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Analysis of Trend Using Nonparametric Test for Rainfall and Rainy-Days in Jodhpur Zone of Rajasthan

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***Abstract*:** The planning, development, and management of water resources are significantly influenced by meteorological processes, which are significantly impacted by climate change. Trends become apparent as a result of these effects. Using nonparametric Mann-Kendall (MK), modified Mann-Kendall (MMK), and Theil-Sen slope estimator tests based on 60 years of data. The current study was conducted to evaluate the historical patterns of annual rainfall and rainy days in the Jodhpur zone of Rajasthan, India (1957-2016). Out of 27 stations, the annual rainfall at seven stations had a significant increasing trend. In the case of annual rainy days, only two stations showed a significant increasing trend. The dramatically increasing trend in rainfall at seven stations in the Jodhpur zone has shown that arid state of Rajasthan has been affected by climate change. The findings of this study could be used as preliminary data for planning and management of agricultural and water resources, as well as for designing soil and water conservation structures to increase the region's water availability.

Keywords: Trend analysis, Mann-Kendal Test, Sen's slope estimator, Rajasthan

Life on Earth depends on water in order to exist. It is the fundamental component on which many meteorological systems rely. Changes in rainfall frequency and pattern have a direct impact on the moisture levels of the soil, stream flows, groundwater levels, and the availability of freshwater reserves. The impacts of anthropogenic and climatic activities are continuously reflected in trends in rainfall, temperature, evapotranspiration, stream flows, and also other meteorological processes (Sen 2013). For the planning and management of water resources at the watershed scale, agricultural engineers, hydrologists, and water scientists must have a comprehensive understanding of rainfall trends. Given that the majority of the nation's agriculture is rain fed in nature, studying rainfall trends is of utmost significance in India. In India, the southwest monsoon, which occurs from June to September, is responsible for nearly 80% of all rainfall (Meshram et al 2017). The management of water resources, agricultural output, and finally the nation's economy are all greatly impacted by fluctuations in the southwest monsoon over India. In certain sections of the country, the monsoon months' significant concentration of rainfall causes a water deficit throughout the other months. A meteorological time series' trend is a deterministic element. The average long-term or regular variation (increasing or decreasing) in a time series is referred to as the trend component. Many recent studies have been conducted on the rainfall and temperature trend analysis in India as well as other parts of the worlds (Rahman and Dawood 2018, Rana et al 2019, Agarwal et al 2021, Harka et al 2021, Sharma and Adhikari 2022). Farooq et al (2021) analysed monthly, seasonal and annual trends in temperature using the non-parametric method for Kazakhstan from 1970 to 2017 and concluded that significant increasing trend in the mean annual temperature for the studied period. Harshavardhan et al (2020) investigated the spatiotemporal trends in rainfall in Krishna River Basin in India from 1965 to 2012.and observed that annual, monsoon and post-monsoon precipitation exhibited a significant negative trend in magnitude from the normal. Salehi et al (2020) examined patterns and identified turning points in Iran's yearly and seasonal rainfall. To conduct the study, the author applied the Mann-Kendall and modified Mann-Kendall tests. Ay and Kisi (2015) found rainfall patterns using ITA and Sen's slope approach for six Turkish. Based on the above review of literature this study is made to determine the trend in annual rainfall & rainy-day and determine the trend magnitude in rainfall & rainy days for Jodhpur zone of Rajasthan provinces.

MATERIAL AND METHODS

Study area: With a total area of 342,239 km^2, Rajasthan is the largest state in India and accounts for over 10% of the overall land area. It is located in the north-western part of the country extending from 23°03′ to 30°12′ north latitude and 69°30′ to 78°17′ east longitude. In the north and northeast, it is bordered by the Indian states of Punjab, Haryana, and Uttar Pradesh; in the southeast, Madhya Pradesh; in the southwest, Gujarat; and in the northwest and west, it has an international boundary with Pakistan. In this study Jodhpur zone of Rajasthan has been selected for study which covers six districts namely Jodhpur, Nagpur, Pali, Barmer, Jalor and Sirohi districts (Fig. 1). The daily data of rainfall and the number of rainy days for 60 years (1957–2016) were obtained from the Department of Water Resources, Govt. of Rajasthan. The location and elevation of all the stations are shown in Table 1.

Methodology: Mann-Kendall test and modified Mann-Kendall test were used to detect trend along with Sen's slope test for magnitude of trend.

Mann-Kendall and modified Mann-Kendall Test: Mann-Kendall test (Mann 1945 and Kendall 1975) has been broadly used to test monotonic trend in hydrological and metrological data (Patra et al 2012, Sa'adi et al 2019, Deoli et al 2020). Mann-Kendall test is suitable for time series data such as hydrological data, metrological data which are not normally distributed (Hameed 2008, Deoli et al 2022).

