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Trend Analysis of Rainfall and Rainy Days of Sehore District of Madhya Pradesh

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SUMMARY

Trend analysis of rainfall has been of great concern during the past century as well as today because of the consideration has been given to global climate change by the scientific community. The study of trends is very important for a country like India whose food security and economy are dependent on the timely availability of water such as 83% water used for agriculture sector, 12% for industrial sector and only 5% for domestic sector(source: MoWR, GOI, 2015-16). So the present study attempted to know the trend of rainfall and rainy days of Sehore district of Madhya Pradesh for the period (1992-2016). The change point analysis has been analyzed for observing any change. For this purpose, rainfall data have been collected from five meteorological stations of Sehore, Astha, Ichhawar, Budhni and Nasrullaganj.Trends of rainfall parameters were analyzed using Mann-Kendall test, Sen's slope test, Spearman's rho test and regression and change point analysis. This study revealed that significant decreasing trend in annual, monsoon and September rainfall have been observed at Sehore, whereas May shows increasing trend of rainfall. Though, rainfall in the month of May has increased significantly at 5% level of significance but there is no significant trend in rainy days. For the period 1992-2016, Pettitt change point analysis revealed that there is no significant change in rainfall and rainy days. The main aim of this study is to provide detailed knowledge of the rainfall regime in a smaller area such as district level is an important prerequisite for agricultural planning and management, for this one should go for micro level climate data analysis.

Keywords: Mann-Kendall test, Pettitt change point analysis, Sen's slope, Spearman's rho test.

1. INTRODUCTION

We can know about flora, fauna and feasible living conditions of humans by knowing the Climate of a particular location. It is broadly governed by different weather parameters like precipitation, temperature, humidity, bright sunshine availability and wind speed on long term basis. Further, rainfall and temperature constitutes major parameters concerning every one. This analysis help us to plan future strategy to overcome any possible abrupt change affecting human being and crops.

Trend analysis helps to indicate whether the climate parameters like rainfall, temperature etc. are increasing or decreasing over time. In addition, an estimate of the trend's magnitude can help to determine whether a statistically significant trend over a period of time is present or not. It is a key for predicting the rainfall and rainy days of a particular place on the basis of yearly, monthly rainfall and rainy days data for planning of the agricultural activities of the area. Several studies relating to changing pattern of rainfall over India observed that there is no clear trend of increase or decrease in average rainfall over the country (Mooley and Parthasarathy, 1984;Thapliyal and Kulshrestha, 1991; Lal,2001;Kumar *et al.*, 2010).

When performing long-term trend analysis on precipitation factors, the trends obtained signify the overall characteristics of the precipitation factors. The intersection where two dissimilar trends meet is called a change point. To determine whether change points exist in the long-term data, Pettitt change point analysis test is commonly used.

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2. MATERIALS AND METHODS

In the present study monthly rainfall and rainy day data for the period of 1992-2016 have been taken from the meteorological observatory located at Rafi Ahmad Kidwai College of Agriculture, Sehore, M.P., India. There are five rain gauge stations in Sehore district namely Astha, Ichhawar, Nasrullaganj, Budhni and Sehore itself. The normal rainfall of Sehore district is 1217.7 mm. The highest rainfall *i.e.* 1412.3mm received at Sehore and minimum at Astha *i.e.* 1054.9 mm. July is the wettest month of the year and about 36% of the annual rainfall takes place during this month only. About 92.4% of the annual rainfall takes place during the southwest monsoon period *i.e.* between June to September. About 6.2% and 1.4% rainfall received during winter and summer season respectively. Hence only 7.6% of the annual rainfall takes place from October to May months. (CGWB, MoWR, Bhopal, 2013). In this study, monsoon period has been defined as the months of July, August and September; Pre-monsoon as the months of April, May and June and winter constituted the month of November, December and January.

2.1 Methodology

Both parametric (regression analysis) and non-parametric statistical methods have been used to test the trends in the rainfall and rainy days meteorological data of the study area. Non-parametric tests are more suitable for non-normally distributed data in comparison to parametric statistical tests (Lanzante, 1996; Jana *et al*., 2015). Change point analysis was also done to know the year from which significant change has occurred.

