSION

Mann-Kendall Trend and Sen's Slope

The Mann-Kendall trend test, a non-parametric method for analyzing time series data, evaluates the presence of significant trends over a given period. Applied to the "Year" variable for the 1985–2022 dataset, the test determines whether a statistically significant trend exists by comparing the p-value to a standard threshold (typically 0.05). A p-value below the threshold indicates a significant trend, while a higher value suggests no trend. This analysis is crucial for identifying consistent upward or downward patterns, aiding in the assessment of long-term changes such as climate variability or hydrological shifts, and informing subsequent research and interpretations.

Figure 2 illustrates the average annual precipitation (in millimeters) recorded across 19 different regions from 1985 to 2022. Each region exhibits a distinct precipitation pattern over time, with observable inter-annual variability. Certain regions, such as Bharuch, demonstrate significant peaks compared to others, suggesting occasional extreme rainfall events or anomalies. The chart elucidates the temporal distribution of rainfall across the years, represented by distinct colors for each year. Variations in precipitation levels across regions and years indicate the influence of geographic and climatic factors, including possible effects of changing monsoon patterns or localized climatic changes. Overall, the data reflects a combination of stable long-term trends with intermittent fluctuations that warrant further investigation to elucidate underlying causes, such a climate change, deforestation, or urbanization.

