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Long Term Rainfall Trend Analysis of Different Time Series in Solapur District of Maharashtra, India

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A B S T R A C T

The long term behaviour of rainfall is necessary to study over space with different time series *viz*. annual, seasonal, monthly and weekly as it is one of the most significant climatic variable. Rainfall trend is an important tool which assesses the impact of climate change and provides direction to cope up with its adverse effects on the agriculture. Nine different stations of Solapur district were selected to carry out trend analysis where rainfed agriculture is major practice. The daily rainfall data of 57 years (1961-2017) of all stations has been processed out study the rainfall variability. To detect the monotonic trend, the non-parametric Mann-Kendall test was applied and the magnitude of trend is estimated by using Sen's Slope estimation method. The declining trends for annual, seasonal and monthly rainfall were found to be statistically significant. Most of the considered time series in different tahsil of Solapur district showed significantly decreasing trend in rainfall, so judicious utilisation of available water is necessary for sustainability in crop production.

Introduction

In primarily agricultural country like India, national economy is largely reliant on the agricultural production. The major agricultural enterprise constituent is still under rainfed cropping and hence agricultural production is still dependant on vagaries of monsoon. This situation is likely to remain so in near future also. The trend analysis helps in water resource management through appropriate measures and formulation of adaptation measures through appropriate strategies. Rainfall trend analysis, on different spatial and temporal scales, has been of great concern during the past century because of the attention given to global climate change from the scientific community (IPCC, 1996). The more accurate information about meteorological parameters and their trends are

also needed for the formulation of weather model, which will help to improve sustainability of water resource management planning. Agricultural production is not excluded from the vagaries of weather, despite many years of advance and improved micro level planning in the country. Climate and weather conditions influence the human activities and environmental resources sustainability, Crop yields and environmental resource sustainability in India is adversely affected due to climate change and highly depend on climatic condition of the area. The future rainfall trend will have its impact globally and will be felt severely in developing countries with agrarian economies, such as India.

Pal and Al-Tabbaa (2009) concluded that there is a decrease in precipitation in hilly regions and increase in the precipitation over rest of the Kerala. They noticed that the climate change is having different effects over different topographies and hence suggested the need of work at regional basis. Atre and Deore (2013) studied the weekly trend at Rahuri in Scarcity Zone of Maharashtra. Upadhye*et al.,* (2016) studied weekly, seasonal, monthly and annual rainfall trend at Akola station in Vidarbh region of Maharshtra.

Considering above suggestions, present study is done to find out the trends in annual, seasonal, monthly and weekly rainfall at nine stations of Solapur district, as a representative district in the scarcity region of Western Maharashtra.

Materials and Methods

Study area

The different locations in Solapur district of Maharashtra *viz.* Akkalkot, Barshi, Karmala, Madha, Malshiras, Mangalvedha, Mohol, Pandharpur and Sangola (Fig. 1) were selected for the present study. The entire study area is confined between latitude 17.10° to 18.32° N and longitude 74.42° to 76.15°E. The total geographical study area is 14,845 km^2.

Solapur district receives an average (1961 to 2017) annual rainfall of 618.6 mm in 39 rainy days. The average rainfall during monsoon season (June to September) is 465 mm. Peak rainfall occur during 4^{th} week of September. The major crops grown in the region are pigeon pea, sunflower and pearl millet during *kharif* season and chickpea, safflower and sorghum during *rabi* season.

Data acquisition

The required data of rainfall at all selected stations was obtained from All India Co-ordinated Research Project on Agrometeorolgy (AICRPAM) at Zonal Agricultural Research Station, Solapur. The acquired data were in the form of daily rainfall for 57 years (1961-2017).

This daily rainfall data was converted to the weekly, monthly, seasonal rainfall data for further use. To obtain seasonal rainfall daily rainfall data was divided in four seasons *viz.* Summer (Mar-May), North-East monsoon (Oct to Dec), South- West monsoon (Jun to Sept) and winter (Dec-Feb).

