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Rainfall variability and trend detection in under changing climatic region for Ahilyanagar district of Maharashtra

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Abstract

This study analyzes rainfall trends on weekly, monthly, seasonal and annual basis for 14 tahsils of Ahilyanagar district, Maharashtra, India. The main objective is to understand spatial and temporal variations in rainfall over a long period (1961–2025) for support better water resource planning. Daily rainfall data were converted into different time series and analyzed using the Mann–Kendall test and Sen slope to detect trends as well as to estimate their magnitude. The results shows mixed rainfall patterns across the district. Weekly trend analysis showed both increasing and decreasing patterns, indicating high variability. Monthly trend analysis indicated significant increases mainly during monsoon months, especially in June, July, August and September, while a slight decreasing trend was observed in May in Shevgaon. At the annual trend analysis, some tahsils such as Akole, Sangamner and Shrirampur showed increasing trends, while remaining tahsils showed no significant trend. Overall, the study highlights uneven rainfall distribution and high climatic variability in the region. The increasing trend indicate the possibility of harvesting excess rainfall whereas the decreasing trend period gives the period in which contingency measures to be taken for sustainable production of crops.

Keywords: Rainfall, trend, ahilayanagar, mann-kendall

Introduction

India's agriculture, food, and energy security depend on adequate water availability and favorable climate conditions. Rainfall is a key determinant of water resources for agriculture, industrial, domestic, and hydroelectric uses. The South-West monsoon provides about 80% of annual rainfall, but its seasonal concentration (June–September) leads to water scarcity during non-monsoon periods (Sebastiane *et al.*, 2023).

Climate change is expected to alter rainfall patterns, increasing the risk of drought and floods, and affecting the hydrological cycle as well as water demand. Due to uneven rainfall distribution and demand–supply mismatch, large storage systems are essential. Therefore, analyzing trends in rainfall and other climatic variables is crucial for developing reliable future climate scenarios (Jain and kumar 2012) ^[1]. Both parametric and non-parametric techniques have been employed for trend detection. Among these, the Mann–Kendall (MK) test (Mann, 1945; Kendall, 1975) ^[2, 3] is widely used as a non-parametric method for identifying trends in hydrological time series data. Atre and Deore (2013) ^[4] examined weekly rainfall trends at Rahuri,

Maharashtra, using the Mann–Kendall test to detect monotonic changes in rainfall time series. The study found a significant increasing trend only during the 36th week, while most monsoon weeks exhibited no significant trend, indicating that the overall monsoon rainfall pattern at Rahuri remained stable with no long-term trend. Joshi *et al.* (2019) ^[5] analyzed 57 years (1961- 2017) of rainfall data from nine stations in Solapur District, Maharashtra, India, using the Mann-Kendall test and Sen's slope estimator to assess long-term rainfall trends. The study revealed statistically significant decreasing trends in annual, seasonal, and monthly rainfall across most tahsils, highlighting the need for efficient water-resource management to sustain agricultural production under changing climatic conditions. Barai and Kalunge (2021) ^[6] studied rainfall trends in Ahmednagar district, Maharashtra using statistical methods like the Mann–Kendall test and Sen's slope to understand changes over time using rainfall data for the period of 19801 to 2012. They found that rainfall in Ahmednagar district generally showed an increasing trend over the 33-year

period, especially during August and in annual rainfall, indicating changing rainfall patterns across different tahsils. Upadhye *et al.*, (2022) ^[7] analyzed the long-term trends in annual rainfall and number of rainy days for Pune district, Maharashtra.

Nandgude *et al.* (2024) ^[8] examined how climate change has affected rainfall extremes and long-term rainfall trends in the upper Krishna river Basin of Maharashtra. They analysed 52 years (1970–2021) of rainfall data from 15 stations in the upper Krishna river basin of Maharashtra and found an overall increasing trend in monsoon and annual rainfall, along with a rise in extreme rainfall events and heavy rainfall days in recent decades.

The present study is conducted in Ahilyanagar district, located in Maharashtra state. The district comprises 14 tahsils and is characterized by a predominantly hot and dry climate. Most parts of the study area experience high temperatures and arid conditions throughout the year, except during the South-West monsoon season. The summer season extends from March to early June, followed by the south-west monsoon, which continues until the end of September. The months of October and November represent the post-monsoon or retreating monsoon phase. Rainfall in the district is primarily received from the south-west monsoon; however, its spatial distribution is highly uneven. The average annual rainfall of the district is 566 mm, and the region is agro-climatically classified as a scarcity zone. The location map of study area is shown in Fig 1.