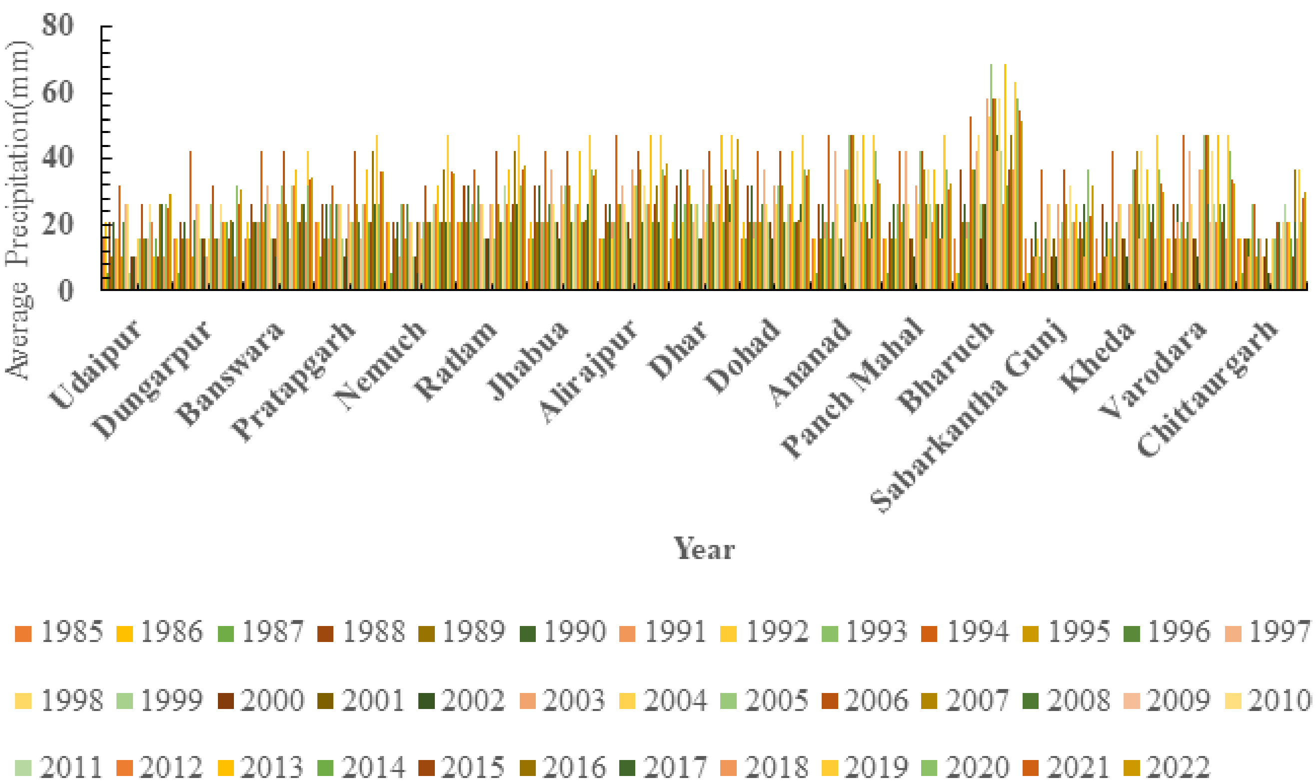

Fig. 2: Fluctuations in Average Precipitation during 1985-2022

The bar graph in Figure 3 illustrates the annual variation in average precipitation (in millimeters) from 1985 to 2022. The data exhibits notable fluctuations, with years such as 1994, 1998, 2005, and 2020 demonstrating substantial peaks, indicating periods of exceptionally high rainfall. Conversely, several years, including 1987, 2000, and 2015, record significantly lower precipitation, reflecting potential dry spells or drought conditions. This variability may be influenced by climatic factors such as alterations in monsoon dynamics, El Niño or La Niña events, and localized weather patterns. The graph demonstrates an overall irregular trend, with no consistent increase or decrease, suggesting that while some years' experience extreme precipitation events, the long-term variability could be attributed to both natural climatic cycles and anthropogenic impacts. This observation underscores the necessity for further investigation into the drivers of these trends and their implications for water resource management and agricultural planning.

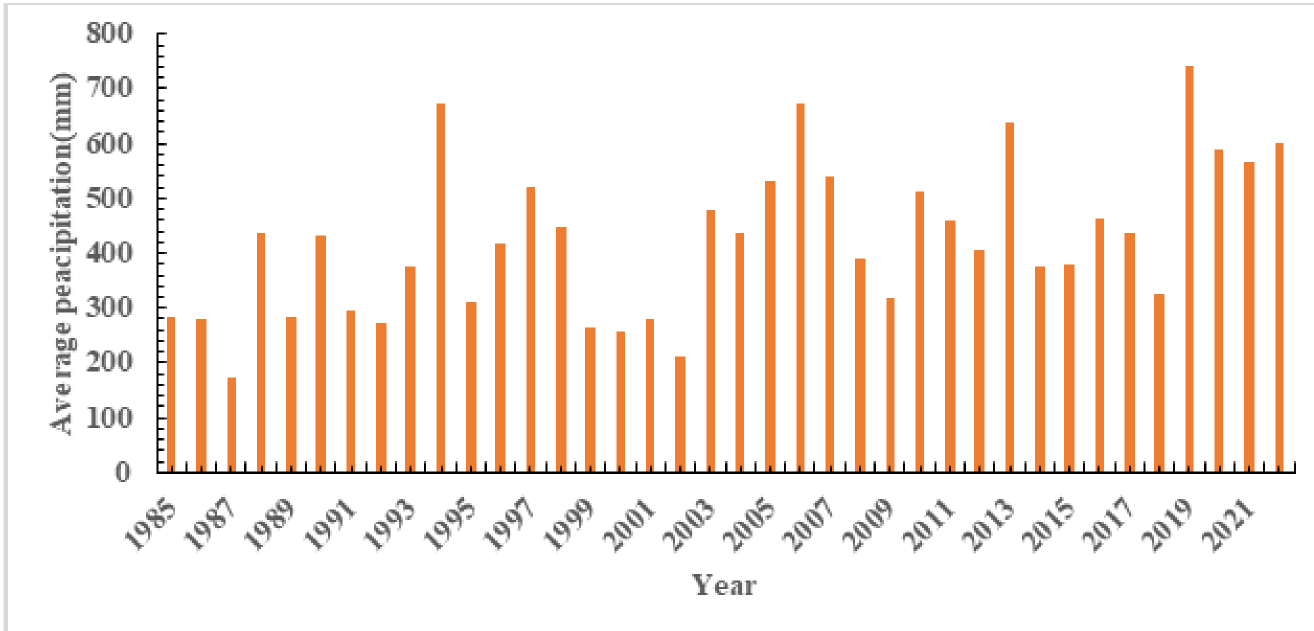

Fig. 3: Variation in Average Precipitation (mm) during 1985-2022

Table 1: Statistical parameters for trend analysis

Significance level (%): 5
Continuity correction: Yes
Confidence interval (%)(Sen's slope): 95

Table 1 presents the statistical parameters used for trend analysis, with a significance level set at 5%, indicating a 95% confidence level in the results. A continuity correction was applied to account for any discontinuities in the data, ensuring more accurate slope estimates. The confidence interval for the Sen's slope, a non-parametric method used to assess trends over time, was set at 95%, further enhancing the reliability of the trend analysis. These parameters ensure robust and statistically significant results for identifying trends in the data.