Rainfall trend analysis

Trend analysis can be simply described as analysis of change over the time series. As rainfall is considered as an independent weather parameter its weekly, monthly, seasonal and annual trend was tested by using Mann - Kendall Test and Sen's slope estimator method.

In Mann-Kendall test the presence of a monotonic increase or decrease in trend was

tested based on normalised test statistic (Z) value. Non-parametric Sen's Slope estimator gives the rate of increase or decrease in trend. Both of these methods are described below in detail.

Mann Kendall method

This is a statistical method which is mostly used to check the null hypothesis of no trend versus alternate hypothesis of the existence of alternative monotonic increasing or decreasing trend of hydro-climatic time series data**.**

For time series less than 10 points S-test can be used and for more than 10 data points normal approximation (Z-test) is used (Gilbert 1987). Annual, seasonal, monthly and weekly rainfall data values were evaluated as ordered time series.

The Mann-Kendall Statistic (S) is given byfollowing Equation.

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

$$sign(X_j - X_k) = \begin{cases} 1 & if \quad (X_j - X_k) > 0 \\ 0 & if \quad (X_j - X_k) = 0 \\ -1 & if \quad (X_j - X_k) < 0 \end{cases}$$

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

Where,

q = Number of tied groups

t_p= Number of data values in the p^{th} group n = Number of years for which data is available

The standard test statistics Z computed as follows:

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

The presence of a statistically significant trend was evaluated using the 'Z' value. A positive or negative value of 'Z' indicates rising or declining trend. Positive or negative trends are determined by the test statistic 'Z' at confidence levels of 99, 95, and 90 per cent. At the 99 per cent significance level, the null hypothesis of no trend is rejected if $|Z| > 2.575$; at the 95 per cent significance level null hypothesis of no trend is rejected at if $|Z| > 1.96$; and at the 90 per cent significance level, the null hypothesis of no trend is rejected if $|Z| > 1.645$.

Sen's slope method

To estimate the true slope of an existing trend (as the change per year) the Sen's non-parametric method is used. The Sen's slope method can be used in cases where trend can be assumed as linear.

If a linear trend is present in a time series, then the true slope (change per unit time) was estimated by using a simple non-parametric procedure developed by Sen (1968). This means that the linear model can be described as:

$$Q_t = \frac{x_i - x_k}{j - k}$$

Provided, i = 1, 2, 3, N and j > k and the Sen's slope estimate is,

$$Q_t = \begin{cases} Q_{\frac{N+1}{2}} & if \; N \; is \; odd \\ \frac{1}{2}\left(Q_N + Q_{\frac{N+1}{2}} \right) & if \; N \; is \; even \end{cases}$$

Median of all slope values gives Q_t, which is magnitude of trend. Positive value indicates increasing and negative value indicates decreasing trend of rainfall. Magnitude of trends was calculated for the statistically significant trends found by Mann- Kendall test.

Results and Discussion

Trends in annual rainfall

The annual rainfall data for the period 1961 to 2017 (57 years) of nine tahsils of Solapur district are analysed using Mann-Kendall test method and Sen's slope estimation method and results are given in table 1.

Out of nine tahsils, the annual rainfall at Akkalkot and Sangola is decreasing at 99 per cent significance level, Pandharpurtahsil is decreasing at 95 per cent significance level and Mangalvedha tahsil at 90 per cent level of significance. There was no trend observed in annual rainfall of Barshi, Karmala, Madha, Malshiras and Mohol. The Sen's slope estimate Q(t) of Akkalkot, Mangalvedha, Pandharpur and Sangola reveals that the annual rainfall at these station is decreasing at 5.21, 2.79, 3.59 and 4.44 mm per year (Table 1).