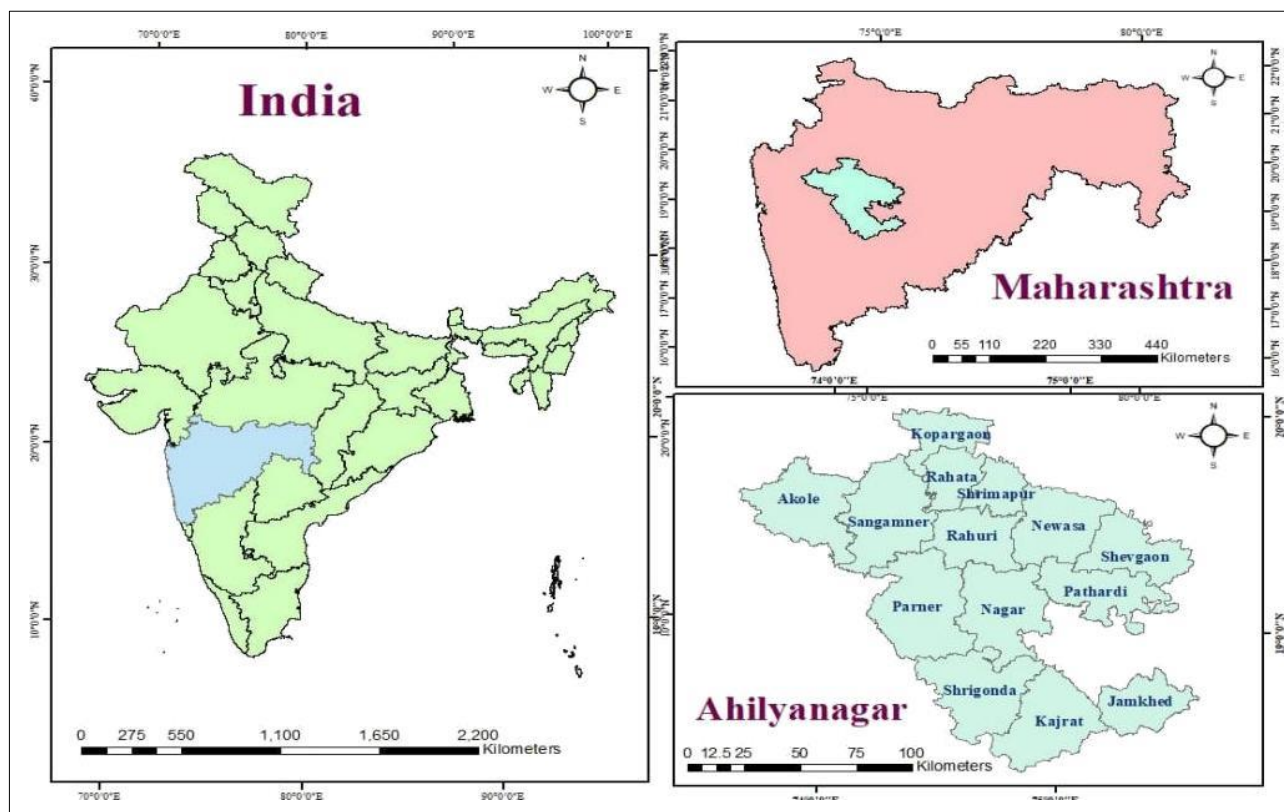


Fig 1: Study area: Ahilyanagar District

Materials and methods

The present investigation covers 14 tahsils of Ahilyanagar district, namely Akole, Jamkhed, Karjat, Kopergaon, Parner, Pathardi, Nagar, Shevgaon, Sangamner, Shrigonda, Shrirampur, Rahata, Rahuri and Newasa. The study area extends between 18.2°N to 19.9°N latitudes and 73.9°E to 75.5°E longitudes encompassing total geographical area 17,048 km².

Mann kendall method

The daily rainfall data of Ahilyanagar district for the period 1961–2025 (65 years) were obtained from the India Meteorological Department (IMD) and Hydrometeorological Department. The data analysed using the Mann-Kendall test and Sen's slope estimator to assess monotonic trends. The test, widely applied for hydro-climatic time series, evaluates the null hypothesis of no trend against the alternative of increasing or decreasing trend (Gilbert, 1987) ^[9]. For datasets exceeding 10 observations, the normal approximation (Z-test) was adopted. The analysis revealed tahsil-wise variations, indicating both

increasing and decreasing rainfall tendencies, with statistical significance observed in selected locations.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sign}(x_j - x_k) \quad (1)$$

Where, S denotes the Mann-Kendall test statistics, x_j and x_k denotes the sequential data value, Sign denotes the signum function.

$$\text{sign}(x_j - x_k) = \begin{cases} 1 & \text{if } x_j - x_k > 0 \\ 0 & \text{if } x_j - x_k = 0 \\ -1 & \text{if } x_j - x_k < 0 \end{cases} \quad (2)$$

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

Where q denotes the total number of tied groups, t_p represents the number of observations in the p^{th} tied group, and n indicates the total length of the data series (number of years). The standardized test statistic Z was then calculated using the following expression.