The most frequently used non-parametric statistical tool for identifying trends in hydro-meteorological time series variables such as water quality, stream-flow, temperature and precipitation is the Mann-Kendall (MK) test. The statistical significance trend detected using a non-parametric model such as Mann-Kendall (MK) test can be complemented with Sen's slope estimation to determine the magnitude of the trend. The Spearman's rho (SR) test is another rank-based non-parametric statistical test that can also be used to detect monotonic trend in a time series (Lehmann, 1975 and Sneyers, 1990).

2.2 Mann-Kendall trend test

The non-parametric Mann-Kendall test is commonly employed to detect monotonic trends in series of environmental data, climate data or hydrological data. Since it is a nonparametric test so its main advantage is that the data need not conform to any particular distribution. The null hypothesis, H_0, is that the data come from a population with independent realizations and are identically distributed. The alternative hypothesis, H_1, is that the data follow a monotonic trend.

This test is rank based method for evaluating the presence of trends in time-series data. The initial value of the Mann-Kendall statistic, S is assumed to be 0 (no trend). If a data value from a later time period is higher than a data value from an earlier time period, 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 such increments and decrements yields the final value of S.

Let *1x*, *2x*, … *jx*,…, *nx* represent *n* data points where *jx* represents the data point at time *j*. Then the Mann-Kendall statistic (S) is given by

$$S = \sum_{i=1}^{n-1} \sum_{j=1}^{n} \text{sgn}(x_j - x_i) \qquad \text{(i)}$$

$$Sgn(x_j - x_i) = \begin{cases} 1\ ;\ if\ \ (x_j - x_i) > 0 \\ 0\ ;if\ \ (x_j - x_i) = 0 \\ -1\ ;if\ \ (x_j - x_i) < 0 \end{cases} \qquad \text{(ii)}$$

A very high positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend. However, it is necessary to compute the probability associated with S and the sample size n to statistically quantify the significance of the trend. The mean of S is E[S] = 0 and the variance $\sigma^2$is:

$$\sigma^2 = \left\{ n(n-1)(2n+5) - \sum_{j=1}^{p} t_j (t_j - 1)(2t_j + 5) \right\} / 18 \quad \text{(iii)}$$

where,

n is the number of data points,

p is the number of tied groups (a tied group is a set of sample data having the same value)

t_j is the number of data points in the jth tied group.

The statistic S is approximately normal distributed provided that the following Z-transformation is employed:

$$Z_{MK} = \begin{cases} \frac{S-1}{\sigma} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sigma} & if\ S < 0 \end{cases} \quad \text{(iv)}$$

Z_{MK} follows the standard normal distribution (Kendall, 1975). The hypothesis of no trend is rejected if $|Z|>Z_{1-\alpha/2}$, Where Z is taken from the standard normal distribution table and α is level of significance (Barnard, 1947).

2.3 Sen's slope estimate

The magnitude of slope of trend is estimated using the approach described by Sen (1968). The Sen's slope estimator is a non-parametric, linear slope estimator that works most effectively on monotonic data. This test computes both the slope (*i.e.* linear rate of change) and intercept according to Sen's method. First, a set of linear slopes is calculated as follows

$$d_k = \frac{x_j - x_i}{j - i}\ for\ 1 \le i \le j \le n \quad \text{(v)}$$

where,

d is the slope,

x denotes the variable,

n is the number of data, and

i, j are indices.

Sen's slope is then calculated as the median from all slopes b = Median d_k. A positive value of b indicates an upward trend, whereas a negative value represents a downward trend.

2.4 Spearman's rho test

SR test is another non-parametric rank-order test. For a given sample data set $\{x_i, i=1,2,\ldots,n\}$, the null hypothesis H_0 of the SR test against trend tests is that all the x_i are independent and identically distributed and the alternative hypothesis is that x_i increases or decreases with i, trend exists. The test statistic is given by (Sneyers, 1990)

$$D = 1 - \frac{6\sum_{i=1}^{n}[R(x_i) - i]}{n(n^2-1)} \quad \text{(vi)}$$

where, $R(x_i)$ is the rank of i^{th} observation x_i in the sample of size n.

