Rainfall Trend in Semi Arid Region – Yerala River Basin of Western Maharashtra, India

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Abstract

The rainfall is the one of the fundamental physical parameter among the climate as for the development of society is concern and it determines the drought as well as the environmental factors for the particular region. Time-series of annual rainfall, number of rainy-days per year and monthly rainfall of 10 stations were analyzed to assess climate variability in semi-arid region of Western Maharashtra. The results showed mixed trends of increasing and decreasing rainfall, which were statistically significant ($p < 0.05$ and $p < 0.01$) only for Koregaon and Palus stations by the Mann–Kendall test. Also, with the exception of Vita and Vaduj stations there was no statistically significant trend in the mean number of rainy-days per year. Increasing and decreasing monthly rainfall trends were found over large continuous areas in the study region. These trends were statistically significant mostly during the winter and spring seasons, suggesting a seasonal movement of rainfall concentration. Results also showed that there is no significant climate variability in the semi-arid environment of Western Maharashtra.

Key Words: *Annual and seasonal rainfall, rainfall variability, Nonparametric methods, Mann–Kendall test, Rainy-days*

1. Introduction

Global water resources are highly sensitive to both climate change and climate variation. Rainfall, the main input to the global hydrological cycle and an important indicator of water resources availability, has shown significant change and variations over the years both globally and regionally. In this region, the rains are highly variable in time, space, amount and duration, and water is the most important limiting factor for biological and agricultural activities. Seasonal changes in rainfall pattern may alter the hydrological cycle and environmental processes (Delitala et al., 2000) as well as the vegetation and the entire ecosystem (Lazaro et al., 2001). Many studies have been conducted for regional climate assessment of some countries of southwest Asia. The results of these studies have clearly shown that there is climate variability in these regions as a result of human interference on the ecosystems.

Land degradation in Yerala River Basin has been increased in the last decades as a result of irregular and uncoordinated exploitation of water resources as well as by the extensive land-use and the use of wood and plants as fuel. Such degradation places those areas in serious risk of desertification. However, climate variability and its potential effects on semi-arid regions have not been adequately and carefully investigated. The impact of human activities on general climate at a global scale is widely accepted. The basic hypothesis of this study was that global climate change could be observed as climate variability in Western Maharashtra.

Variability in rainfall data may provide a general gauge regarding changes in the natural behavior of ecosystems. A key step in this process is the ability to reveal that a change or trend is present in the rainfall records. The linear relationship is the most common method used for detecting rainfall trends (Hameed et al., 1997). On the other hand, the Mann–Kendall (MK) test has been widely used to evaluate a presence of a statistically significant trend in hydrological and climatologically time-series (Hirsch and Slack, 1984; Yue et al., 2002). Also, several studies have analyzed rainfall trends in semi-arid regions all over the world.

They observed that the annual mean values of air temperature, evaporation, sunshine and wind speed have all declined, while annual rainfall and mean relative humidity have slightly increased. Rainfall is the most important variable for agricultural water management in dry land farming in India. Moreover, the knowledge of trends in annual rainfall and number of rainy-days are very important for agricultural planning in any region. In this context, the objective of this study was to investigate rainfall variability in semi-arid region of Western Maharashtra using non- parametric analysis methods.

2. Study area

The study area lies in western part of Maharashtra state bounded by Latitude 16^0 55’ to 17^0 28’ N and Longitude 74^0 20’ to 74^0 40’ E. falling in part survey of India topographical sheet No. 47 K – 5, 6, 7, 8, 10, 11, 12 and 47 L - 9 on the scale 1:50,000 **(Fig. 1)** it covers total area of 3035 km^2 includes two districts (Satara and Sangli) in Maharashtra.

The average annual rainfall increases from 1900 mm in the western side to 600 mm in the east side. Geology of the area is dominantly covered by basaltic rock. The area has suffered a lot by tectonic movement in the past as evidenced by varying fold, fault and lineament association with hills located in the western side of study area.

