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Spatio-temporal Rainfall Trend Analysis Using Mann–Kendall Test and Sen's Slope Estimator for Blocks of Palghar District in Maharashtra

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Abstract
The study of the rainfall variability and its trends is a good tool for the policy makers for agricultural planning, water resource assessment, hazard mapping, flood frequency analysis *etc*. Therefore, several studies have been conducted by various researchers in order to know the spatial and temporal variability of rainfall. In this study, we analyzed the variability and trends annual & seasonal rainfall of the eight blocks of Palghar district for the period 1998–2022, The daily rainfall data taken from Department of Agriculture, Maharashtra State. The original Mann–Kendall (M–K) test has been applied to the rainfall dataset in conjunction with Sen's Slope Estimator. The block wise analysis of annual rainfall variability reveals a considerable variation over 25 years. The result concluded that M–K test, with a Kendall's tau of 0.460 and 0.337 (significant at a 5% level), shows an increasing trend in annual rainfall in Dahanu and Talasari block respectively. The Sen's slope, which measures the rate of change annually, has a value of 47.0 & 36.1 mm respectively. Whereas rainfall trend at Vasai block was decreased annually during 1998-2022, with the Sen's slope rate -14.5 mm rainfall. Non-significant increasing as well as non-significant decreasing trend was observed in the Wada, Vasai, Mokhada, Jawhar, Palghar and Mokhada blocks of Palghar District during pre-monsoon, monsoon and post-monsoon seasons during (1998–2022), And the rainfall shows significant increasing trend during winter at Vasai, Jawhar, Mokhada, Palghar and Vikramgad. Since this study could help policymakers in agricultural planning, valuable climatic and water resource management decisions.

Keywords: Rainfall variability, trend analysis, Mann-Kendall test, Sen's slope estimator

Introduction
The rainfall pattern and distribution play an important role in the planning and management of projects related to resources like agriculture production, water requirement, irrigation and reservoir operation. The change in the distribution of rainfall response is an alarming situation to water resource manager, as these changes in rainfall frequency and quantity are altering the pattern of stream flows and demands, soil moisture and ground water reserves (Srivastava *et al* 2014) [14]. The precipitation change can show impact on the society which is why we need up-to-date Information to estimate the spatial distribution and variability. In India, several attempts are made in the past to determine trend in the rainfall at national and regional scales (Singh *et al* 2005, Joshi and Rajeevan 2006, Murphy and Timbal 2008, Chowdary and Beecham 2010) [15, 5, 9, 3]. Trend analysis has been proved to be a useful tool which provides the information on possibility change of future (Yue and Hashino 2007) [18]. Several studies have specified the issue of trends in rainfall in India since last century (Kripalani et. al. 2003, Sahai *et al* 2003) [7, 12]. Long-term spatial and chronological rainfall pattern based on 102 years of rainfall data from 12 meteorological stations of Gangetic West Bengal between 1901 and 2002 have been analysed on a weekly, seasonal and annual scale (Ghosh 2018) [4]. The results of that study showed that, between 1901 and 2002, the average annual precipitation increased 2.61 percent while the post-monsoon precipitation increased considerably by 33.87 percent. Wang and Xu (2014) [17] found a descending trend in annual precipitation in Haihe River Basin, China. Nichols and Lavery (1992) [10] found increasing summer rainfall in eastern Australia during 1950s Declining rainfall trends for the period of 1911-1980 over 28 meteorological stations in Nigeria was found by (Adefalalu 1986) [1]. Spatial and seasonal differences in rainfall trend were observed on Canadian prairies (Akinremi *et al*., 2001) [2]. Parthasarathy and dhar (1975) [11] reported that the rainfall over India was increased from 1431 mm to 1960 mm. Wadood and Kumari (2009) [16] noticed a considerable increase in average monthly maximum rainfall pattern with high variability in recent decades in Jharkhand, India.

The analysis showed that wide variation exists in the rainfall amounts with variation from 159 mm to 2123 mm. Keeping this in view, Present research study was undertaken to know about rainfall trend in blocks of Palghar districts.