Under the null hypothesis, the distribution of D is asymptotically normal with the mean and variance (Lehmann 1975, Sneyers 1990) as follows:

$$E(D) = 0,\ V(D) = \frac{1}{n-1}$$

2.5 Pettitt's change point analysis test

There are various methods to determine change point analysis of a time series (Chen and Gupta, 2000). In this study, we used the nonparametric approach developed by Pettitt (1979) to detect change points in rainfall and rainy days 'time series'. The null hypothesis of the test is H_0: The T variables follow one or more distributions that have the same location parameter (no change point), against the alternative hypothesis H_1: a change point exists. This test uses a modification of Mann-Whiney $U_{t,N}$, that tests whether two sample sets $x_1, x_2, \ldots, x_t$ and $x_{t+1}, x_{t+2}, \ldots, x_N$ are from the same population. The test statistic $U_{t,N}$ is defined as

$$U_{t,n} = U_{t-1,N} + \sum_{j=1}^{N} \text{sgn}(x_j - x_i) \text{ for } t = 1,2,\ldots,N \quad \text{(vii)}$$

and $Sgn\ (x_t - x_j)$ as equation (ii)

The test statistics counts the number of times an observation of first sample exceeds an observation of the second sample. The test statistics K_N and associated probability (P) used in the test are given as

$$K_N = \max_{1 \le t \le N} |U_{t,N}| \quad \text{(viii)}$$

$$P \cong 2\exp\{-6(K_N)^2 / (N^3 + N^2)\} \quad \text{(ix)}$$

3. RESULTS AND DISCUSSION

The mean, coefficient of variation (%) and its percentage contribution of monthly rainfall and rainy days for the period of 1992-2016 has been delineated in Table 1.

Table 1. Monthly rainfall and rainy days statistics for the period (1992-2016)

Month/Period	Mean monthly rainfall (mm) (1992-2016)			Mean monthly rainy days (1992-2016)		
	Mean (mm)	CV (%)	% Contribution	Mean (Nos)	CV (%)	% Contribution
Jan	43.42	160.03	0.77	3	148.34	1.38
Feb	61.07	177.62	1.09	2	160.29	1.06
Mar	35.68	245.66	0.64	3	185.97	1.28
Apr	9.18	166.63	0.16	1	154.71	0.34
May	20.16	216.93	0.36	2	234.36	0.70
Jun	621.31	65.86	11.08	30	51.54	13.64
Jul	1992.72	36.46	35.53	69	27.53	31.04
Aug	1705.35	45.06	30.41	62	29.65	28.01
Sep	856.04	60.24	15.263	38	52.51	17.27
Oct	162.24	108.24	2.89	8	99.83	3.469
Nov	59.02	243.42	1.05	3	249.61	1.42
Dec	41.91	283.28	0.75	1	279.05	0.377
Annual	5608.12	24.62	100	223	18.12	100
Monsoon	4554.11	28.25	81.21	170	19.25	76.33
Premonsoon	650.65	64.93	11.60	33	52.62	14.69
Winter	144.36	187.02	2.57	7	158.23	3.18

Monsoon rainfall accounts for 81.20 per cent of the annual rainfall and is received in 76.32 per cent of the annual rainy days whereas pre-monsoon and winter rainfall which accounts for 11.60 and 2.57 percent of the annual rainfall and is received in 14.68 and 3.18 percent of the annual mean rainy days. This reveals that intensity of rainfall is higher during monsoon. The month of July receives highest monthly rainfall of 1992.72 mm spread over 69 rainy days followed by the month of August, which receives on an average 1705.348 mm of rainfall spread over 62 rainy days. On an average 856.04 mm rainfall spread over 38 rainy days is received during the month of September. Very less rainfall is received during the month of November to May. July to September accounts for about 81.20 percent of the annual rainfall and the months of June and October accounts for about 13.97 per cent of the annual rainfall. Remaining 7 months accounts for only 4.82 per cent of the annual rainfall.