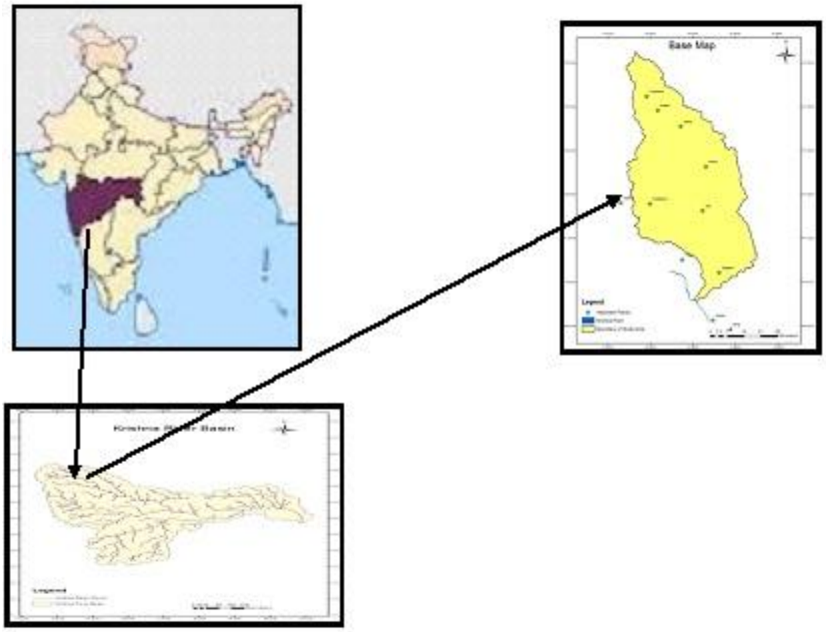


Fig. 1 Spatial distribution of selected stations in Semi-arid region of Yerala River Basin

The wet and dry seasons generally occur between July and October and between January and May, respectively. The climate of the region is defined as subtropical with hot and dry weather in the summer. The main cause of annual rainfall variability in Western Maharashtra is the changing position of synoptic systems.

3. Materials and Methods

Rainfall data of ten stations operated by the meteorological organization of Western Maharashtra were used to evaluate rainfall variability in semi-arid zones throughout the country (Table 1). These stations were selected because they have rainfall records of at least 12 years and are fairly evenly spread throughout the study region. The data set has included annual rainfall, number of rainy-days per year and monthly rainfall. The number of rainy-days per year was defined as the number of days of the year with a rainfall amount greater than 1 mm.

The homogeneity of the rainfall time-series was determined by Thom test (Thom, 1966) at the 95% confidence level. This test assesses variations of the time-series data from a central value, usually the median. The Thom test is described in detail by (Buishand, 1982) and (Rodrigo et al., 1999).

3.1 The MK test, usually used to assess the trend of a time-series, was applied by considering the statistic S as:

$$\mathbf{S} = \sum_{i=2}^{n}\sum_{j=1}^{i-1} sign\,(x_i - x_j) \tag{1}$$

Where the x_j are the sequential data values, n is the length of the time-series and sign $(x_i – x_j)$ is -1 for $(x_i – x_j) < 0$; 0 for $(x_i – x_j) = 0$ and 1 for $(x_i – x_j) > 0$.

The mean E[S] and variance V[S] of the statistic S were obtained as:

$$E[S] = 0 \tag{2}$$

$$\boldsymbol{Var}\,[\boldsymbol{S}] = \frac{1}{18}\left(\mathrm{n(n-1)(2n+5)} - \sum_{p=1}^{q} t_p\,(t_p - 1)(2t_p + 5)\right) \tag{3}$$

Where tp is the number of ties for the p^{th} value and q is the number of tied values. The second term represents an adjustment for tied or censored data. The standardized statistical test (ZMK) was computed by:

$$\mathrm{Z_{MK}} = \begin{cases} \dfrac{S-1}{\sqrt{Var\,(S)}} & if\ S > 0, \\ 0 & if\ S = 0, \\ \dfrac{S+1}{\sqrt{Var\,(S)}} & if\ S < 0 \end{cases} \tag{4}$$

Table 1 Weather stations with geographical coordinates located in the semi-arid region of Western Maharashtra in India

