International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
www.chemijournal.com
IJCS 2020; SP-8(2): 130-135

Received: 16-01-2020
Accepted: 17-02-2020

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Trend analysis of monsoon season monthly rainfall of Nagwan watershed

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DOI: https://doi.org/10.22271/chemi.2020.v8.i2c.9671

Abstract
The daily rainfall data for a period of 32 years from 1983-2014 of gauging station located in Nagwan watershed of Hazaribagh, Jharkhand were analyzed to study variation of monsoon months and monsoon season rainfall distribution pattern and its trend. The monsoon months and monsoon season rainfall series from daily data were developed. The mean, standard deviation, coefficient of variation, coefficient of skewness and kurtosis of monsoon months and monsoon season rainfall series were calculated. The percentage contributions of monthly rainfall to monsoon season rainfall values were also calculated. Frequency distributions of monsoon months and monsoon season rainfall were developed. The monsoon months and monsoon season rainfall time series were splitted in four sub-periods viz. 1983-1989, 1990-1999, 2000-2009 and 2010-2014. The difference in mean of monsoon months and monsoon season rainfall were tested by student t-test at 5% level of significance. The trend in monthly and monsoon season rainfall were tested by Mann-Kendall rank correlation test, Sen's slope estimator method and by regression test for linear trend. The value of Mann-Kendall statistic is negative for June, July, August, September and Monsoon season rainfall indicating a falling trend. However trend is not significant in all the cases at 5% significance level. Rising trend for the month of August and falling trend in case of June, July, September and Monsoon season are observed by Sen's method. No significant rising or falling trend on the regression slope for all the time series is observed at 5% level of significance.

Keywords: Nagwan, monsoon, Hazaribagh

1. Introduction
The dependence of Indian agriculture on the monsoon is as old as civilization. The basic source of water is precipitation in the form of rainfall and snowfall. Presently, 70% area in country is rainfed which contribute 50% of the food grain. While remaining 50% food is produced by irrigated area which is only around 30% of cultivated land (Dinkar, 1990) [3]. There is wide fluctuation in the food production in rainfed areas depending on amount and distribution of rainfall during monsoon season because Indian subcontinent gets nearly 75% of its annual rainfall during the four monsoon month from, June to September (Dhar et.al., 1974) [2]. The Indian agriculture is mostly rainfed (around 60% of arable land) and monsoon plays a major role not only in agriculture but also in allied day to day activities. The knowledge amount of rainfall, number of rainy days and its distribution over the cropping season are important for timely preparation of seed bed, selection of crop varieties, choice of cropping pattern (Ray *et al.*, 2014) [8]. India has skewed pattern of rainfall distribution, receiving 50 percent of its annual rainfall in just 15 days. The success or failure of crops is closely linked with the rainfall pattern. The important characteristics of rainfall influencing production are date of onset of monsoon, duration of wet spell, dates of occurrence and duration of intervening dry spells, distribution of weekly rainfall and number of rainy days. For drive maximum benefit for agriculture one must have a proper knowledge of distribution of rainfall amount in time and space. With crop predominantly depend on natural rainfall; most spectacular climatic event of agricultural relevance is the occurrence of commencement of the monsoon rain. Chand (2011) [1] analyzed that 90.3% of the total annual rainfall in Jhansi is received during SW monsoon months (June- September) with high intensity causes moderate to severe erosion.

Rainfall is the main linking component of the hydrological cycle, which generally varies from place to place and month to month in a cyclic pattern. The life style and socio-economic activities of people in the region heavily rely on the rainfall. Intergovernmental Panel on

