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Parametric and Non-parametric Trend Analysis of Precipitation for Malkangiri

Kanhu Charan Panda[1], Subodh Hanwat[1]*, Ramesh Verma[1] and Gaurav Sharma[2]

[1]*Department of Farm Engineering, Institute of Agricultural Sciences, BHU, Varanasi, UP-221005, India*
[2]*National Institute of Hydrology, Bhopal, MP – 462016, India*

**Corresponding author*

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A B S T R A C T

The present study is mainly concerned with the changing trend of rainfall in a district of Odisha. We have given an effort to analyse one of the most important climatic variable, i.e., precipitation, for analysing the rainfall trend in the area. Daily rainfall data of 102 years from 1901 to 2002 has been processed in the study to find out the monthly variability of rainfall for which the Mann-Kendall (MK) test has been used together with the Sen's Slope Estimator for the determination of trend and slope magnitude. A monthly precipitation trend has been identified here to achieve the objective, which has been shown with 102 years of data. There are rising rates of precipitation in some months and a decreasing trend in some other months obtained by these statistical tests suggesting overall insignificant changes in the area.

Introduction

Water resource has become a prime concern for any development and planning, including food production, flood control, and adequate water resource management. Studies have demonstrated that global surface warming is occurring at a rate of 0.74 ± 0.18 °C over 1906–2005 (IPCC, 2007). The impact of climate change in the future is quite severe, as given by IPCC reports, which signify that there will be a reduction in the freshwater availability because of climate change. IPCC has also been revealed that by the middle of the 21st century, a decrease in annual average runoff and availability of water will project up to 10-30% (IPCC, 2007). Various researchers have contributed to the study of climate change (Dessens and Bucher, 1995; Serra *et al.*, 2001; Marengo, 2004) with long term data. The study of different time series data has proved that trend is either decreasing or increasing, both in case of temperature and rainfall. Human interference is also leading to climate change with changing land use from the impact of agricultural and irrigation practices (Kalnay and Cai, 2003).

It is found that all India mean annual temperature is rising at the rate of 0.05 °C/decade over 1901–2003 which is mostly due to the rise of maximum temperature (0.07 °C/decade) rather than because of the rise of minimum temperature (0.02 °C/decade) (Kothawale and Rupa Kumar, 2005). There will be a fall of -0.38°C per century in the north Indian average temperature with a contrasting rise of 0.42°C per century depicted by the average temperature of India during the last half of the 20th century (Arora *et al.,* 2005). Central Water Commission (CWC, 2005) reported that annual average precipitation received by India is about 4000 billion cubic meters (BCM). Out of that, utilised surface water and groundwater resources are approximated to be only 690 and 432 BCM, respectively. Again, in the report of CWC, 2008, the annual average precipitation has been approximated to be 3882.07 BCM, and utilisable total surface water and total replenishable groundwater is estimated to be about 690 BCM and 433 BCM correspondingly. Therefore, it is apparent from the report that there is a reduction in the annual average rainfall over the country, signifying a decreasing trend in the precipitation. So there will be fluctuation in the availability of water, and due to the irregularity of rainfall in most areas, difficulty in the availability of water is rising.

Some researchers have also studied the availability of quality freshwater which is of the biggest concern for the last half-century, because of higher demographic pressure leading to climatic variability (Gleick, 1993, 2000; Vörösmarty *et al.,* 2000; Shiklomanov and Rodda, 2003; Milliman *et al.,* 2008). The problem is flimsy in India and China, where the population is very high and posing a continuous threat to the freshwater. According to Gleick (2000), these two countries use about 40% of global freshwater for irrigation. Some parts of the French Mediterranean area have been studied by Chaouche *et al.,* (2010), which is sensitive to climate change. Mann-Kendall Test has been used to find any trend of rainfall, temperature, and evapotranspiration (both monthly and annual), which has shown some signs in case of rainfall and temperature.

MK Test has been used to analyse the long term rainfall trend in Zambia by Kampata *et al.,* (2008). The trend of precipitation and run-off is also studied by Xu *et al.,* (2010) in major Chinese rivers in order to find out any human intervention in the trend from 1951 to 2000. He has also used the Mann-Kendall statistics for the detection of the trend of precipitation. According to some researchers (Alcamo and Doll, 2003; Arnell *et al.,* 2004), rising pressure of man on land use is the cause of adverse impact on the environment resulting in extreme weather conditions and change in climatic parameters for the short term period.

The prime objective of this study is to analyse the trend of precipitation in the Malkangiri district of Orissa.

Materials and Methods

Study area

The study area ‘Malkangiri’ shown in Figure 1 is the southernmost district of Odisha state of India. The district lies between north latitudes 17º47’58” and 18º44’18” and East longitudes 81º23’23” and 82º27’05”. The hills and forests cover almost seventy-six percent of the total geographical area of the district. Based on the soil characteristic, cropping pattern, climatological and topographical features, the district has been subdivided into two agro-climatic zones, namely South Eastern Ghat and Eastern Ghat highland. The South Eastern Ghat occupies almost the entire Malkangiri district. It is characterized by a warm climate with a maximum temperature of 34ºC and a minimum temperature of 13ºC. The principal crop is rice. The Eastern Ghat Highland has a tiny portion in the eastern corner of the district, characterized by Eastern Ghat Highland. The climate is warm and humid. The maximum temperature is 34º C, and the minimum temperature is 8ºC. The principal crops are paddy, wheat, and vegetables. The average annual rainfall varies from 994.05 mm to 1809.53 mm.