The Standard deviation (SD) and Coefficient of Variation (CV) of the monthly rainfall and rainy days classify the degree of variability associated in the monthly rainfall and rainy days. In case of monthly rainfall the coefficient of variation is less significant in the months of June, July, August and September (CV <75%) (Jana *et al.* 2015) Monsoon rainfall has minimum coefficient of variation that is 28.24% than pre-monsoon 64.92 %. Winter rainfall has highest coefficient of variation of 187.02%. In case of rainy days, Monsoon rainy days has minimum coefficient of variation 19.2 % than pre-monsoon (52.6%). Winter rainy days has highest coefficient of variation of 158.2 %. It can be inferred that rains during southwest monsoon are more reliable. In Southwest monsoon, July and August are generally the active monsoon months. June is the onset month which witnesses an outburst of rain while September is the withdrawal month, receiving more of the sporadic rain.

Trend analysis of the two climatic parameters viz. rainfall and rainy days has been done using one parametric and three non-parametric tests and the results are as follows.

3.1 Trend Analysis of monthly rainfall and rainy days

The rainfall and rainy days data set of Sehore District for the period of 1992 – 2016 have been divided in three time series (i) for the period of 1992 – 2016 (ii) for the period of 1992 – 2004 (iii) for the period of 2005 – 2016 and have been analysed separately.

For the period 1992-2016, significant decreasing trend in annual, monsoon and September rainfall are observed, whereas May shows increasing rainfall (Table 2). Though, rainfall in the month of May has

Table 2. Trend analysis of monthly rainfall

Month/ Period	1992-2016				1992-2004				2005-2016			
	MK	SR	Reg.	S.Slope	MK	SR	Reg.	S.Slope	MK	SR	Reg.	S.Slope
Jan	1.53	0.26	3.52	0.58	0.00	-0.01	5.09	0.00	1.11*	0.59	12.25	0.27
Feb	0.00	-0.09	0.32	0.00	0.61	0.17	10.75	2.61	0.21	0.23	8.29	0.08
Mar	1.42	0.33	3.00	0.28	-0.40	-0.16	0.43	0.00	-0.07	0.03	-7.37	0.00
Apr	0.17	-0.05	0.15	0.00	1.03	0.31	1.20	0.68	0.29	0.24	1.54	0.00
May	2.28*	0.49*	0.94	0.07	1.50	0.44	2.48	0.00	-0.76	-0.18	4.59	0.00
Jun	0.00	0.05	1.48	-0.48	0.43	0.15	12.99	17.52	-0.21	0.21	36.57	0.00
Jul	1.47	0.28	38.82	32.94	1.04	-0.28	-22.92	-35.27	1.03	0.62	127.17	1.21
Aug	0.21	-0.02	0.69	7.38	-0.55	-0.14	0.94	-38.62	0.62	0.32	5.93	2.92
Sep	-0.40*	-0.14*	-14.59*	-7.31	-0.18	-0.08	-9.09	-31.19	-1.44*	-0.35*	-48.89*	-2.76
Oct	-0.92	-0.28	-6.43	-3.59	-0.00	-0.04	-0.09	-0.47	0.69	0.39	1.85	0.33
Nov	-0.46	-0.04	0.48	0.00	0.35	-0.13	-2.90	0.00	0.00	-0.09	-7.92	0.00
Dec	-0.99	-0.21	-1.99	0.00	-1.19	-0.39	-4.70	0.00	0.09	0.07	1.80	0.00