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

The existence of a statistically significant trend was determined based on the value of the standardized test statistic Z . A positive Z value signifies an increasing trend, whereas a negative Z value denotes a decreasing trend.

Sen's slope method

The magnitude of the trend was quantified using the Sen's slope estimator proposed by Pranab Kumar Sen (1968)^[10]. This non-parametric method is robust for detecting monotonic trends in hydrometeorological time series and estimates the true slope as the median of all pairwise slopes.

The individual slopes between data points are computed using equation (5):

$$Q_i = \frac{x_i - x_k}{j - k} \text{ for } i = 1, 2, 3, \dots, n \quad (5)$$

For $(1 \leq i < j \leq n)$,

Where X represents the variable of interest, n is the total number of observations, and j, k are time indices. A positive slope indicates an increasing trend, whereas a negative slope denotes a decreasing trend.

Results and Discussion

Weekly rainfall variability and trends

Weekly rainfall trends for the period 1961-2025 were analysed using the Mann-Kendall test and Sen's slope estimator as shown in Table 1. Both increasing and decreasing trends were observed in different weeks across the tahsils is shown in Fig. 2.

Akole shows increasing trends in weeks 26, 28, 30, 31, 32, 35, 36, and 40 with Sen's slope values of 0.2, 0.3, 0.7, 0.6, 0.3, 0.1, 0.1, and 0.1 mm per year, respectively, while Jamkhed shows an increasing trend in week 40 with 0.26 mm per year. The spatial occurrence of these trends can also be observed in Fig. 2.

Karjat showed increasing trends in weeks 23, 25, and 40 (0.2, 0.008, 0.2 mm per year) and a decreasing trend in week 13 (-0.1

mm per year). Kopargaon shows increasing trend in weeks 34 and 36 (0.05 and 0.1 mm per year) and a decreasing trend in week 21 (-0.1 mm per year), as shown in Table 1.

Nagar shows increasing trend in week 4, 6, and 52 (0.07, 0.2, and 0.1 mm per year), while Newasa shows increasing trend in week 36 and 38 (0.22 and 0.30 mm per year) and a decreasing trend in week 33 (-0.13 mm per year).

Parner shows increasing trend in week 23, 35, and 36 (0.2, 1.0, and 0.14 mm per year). Pathardi showed an increasing trend in week 40 (1.95 mm per year) and a decreasing trend in week 33 (-1.77 mm per year). Rahata shows an increasing trend in week 38 (1.84 mm per year) and decreasing trends in weeks 44 and 45 (-1.85 and -1.74 mm per year).

Whereas Rahuri shows increasing trends in weeks 34, 36, and 40 (1.8, 2.1, and 1.7 mm per year). Sangamner showed an increasing trend in week 38 (1.70 mm per year) and a decreasing trend in week 33 (-1.75 mm per year). Shevgaon showed an increasing trend in week 40 (1.8 mm per year) and decreasing trends in weeks 13 and 33 (-1.7 and -2.1 mm per year). Shrigonda tahsil shows increasing trends in weeks 36 and 37 (1.9 and 1.6 mm per year). These weekly rainfall trend patterns are also illustrated in Fig. 2.

Table 1: Trend in weekly rainfall trend of different tahsils of Ahilyanagar district

Tahsil	Increasing Trend	Decreasing Trend
Akole	26, 28, 30, 31, 32, 35, 36, 40	-
Jamkhed	40	-
Karjat	23, 25, 40	13
Kopargaon	34, 36	21
Nagar	4, 6, 52	-
Newasa	36, 38	33
Parner	23, 35, 36	-
Pathardi	40	33
Rahata	38	44, 45
Rahuri	34, 36, 40	-
Sangamner	38	33
Shevgaon	40	13, 33
Shrigonda	36, 37	-
Shrirampur	19	-

Note: 99.5% significance level if $|Z| \geq 2.81$; 99% significance level if $Z > \pm 2.54$; 95% significance level if $Z > \pm 1.96$; +90% significance if $Z > \pm 1.64$.