From table 1 it is also observed that the value of Mann-Kendall test Z and Sen's slope estimate Q(t) of Barshi, Karmala, Madha, Malshiras and Mohol is negative. It indicates decreasing trend even though it is statistically not significant.

Trends in seasonal rainfall

Seasonal trend analysis was carried out considering four seasons in a calendar year viz. winter; summer, South-West monsoon and North-East monsoon by using Mann-Kendall test and Sen's slope estimate method and the results are presented in the table 2. From table 2 it is observed that, for summer season there was decreasing rainfall trend in Sangola at 99 per cent level significance with magnitude of 0.99 mm per season. Karmala, Malshiras and Mohol tahsil summer season rainfall showed decreasing trend at 95 per cent level of significance with magnitude 0.36, 0.33 and 0.99 mm per season respectively.

Also, there was decreasing trend in summer season rainfall in Barshitahsil at 90 per level of significance and decreasing by 0.31 mm per season. Trend analysis of South-West monsoon rainfall showed Akkalkot and Sangola tahsil has decreasing trend at 95 per cent and 90 per cent level of significance decreasing by 3.51 and 2.22 mm per season. In case of North-East monsoon rainfall, there was no trend observed in all nine tahsils.

Trends in monthly rainfall

Trend analysis of monthly rainfall was carried out for six months May, June, July, August, September and October and the results are presented in table 3. From table 3 it is observed that in the month of May Malshiras and Sangola tahsil showed decreasing trend of rainfall at 99 per cent level of significance. The rate of decreasing rainfall is 0.08 and 0.51 mm per month respectively. In Akkalkot, Barshi, Mangalvedha, Mohol and Pandharpurtahsils decreasing rainfall trend was observed at 90 per cent level of significance. In Akkalkot and Mohol tahsil rate of decreasing rainfall is 0.04 and 0.12 mm per year. Decreasing rainfall trend in June month was observed only in Sangola tahsil at 90 per cent level of significance and the rate of decreasing was 1.93 mm per month. From table 3, in the month of July decreasing rainfall trend was observed at 90 per cent level of significance and it is decreasing at 0.11 mm per month. From table 3 it is observed that in Malshiras and Sangola tahsil rainfall trend is decreasing but it is statistically non-significant in the month of October.

Table.1 Trend in annual rainfall and its magnitude of selected tahsils of Solapur district

Tahsil	Mann-Kendall test	Sen's slope estimate	Trend
	Test Z	Q(t) (mm/year)	
Akkalkot	-2.92**	-5.21	Decreasing
Barshi	-0.68	-	No trend
Karmala	-1.61	-	No trend
Madha	-0.12	-	No trend
Malshiras	-0.58	-	No trend
Mangalvedha	-1.67+	-2.79	Decreasing
Mohol	-1.33	-	No trend
Pandharpur	-2.00*	-3.59	Decreasing
Sangola	-2.69**	-4.44	Decreasing

** 99 per cent significance level if Z >±2.54; * 95 per cent significance level if Z >±1.96; + 90 per cent significance if Z >±1.

Table.2 Trend in seasonal rainfall and its magnitude of selected tahsils of Solapur district

Tahsil	Winter			Summer			S-W monsoon			N-E monsoon		
	Test Z	Q (t)	Trend	Test Z	Q (t)	Trend	Test Z	Q (t)	Trend	Test Z	Q (t)	Trend
Akkalkot	-0.78	-	No	-1.63	-	No	-2.18*	-3.51	Dec.	0.1	-	No
Barshi	0.08	-	No	-1.86+	-0.31	Dec.	0.12	-	No	-0.13	-	No
Karmala	-0.46	-	No	-2.21*	-0.36	Dec.	-0.52	-	No	-0.81	-	No
Madha	0.45	-	No	-0.18	-	No	0.32	-	No	-0.47	-	No
Malshiras	1.42	-	No	-2.28*	-0.19	Dec.	0.27	-	No	-0.93	-	No
Mangalvedha	-0.08	-	No	-1.18	-	No	-1.36	-	No	-0.45	-	No
Mohol	0.32	-	No	-2.13*	-0.33	Dec.	-0.72	-	No	-0.63	-	No
Pandharpur	0.22	-	No	-1.49	-	No	-1.15	-	No	-0.47	-	No
Sangola	0.43	-	No	-3.72**	-0.99	Dec.	-1.67+	-2.22	Dec.	-1.37	-	No