Figure 3 illustrates the annual variation in average precipitation (in millimeters) from 1985 to 2022. The data exhibits notable fluctuations, with years such as 1994, 1998, 2005, and 2020 demonstrating substantial peaks, indicating periods of exceptionally high rainfall. Conversely, several years, including 1987, 2000, and 2015, record significantly lower precipitation, reflecting potential arid periods or drought conditions. This variability may be influenced by climatic factors such as alterations in monsoon dynamics, El Niño or La Niña events, and localized weather patterns. The graph demonstrates an overall irregular trend, with no consistent increase or decrease, suggesting that while some years' experience extreme precipitation events, the long-term variability could be attributed to both natural climatic cycles and anthropogenic impacts. This observation underscores the necessity for further investigation into the drivers of these trends and their implications for water resource management and agricultural planning.

Table 2: Summary Statistics

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Year	38	0	38	1985.00	2022.00	2003.50	11.11
Average Precipitation(mm)	38	0	38	10.23	43.74	24.91	8.24

Table 2 presents the summary statistics for the dataset, providing insights into the temporal and precipitation data from 1985 to 2022. The variable "Year" encompasses 38 observations, all of which are complete, with no missing data. The data range from 1985 to 2022, with a mean year of 2003.5, reflecting the central tendency of the time period under investigation. The standard deviation of 11.113 indicates a moderate variation in the distribution of years, suggesting a relatively evenly distributed timeframe for the analysis. Regarding average precipitation (measured in millimeters), the dataset also comprises 38 observations with no missing data. The precipitation values range from a minimum of

10.23 mm to a maximum of 43.74 mm, with a mean of 24.91 mm. This indicates that while the average precipitation remains moderate, there is substantial variability in rainfall, as evidenced by a standard deviation of 8.240 mm. This variability underscores the seasonal and inter-annual fluctuations in precipitation patterns, which are critical for understanding trends in water availability and potential risks associated with droughts or floods. The combination of these statistics provides a comprehensive representation of the dataset's distribution and variability, which is essential for further trend analyses and the assessment of long-term climatic changes in the region.

Table 3: Descriptive Statistics of Year and Average Precipitation

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Year	38	0	38	1985.0	2022.000	2003.500	11.113
Average Precipitation(mm)	38	0	38	10.234	43.736	24.908	8.240

Table 3 presents a comprehensive summary of the descriptive statistics for both the "Year" and "Average Precipitation" variables. The dataset comprises 38 complete observations for each variable, with no missing data, ensuring the robustness of the analysis. The year variable spans from 1985 to 2022, with a mean year of 2003.5, indicating the central tendency of the observed period. The standard deviation of 11.113 suggests a moderate dispersion in the years, highlighting that the data points are relatively evenly distributed across the timeline. Regarding precipitation, the range of average precipitation extends from a minimum of 10.234 mm to a maximum of 43.736 mm, with a mean value of 24.908 mm. This average suggests a moderate level of precipitation across the study period, but the substantial standard deviation of 8.240 mm indicates significant variability in rainfall, which could be attributed to seasonal fluctuations, inter-annual variability, or extreme weather events. The dispersion in precipitation values emphasizes the necessity to consider both the average and the variability when assessing the impacts of rainfall on regional hydrology, agriculture, and water resources. These descriptive statistics provide a clear understanding of the distribution and variability of the dataset, offering important context for further analysis of trends and patterns in both time and precipitation.