Climate Change has reported that future climatic change is likely to affect the agriculture, increase of risk of hunger and water scarcity and may lead to rapid melting of glaciers. Rainfall is one of the main climatic factors that can indicate the climate change. It is reported that a higher or lower or changes in the rainfall distribution would influence the spatial and temporal distribution of runoff, soil moisture, groundwater reserves and would alter the frequency of drought and floods. While the observed monsoon rainfall at all-India level does not show any significant trend, regional monsoon variations have been recorded. A trend of increase in monsoon seasonal rainfall have been found along the west coast, northern Andhra Pradesh and north-western India while a trend of decreasing monsoon seasonal rainfall has been observed over eastern Madhya Pradesh, north-eastern India and some parts of Gujarat and Kerala (Kumar and Singh, 2011) [4]. Trends in rainfall in response to climate change have been studied by various researchers like Mohanty (2001) [6] studied the rainfall characteristics of Vidarbha region of the daily data of 33 years (1966 - 1998) using frequency analysis and Soni and Kumar (2002) [11] studied the weather cycle phenomenon for Malwa region of M.P. Daily rainfall data from 1991-2000 from eight districts of Malwa region were analyzed using Markov chain model. Rath *et al*. (1996) [7] analyzed the forecasting of dry and wet spells for agricultural management and planning of Boudh district of Orissa, situated on the bank of river Mahanadi. Markov Chain has been applied to know the probability of having different condition of dry and wet pentads and also forward and backward accumulation of rain water suitable for the crop production. These researchers have emphasized that the knowledge of rainfall variations is essential for proper water management practices.

A comprehensive knowledge of the trend and persistence in rainfall of the area is of great importance because of economic implications of rain sensitive operations. Climate change through Global/Regional circulation Model may predict higher forecast for future, which is subjected to debate. However, trend analysis for long term climatological data are likely to provide realistic trend in the climate. The analysis of historical climatological data with appropriate statistical tools can lead to valuable information about the trend of climatological parameters of a location like Sharma and Kumar (2003) [10] analysed rainfall of 20 years of Nagpur district to suggest the probable date of onset of monsoon and occurrence of dry spells using criteria given by Markov chain model. Keeping the above points into consideration, this study was undertaken with the following objectives:

1. To study variation in distribution pattern of monsoon monthly and monsoon seasonal rainfall data series for Nagwan watershed of Hazaribagh district, Jharkhand
2. To examine monsoon monthly and monsoon seasonal rainfall data series for trend analysis.

2. Materials and Methods

2.1 Study Area and Collection of Data

The daily rainfall data for the period of 32 years (1983-2014) were obtained from the Soil Conservation Department of Damodar Valley Corporation (D.V.C.), Hazaribagh, Jharkhand for the gauging station located in the Nagwan watershed for the study.

Nagwan watershed having a total area of nearly 9576 ha is located at the upper part of the Sewani River within the Damodar-Barakar catchment. The watershed is just 7 km from the Soil Conservation Department of D.V.C. at Hazaribagh, Jharkhand and is having well documented long term time-series database on hydrology and sediment-yield. Its measuring station is located at 85°24 E and 24° 03 N. The total annual rainfall of 1206 mm is distributed mainly between June to September, with about 15 rainy days per month. The average storm intensity, by considering storms of more than 30 min duration, is about 10 cm/hr. Out of the total watershed area about 55.00% is under agriculture, 17.22% is under forest and about 21.77% is a wasteland. The agriculture is mostly rainfed as only 20% irrigation is available in the area through sources other than rain.

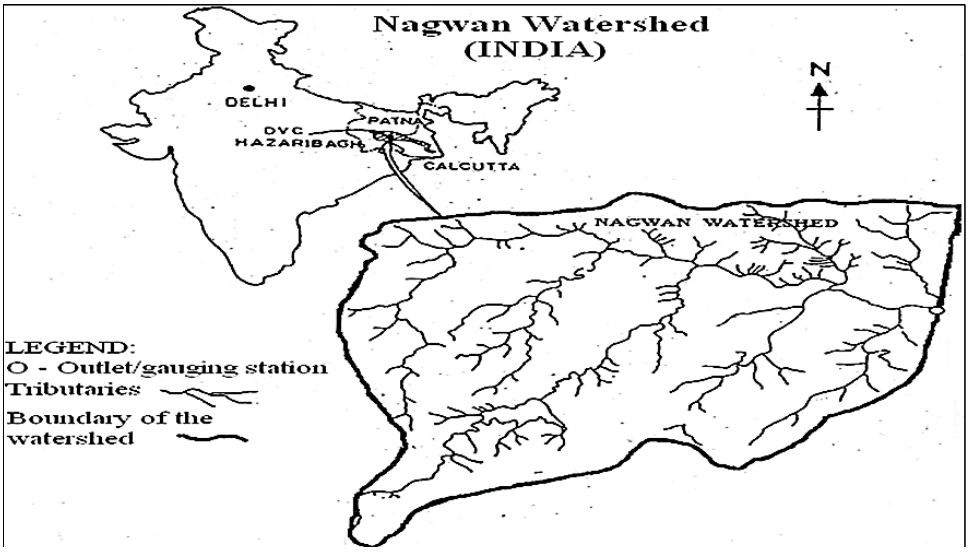

Fig 1: Location and topographic map of Nagwan watershed

2.2 Analysis of Data

2.2.1 Statistical properties of rainfall data series

The daily data of June, July, August and September months were converted into monthly and monsoon season data series of rainfall. The mean, standard deviation, coefficient of variation, coefficient of skewness and coefficient of kurtosis of the data series were calculated using the following equations:

$$\bar{x} = \frac{\sum_{i=1}^{N} x_i}{N} \qquad \ldots (2.1)$$

$$\sigma_{n-1} = \sqrt{\frac{(x_i-\bar{x})^2}{N}} \quad \ldots (2.2)$$

$$C.V = \frac{\sigma_{n-1}}{\bar{x}} * 100 \quad \ldots (2.3)$$

$$c_s = \frac{m_3}{(\sqrt{m_2})^3} \quad \ldots (2.4)$$

$$c_k = \frac{m_4}{{m_2}^2} \quad \ldots (2.5)$$

Where,
x_i= variate, (rainfall)
$\bar{x}$ = mean of variate
σ_{n-1} = standard deviation of variate
C.V =coefficient of variation of variate
c_s = coefficient of skewnes
c_k = coefficient of kurtosis
m_2 =second moment about mean,
m_3 =third moment about mean,
m_4 =fourth moment about mean.

2.2.2 Comparison of Mean

One of the methods to find if there is any trend in any two intervals is to test if the mean for the period differ significantly. The period 1983-2014 was spilt into 1983-1989, 1990-1999, 2000-2009, and 2010-2014 sub-periods for this purpose. If $\bar{x}_1$ and σ_1 are the mean annual rainfall and standard deviation of the first period which has size n_1, $\bar{x}_2$, $\sigma_2$and n_2 are the corresponding quantities of the second series, then:

$$t = \frac{\bar{x}_1-\bar{x}_2}{s} \sqrt{\left\{\frac{n_1 n_2}{n_1+n_2}\right\}} \quad \ldots (2.6)$$

Where,

$$s=\sqrt{\left\{\frac{(n_1-1)\sigma_1^2+(n_2-1)\sigma_2^2}{n_1+n_2-2}\right\}} \quad \ldots (2.7)$$

is distributed as student 't' with $(n_1 + n_2 - 2)$degee of freedom. The calculated value of't' was compared with tabulated value of't' and hypothesis of no difference in the means of sub-periods was tested at 5% level of significance.

2.2.3 Trend Analysis

A steady and regular movement in a time series through which values are, on average, either increasing or decreasing is termed as trend. To test whether the rainfall over Nagwan watershed is having any decreasing or increasing trend, monthly and monsoon season series of rainfall were analyzed to understand the variability and trend of rainfall.
The following statistical tests were employed to examine the series:

2.2.3.1 The Mann-Kendall's Rank Correlation Test

This test is based on the proportionate number of subsequent observations which exceed a particular value. In this test number of times x_j is greater than x_i was determined in all pairs of observations (x_i, x_j; j>i) of sequence $x_1,x_2,\ldots,x_n$. The ordered (i,j) subsets are (i=1, j=2,3,4,…,N), (i=2, j=3,4,…,N)….,(i=N-1,j=N).
Let p number of times x_j is greater than x_i, then test statistics τ was calculated:

$$\tau = \frac{4p}{N(N-1)} - 1 \quad \ldots (2.8)$$

The statistics has following parameters:

$$E(\tau)=0 \quad \ldots (2.9)$$

$$Var(\tau)=\frac{2(2N+5)}{9N(N-1)} \quad \ldots (2.10)$$

$$\text{Standard test statics}=\frac{\tau}{\sqrt{var(\tau)}} \quad \ldots (2.11)$$

Since the statistics converges rapidly to a standard normal distribution as N increases, therefore, the hypothesis of no trend in the series was tested at 5 percent level of significance by comparing calculated value of standard test statistic with tabulated value of standard normal variate.