Note: ** 99 per cent significance level if Z >±2.54; * 95 per cent significance level if Z >±1.96; + 90 per cent significance if Z >±1.64.

Table.3 Trend in monthly rainfall and its magnitude of selected tahsils of Solapur district

Tahsil	May			June			July			August			September			October		
	Test Z	Q (t)	Trend	Test Z	Q (t)	Trend	Test Z	Q (t)	Trend	Test Z	Q (t)	Trend	Test Z	Q (t)	Trend	Test Z	Q (t)	Trend
Akkalkot	-1.95+	-0.04	Dec.	-0.28	-	No	-1.84+	-1.32	Dec.	-1.48	-	No	-0.54	-	No	1.11	-	No
Barshi	-1.78+	0	Dec.	0.91	-	No	-0.54	-	No	0.67	-	No	-0.52	-	No	1.36	-	No
Karmala	-1.04	-	No	-0.3	-	No	-0.83	-	No	0.3	-	No	-0.33	-	No	0.12	-	No
Madha	-1.37	-	No	1.14	-	No	0.39	-	No	0.44	-	No	-0.3	-	No	0.11	-	No
Malshiras	-2.67**	-0.08	Dec.	0.18	-	No	-0.59	-	No	0.61	-	No	-0.21	-	No	-0.43	-	No
Mangalvedha	-1.76+	0	No	0	-	No	-0.35	-	No	-0.1	-	No	-1.55	-	No	0.2	-	No
Mohol	-1.72+	-0.12	Dec.	-0.09	-	No	-1.05	-	No	-0.21	-	No	-0.5	-	No	0.3	-	No
Pandharpur	-1.94+	0	No	0.02	-	No	-1.53	-	No	0.05	-	No	-0.41	-	No	0.17	-	No
Sangola	-3.5**	-0.51	Dec.	-1.93+	-1.09	Dec.	-0.72	-	No	0.48	-	No	-0.35	-	No	-0.29	-	No

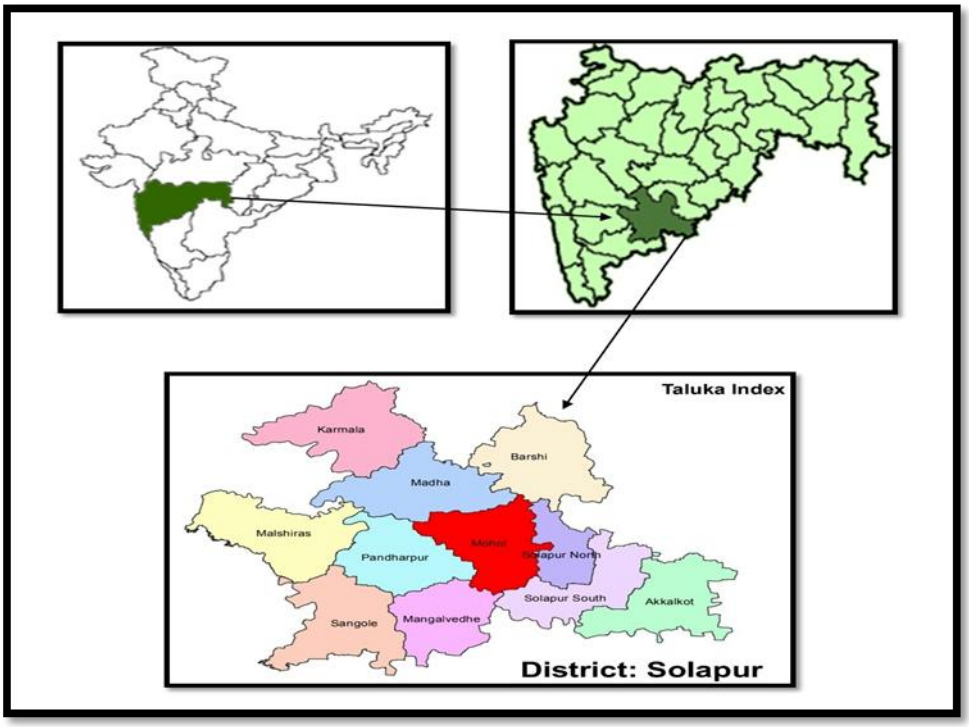
Note: ** 99 per cent significance level if Z >±2.54; * 95 per cent significance level if Z >±1.96; + 90 per cent significance if Z >±1.