Table 3. Trend analysis of monthly rainy days

Month/ Period	1992-2016				1992-2004				2005-2016			
	MK	SR	Reg.	S.Slope	MK	SR	Reg.	S.Slope	MK	SR	Reg.	S.Slope
Jan	0.96	0.19	0.11	0.00	0.33	0.14	0.17	0.00	2.14*	0.66	0.71	0.26
Feb	0.26	0.07	0.08	0.00	-0.13	-0.03	0.22	0.00	1.62	0.52	0.47	0.08
Mar	1.80*	0.36*	0.19	0.00	-0.08	-0.03	-0.17	0.00	0.57	0.13	0.41	0.00
Apr	-0.28	-0.07	-0.02	0.00	0.21	0.09	0.03	0.00	1.00	0.34	0.11	0.00
May	0.98	0.19	-0.01	0.00	0.67	0.18	0.29	0.00	0.99	0.27	-0.18	0.00
Jun	-0.33	-0.04	0.11	-0.13	0.55	0.22	1.05	1.00	0.00	0.07	0.52	0.00
Jul	1.01	0.23	0.86	0.51	-0.25	-0.08	-0.09	-0.13	0.68	0.25	1.44	1.21
Aug	0.56	0.13	0.29	0.38	-0.18	-0.03	-0.09	-0.57	1.30	0.39	2.11	2.92
Sep	-1.26	-0.24	-0.79	0.71	-0.42	-0.19	-1.03	-0.67	-1.78*	-0.61*	-2.39*	-2.75
Oct	-1.23	-0.28	-0.34	0.22	-0.31	-0.09	-0.08	-0.20	1.12	0.36	0.42	0.33
Nov	-0.45	-0.12	-0.02	0.00	-0.30	-0.12	-0.15	0.00	-0.63	-0.24	-0.36	0.00
Dec	-0.92	0.19	0.08	0.00	-0.67	-0.23	-0.05	0.00	0.27	0.12	0.13	0.00

increased significantly at 5% level of significance but there is no significant trend in rainy days, indicating an increase in rainfall intensity in the month of March. For the period 1992-2004 and 2005-2016, similar trend analysis has been applied.

It is interesting to observe that when the analysis is made separately for the data up to 2004 and after 2005 to 2016 then different trends has been observed. For the period 1992-2004, no significant trend has been observed for rainfall and rainy days at 5% level of significance. During the last decade *i.e.* for the period 2005-2016, decreasing trend has been observed in September rainfall at 5% level of significance with significant decrease in rainy days. On the other hand, though winter rainfall has been decreased from November month to December but in January it is increased significantly and likewise the rainy days has also been changed and increased significantly at 5% level of significance during January indicating an increase in rainfall intensity in the winter rainfall.

Annual and monsoon rainfall has decreased significantly with no significant decrease in annual and monsoon rainy days which indicating a decrease in rainfall intensity in annual and monsoon rainfall. On the other hand, rainfall amount has increased during May without significant change in rainy days. This phenomenon indicates increase in rainfall intensity. On observing Sen's slope, it was found that the month June, September and October rainfall has showed the downward trend for 25 years.

Monthly and yearly anomaly clearly depicts as how rainfall and rainy days has changed over time (anomaly is that which shows deviation from mean). Anomaly plot for rainfall (mm) showing annual and monthly anomaly (Fig. 1 and 2) indicate that the year 2006 has maximum positive annual anomaly which means year 2006 receives rainfall more than their mean rainfall of all the years. On the other hand year 2000 has maximum negative annual anomaly which means year 2000 receives rainfall less than mean rainfall. Similarly for monthly anomaly, July month has receives rainfall more than their mean rainfall of all the months, whereas April month receives less rainfall than their mean. Similarly anomaly plot for rainy days showing annual and monthly anomaly (Fig. 3 and 4).