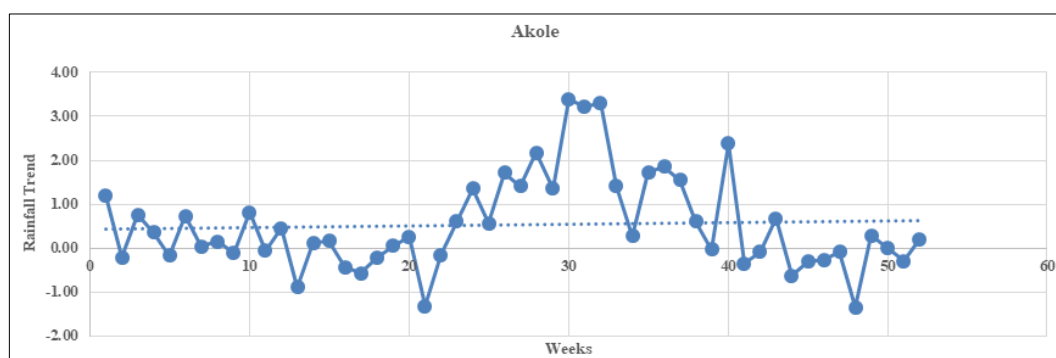


Fig 2: Weekly increasing trend for Akole tahsil

Monthly rainfall variability and trends

The monthly rainfall trends for the different tahsils in Ahilyanagar district was calculated using the Mann-Kendall test and Sen's slope estimator, and the results are shown in Table 2. The analysis showed that in May, a statistically significant decreasing trend was observed only in Shevgaon with a Sen's slope $Q(t)$ of -0.01 mm per year. In June and July,

a significant increasing trend was observed only in Akole with Sen's slope values of 1.70 and 2.70 mm per month, respectively. In August, a statistically significant increasing trend was detected in Akole, Kopargaon, Nagar, Parner, Rahata, Rahuri and Shrigonda with Sen's slope $Q(t)$ values of 1.6, 0.6, 1.0, 0.5, 0.7, 0.9, and 0.4 mm per month, respectively. In September, Kopargaon, Parner, Pathardi, Rahata, Sangamner and

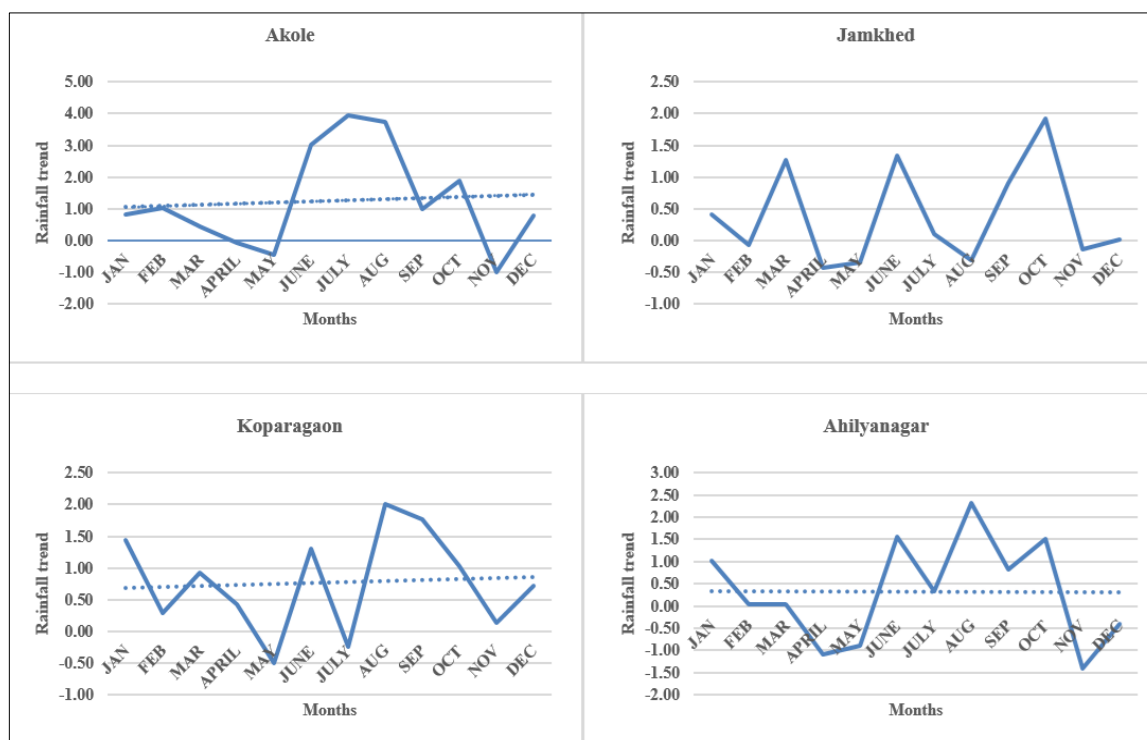
Shrirampur showed an increasing trend with Sen's slope values of 0.9, 1.1, 1.1, 1.1, 1.0, and 1.8 mm per month, respectively. In October, an increasing trend was observed in Akole, Jamkhed, Pathardi, Rahata, Shevgaon and Shrirampur with

Sen's slope $Q(t)$ values of 0.5, 0.8, 0.6, 0.5, 0.6, and 0.5 mm per month, respectively. However, in Karjat and Newasa tahsils, no trend was observed in the monthly rainfall as shown in Fig 3.