Materials and Methods

A. Study Area

Palghar lies between 72^0 45 & 73^0 48 East Longitude and 18^0 42 and 20^0 20 North Latitude. The Eastern part of the district has Sahyadri ranges, which comprises of mainly forest area. Arabian sea toward west while, Gujarat State towards north. Thane & Mumbai district are towards South side of the district. The total geographical area of the district is 517634 ha. Palghar districts comprises of eight blocks namely Vasai, Jawhar, Vikramgad, Wada, Talasari, Palghar, Mokhada and Dahanu, six blocks of the district are tribal. Topographically it has much diverse condition.ie. hilly, saline, plataue zone and characterized by high iritic rainfall. The district is characterized by warm & humid climate. The district receives assured rainfall of about 2305.4-millimeter form south west Monsoon during the month of June to September. Generally, the highest rainfall is recorded in the month of July and later on there is gradual decline in the rainfall. On an average temperature range from 16^0 c to 32.3^0 c The humidity of district ranges from 61 to 86 percent throughout the year.

B. Data Collection

The daily rainfall data of eight blocks *viz.* Vasai, Jawhar, Vikramgad, Wada, Talasari, Palghar, Mokhada and Dahanu of Palghar Districts were taken from Department of Agriculture, Maharashtra State (maharain.maharashtra.gov.in) for period of 1998 – 2022.

C. Methodology

For several years, the researchers and hydrologists are interested in trend analysis of meteorological variables such as rainfall, temperature, relative humidity, wind velocity, and stream flow. The preceding studies suggested the non-parametric Mann-Kendall test is the most widely used method. Trend analysis of the selected area for rainfall is carried out in this study, The non-parametric (Mann-Kendall) test (Kendall, 1975) [6], due to its insensitivity to the normal distribution of data time series and outliers, this statistical model is mostly used for patterns identifying in hydro-meteorological data time series

D. Mann–Kendall (MK) Test for Trend Analysis

The Mann-Kendall (MK) test is a non-parametric trend analysis for identifying the increasing and decreasing pattern in time series of the data. It compares the relative magnitudes of sample data rather than the data values. The (MK) test is first implemented using the null hypothesis H0 of no trend testing, that is, the observations xi are randomly ordered in time, against the alternative hypothesis H1, where there is an increasing or decreasing monotonic trend. The data values evaluated as ordered time series are compared with all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all these increments and decrements yields the final value of S. The M-K test statistic S is computed as:

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

$$Sgn(x_j - x_k) = \begin{cases} -1 if (x_j - x_k) < 0 \\ 0 if (x_j - x_k) = 0 \\ + if (x_j - x_k) > 0 \end{cases}$$

Where,

xj and xk are the annual values in years j and k, j > k, respectively.

If n < 10 then the value of |S| is compared directly with the theoretical distribution of S that is derived by Mann - Kendall test. The two tailed test is used. At some probability level H0 is rejected in favor of H1 if the absolute value of S equals or exceeds a specified value Sα/2, where Sα/2 is the smallest S having the probability less than α/2. A positive (negative) value of S indicates an upward (downward) trend (Salmi *et. al.* 2002) [13].

For n ≥ 10, the statistic S is approximately normally distributed with the mean and variance as follows.

$E(S) = 0$ $VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p\left(t_p - 1\right)\left(2t_p + 5\right)\right]$

q is the number of tied groups and t_p is the number of data values in the p th group.
The standard test statistic Z is computed as.

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

The presence of a statistically significant trend is evaluated using the Z value. A positive (negative) value of Z indicates an upward (downward) trend. To test for either an upward or downward monotonic trend (a two - tailed test) at α level of significance, H0 is rejected if $|Z| > Z_{1-\frac{\alpha}{2}}'$ where $Z_{1-\frac{\alpha}{2}}'$ is obtained from the standard normal cumulative distribution tables.