The MK test for a time series P_1, P_2 P_3…. P_n of length n is given as

$$S = \sum_{j=1}^{n-1} \sum_{k=j+1}^{n} sgn(P_k - P_j) \quad (1)$$

$$sgn(P_k - P_j) = \begin{cases} 1 \; if P_k > P_j \\ 0 \; if P_k = P_j \\ -1 \; if P_k < P_j \end{cases} \quad (2)$$

where, sgn ($p_k - P_j$) enotes the signum function of P_k and P_j. P_j and P_k are the rainfall values at time j and k for j < k. The value of S is generally positive when trend is increasing and negative when trend is decreasing. The variance of the MK statistic is given as

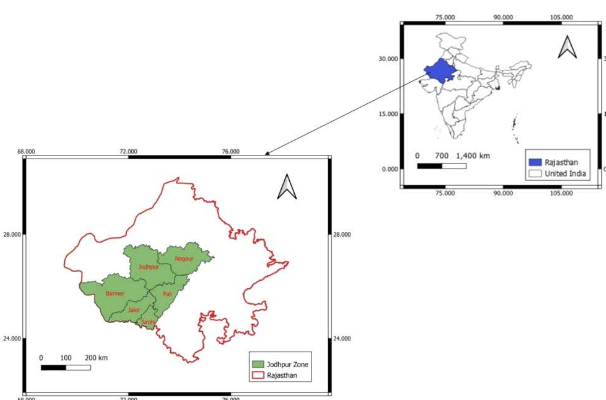

Fig. 1. Study area

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{m=1}^{q} t_m (t_m - 1)(2t_m + 5)}{18} \quad (3)$$

where q is the number of tied group and t_m is the total data values in m^{th} group.

The Z value is calculated after the calculation of the variance of time series data by following formula

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

The modified Mann-Kendall (Hamed and Rai 1998) is used to consider the effect of autocorrelation in time series.

Table 1. Location and elevation of all the stations

District	Station	Latitude	Longitude	MSL (m)
Barmer	Barmer	25.75	71.40	190
	Chohtan	25.48	71.07	172
	Siwana	25.48	72.42	170
	Sheo	26.18	71.25	236
Jodhpur	Jodhpur	26.30	73.03	258
	Bilara	26.19	73.71	271
	Osian	26.72	72.92	334
	Shergarh	26.33	72.30	252
	Phalodi	27.13	72.37	229
Pali	Pali	25.78	73.33	219
	Desuri	25.28	73.55	375
	Bali	25.18	73.28	304
	Jaitaran	26.20	73.94	302
	Raipur	26.05	74.05	351
Nagpur	Nagpur	27.20	74.75	385
	Nawa	27.00	75.00	366
	Jayal	27.22	74.18	309
	Degana	26.90	74.33	345
Sirohi	Abu Road	24.48	78.80	300
	Sirohi	24.88	72.88	320
	Mt. Abu	24.53	72.74	1186
	Pindwara	24.78	73.06	368
	Sheoganj	25.16	73.07	269
Jalore	Jalore	25.35	72.62	163
	Ahore	25.33	72.75	192
	Bhinmal	25.02	72.29	149
	Sanchore	24.75	71.77	60

MK test produces false results due to the presence of autocorrelation in time series data, in this case Modified MK test give correct results. Hence, accounting for autocorrelation in time series becomes very important.

The auto correlation coefficient has been calculated by t-test as

$$t = |\rho_1|\sqrt{\frac{n-2}{1-\rho_1^2}} \qquad (5)$$

where 't' is the t-value and n is the number of observations. P is the auto correlation coefficient which is given by

$$\rho = \frac{\sum_{t=1}^{n-k}(x_t-\bar{x}_t)(x_{t+k}-\bar{x}_{t+k})}{\sqrt{\left[\sum_{t=1}^{n-k}(x_t-\bar{x}_t)^2 \sum_{t=1}^{n-k}((x_{t+k}-\bar{x}_{t+k})^2)\right]}} \qquad (6)$$

where x_t is the observed value, X_t is the mean of first 'n-k' terms and X_{t+k} is the mean of last 'n-k' terms.

If the serial correlation in the rainfall data has been determined the trend in data has been calculated by MMK test and a correction factor is given as follow

$$= 1 + \frac{2}{n(n-1)(n-2)} \sum_{k=1}^{n-1}(n-k)(n-k-1)(n-k-2)\rho_k) \qquad (7)$$

where n is the total observation, n^*_s is the effective observation for autocorrelation and p_k is the function of autocorrelation. Variance of MMK test has been calculated by multiplying the variance of MK test by correction factor as

$$Var(S*) = Var(S)\frac{n}{n_S^*} \qquad (8)$$

Z- value of MMK test is computed as MK test by using modified variance var(S*).