Table 2: Trend in monthly rainfall and its magnitude of 14 tahsils of Ahilyanagar district

Month/Trend	Increasing Trend			Decreasing Trend			No Trend
	Tahsil	Test z	Q(t)	Tahsil	Test z	Q(t)	
May	-	-	-	Shevgaon	-2.04*	-0.01	Akole, Jamkhed, Karjat, Kopargaon, Nagar, Newasa, Parner, Pathardi, Rahata, Rahuri, Sangamner, Shrigonda, Shrirampur
June	Akole	2.9**	1.70	-	-	-	Jamkhed, Karjat,
July	Akole	3.9***	2.7	-	-	-	Kopargaon, Nagar, Newasa, Parner, Pathardi, Rahata, Rahuri, Sangamner, Shevgaon, Shrigonda and Shrirampur
August	Akole	3.6***	1.6	-	-	-	Jamkhed, Karjat, Newasa, Pathardi, Sangamner, Shevgaon and Shrirampur
	Kopargaon	2*	0.6	-	-	-	
	Nagar	2.3*	1	-	-	-	
	Parner	1.6+	0.5	-	-	-	
	Rahata	1.7+	0.7	-	-	-	
	Rahuri	2.1*	0.9	-	-	-	
September	Shrigonda	1.6+	0.4	-	-	-	Akole, Jamkhed, Karjat, Nagar, Newasa, Rahuri, Shevgaon and Shrigonda
	Kopargaon	1.7+	0.9	-	-	-	
	Parner	1.8+	1.1	-	-	-	
	Pathardi	1.6+	1.1	-	-	-	
	Rahata	1.7+	1.1	-	-	-	
	Sangamner	1.7+	1	-	-	-	
October	Shrirampur	2.9**	1.8	-	-	-	Karjat, Kopargaon, Nagar, Newasa, Parner, Rahuri, Sangamner and Shrigonda
	Akole	1.6+	0.5	-	-	-	
	Jamkhed	1.9+	0.8	-	-	-	
	Pathardi	1.9+	0.6	-	-	-	
	Rahata	1.8+	0.5	-	-	-	
	Shevgaon	2*	0.6	-	-	-	
November	-	-	-	-	-	-	All tahsils
December	-	-	-	-	-	-	

Note: 99.5% significance level if $|Z| \geq 2.81$; 99% significance level if $Z > \pm 2.54$; 95% significance level if $Z > \pm 1.96$; +90% significance if $Z > \pm 1.64$.