2.2.3.2 Sen's Slope Estimator

The magnitude of the slope of trend is estimated using the approach described by Sen (1968) [9]. The Sen's slope estimator is a nonparametric, linear slope estimator that works most effectively on monotonic data. Sen's slope estimator is found to be a powerful tool to determine the magnitude of the trend line. Sen's slope has the advantage over the regression slope in the sense that it is not much affected by gross data errors, outliers or missing data. The Sen's slope is estimated as the median of all pair-wise slopes between each pair of points in the dataset. Each individual slope (m_{ij}) is estimated using the following equation:

$$m_{ij}=\frac{(Y_i-Y_j)}{(j-i)} \quad \ldots (2.12)$$

Where, i = 1 to n-1, j = 2 to n, Y_j and Y_i are data values at time j and I (j>i), respectively. If there are n values of Y_j in the time series, there will be N=n (n-1)/2 slope estimates. The Sen's slope is the median slope of these N values of slopes. The Sen's slope is:

$$m = m_{\left[\frac{N+1}{2}\right]}, \text{ if n is odd} \quad \ldots (2.13)$$

$$m = \frac{1}{2}\left(m_{\left[\frac{N}{2}\right]} + m_{\left[\frac{N+2}{2}\right]}\right), \text{ if n is even} \quad \ldots (2.14)$$

Positive Sen's slope indicates rising trend while negative Sen's slope indicates falling trend.

2.2.3.3 Linear Regression Analysis

Linear regression analysis is a parametric model and one of the most commonly used methods to detect a trend in a data series. However, this method requires the assumption of normality of residuals (McBean and Motiee, 2008) [5]. Viessman (1989) [12] reported that many hydrological variables exhibit a marked right skewness partly due to the influence of natural phenomena and do not follow a normal distribution. This model develops a relationship between two variables (dependent and independent) by fitting a linear equation to the observed data. The data is first checked whether or not there is a relationship between the variables of interest. This can be done by using the scatter plot. If there appears no association between the two variables, linear regression model will not prove a useful model. A numerical measure of this association between the variables is the correlation coefficient, which range between -1 to +1. The linear regression model is generally described by the following equation:

$$Y = m.\ X + C \quad \ldots (2.15)$$

Where, Y is the dependent variable, X is the independent variable, m is the slope of the line and C is the intercept constant. The coefficients (m and C) of the model are determined using the Least-Squares method, which is the most commonly used method. t-test is used to determine whether the linear trends are significantly different from zero at the 5% significance level.

3. Results and Discussion

3.1 Statistical Properties of Rainfall Data

Daily rainfall data obtained from Soil Conservation Department of Damodar Valley Corporation, Hazaribagh, Jharkhand for the gauging station located in the Nagwan watershed for the months of June, July, August and September were converted into monthly and monsoon season rainfall data series of 32 years. The mean, standard deviation, coefficient of variation, coefficient of skewness, and kurtosis of June, July, August and September months and monsoon season were calculated using Equation 2.1 through Equation 2.5 and are given in Table 1. It is clear that there are 20, 17, 18, 15 and 17 year for June, July, August and September months and monsoon season rainfall series respectively in which rainfall are less than the mean rainfall. There are 12, 15, 14, 17 and 15 years respectively in which rainfall is the more than the mean rainfall. The mean rainfall for different months for the months of June, July, August and September shows that highest rainfall was received in the month of July followed by August, September and June. The percentage contribution of mean monthly rainfall of June, July, August and September months to mean seasonal rainfall in percentage is 20.40, 28.60, 27.75, 22.48 respectively.

The detailed statistics of rainfall of all the four months is presented in Table 1. The monsoon rainfall varies from 451.24 to 1440 mm. The coefficient of variation, which is the statistical measure of the distribution of data points in data series around the mean of different month, varies from 45.27 to 69.86%. June month rainfall shows a high coefficient of variation of 69.86%. The skewness of all data series of months is found to vary from 0.08 to 1.29. June to September month rainfall has positive skewness which shows that data are right skewed. The July month rainfall has skewness close to zero which shows near normal distribution of rainfall. The kurtosis of all data series varies between -1.01 to 1.62. The positive kurtosis shows a peak distribution while a negative kurtosis shows a flat distribution.

The frequency distribution of rainfall depth for the month of June, July, August and September show that rainfall of July, September and Monsoon season is having a single peak and the distribution is skewed towards right whereas the rainfall of June and August are having two peaks. The distribution of June month rainfall is skewed towards right side whereas in case of August it is almost equally distributed.