Table.4 Trends in weekly rainfall and its magnitude of selected Tahsil of Solapur district

SMW	Akkalkot		Barshi		Karmala		Madha		Malshiras		Mangalvedha		Mohol		Pandharpur		Sangola	
	Test Z (MK)	Q(t)	Test Z (MK)	Q(t)	Test Z (MK)	Q(t)	Test Z (MK)	Q(t)	Test Z (MK)	Q(t)	Test Z (MK)	Q(t)	Test Z (MK)	Q(t)	Test Z (MK)	Q(t)	Test Z (MK)	Q(t)
22	-0.64	-	0.38	-	1.38	-	1.84+	0	0.18	-	-0.5	-	0.26	-	-1.27	-	-1.34	-
23	0.39	-	1.29	-	0.33	-	1.24	-	0.01	-	1.01	-	-0.49	-	1.47	-	0.67	-
24	-0.01	-	1.27	-	-0.44	-	1.58	-	-0.03	-	0.13	-	0.56	-	0.49	-	-0.12	-
25	-1.05	-	-0.15	-	1.12	-	-0.11	-	0.19	-	-0.78	-	-0.18	-	-0.55	-	-0.52	-
26	-0.84	-	0.66	-	-1.97*	-0.18	0.11	-	-1.17	-	-1.14	-	-1.05	-	-1.16	-	-2.97**	-0.21
27	-0.63	-	0.85	-	1.02	-	1.71+	0.1	0.39	-	-0.56	-	-0.03	-	-0.93	-	-0.79	-
28	-0.23	-	-0.82	-	-0.94	-	0.62	-	1.79+	0.1	1.07	-	-0.81	-	0.39	-	1.43	-
29	-0.81	-	-1.15	-	-0.08	-	0.05	-	-0.27	-	-0.94	-	-1.22	-	-1.43	-	-1	-
30	-0.56	-	-0.89	-	1.25	-	0.08	-	-0.42	-	-0.6	-	-1.4	-	-0.49	-	0.02	-
31	-1.12	-	0.46	-	0	-	-0.41	-	0.85	-	-0.8	-	-1.5	-	0.19	-	-0.29	-
32	-0.22	-	0.34	-	-0.62	-	0.3	-	0.12	-	0.62	-	0	-	1.05	-	0.03	-
33	-1.03	-	-0.39	-	-0.45	-	-0.3	-	0.43	-	-1.67+	-0.02	-0.61	-	-0.83	-	-0.3	-
34	0.65	-	1.72+	0.14	1.81+	0.05	0.98	-	2.14*	0.14	1.45	-	1.31	-	1.38	-	0.3	-
35	1.29	-	0.72	-	1.12	-	1.17	-	1.28	-	1.51	-	1.31	-	1.43	-	1.62	-
36	1.51	-	0.12	-	0.49	-	1.92+	0.2	1.42	-	1.05	-	0.49	-	2.27*	0.14	0.66	-
37	0.01	-	0.63	-	1.49	-	1.55	-	1.14	-	-0.31	-	0.03	-	0.47	-	0.37	-
38	-0.58	-	-0.62	-	-0.67	-	-1.82+	-0.54	-0.83	-	-1.52	-	-1.01	-	-0.39	-	-1.18	-
39	-0.1	-	-0.6	-	-0.68	-	-0.8	-	0.19	-	0.34	-	-0.8	-	-0.72	-	0.06	-
40	1.42	-	0.85	-	1.14	-	0.95	-	1.65+	0.29	0.87	-	0.63	-	-0.51	-	0.26	-
41	0.68	-	0.55	-	-0.27	-	0.96	-	0.25	-	0.08	-	-0.26	-	1.18	-	0.61	-
42	1.14	-	-0.07	-	0.7	-	1.19	-	-0.11	-	0.39	-	1.36	-	0.61	-	0.41	-
43	-0.77	-	0	-	-0.8	-	0.29	-	-1.47	-	-1.03	-	-0.83	-	-1.15	-	-1.01	-