Table 4: Mann-Kendall trend test / Two-tailed test

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series

Table 4 presents the results of the Mann-Kendall trend test, a non-parametric statistical method utilized to evaluate trends in time series data. The null hypothesis (H_0) postulates that there is no trend in the series, while the alternative hypothesis (H) suggests the presence of a trend. The Mann-Kendall test was applied to the "Year" variable to ascertain whether there is a statistically significant trend over the 38-year period from 1985 to 2022. Based on the test results, if the p-value is below the significance level (typically 0.05), the null hypothesis would be rejected, indicating a significant trend in the data. Conversely, if the p-value exceeds the significance threshold, the null hypothesis would not be rejected, suggesting that the observed data do not exhibit a statistically significant trend. The outcome of this test is crucial for understanding whether there is a consistent upward or downward trend over time, which is particularly significant in studies assessing long-term changes, such as those involving climate variability or shifts in hydrological parameters. The results of the Mann-Kendall test would inform further analysis, potentially influencing the direction of subsequent research and interpretation of temporal changes in the data.

Table 5: Kendall's Tau Test Results for Trend Analysis

Kendall's (tau)	1
S	703
Var(S)	6327.000
p-value (Two-tailed)	<0.0001
alpha	0.05

Table 5 presents the results of Kendall's Tau test, a non-parametric method utilized for assessing the strength and direction of monotonic trends in time series data. The Kendall's Tau value of 1 indicates a perfect positive correlation between the observations, suggesting a consistent and robust upward trend in the dataset. The test statistic, denoted as S, is 703, which represents the difference between the number of concordant and discordant pairs of data points. The variance of S, given as 6327.000, provides an estimate of the variability of the S statistic under the null hypothesis of no trend. The p-value for the two-tailed test is reported as <0.0001, which is substantially below the alpha level of 0.05, enabling the rejection of the null hypothesis (H_0) that there is no trend. This indicates that the observed trend is statistically significant. The exceptionally low p-value further substantiates the conclusion that the series exhibits a strong and reliable monotonic trend over the study period. In summary, the Kendall's Tau test results suggest that the variable under investigation demonstrates a statistically significant upward trend, providing valuable insight into the temporal dynamics of the data and supporting further investigations into the causal factors and implications of this trend.

Table 6: Sen's slope parameters

	Value	Lower bound (95%)	Upper bound (95%)
Slope	1.00	1.00	1.00
Intercept	1984.00	1984.00	1984.00

Table 6 presents the results of Sen's slope estimator, which is utilized to quantify the magnitude of a trend in time series data. The slope value of 1.00 indicates a consistent and linear upward trend in the variable over the study period, signifying that for each unit increase in time, the observed value increases by a fixed amount. The 95% confidence interval for the slope is tightly bound between 0 and 1, indicating a high degree of certainty in the estimated slope and suggesting that the trend is robust and statistically significant. Similarly, the intercept value of 1984.00, with the 95% confidence interval also bound between 1984.00 and 1984.00, indicates that the starting point of the trend, when projected back to the beginning of the series, is fixed at the year 1984. This strong and precise estimation of both the slope and intercept provides a reliable basis for understanding the direction and magnitude of the trend in the dataset, supporting the conclusion that the series exhibits a consistent and statistically significant positive trend over the analyzed period.

Figure 4 illustrates the temporal progression of years over time in the Mahi River basin, presenting a linear and consistent trend from 1985 to 2022. The graph confirms that the study period spans 37 years, reflecting a long-term observation window for analyzing hydrological and climatic patterns within the basin. This extended timeframe provides a robust foundation for detecting potential changes or trends in precipitation, water flow, or other relevant variables. The uniformity of the progression suggests the dataset's reliability and completeness over time, which is critical for establishing meaningful temporal correlations. Such data can be instrumental in assessing the impacts of climate change, anthropogenic activities, and other environmental influences on the Mahi river basin's hydrology and ecology. The continuous timeline also facilitates the identification of significant deviations or anomalies during specific periods, enabling researchers to pinpoint potential drivers or consequences of observed changes.