E. Sen´S Slope Estimator
If a linear trend is present in a time series, then the true slope (change per unit time) can be estimated by using a simple nonparametric procedure developed by Sen (1968). This means that linear model f (t) can be described as

$$f(t) = Qt + B$$

where, Q is the slope B is a constant.
To derive an estimate of the slope Q, the slopes of all data pairs are calculated

$$Q_i = \frac{(x_j - x_k)}{j-k}, i = 1, 2 \ldots . N, j > k$$

If there are n values xj in the time series we get as many as 2)1 N slope estimates Qi.
The Sen's estimator of slope is the median of these N values of Qi. The N values of Qi are ranked from the smallest to the largest and the Sen's estimator is too much a given measure of heterogeneity.

$$Q_{med} = \begin{cases} Q_{[(N+1)/2]}\ if\ N\ is\ odd \\ Q_{\frac{[N/2]+[(N+2)/2]}{2}}, If\ N\ is\ even \end{cases}$$

The Q_{med} sign reflects data trend reflection, while its value indicates the steepness of the trend. To determine whether the median slope is statistically different than zero, one should obtain the confidence interval of Q_{med} at specific probability.
A 100(1-α) % two-sided confidence interval about the slope estimate is obtained by the non-parametric technique based on the normal distribution. The method is valid for n as small as 10 unless there are many ties. At first it is computed that,

$$C_a = Z_{1-\frac{\alpha}{2}} \sqrt{Var(S)}$$

Where, VAR (S) has been defined in above equation, Z1-α/2 is obtained from the standard normal distribution Next M1 = (N - Cα)/2 and M_2 = (N + Cα)/2 are computed. The lower and upper limits of the confidence interval, Qmin and Qmax, are the $M1^{th}$ largest and the $(M_2 +1)^{th}$ largest of the N ordered slope estimates Qi. If M1 and/or M_2 are not a whole number, the respective limits are interpolated. To obtain an estimate of B in equation f(t) the n values of differences xi – Qti are calculated. The median of these values gives an estimate of B. The estimates for the constant B of lines of the 99% and 95% confidence intervals are calculated by a similar procedure.

Results and Discussions
Annual rainfall trend analysis
In this study, the rainfall trend has been analyzed with respect to time from 1998 to 2022. Kendall's tau, which ranges from 0 to 1 (0 represents no relationship and 1 represents perfect relationship), measures the non-parametric relationship between the columns of ranked data.
Kendall's tau values 0.180, 0.460, 0.233, 0.193, 0.133,0.337 of Wada, Dahanu, Palghar, Jawhar, Mokhada, Tasari and Vikramgad are positive means it indicates increasing trend of rainfall during 1998- 2022. But p- value of Dahanu & Talasari block observed 0.001 & 0.019 shows highly significant increasing trend. Kendall's tau of Vasai is -0.140 with p-value 0.338 definitely indicate non-significant decreasing trend.
The Sen's slope estimator analysis of annual rainfall shows increasing trend for Wada, Dahanu, Palghar, Jawhar, Mokhada, Tasari and Vikramgad with the 16.90, 47.03, 27.12, 34.27, 17.86, 36.13 & 24.65 mm (Table 1).

Table 1: Mann-Kendall Annual rainfall trend analysis with Sen's Slope Estimator for the period of (1998 -2022)

Name of the block	Kendall's tau	S value	p-value	Significance	Sen's slope	Trend
Vasai	-0.140	-42	0.338	No	-14.60	Decreasing
Wada	0.180	54	0.216	No	16.90	Increasing
Dahanu	0.460	138	0.001	Yes	47.03	Increasing
Palghar	0.233	70	0.107	No	27.12	Increasing
Jawhar	0.193	58	0.183	No	34.27	Increasing
Mokhada	0.133	40	0.362	No	17.86	Increasing
Talasari	0.337	101	0.019	Yes	36.13	Increasing
Vikramgad	0.200	60	0.168	No	24.65	Increasing

Seasonal rainfall trend
Pre-monsoon (March- May)
The seasonal trends found by the Mann–Kendall test analysis was almost similar to the rainfall trend found by the Sen's slope estimator. Most of the trends were non-significant at 5% confidence levels. The Man- Kendall test for Pre- monsoon season reveals that Vasai, Palghar, Jawhar & Mokhada shows non-significantly increasing trend with Kendall tau values 0.070, 0.195, 0.066, 0.117 respectively, while Wada, Dahanu, Talasari & Vikramgad shows non-significantly decreasing

trend with Kendall tau -0.021, -0.112, -0.097 & -0.157 respectively, for the period of 1998- 2022 (Table 2).