SN	Rainguage Station	Sample Size (Year)	Latitude	Longitude	Altitude (m)
1	Dahiwadi	13	74°33'02.63" E	17°42'16.20" N	714
2	Isalampur	13	74°15'57.88" E	17°03'01.91" N	590
3	Kadegaon	13	74°19'56.40" E	17°18'07.58" N	675
4	Karad	51	74°13'33.01" E	17°18'11.73" N	580

5	Koregaon	13	74°13'40.82" E	17°43'16.94" N	727
6	Miraj	13	74°38'55.05" E	16°49'23.37" N	562
7	Palus	13	74°27'27.12" E	17°05'29.28" N	570
8	Tasgaon	13	74°36'14.03" E	17°02'22.56" N	585
9	Vaduj	13	74°27'14.37" E	17°35'24.82" N	720
10	Vita	17	74°32'16.04" E	17°16'27.70" N	680

Positive values of Z_{MK} indicate increasing trends while negative Z_{MK} indicate decreasing trends. When testing either increasing or decreasing monotonic trends at a p significance level, the null hypothesis was rejected for absolute value of Z greater than Z1-p/2, obtained from the standard normal cumulative distribution tables. In this work, significance levels of $p = 0.01$ and 0.05 were applied. The non-parametric estimate of the trend slope magnitude was obtained as (Hirsch et al., 1982):

$$\beta = Median \left[\frac{(x_j - x_i}{(j - i)} \right] \quad for\ all\ i < j, \tag{5}$$

Where x_j and x_i are data points measured at times j and i respectively.

3.2. Test of randomness

Autocorrelation functions are commonly used for checking randomness in a data set. This randomness is ascertained by computing autocorrelations for data values at varying time lags. If random, such autocorrelations should be near zero for any and all time-lag separations. If non-random, then one or more autocorrelation values will be significantly non-zero. These functions were used to test the randomness of annual rainfall and rainy days per year time-series. The randomness of the data set was tested by the autocorrelation function for the confidence bands (CB) given by

$$CB = \frac{Z_i - \alpha/2}{\sqrt{n}} \tag{6}$$

Where z is the percent point function of the normal distribution n is the sample size and α is the significance level. Thus, the CB has fixed width that depends on the sample size.

4. Results and Discussion

4.1. Annual rainfall

The descriptive statistics of annual rainfall such as the coefficient of variation (C_v), coefficients of skewness (C_s) and coefficients of kurtosis (C_k) are presented in Table 2. The mean values of C_v, C_s and C_k for the study region were 0.339%, -0.108 and 0.17, respectively. For all stations C_v was higher than 0.25%, except for the Vaduj station (0.23%) which is located in the north of the study area. These indexes demonstrate high annual rainfall variability in the semi-arid regions of Western Maharashtra.

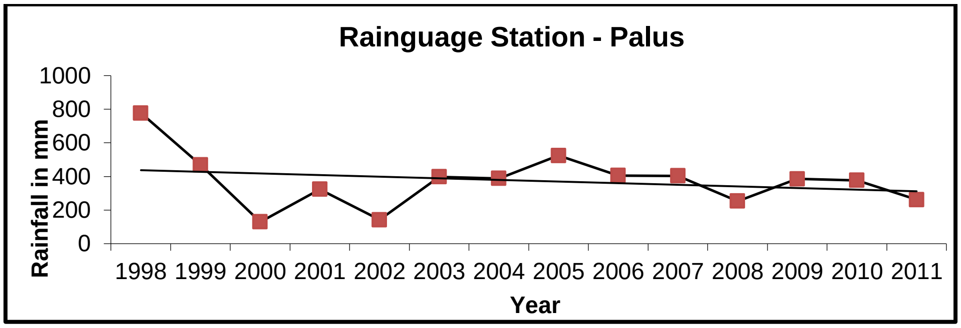
The highest values of coefficient of kurtosis were found for the Koregaon and Vita stations. Despite the low values for the degree of skewness, with the exception of Vita, these stations showed a high degree of peakedness which is quite different from that of a normal distribution. The CV values decline from the south to north of the study area, with a maximum value of 0.43% at the Palus station. There was a mix of increasing and decreasing of rainfall trends widespread throughout the study area. This result suggests that the rainfall trends in a few provinces must be attributed to local changes in the rainfall regime rather than the large-scale patterns of atmospheric circulation. The mean annual rainfall of the study region is relatively low, ranging from 382.81mm at Palus to 848.54mm at the Koregaon station. In general, the standard deviation is high, ranging from 164.37 to 298.88 mm. The MK test indicated statistically significant trends for only two stations. Fig. 2 shows decreasing and increasing trends in annual rainfall for the Palus and Koregaon stations. The annual rainfall showed a decreasing trend of 1.45 mm/year (statistically significant at $p < 0.001$) at the Palus station and an increasing trend of 1.3 mm/year (statistically significant at $p < 0.05$) at the Koregaon station. The autocorrelation functions for the annual rainfall time-series for Palus and Koregaon stations are shown in Fig. 3. It was observed that all autocorrelation coefficients fall within the 95% confidence limits. Therefore, these two time-series are strongly random.