Table 1: Statistical properties of rainfall series

Series	June	July	August	September	Monsoon season
Mean, mm	194.00	271.56	263.72	213.71	950.27
Median, mm	159.50	264.00	240.50	221.17	909.50
Minimum value, mm	0.00	75.00	86.00	47.16	451.24
Maximum value, mm	593.00	494.00	547.00	410.00	1440.00
Standard Devition, mm	135.54	133.49	119.61	96.75	265.87
Coefficient of Variation, %	69.86	49.16	45.35	45.27	27.98
Skewness	1.29	0.08	0.83	0.11	0.12
Kurtosis	1.62	-1.01	0.17	-0.62	-1.09

3.2 Rainfall Variation between Time Periods

3.2.1 Comparison of Mean between Time Periods

The monthly and monsoon seasonal rainfall were splitted four sub period, viz. 1983-1989, 1990-1999, 2000-2009 and 2010-2014. The mean, standard deviation and coefficient of variation of monthly and monsoon seasonal rainfall of these sub-periods were calculated by using Equation 2.1 to Equation 2.3 and are given in Table 2. The hypothesis of no significant difference in mean of June, July, August and September monthly rainfall and monsoon season rainfall of sub-period 1983-1989 and other sub-periods were tested by student t-test at 5% level of significance. The value of t_{cal} and t_{tab} are given in Table 2. It is obvious from the Table that the values of t_{cal} are less than that of t_{tab} for the sub-periods of 1990-1999, 2000-2009 and 2010-2014 for June July, August and September months except 2010-2014 sub-period of July month and Monsoon season. Therefore there is no significance difference in the mean values of periods of 1990-1999, 2000-2009 and 2010-2014 for all the months except 2010-2014 sub-period of July month and Monsoon season at 5% level of significance.

3.2.2 Trend Analysis

3.2.2.1 Mann-Kendall rank correlation test

Mann-Kendall test is a non-parametric test for finding trends in the time series. This test compares the relative magnitude of data rather than data values themselves. The benefit of this test is that data need not to confirm any particular distribution. In this test, each data value in the time series is compared with all subsequent values. Initially the Mann-Kendall statistics is assumed to be zero and if a data value in subsequent time periods is higher than a data value in the previous time period the statistics is incremented by one and vice-versa. The net result of all such increments and decrements gives the final value of statistics. A positive value of statistics indicates an increasing trend and negative value indicates a decreasing trend. The Mann-Kendall test was used to test the randomness of monthly and monsoon seasonal rainfall series of 32 years.

Table 2: Statistical parameters of monthly and monsoon season rainfall of different sub-periods

Month	Sub-period	Mean	Standard deviation	Coefficient of variation	t_{cal}	t_{tab}
June	1983-1989	271.71	190.02	69.93		
	1990-1999	199.50	98.66	49.45	1.03	2.13
	2000-2009	170.80	116.13	67.99	1.36	2.13

	2010-2014	120.60	74.88	62.08	1.67	2.23
July	1983-1989	324.28	81.38	25.10		
	1990-1999	299.30	134.07	44.79	0.44	2.13
	2000-2009	277.90	131.85	47.44	0.81	2.13
	2010-2014	129.60	91.64	70.70	3.88	2.23
August	1983-1989	267.86	152.28	56.85		
	1990-1999	271.30	84.54	31.16	-0.06	2.13
	2000-2009	232.20	106.24	45.75	0.57	2.13
	2010-2014	305.80	135.38	44.27	-0.44	2.23
September	1983-1989	210.57	84.18	39.98		
	1990-1999	230.00	123.02	53.48	-0.36	2.13
	2000-2009	234.26	70.34	30.02	-0.63	2.13
	2010-2014	144.41	60.22	41.70	1.50	2.23
Monsoon season	1983-1989	1074.71	224.38	20.88		
	1990-1999	1003.10	242.65	24.19	0.62	2.13
	2000-2009	915.14	254.45	27.80	1.33	2.13
	2010-2014	740.61	246.95	33.34	2.44	2.23

The standard test statistics of all the series were calculated using Equation 2.8 to Equation 2.9. The summary of Mann-Kendall analysis is presented in Table 3. The value of Mann-Kendall rank statistics is negative for June, July, August, September and Monsoon season rainfall. The negative s-statistic indicates a falling trend. The computed standard test statistic as shown in Table 3 shows that it is less than the z-value (±1.96) corresponding to 5% level of significance in all the cases which indicates that no significant trend is detected in these rainfall series.