Sen's Slope estimator: Sen's slope estimator test (Sen

Table 2. Annual rainfall and rainy-days characteristics over the study area

District	Station	Minimum		Maximum		Mean		CV%	
		Rainfall	Rainy days	Rainfall	Rainy days	Rainfall	Rainy days	Rainfall	Rainy days
Barmer	Barmer	29.6	3	484	25	283.3	14.5	60.5	36.5
	Chohtan	38.8	2	654.8	26	291.9	14.5	64.8	48.9
	Siwana	35.6	3	753.6	28	360.5	14.6	54.2	41.5
	Sheo	30.8	3	515.5	25	226.1	16.9	41.3	38.4
Jodhpur	Jodhpur	92	10	819.4	31	364.7	22.1	49.8	42.5
	Bilara	128.1	9	756	34	426.8	20.5	44.6	42.3
	Osian	94	8	652.9	28	615.8	17.9	46.6	36.4
	Shergarh	42.6	5	569	36	251.8	16	61.5	57.4
	Phalodi	65.5	6	421	31	234.5	15.8	56.2	29.4
Pali	Pali	91	7	818	37	418.5	25.2	37.8	36.4
	Desuri	199.5	12	1233.3	39	640	27.9	65.4	50.5
	Bali	174	11	1178.5	47	588.8	25.6	31.2	50.1
	Jaitaran	122.7	12	888.5	42	423.5	22.9	52.3	47.8
	Raipur	116	10	970	40	485.4	23.5	42.1	41.3
Nagpur	Nagpur	107	10	660.5	40	380.7	23	66.6	36.8
	Nawa	188.5	15	875	39	455.9	23.2	36.6	39.7
	Jayal	70	6	698.4	41	370.8	23.1	33.3	33.3
	Degana	120.5	8	778.5	40	422.5	23.2	45.7	38.9
Sirohi	Abu Road	116	12	1306.5	55	670.5	29.9	49.9	43.5
	Sirohi	191.4	8	1514.4	42	703.9	31.6	41.6	44.4
	Mt. Abu	370.5	25	3102.5	91	1586.5	51	50.6	22.5
	Pindwara	145.7	17	1435.5	51	708.5	31.5	59.7	29.7
	Sheoganj	106.6	7	1119.2	41	552.6	22.9	40.3	36.5
Jalore	Jalore	52	6	795	27	420	19.8	25.4	42.6
	Ahore	105.6	8	817.8	34	399.5	20.1	18.7	39.9
	Bhinmal	49	4	837.5	37	406.6	18.8	36.4	39.8
	Sanchore	29	3	938	38	398	18.8	42	25.5

1968) is used to calculate magnitude of trend as a trend slope which is a nonparametric test. The total slope has been estimated by computing slope for all time point pair using the median of all slopes.

In this method, first the slope (S_i) of all data pairs are calculated by

$S_i = (y_j - y_k)/(j-k)$ for i=1, 2, 3……N (9)

Where y_j and y_k are values at j and k for j > k respectively. The median of these N values is Sen's slope estimator and calculated as

$$S_{\frac{N+1}{2}} \quad for\ N\ is\ odd$$

$$\frac{1}{2}(S_{\frac{N}{2}} + S_{\frac{N+2}{2}} \quad for\ N\ is\ even \qquad (10)$$

RESULTS AND DISCUSSION

Variation of rainfall: The mean annual rainfall at different stations varied from 226.1 for Sheo to 1586.5 for Mt. Abu (Table 2). The highest rainfall (370.5mm) was d at Mt. Abu station of Sirohi whereas the minimum rainfall (29 mm) was at Sanchore station of Jalore. The mean annual rainy-days were varying from 14.5 for Barmer station to 51 for Mt. Abu station. The minimum number of annual rain days 2 was observed at Chohtan station of Barmer whereas the maximum number of rainy days 91 was observed at Mt. Abu station.

Autocorrelation test: In annual rainfall and rainy-days no station showed autocorrelation in data hence all the trends were calculated using the Mann-Kendall test only.