Data

For this study, we have obtained area-weighted average monthly rainfall data for 102 years from 1901 to 2002. We have acquired the data from the India Water Portal (www.india-waterportal.org).

The Mann-Kendall test (M-K test)

This method tests if there is a trend in the time series data. It is a non-parametric rank-based procedure, robust to the influence of extremes and suitable for application with skewed variables (Hamed 2008). More particularly, this technique can be adopted in cases with non-normally distributed data, data containing outliers, and non-linear trends (Helsel and Hirsch 1992; Birsan *et al.*, 2005). According to this test, the null hypothesis H_0 indicates that the deseasonalised data $(x_1 ... x_n)$ is a sample of n independent and identically distributed random variables (Hirsch *et al.*, 1982). The alternative hypothesis H_1 of a two-sided test is that the distributions of x_k and x_j are not identical for all $k, j \leq n$ with $k \neq j$. The test statistic S is given below in Eq. 1 (Kahya and Kalayci 2004):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k) \quad \ldots (1)$$

Where sgn() is the signum function. The S statistic is assumed to be asymptotically normal, where the sample size n is greater than 10, with E(S) =0 and

$$Var(S) = \left[n.(n-1).(2n+5) - \sum_t t.(t-1).(2t+5)\right] \quad \ldots (2)$$

Where t refers to the extent of any given tie, and Σt states the overall summation ties. The standard normal variate Z is computed by Eq. 3. (Partal and Kahya 2006).

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & \text{if } S < 0 \end{cases} \quad \ldots (3)$$

Therefore, in case $|Z| \leq Z_{1-\alpha/2}$ in a two-sided test for trend, the null hypothesis H_0 should be accepted at the α level of significance. A positive value of S connotes an "upward trend," while a negative value of S indicates a "downward trend."

The sequential version of the Mann-Kendall test

This method is used to test an assumption about the beginning of the trend development within a sample (Taubenheim 1989; Sneyers 1990). The null hypothesis H_0 presumes that the sample under investigation shows no beginning of a developing trend. This rank-based test considers the relative values of all terms in the time series $(x_1, x_2, x_3, .. x_n)$. The following steps are applied in order to accept or reject the null hypothesis (Gerstengarbe and Werner 1999):

Definition of the test statistic: The test statistic t_j variables are computed as follows:

$$t_j = \sum_{i}^{j} n_j \quad \ldots (4)$$

where n_j denotes for each element x_j ($j>k$) the number of cases $x_j > x_k$, with $j = 1,2,\ldots,n$ and $k = 1,2,\ldots,j-1$. The distribution of t_j is asymptotically normal with $E(t_j)=[j(j-1)]/4$ and $Var(t_j)=[j(j-1)(2j+5)]/72$.

i. Calculation of the reduced variables: A reduced variable, called statistic u(t), is calculated for each of the test statistic variables t_j as follows:

$$u(t) = \frac{t_j - E(t_j)}{\sqrt{Var(t_j)}} \quad \ldots (5)$$

ii. Determination of the starting point of a trend development: Similarly to the calculation of progressive rows of statistic u(t), the retrograde rows of statistic u´(t) are computed backward starting from the end of series. The intersection point of the progressive and retrograde rows of the statistics u(t) and u´(t) provides the point in time of the beginning of a developing trend within the time series. The null hypothesis H_0 should be rejected when at least one of the reduced variables is greater than a chosen level of significance of the Gaussian distribution.

The Sen's estimator of slope

This test is applied in cases the trend is assumed to be linear, depicting the quantification of change per unit time (Sen 1968; Gilbert 1987). De Lima *et al.,* (2005) point out the utility of this estimator in cases there are missing values or other gaps in the data, as it remains unaffected from outliers or gross errors. The slope estimates Q_i of N pairs of data are calculated as $Q_i = (x_j - x_k)/(j-k)$ for $i = 1,\ldots,N$ where x_j and x_k are data values at times j and k ($j>k$), respectively. The Sen's estimator of slope derives from the above N values of Q_i and equals to their median. When there is only one datum in each period, then $N=n(n-1)/2$, where n corresponds to the number of periods. The N values of slopes are ranked from the smallest to largest, and if N is odd, Sen's estimator of the slope is calculated as $Q_{median}=Q_{(N+1)/2}$. On the other hand, in case that N is even, the estimator arises from $Q_{median}=[Q_{N/2} + Q_{(N+2)/2}]/2$.

Results and Discussion

Trend analysis of the Malkangiri district basin has been done in the present study with 102 years of precipitation data from 1901 to 2002. Mann-Kendall and Sen's Slope Estimator has been used for the determination of the trend. Parametric trend analysis was performed for monthly, seasonal, and annual temporal frequencies. For the sake of trend analysis, we have divided the whole year into four seasons, i.e., pre-monsoon season (March-May), monsoon season (June-September), post-monsoon season (October-November) and Winter season (December- February).