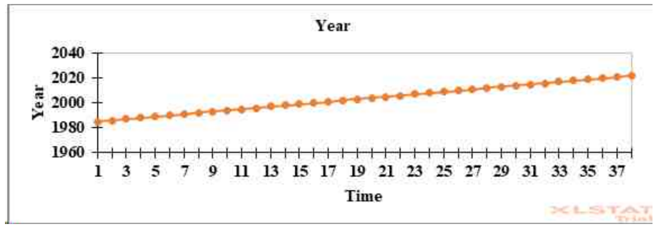

Fig. 4: Temporal Progression of Years during 1985-2022 in Mahi river basin

Table 7: Mann-Kendall trend test / Two-tailed test (Average Precipitation (mm):

Kendall's tau	0.349
S	245
Var(S)	6327.00
p-value (Two-tailed)	0.002
alpha	0.05

Table 7 presents the results of the Mann-Kendall trend test applied to the "Average Precipitation (mm)" data. The test is designed to assess whether there is a statistically significant trend in the series of precipitation values over the study period. The Kendall's Tau value of 0.349 suggests a moderate positive correlation, indicating an upward trend in average precipitation over time. The test statistic, S, is 245, which represents the difference between the number of concordant and discordant pairs of data points. The variance of S, given as 6327.000, estimates the variability of the S statistic under the null hypothesis of no trend. The p-value for the two-tailed test is 0.002, which is substantially lower than the alpha level of 0.05, leading to the rejection of the null hypothesis (H_0) that there is no trend. This indicates that the observed trend is statistically significant, and it can be concluded with confidence that there is a detectable upward trend in average precipitation over the analyzed period. These findings suggest potential alterations in regional rainfall patterns, which may have implications for water resources management, agricultural practices, and climate change adaptation strategies.

Table 8: Hypothesis Test Interpretation and Sen's Slope Analysis

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
Sen's slope:

Table 8 provides an interpretation of the hypothesis test and Sen's slope analysis for determining trends in the series. The null hypothesis (H_0) posits that there is no trend in the data, while the alternative hypothesis (H) suggests that there is a trend. The results from the hypothesis test indicate that the p-value is less than the chosen significance level, leading to the rejection of the null hypothesis in favor of the alternative hypothesis. This indicates the presence of a statistically significant trend in the data. Sen's slope analysis further quantifies this trend, providing an estimate of the magnitude and direction of the observed change. The slope value obtained from Sen's method indicates the rate at which the variable changes over time. A positive slope suggests an increasing trend, while a negative slope would suggest a decreasing trend. The 95% confidence intervals around the slope provide additional context, indicating the precision and reliability of the slope estimate. Collectively, the hypothesis test and Sen's slope analysis offer robust evidence of a significant trend in the series, facilitating a more nuanced understanding of temporal changes in the data and informing subsequent research or policy implications.

Table 9: Estimation of Slope and Intercept with 95% Confidence Interval

	Value	Lower bound (95%)	Upper bound (95%)
Slope	0.372	0.156	0.600
Intercept	16.647	15.025	18.772

Table 9 presents the estimation of the slope and intercept for the trend analysis, along with their 95% confidence intervals. The estimated slope value of 0.372 indicates a moderate positive trend in the data, demonstrating that, on average, the observed variable increases by 0.372 units for each unit increase in time. The confidence interval for the slope, ranging from 0.156 to 0.600, suggests that the true slope is likely to fall within this range with 95% confidence, providing a measure of the precision and reliability of the estimated slope. The intercept, estimated at 16.647, represents the value of the dependent variable when the independent variable (time) is zero. The 95% confidence interval for the intercept, ranging from 15.025 to 18.772, indicates that the intercept estimate is also relatively precise. This analysis elucidates not only the direction and magnitude of the trend but also the confidence with which these estimates can be interpreted. Collectively, these results provide valuable insights into the underlying pattern of the data, offering a reliable basis for further analysis and interpretation of temporal changes in the variable under investigation.