3.2.2.2 Sen's Slope Estimator

The magnitude of the slope of trend is calculated using the approach given by Sen. The sen's slope estimator is non-parametric, linear slope estimator that works most effectively on monotonic data. The Sen's slope technique is used to determine the magnitude of the trend line. The approach involves computing slopes for all the pair of ordinal time points using the median of these slopes as an estimate of overall slope. The magnitude of trend was calculated using Equations 2.12 to 2.14. The estimated Sen's slopes are presented in Table 3. A positive slope gives rising trend and vice-versa. It can be seen from Table 3 that for the month of August the trend is rising whereas in case of June, July, September & Monsoon Season trend is falling.

Table 3: Mann-Kendall rank statistics, Sen's slope estimator and regression coefficient for different rainfall series

	June	July	August	September	Monsoon season
Mann-Kendall rank statistics	-1.75	-1.88	-0.13	-0.81	-2.30
Sen's slope value	-4.7	-5.46	0.43	-1.49	-10.86
Linear trend constants					
a	278.248	352.994	252.7802	240.8065	1127.516
b	-5.10594	-4.55645	0.66294	-1.64242	-10.7426
r	-0.34781	-0.3363	0.051174	-0.15675	-0.37306
t_{cal}	-0.80800	-0.84000	0.00070	-0.00410	-0.00047
t_{tab}	2.036	2.036	2.036	2.036	2.036

3.2.2.3 Regression test for linear trend

There is another alternate type of test which is used assuming that the trend is approximately linear. The standard method of linear regression is used for determining the trend. A null hypothesis is used for determining the trend. A null hypothesis is to be tested in this case is that the slope of line is zero. The value of regression coefficients for time series of June, July, August, September and Monsoon season rainfall series are given in Table 3. The value of correlation coefficient computed for these time series is also given in Table 3. The value of t-calculated is less than the tabulated value for all the time series, therefore null hypothesis that the slope of line is zero is not rejected at 5% level of significance. The trend obtained by regression analysis is same as given by Mann-Kendall analysis. Test of significance at five percent significance level was carried out on the regression slope for all the time series and no significance rising or falling trend was found.

4. Conclusions

The following are the conclusions of the study:

1. The mean monthly rainfall for the study period for the month of June, July, August and September are 194, 271.56, 263.72 and 213.71 mm with a coefficient of variation 69.86, 49.16, 45.35 and 45.27%.Out of 32 years considered 12, 15, 14 and 17 years rainfall is more than the mean rainfall of the month of June, July, August and September.
2. The Monsoon season rainfall varies from 451 to 1440 mm with coefficient of variation of 0.28%. The mean of Monsoon season rainfall for the study period is and 950.27 mm. There are 15 years in which rainfall is more than the mean rainfall.
3. The skewness of monthly rainfall series varies from 0.08 to 1.29. June to September month rainfall has positive skewness and shows that data are right skewed. The July month rainfall has skewness close to zero which shows near normal distribution of rainfall. The kurtosis of monthly rainfall series varies from -1.01 to 1.62. The positive kurtosis shows a peak distribution in case of June and August months while a negative kurtosis shows a flat distribution in case of July and September months.

4. The frequency distribution of rainfall depth shows that rainfall of July, September and Monsoon season is having a single peak and the distribution is skewed towards right whereas the rainfall of June and August are having two peaks. The distribution of June month rainfall is skewed towards right side whereas in case of August it is almost equally distributed.
5. No significant difference in mean values of monsoon month and monsoon season rainfall between sub-period 1983-1989 and 1990-1999, 2000-2009 and 2010-2014 except 2010-2014 sub-period of July month and Monsoon season was observed at 5% level of significance.
6. The value of Mann-Kendall statistic is negative for June, July, August, September and Monsoon season rainfall indicating a falling trend. However trend is not significant in all the cases at 5% significance level.
7. Rising trend for the month of August and falling trend in case of June, July, September and Monsoon season are observed by Sen’s method. No significant rising or falling trend on the regression slope for all the time series is observed at 5% level of significance.

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