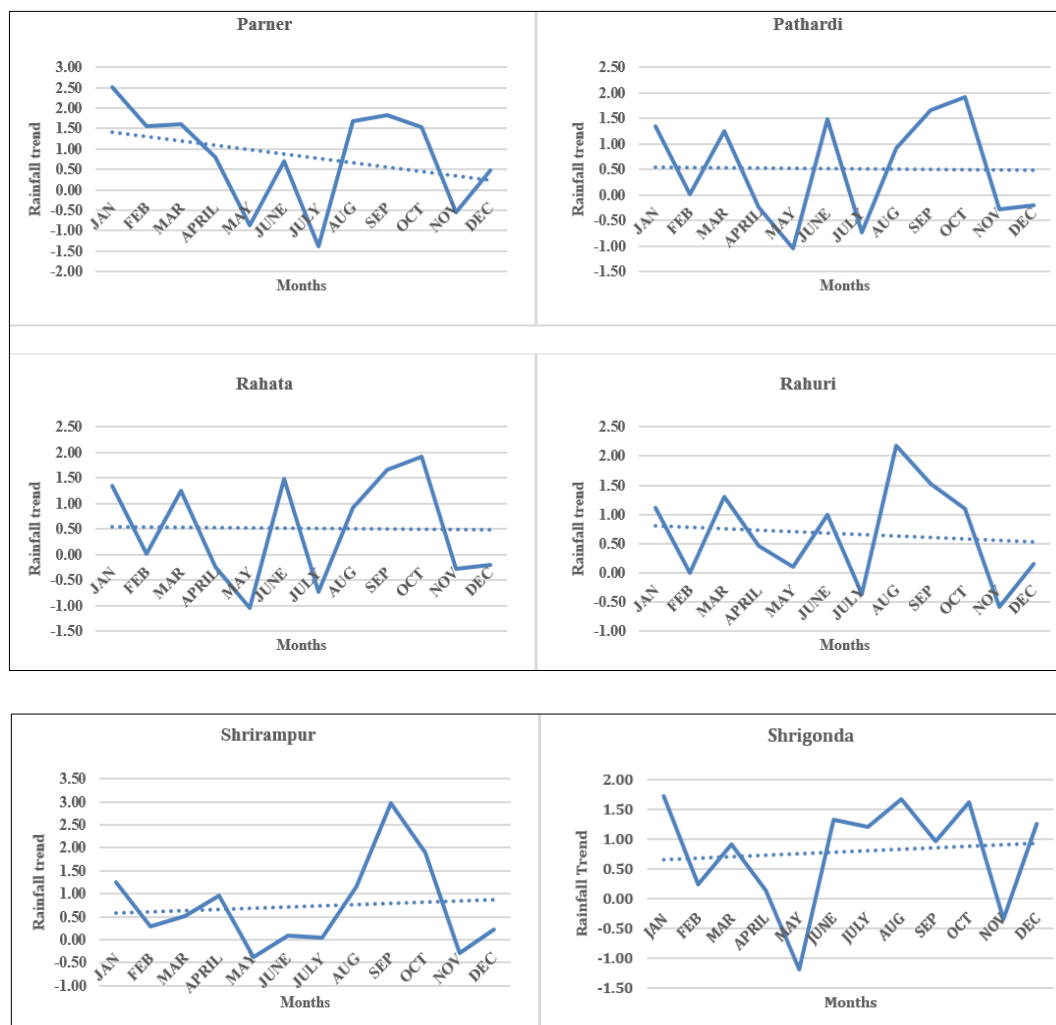


Fig 3: Monthly rainfall trend analysis for Ahilyanagar district

Seasonal rainfall variability and trends

The seasonal rainfall trends for the period 1961–2025 were analysed using the Mann-Kendall test and Sen's slope estimator, and the results are presented in Table 3. The analysis showed that during the winter season, a statistically significant increasing trend was observed in Parner, whereas Rahata shows a decreasing trend with a Sen's slope of -0.2 mm per season. The spatial pattern of these trends can also be observed in Fig. 4.

In the Summer season, a statistically significant decreasing trend was detected in Nagar with Sen's slope $Q(t)$ values of -1.80 mm per, season.

In the South-West monsoon season, a statistically significant increasing trend was detected in Akole, Karjat, Nagar, Sangamner, Shrigonda, and Shrirampur with Sen's slope $Q(t)$ values of 6.8, 1.9, 3.4, 1.9, 1.7, and 2.6 mm per season, respectively, as shown in Table 3.

In the North-East monsoon season, only Sangamner shows an increasing trend with a Sen's slope $Q(t)$ of 0.6 mm per season. Overall, tahsils Jamkhed, Kopergaon, Newasa, Pathardi, Rahata, Rahuri, and Shevgaon showed no trend in seasonal rainfall as shown in Fig 4.

Table 3: Trend in seasonal rainfall and its magnitude of selected tahsils of Ahilyanagar district

Season/Trend	Increasing			Decreasing		
	Tahsil	Test Z	$Q(t)$	Tahsil	Test Z	$Q(t)$
Winter	Parner	2.5*	00	Rahata	-1.9+	-0.2
Summer	-	-	-	Nagar	-1.80	-0.16
S-W monsoon	Akole	4.5***	6.8	-	-	-
	Karjat	1.7+	1.9	-	-	-
	Nagar	2.4*	3.4	-	-	-
	Sangamner	3.1**	1.9	-	-	-
	Shrigonda	1.9+	1.7	-	-	-
N-E monsoon	Shrirampur	2**	2.6	-	-	-
	Sangamner	1.8+	0.6	-	-	-

Note: 99.5% significance level if $|Z| \geq 2.81$; 99% significance level if $Z > \pm 2.54$; 95% significance level if $Z > \pm 1.96$; +90% significance if $Z_{\text{mod}} 1.64$