Table 2 Minimum rainfall (R_m), maximum rainfall (R_x), mean rainfall (R_e), standard deviation (SD), coefficient of variation (C_v), coefficients of skewness (C_s), coefficients of kurtosis (C_k) and time-series trend by Mann–Kendall test (Trend MK). The values in the column p-value refer to the significance level of the trends (MK tests)

Sr. No.	**Station**	**R_m (mm)**	**R_x (mm)**	**R_e (mm)**	**SD (mm)**	**C_v**	**C_s**	**C_k**	**P-Value**	**Trend (MK)**
1	Dahiwadi	311	977.1	569.823	192.858	0.34	-0.13	-0.2	0.1	0.359
2	Isalampur	291	1412.6	768.654	278.978	0.36	0.15	-0.5	0.858	0.051
3	Kadegaon	288.23	1038.4	603.359	245.857	0.41	-0.41	-0.8	0.042	0.436
4	Karad	425.86	1178.4	800.762	235.25	0.29	-0.03	-0.2	0.252	0.256
5	Koregaon	388.6	1422.3	848.549	298.885	0.35	-0.21	0.3	0.51	0.154
6	Miraj	321	908.9	569.656	177.137	0.31	0.94	2.4	0.306	0.231
7	Palus	130	777	382.815	164.885	0.43	-0.09	-0.3	0.59	-0.128 [a]
8	Tasgaon	167.4	777	547.177	166.381	0.30	-0.09	-0.4	0.858	0.051
9	Vaduj	175.3	1006.1	602.665	225.386	0.37	0.34	-1.0	0.51	0.154
10	Vita	299.3	858	705.1	164.372	0.23	-1.55	2.4	0.675	0.103

[a] Trends statistically significant at $p < 0.05$.

[b] Trends statistically significant at $p < 0.01$.



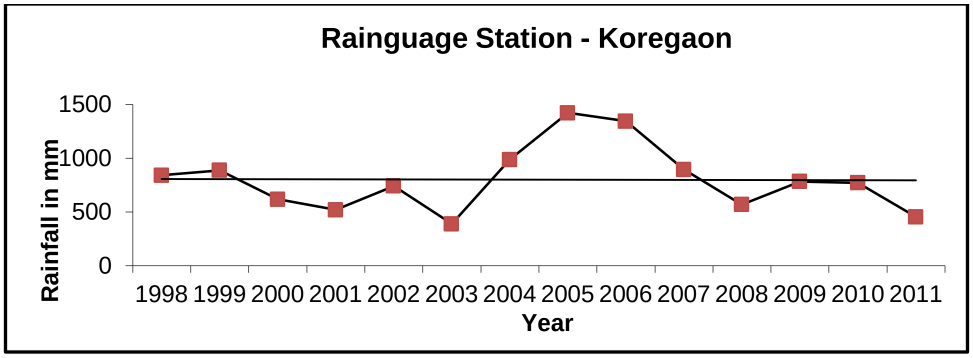


Fig. 2 Annual rainfall fluctuations and straight line trends for Stations: (a) Palus and (b) Koregaon