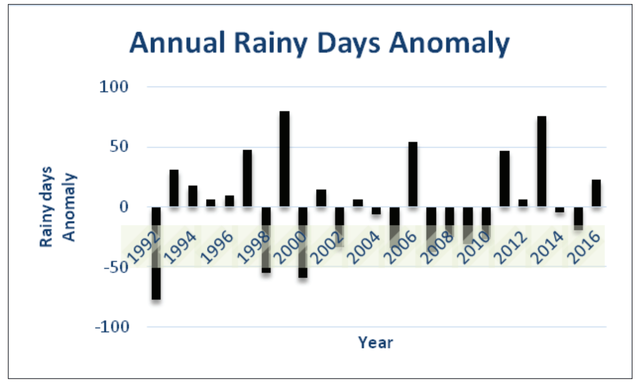


Fig 3. Anomaly plot for rainy days showing annual anomaly

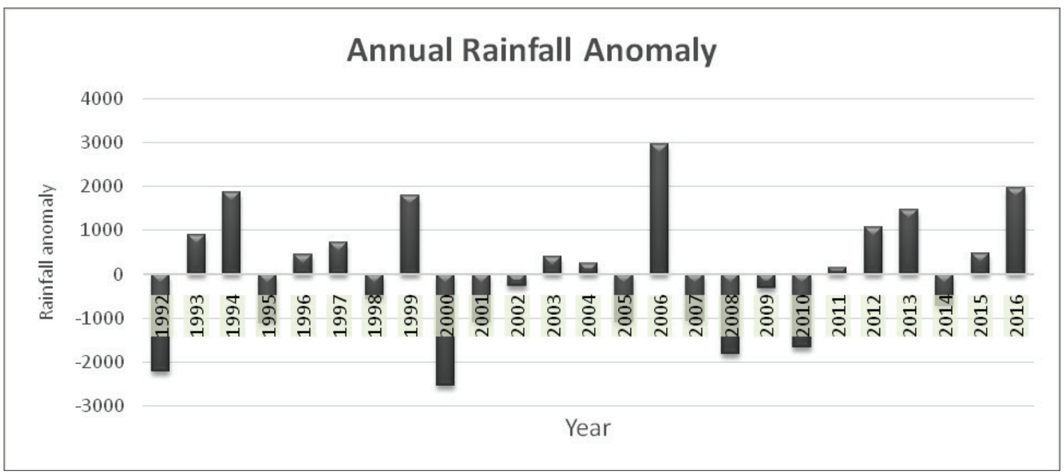


Fig 1. Anomaly plot for rainfall (mm) showing annual anomaly

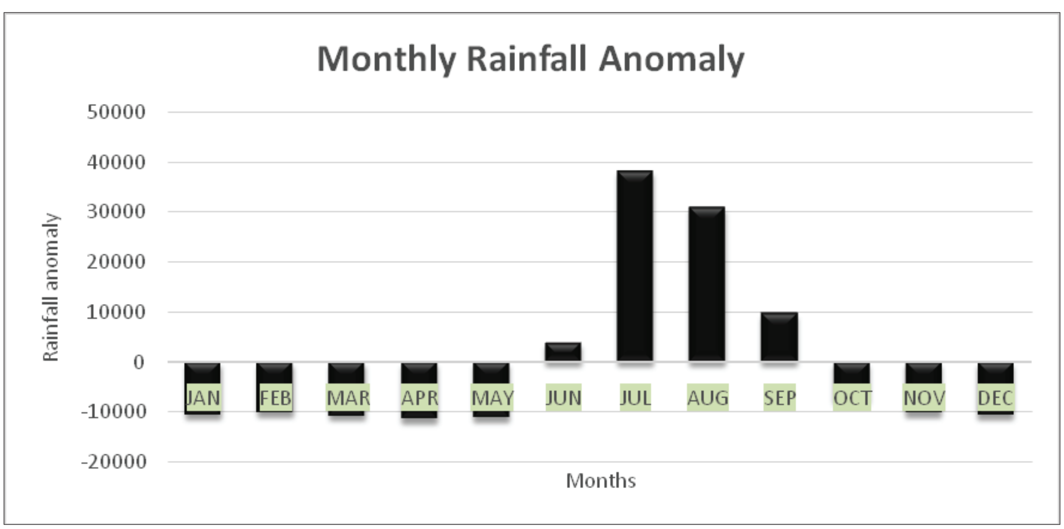


Fig 2. Anomaly plot for Rainfall (mm) showing monthly anomaly

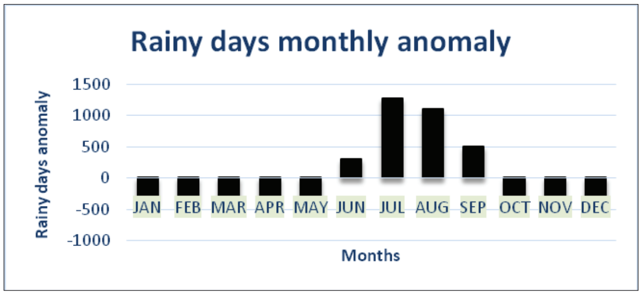
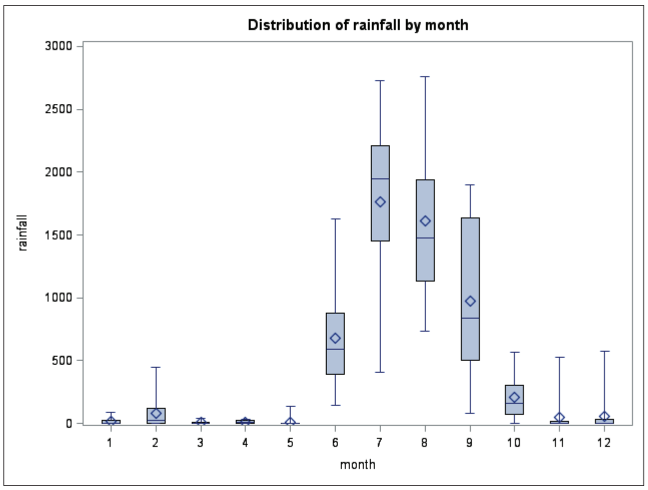
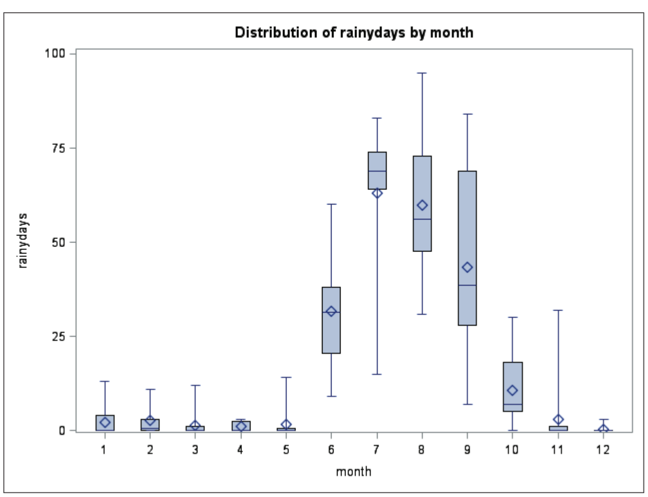


Fig 4. Anomaly plot for rainy days showing monthly anomaly



The distribution of rainfall and rainy days of the time period from 1992 to 2016 can be visualized from fig5 and 6. It is evident from fig5 that after May the rainfall has increased in the Month of June to September and after September rainfall has decreases. Similarly, for the rainy days same pattern has been observed (Fig 6).

Fig 5. Box-plot of monthly rainfall representing period 1992-2016



(1 to 12 on x-axis are months)

Fig 6. Box –plot of monthly rainy days representing period 1992-2016

3.2 Change Point Analysis

The Pettitt test was used to detect changes in annual rainfall and annual rainy days for the period 1992-2016. For annual rainfall the calculated value of K_T is 1810 with p=0.968 and for annual rainy days, the calculated value of K_T is 1932 with p=0.875. Both for annual rainfall and annual rainy days, no change point was detected for the 25 years.

4. CONCLUSIONS

Historical meteorological data of Sehore on rainfall and rainy days has been analyzed with Mann Kendall Z statistic, Sen's slope and Regression slope test. The study reveals that for the period 1992-2016, significant decreasing trend in annual, monsoon and September rainfall are observed, whereas May shows increasing rainfall. Though, rainfall in the month of May has increased significantly at 5% level of significance but there is no significant trend in rainy days, indicating an increase in rainfall intensity. In the month of March. Sen's slope showed that the month June, September and October rainfall has showed the downward trend for the 25 years. This study has also observed that no significant change in rainfall, rainy days are noticed at Sehore District.

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