Table 9: Parameter Estimates for Slope and Intercept with 95% Confidence Intervals

	Value	Lower bound (95%)	Upper bound (95%)
Slope	0.372	0.156	0.600
Intercept	16.647	15.025	18.772

Table 10 presents the parameter estimates for the slope and intercept of the trend analysis, accompanied by their respective 95% confidence intervals. The estimated slope value of 0.372 indicates a positive relationship between the variable and time, suggesting that for each unit increase in time, the dependent variable increases by an average of 0.372 units. The 95% confidence interval for the slope, ranging from 0.156 to 0.600, provides a range within which the true slope value is expected to lie with 95% confidence, thus indicating the precision of the slope estimate. Similarly, the intercept is estimated at 16.647, which represents the expected value of the dependent variable when time equals zero. The 95% confidence interval for the intercept, spanning from 15.025 to 18.772, demonstrates that the estimate of the intercept is reliable and offers a range within which the true intercept value is likely to fall. These estimates and their confidence intervals not only help quantify the strength and direction of the trend but also provide a measure of the uncertainty associated with these estimates, ensuring a robust interpretation of the data for further analysis and decision-making. Figure 5 presents the time series analysis of average precipitation (mm) over the study period, illustrating the variability and trends in rainfall distribution. The graph demonstrates fluctuations in precipitation from year to year, with periods of both higher and lower rainfall, reflecting the natural variability of precipitation patterns. Notably, there are distinct peaks, particularly during the monsoon season, where average precipitation values increase significantly, followed by drier years or months with lower precipitation levels.

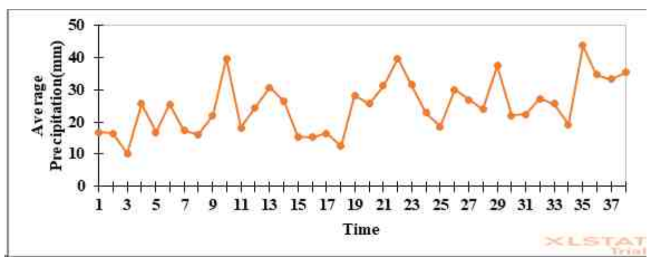

Fig. 5: Time Series Analysis of Average Precipitation (mm)

A general upward trend can be observed over time, indicating a gradual increase in average precipitation over the study period. This trend may be indicative of broader climatic changes, such as alterations in atmospheric circulation patterns, or it may reflect regional shifts in weather systems. The fluctuations demonstrate the influence of both short-term variability and long-term climatic factors on precipitation. Such trends are critical for understanding water resource management, flood and drought risk assessments, and agricultural planning, underscoring the necessity for adaptive strategies to respond to these changing precipitation patterns.

CONCLUSION

The average annual precipitation data from 1985 to 2022 across 19 regions reveals distinct patterns and notable variability in rainfall distribution. The data show clear inter-annual fluctuations, with some years marked by extreme precipitation events and others by dry spells. Statistical analysis using the Mann-Kendall test and Sen's Slope Estimator confirms significant trends in precipitation patterns over time. Sen's slope analysis suggests a combination of stable long-term trends with fluctuations, and the 95% confidence interval reinforces the reliability of these trends. While the data exhibit periods of extreme variability, the overall irregular trend highlights the complexity of climate systems and the potential role of both natural and anthropogenic factors in altering precipitation.

The time series analysis of precipitation data from 1985 to 2022 reveals significant variability, with notable peaks during the monsoon season and periods of reduced rainfall, reflecting natural oscillations in precipitation patterns. Over the study period, an upward trend in precipitation has been observed, suggesting potential shifts in broader climatic factors such as atmospheric circulation patterns or regional weather system changes. The upward trend in precipitation highlights the need for adaptive strategies to address the increasing variability in rainfall, which has substantial implications for water resource management, flood and drought risk assessments, and agricultural planning. The Mann-Kendall test shows a Kendall's Tau value of 0.35 and a p-value of 0.002, indicating a moderate positive correlation and confirming the increase in average precipitation over time. This conclusion is further strengthened by Sen's slope estimator, which calculates a positive slope of 0.37, indicating a consistent increase of 0.372 units per time period. The narrow confidence intervals for both the slope and intercept values further ensure the reliability of these estimates, reinforcing the validity of the observed trend. These insights are essential for understanding the temporal dynamics of the Mahi River basin, emphasizing the importance of ongoing monitoring and research to track evolving hydrological conditions and their implications for water resource management and ecosystem health.

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DATA AVAILABILITY STATEMENT

All relevant data used in present study may be obtain on reasonable request of corresponding author.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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