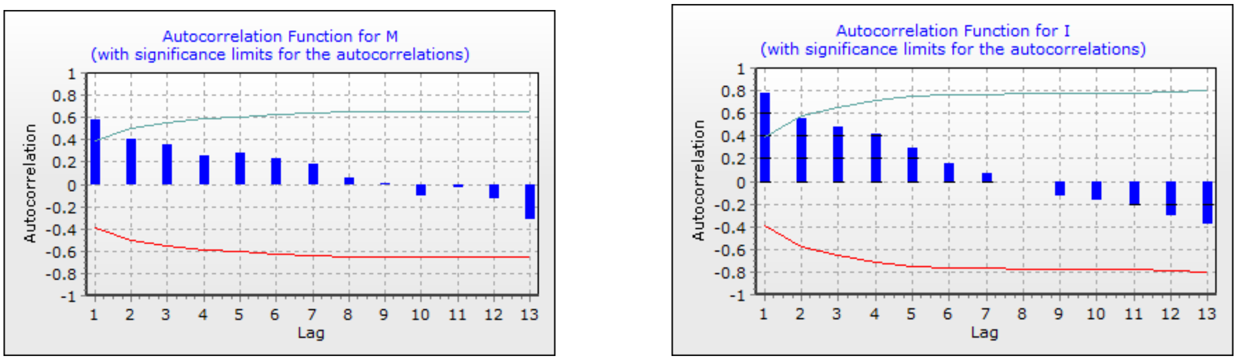


Fig. 3 Autocorrelation plots for stations: (a) Palus and (b) Koregaon. Upper and lower dashed lines are 95% confidence bands.

4.2. Number of rainy-days

The mean of the number of rainy-days per year was 62.4, which occurred within the 10–50-day range suggested by (Noy-Meir 1973). The minimum and maximum numbers of rainy-days per year are 14 and 102 for Kadegaon and Koregaon stations, respectively. The homogeneity Thom's test for annual number of rainy-days showed that all analyzed time-series were homogeneous at $p < 0.05$ according to the Thom test.

The negative trend of 2.8 rainy-days per year observed at the Palus station was due to a reduction of 0.84 mm/year in the annual rainfall. Similarly, the maximum positive trend of 2.19 rainy-days per year observed at the Koregaon station was due to an increase of 0.54 mm/year in the annual rainfall. These trends are statistically significant at $p < 0.01$ while the decreasing and increasing trends observed in other stations are not statistically significant. Therefore, the decrease in the annual rainfall resulted in a corresponding decrease in the number of rainy-days. The number of rainy-days per year is significantly correlated to the annual rainfall for all stations at 1% or 5% significance levels by t-test (Table 3). Therefore, an approximate value of the annual rainfall may be obtained by simply counting the number of rainy-days. The results also showed that the mean number of rainy-days per year ranged from 51.53 at Dahiwadi to 77.7 at the Karad station. It is observed that the decrease in the number of rainy-days is more significant than that of annual rainfall in India.

Table 3 Mean rainy-day per year (MRD), trend value and p value, the values in the column p-value refer to the significance level of the trend (MK tests)

Sr. No.	Stations	MRD	P value	Trend
1	Dahiwadi	51.53	0.903	0.039
2	Isalampur	60.84	0.806	0.065
3	Kadegaon	57.92	0.006	0.597
4	Karad	77.76	0.625	0.116
5	Koregaon	74.53	0.501	0.156
6	Miraj	56	0.204	0.282
7	Palus	55.69	1	0.013
8	Tasgaon	63.84	0.903	0.039
9	Vaduj	59.23	0.435	0.179
10	Vita	67.46	0.541	0.142

Fig. 4 shows the decreasing and increasing trends of rainy-days per year for the Kadegaon and Dahiwadi stations, respectively. The number of rainy-days per year at the Kadegaon station had a decrease over the study period of approximately 20-22 days while the Dahiwadi station had an increase of 10-12 days. Out of the 8 other stations, no statistically significant negative or positive trends were observed. The autocorrelation plots for the Kadegaon and Dahiwadi stations are presented in Fig. 5. Once the autocorrelations are all close to zero for all time-lag separations, the number of rainy-days as well as the annual rainfall time-series are random in study area.