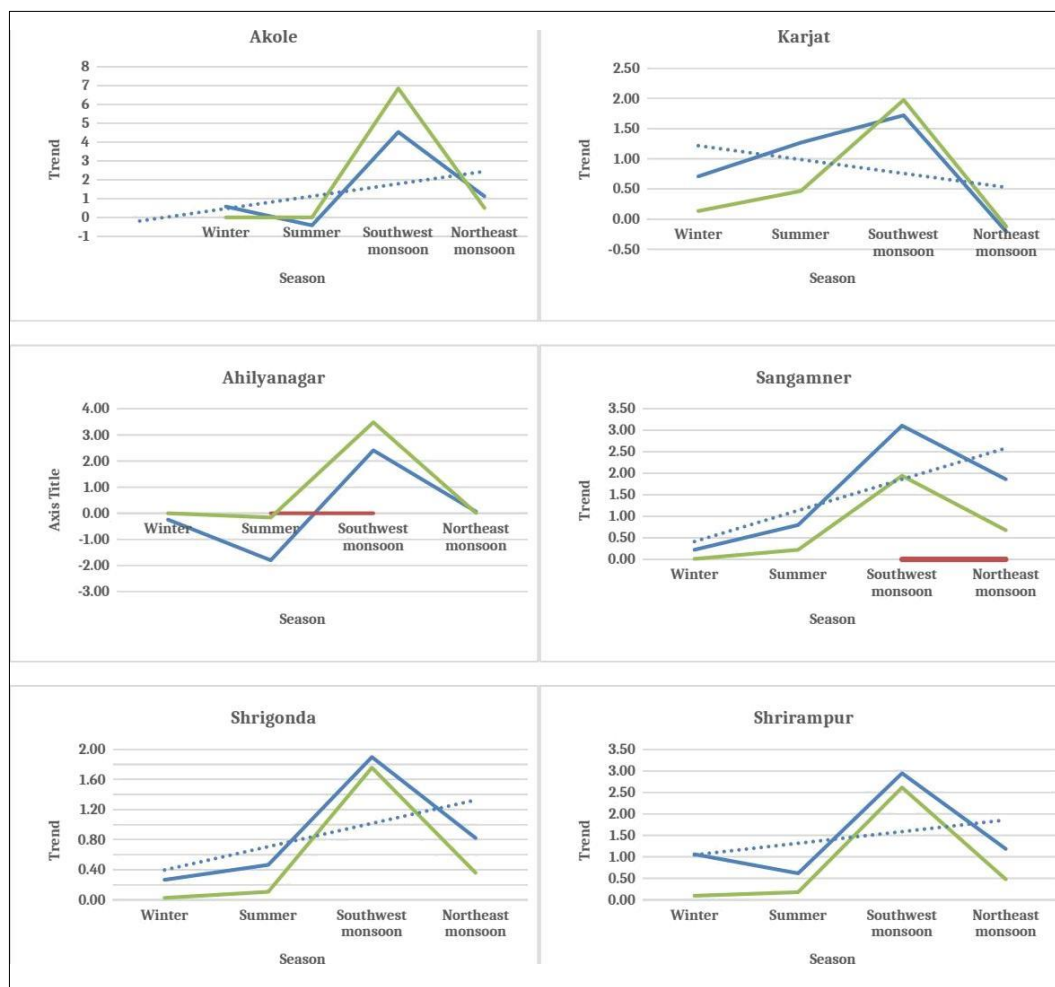


Fig 4: Seasonal rainfall trend analysis for Ahilyanagar district

Annual rainfall variability and trends

The annual rainfall data for the period 1961–2025 (65 years) for fourteen tahsils of Ahilyanagar district were analysed using the Mann–Kendall test and Sen’s slope estimator, and the results are presented in Table 4. Among the tahsils, a statistically significant increasing trend was observed in Akole, Karjat, Nagar, Rahuri, Sangamner, Shrigonda and Shrirampur with sens slope $Q(t)$ of 8.34, 2.97, 3.28, and 2.56 mm per year, respectively whereas in rest of tahsils viz, Jamkhed, Kopargaon,

Newasa, Parner, Pathardi, Rahata, Shevgaon there was no trend observed in annual rainfall.

The negative sign of Test Z of Rahata tahsil indicate decreasing trend and positive sign of Test Z of Akole, Jamkhed, Karjat, Kopargaon, Nagar, Newasa, Parner, Pathardi, Rahuri, Sangamner, Shevgaon, Shrigonda and Shrirampur tahsils indicate increasing trend but it is statistically non significant as shown in fig 5.

Table 4: Trend in annual rainfall and its magnitude of different tahsils of Ahilyanagar district

Tahsil	Test Z	$Q(t)$ (mm/year)	Trend
Akole	4.92***	8.34	Increasing
Jamkhed	0.75	1.48	No Trend
Karjat	1.63	2.42	Increasing
Kopargaon	1.12	1.25	No Trend
Nagar	1.62	2.21	Increasing
Newasa	0.63	0.68	No Trend
Parner	0.93	1.27	No Trend
Pathardi	1.19	1.84	No Trend
Rahata	-0.15	-0.12	No Trend
Rahuri	1.52	1.98	Increasing
Sangamner	3.02**	2.97	Increasing
Shevgaon	0.75	0.96	No Trend
Shrigonda	2.01*	2.56	Increasing
Shrirampur	2.59**	3.28	Increasing

Note: 99.5% significance level if $|Z| \geq 2.81$; 99% significance level if $Z \geq \pm 2.54$; 95% significance level if $Z \geq \pm 1.96$; +90% significance level if $Z \geq \pm 1.64$.