Table 3. Result of Mann Kendall Test for annual rainfall and rainy-days

District	Station	Z-statistics		Significant trend	
		Annual rainfall	Annual rainy days	Annual rainfall	Annual rainy days
Barmer	Barmer	1.23	1.53	No	No
	Chohtan	2.32	1.5	Yes	No
	Siwana	1.30	1.58	No	No
	Sheo	1.54	2.45	No	Yes
Jodhpur	Jodhpur	1.74	1.22	No	No
	Bilara	1.05	1.54	No	No
	Osian	1.12	1.83	No	No
	Shergarh	2.01	1.32	Yes	No
	Phalodi	-0.35	0.95	No	No
Pali	Pali	2.15	0.54	Yes	No
	Desuri	1.31	1.98	No	Yes
	Bali	1.99	1.53	Yes	No
	Jaitaran	2.10	1.64	Yes	No
	Raipur	1.98	0.9	Yes	No
Nagpur	Nagpur	0.98	1.64	No	No
	Nawa	1.10	1.52	No	No
	Jayal	0.54	1.44	No	No
	Degana	0.62	1.25	No	No
Sirohi	Abu Road	-0.12	-0.68	No	No
	Sirohi	0.58	-0.75	No	No
	Mt. Abu	-0.44	-0.52	No	No
	Pindwara	-0.95	-0.47	No	No
	Sheoganj	0.12	0.46	No	No
Jalore	Jalore	0.35	1.02	No	No
	Ahore	1.26	1.21	No	No
	Bhinmal	1.96	1.32	Yes	No
	Sanchore	-0.35	1.2	No	No

Table 4. Trend magnitude and percentage change in annual rainfall and rainy-days

District	Station	Trend magnitude		Percentage change (%)	
		Annual rainfall	Annual rainy days	Annual rainfall	Annual rainy days
Barmer	Barmer	1.98	0.065	32.5	36.5
	Chohtan	2.45	0.073	54.6	33.9
	Siwana	3.60	0.07	81.6	37.8
	Sheo	1.84	0.082	54.3	31.2
Jodhpur	Jodhpur	1.32	0.047	21.5	39.4
	Bilara	1.55	0.050	23.5	35.8
	Osian	2.02	0.112	29.7	11.2
	Shergarh	1.21	0.077	47.1	33.5
	Phalodi	-0.8	0.032	-18.9	36.7
Pali	Pali	1.83	0.021	33.6	17.8
	Desuri	2.05	0.034	54.8	12.6
	Bali	3.21	0.063	74.3	15.8
	Jaitaran	2.55	0.132	42.9	17.9
	Raipur	1.5	0.065	33.3	19.7
Nagpur	Nagpur	1.4	0.032	29.4	18.7
	Nawa	0.2	0.038	47.2	28.4
	Jayal	0.68	0.098	51.3	22.3
	Degana	0.86	0.043	22.2	14.5
Sirohi	Abu Road	4.5	0.088	32.6	16.6
	Sirohi	-0.65	-0.135	-29.8	-15.5
	Mt. Abu	-0.5	-0.074	-23.6	-18.7
	Pindwara	1.15	0	36.8	35.7
	Sheoganj	-1.4	0.023	-25.2	33.8
Jalore	Jalore	3.35	0.035	32.7	27.4
	Ahore	2.49	0.048	59.7	39.9
	Bhinmal	1.25	0.066	40.5	21.5
	Sanchore	0.96	0.041	29.8	13.5

Trend analysis in annual rainfall and rainy-days: Out of 27 stations 22 station shows an increasing trend in rainfall whereas 5 station shows decreasing rainfall trend from which 7 stations namely Chohtan (2.32), Shergarh (2.01), Pali (2.15), Bali (1.99), Jaitaran (2.10), Raipur (1.98) and Bhinmal (1.96) show significant increasing trend at (Table 2) whereas no station shows significant negative trend. On annual rainy days, 23 stations show an increasing trend and 4 stations show a decreasing trend. Only 2 stations namely Sheo (2.45) and Desuri (1.98) stations show a significant increasing trend whereas no stations show a significant negative trend.

Magnitude of trend and percentage change in annual rainfall and rainy-days: In annual rainfall the lowest positive magnitude of trend was 0.2 mm/year for Nawa station and highest positive was 4.5 mm for Abu Road Station. Stations, varied between -0.5 to -1.4 mm/year. In annual rainy-days the magnitude of trend varies between -0.135 mm/year and 0.132 mm/year (Table 4). The maximum percentage positive change in rainfall is detected 81.6% for Siwana Station and minimum positive percentage change is detected for Jodhpur Station (21.5%) whereas the maximum negative change was -29.8% for Sirohi Station and minimum negative percentage change (-18.9%) for Phalodi Station. In annual rainy-days the percentage changes have been varied from -18.7% for Mt. Abu Station to 39.9% for Ahore Station.

CONCLUSIONS

The present study successfully attempted to assess the temporal trend in annual rainfall and rainy days for the Jodhpur zone of Rajasthan. Out of the 27 stations, the annual rainfall at seven stations Chohtan, Shergarh, Pali, Bali, Jaitaran, Raipur) and Bhinmal show a significant increasing trend (1.96 mm/year to 2.32 mm/year). Similarly, on annual rainy days, Sheo and Desuri show an increasing rainfall trend with 2.45 mm/year and 1.98 mm/year. No station in annual rainfall as well as in annual rainy days showed a significant negative trend. The results of this study will be beneficial for water resource information and planning and designing of soil and water conservation structures for improving water availability in the area.

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