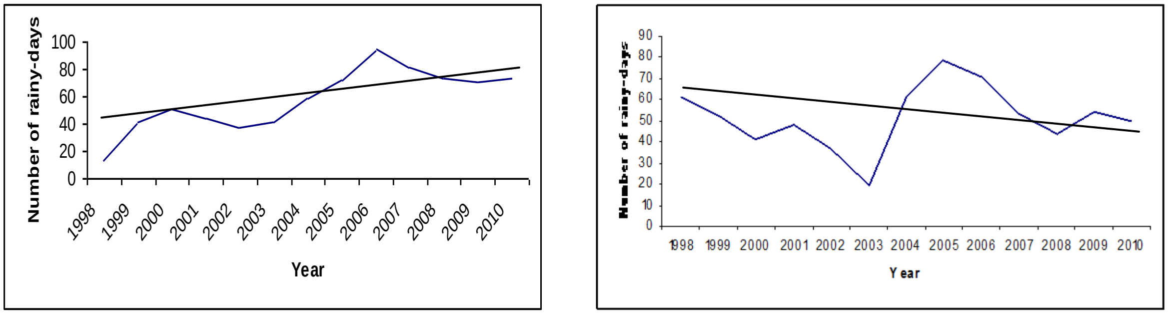


Fig. 4 Annual course of the number of rainy-days per year and straight line trend for stations (a) Kadegaon and (b) Dahiwadi

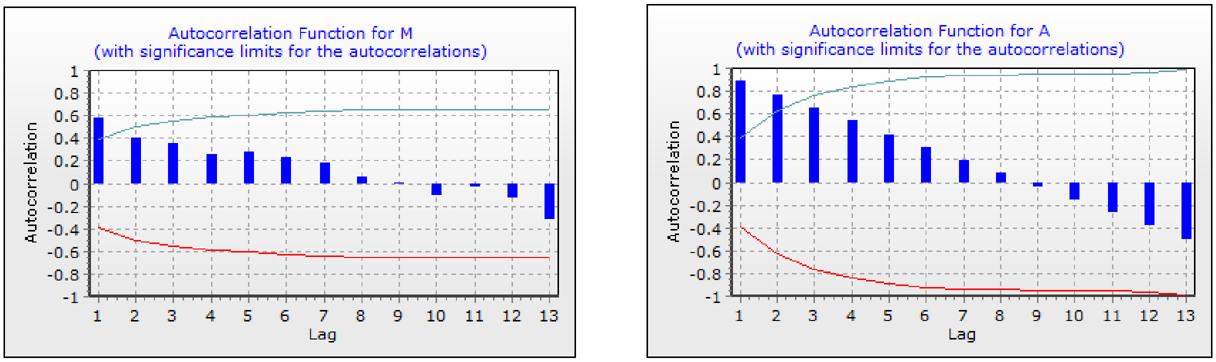


Fig. 5 Autocorrelation plots for stations: (a) Kadegaon and (b) Dahiwadi. Upper and lower lines are 95% confidence bands.

5. Conclusions

This study investigated rainfall variability in semi-arid region of Western Maharashtra by analyzing data for annual rainfall and number of rainy-days per year collected at 10 stations. Results showed that all analyzed time-series were homogeneous at $p < 0.05$ according to the Thom test. On the other hand, the Mann–Kendall test applied to the annual rainfall time-series showed statistical significance at $p < 0.05$ or $p < 0.01$ and increasing and decreasing trends for only two stations. Most of the stations showed no statistically significant negative and positive trends widespread throughout the region. Only local and isolated trends in the rainfall data were found. The stations with significant trends in the number of rainy-days did not show a consistent spatial pattern. These results also indicated that for the analyzed time-period, there was no significant climate change in the semi-arid region of Western Maharashtra. The stations with significant annual rainfall trends are evenly distributed to the north and south of the region and the northern stations showed positive trends while the southern stations showed negative trends. The correlations between annual rainfall and number of rainy-days were statistically significant for all stations. Therefore, the number of rainy-days has a significant relation to annual rainfall in Study area. The results also suggest the need for further investigation on local anthropogenic intervention in the environment, which could be one of the major causes of climate change in semi-arid regions.

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