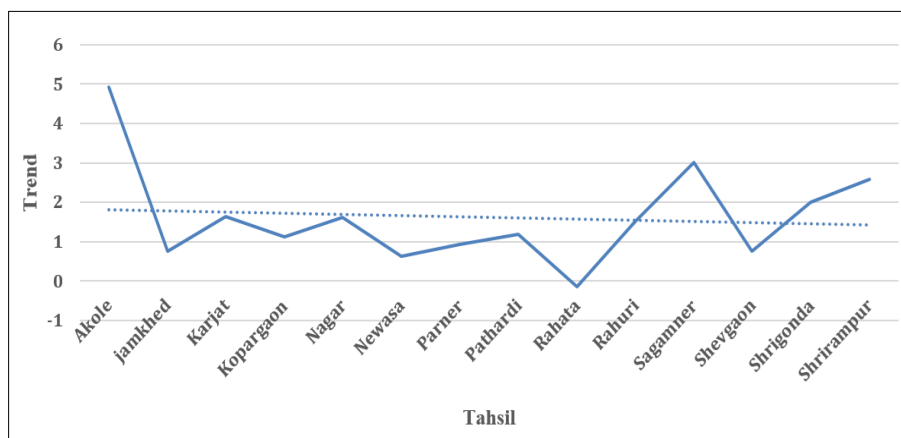


Fig 5: Tahsil wise annual rainfall trend analysis for Ahilyanagar district

Conclusion

The trend analysis for Ahilyanagar district (1961–2025) revealed spatial and temporal variability in rainfall across tahsils, with a predominance of weak increasing trends at weekly scale and isolated significant declines in Shevgaon. Seasonal and annual patterns indicated mixed but largely non-significant changes, suggesting high climatic variability. Considering concurrent fluctuations in temperature and relative humidity, efficient water management is essential. The increasing trend in rainfall in different weeks and months at respective tahsils are helpful in planning water harvesting measures whereas the decreasing trend period should be considered for planning of preparedness and real time contingency measures.

References

- Jain SK, Kumar V. Trend analysis of rainfall and temperature data for India. *Current Science*. 2012;102(1):37-49.
- Mann HB. Non-parametric test against trend. *Econometrica*. 1945;(13):245-259.
- Kendall MG. Rank Correlation methods. Charles Griffin, London. 1975.
- Atre AA, Deore SS. Detection of trends in weekly rainfall at Rahuri in scarcity zone of Maharashtra, Theme-IX: Hydrological Response of Watershed Development Programme. 2013.
- Joshi JK, Upadhye SK, More DD. Long term rainfall trend analysis of different time series in Solapur district of Maharashtra, India. *International Journal of Current Microbiology and Applied Sciences*. 2019;8(12):2359-2367.
- Barai VN, Kalunge RM. Trend analysis of rainfall using Mann-Kendall, Sen's slope, moving average and least square techniques for Ahmednagar district of Maharashtra. *International Journal of Agricultural sciences*. 2021;17(1):19-25.
- Upadhye SK, Sthool VA, Munde PS, Jadhav JD, Bagade SV. Trend Analysis of Annual Rainfall and Rainy Days Over Pune District of Maharashtra. *Journal of Agriculture Research and Technology*. 2022;47:145-152.
- Nandgude SB, Nagarkar SS, Atre AA, Gorantiwar SD, Patil MR. Climate Change Impacts on Rainfall Extremes and Historical Rainfall Trends Over Upper Krishna River Basin, Maharashtra, India. *Indian Journal of Ecology*. 2024;51(1):32-37.
- Gilbert RO. Statistical methods for environmental pollution monitoring. John Wiley and Sons. 1987.
- Sen PK. Estimates of the regression coefficient based on Kendall's tau. *Journal of the American statistical association*. 1968;63(324):1379-1389.
- Chhabra V, Haris AA. Temperature Trends and their impact on rabi crops in changing climatic scenario of Bihar. *Scholars Journal of Agricultural and Veterinary Sciences*. 2014;1(4A):230-234.
- Kumar V, Jain SK, Singh Y. Analysis of long-term rainfall trends in India. *Hydrological Sciences Journal*. 2010;55(4):484-496.
- Mandal UK, Nayak DB, Mullick S, Samui A, Jana AK, Mahanta KK, *et al*. Trend analysis of weather parameters over Indian Sundarbans. *Journal of Agrometeorology*. 2019;21(3):307-615.
- Sebastian DE, Murtugudde R, Ghosh S. Soil vegetation moisture capacitor maintains dry season vegetation productivity over India. *Scientific Reports*. 2023;13:1-10.
- Upadhye SK, Taley SM, Karunakar AN, Jadhav KA. Trends in rainfall and rainy days of Akola in Vidarbha region. *Proceedings of third National Conference on Water, Environment and Society (NCWES)*. 2016:342-347.