The Sen's slope estimator analysis of Pre-monsoon rainfall shows increasing or decreasing trend with the 0.00 mm. From the analysis and findings, it concludes that, rainfall varies in different block which are evident in the given results.

Table 2: Mann-Kendall Pre-monsoon rainfall trend analysis with Sen's Slope Estimator for the period of (1998 -2022)

Name of the block	Kendall's tau	S value	p-value	Significance	Sen's slope	Trend
Vasai	0.070	17	0.67	No	0.00	Increasing
Wada	-0.021	-5	0.92	No	0.00	Decreasing
Dahanu	-0.112	-26	0.49	No	0.00	Decreasing
Palghar	0.195	41	0.24	No	0.00	Increasing
Jawhar	0.066	13	0.71	No	0.00	Increasing
Mokhada	0.117	23	0.49	No	0.00	Increasing
Talasari	-0.097	-19	0.57	No	0.00	Decreasing
Vikramgad	-0.157	-33	0.34	No	0.00	Decreasing

Southwest Monsoon (June to September)

Southwest monsoon contributed more than other season to annual total rainfall during the period of 1998- 2022. Kendall's tau values of Wada, Dahanu, Palghar, Jawhar, Mokhada, Tasari and Vikramgad are 0.180, 0.460, 0.233, 0.193, 0.133,0.337 respectively. It indicates increasing trend of rainfall observed during Monsoon season of 1998-2022. Among the blocks of increasing trends, highly significant trend was observed at the 5% significance levels in the Dahanu and Talasari with the p- value 0.00 & 0.05 respectively.

The Sen's slope estimate analysis of *southwest*-monsoon rainfall shows rising trend in a vasai, wada, Dahanu, Palghar, Jawhar, Mokhada, Talasari, and Vikramgad with 18.05, 18.05,46.17, 21.68, 30.00, 21.61, 32.01, 23.44 mm respectively (Table 3).

Table 3: Mann-Kendall *Southwest*-monsoon rainfall trend analysis with Sen's Slope Estimator for the period of (1998 -2022)

Name of the block	Kendall's tau	S value	p-value	Significant	Sen's slope	Trend
Vasai	-0.113	-34	0.44	No	18.05	Increasing
Wada	0.180	54	0.22	No	18.05	Increasing
Dahanu	0.480	144	0.00	Yes	46.17	Increasing
Palghar	0.207	62	0.15	No	21.68	Increasing
Jawhar	0.200	60	0.17	No	30.00	Increasing
Mokhada	0.153	46	0.29	No	21.61	Increasing
Talasari	0.287	86	0.05	Yes	32.01	Increasing
Vikramgad	0.207	62	0.15	No	23.44	Increasing

Post-monsoon (October – December)

The test results of Mann- Kendall shows that trend of rainfall in Post-monsoon (October – November) season was non-significantly increasing with positive values 0.62, 0.19, 0.71, 0.67, 0.57 & 0.71 in Wada, Dahanu, Palghar, Jawhar, Talasari and Vikramgad due to the derived p- value is more than 0.05 (level of significance). It indicates that null hypothesis H0 is not rejected.

Kendall tau of Wada, Dahanu, Palghar, Jawhar, Talasari and Vikramgad is 0.073, 0.191, 0.057, 0.064, 0.084, 0.057 respectively. Kendall tau shows the value of Vasai & Mokhada is -0.101 & 0.013 so it is considered as decreasing trend of rainfall in Vasai & Mokhada respectively. (Table 3).