Note: ** 99 per cent significance level if Z >±2.54; * 95 per cent significance level if Z >±1.96; + 90 per cent significance if Z >±1.64. 2. – indicate 'No trend

Fig.1 Tahsilwise location map of Solapur district



Trends in weekly rainfall

There exists increasing rainfall trend in Barshi and Karmala tahsil in 34th SMW. In Madhatahsil increasing rainfall trend was observed in 22nd, 27th and 36th SMW. Malshirastahsil also showed increasing trend in the rainfall of 28th, 34th and 40th SMW. 36th SMW showed increasing rainfall trend in Pandharpurtahsil. Decreasing rainfall trend was observed in Karmala, Madha, Mangalvedha and Sangola tahsils in 26th, 38th, 33th and 26th SMW respectively. Level of significance of these trends and their magnitude are given in table 4.

Thus, there exists decreasing rainfall trend in annual, seasonal, monthly and weekly rainfall in Solapur district. Water harvesting measures such as farm pond, tube well recharging, on farm contour bunding, compartmental bunding, ridges and furrows and tied ridges should be necessarily carried out before the commencement of monsoon in the study area. Moisture conservation practices like hoeing, harrowing after effective rainfall, broad bed furrows, organic, residue or vertical mulching, contour cultivation, vegetative barriers, etc. and judicious utilisation of water harvested for protective and supplemental irrigation through pressurised irrigation system i.e. drip and sprinkler irrigation, will assure availability of moisture in the soil and sustainable crop production.

Results of trend analysis using Mann-Kendall test Z and Sen's Slope estimate method revealed that Akkalkottahsil showed decreasing rainfall trend in annual, south-west monsoon rainfall as well as rainfall in the month of May and July. In Barshitahsil decreasing rainfall trend was observed in summer season and in the month of May and increasing rainfall trend in SMW 34th. In Karmala tahsil decreasing rainfall trend was observed only in summer season. Madhatahsil showed increasing rainfall trend in 22nd, 27th and 36th SMW. Malshirastahsil showed

decreasing trend of rainfall in summer season and in the month of May and increasing rainfall trend in 28th, 34th and 40th SMW. Annual rainfall of Mangalvedha tahsil showed decreasing trend and 33rd SMW also showed decreasing rainfall trend there. Decreasing rainfall trend was observed in Mohol tahsil in summer season and in the month of May. Annual rainfall in Pandharpurtahsil showed decreasing trend and 36th SMW showed increasing trend. In Sangola tahsil decreasing rainfall trend was observed in annual, summer and South-West monsoon rainfall as well rainfall in the month of May, June and July and 26th SMW also showed decreasing trend. Most of the considered time series in different tahsil of Solapur district showed decreasing trend in rainfall, so judicious utilisation of available water is necessary for sustainability in crop production.

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