The Sen's slope estimator analysis of post-monsoon rainfall shows rising trend in a Wada, Dahanu, Palghar, Jawhar, Talasari and Vikramgad with 0.92, 1.64, 0.40, 1.19, 0.79 and 0.83 respectively, while Vasai and Mokhada block observed the decreasing trend with -1.81 and -0.08 mm.

Table 4: Mann-Kendall Post-monsoon rainfall trend analysis with Sen's Slope Estimator for the period of (1998 -2022)

Name of the block	Kendall's tau	S value	p-value	Significant	Sen's slope	Trend
Vasai	-0.101	-30	0.50	No	-1.81	Decreasing
Wada	0.073	22	0.62	No	0.92	Increasing
Dahanu	0.191	57	0.19	No	1.64	Increasing
Palghar	0.057	17	0.71	No	0.40	Increasing
Jawhar	0.064	19	0.67	No	1.19	Increasing
Mokhada	-0.013	-4	0.94	No	-0.08	Decreasing
Talasari	0.084	25	0.57	No	0.79	Increasing
Vikramgad	0.057	17	0.71	No	0.83	Increasing

Winter (December - February)

Here p- value of Vasai, Palghar, Jawhar, Mokhada & Vikramgad observed 0.001, 0.001, 0.001, 0.004, 0.024 respectively, it resulted highly significant increasing trend of rainfall in these blocks during winter season. As the p- value less than 0.05 (level of significance 5%) therefore, it indicates that null hypothesis H0 is rejected and alternative hypothesis is accepted. While Wada, Dahanu & Talasari blocks shows non- significant increasing trend of rainfall. Table 5 shows Mann-Kendall trend analysis with Kendall tau 0.593, 0.290, 0.319, 0.550, 0.550, 0.487, 0.219, 0.382 for Vasai, Wada, Dahanu, Palghar, Jawhar, Mokhada, Talasari and Vikramgad respectively (Table 5).

There is no more change observed in the magnitude of rainfall by Sen's slope in all blocks in winter season.

Table 5: Mann-Kendall winter season rainfall trend analysis with Sen's Slope Estimator for the period of (1998 -2022)

Name of the block	Kendall's tau	S value	p-value	Significance	Sen's slope	Trend
Vasai	0.539	98	0.001	Yes	0.00	Increasing
Wada	0.290	61	0.075	No	0.00	Increasing
Dahanu	0.319	58	0.055	No	0.00	Increasing
Palghar	0.550	100	0.001	Yes	0.00	Increasing
Jawhar	0.550	100	0.001	Yes	0.00	Increasing
Mokhada	0.487	80	0.004	Yes	0.00	Increasing
Talasari	0.219	43	0.188	No	0.00	Increasing
Vikramgad	0.382	55	0.024	Yes	0.00	Increasing

Conclusion

As per the analysis of spatio-temporal annual & seasonal rainfall variability over eight blocks of Palghar district, it is concluded that annual rainfall trend was increased in blocks namely Wada, Dahanu, Palghar, Jawhar, Mokhada, Talasari & Vikramgad; whereas in Vasai block rainfall trend was decreased by Kendall tau –1.140 and Sen's slope -14.0 mm during 1998 -2022. This result obtained is might helpful to decision makers of the Vasai block for water supply and management. The trend analysis concluded that M–K test, with a Kendall's tau of 0.460 and 0.337 (significant at a 5% level), shows an increasing trend of annual rainfall in Dahanu and Talasari block respectively. Rainfall trend analysis of seasonal rainfall, winter rainfall analyzed the p- value of Vasai, Palghar, Jawhar, Mokhada & Vikramgad are 0.001, 0.001, 0.001, 0.004, 0.024 respectively, it resulted highly significant increasing trend of rainfall in these blocks during winter season. No change in Sen's slope amounts was obtained in the winter season in all over blocks. Overall results confirm that are temporal and spatial differences were observed in rainfall trends in eight blocks.

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