The result of trend analysis is presented in Figure 2. The green coloured trend line indicates an increasing trend while the red coloured trend lines show the decreasing trend. From figure 2 it can be said that among February, April, September, and December months and seasons, pre-monsoon and winter seasons show decreasing rainfall trend. The rest of the monthly, seasonal, and annual rainfall trend is positive.

The equations of trend lines are presented in Table 1. The equation with a positive coefficient of 'x' shows an increasing trend and vice versa.

In the Mann-Kendall test, the Z statistics presented in Table 2 revealed the trend of the series for 102 years for a monthly, seasonal, and annual basis. The positive value of the Z statistic shows an increasing trend while the negative values show a decreasing trend. The months of February, April, and December and the pre-monsoon and winter seasons show a decreasing trend. In rest of the cases of monthly, the seasonal and annual trend shows an increment. The result of nonparametric test supports the results obtained by parametric tests. Sen's slope for all the months and seasons are shown in Table 2. It indicates the magnitude of increase or decrease in the trend line. The months of January and December have zero Sen's slope, which indicates that there is almost no change in the precipitation trend.

For the Mann-Kendall test, we have considered 95% confidence interval, i.e., p-value less than 0.05 is considered to be significant. It can be seen from Table 2 that the month of October and post-monsoon season have significant trend rest of the months, and seasons have no significant trend.

Table.1 Monthly, seasonal and annual trend line equation

Period	Equation of trend line
January	y = 0.010x + 2.666
February	y = -0.028x + 9.755
March	y = 0.017x + 8.519
April	y = -0.240x + 49.96
May	y = 0.081x + 42.17
June	y = 0.273x + 138.0
July	y = 0.281x + 228.4
August	y = 0.381x + 212.9
September	y = -0.370x + 219.5
October	y = 0.548x + 97.47
November	y = 0.087x + 42.83
December	y = -0.007x + 4.189
Annual	y = 1.035x + 1056.
Pre Monsoon	y = -0.141x + 100.6
Monsoon	y = 0.565x + 799.0
Post Monsoon	y = 0.636x + 140.3
Winter	y = -0.025x + 16.61

Table.2 Sen's slope

Period	Sen's Slope	p-value	z stat
January	0	0.1455	1.456
February	-0.01	0.2010	-1.279
March	0.05	0.7477	0.322
April	-0.092	0.1036	-1.628
May	0.17	0.1952	1.295
June	0.245	0.3284	0.977
July	0.323	0.2370	1.183
August	0.418	0.2336	1.191
September	-0.523	0.1171	-1.567
October	0.55	0.0198	2.330
November	0.01	0.5319	0.625
December	0	0.9433	0.071
Annual	1.262	0.0913	1.689
Pre Monsoon	-0.168	0.5592	-0.584
Monsoon	0.562	0.3256	0.983
Post Monsoon	0.5	0.0310	2.157
Winter	-0.42	0.2808	-1.079

Fig.1 Location map of Malkangiri (Pattnaik *et al.*, 2008)

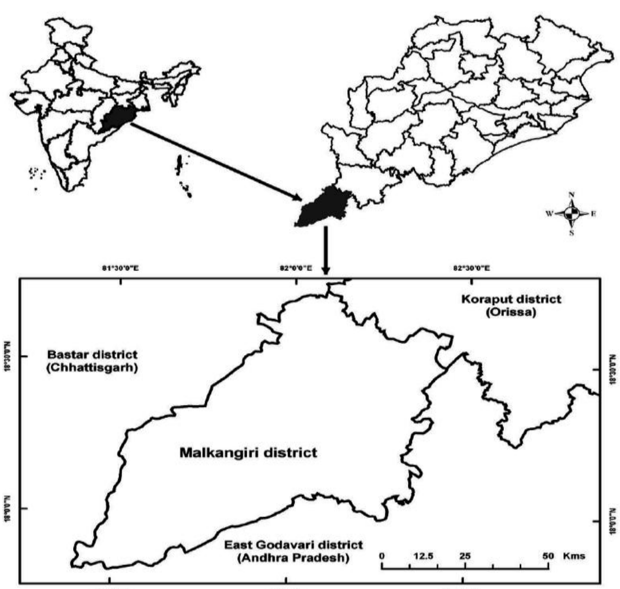
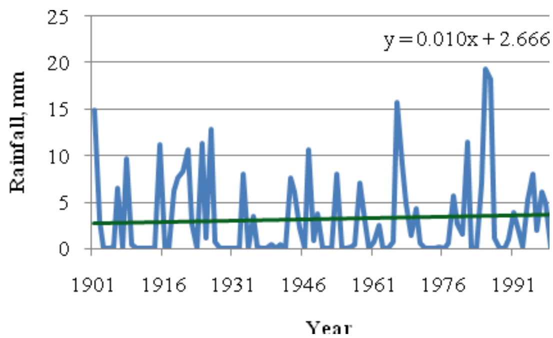
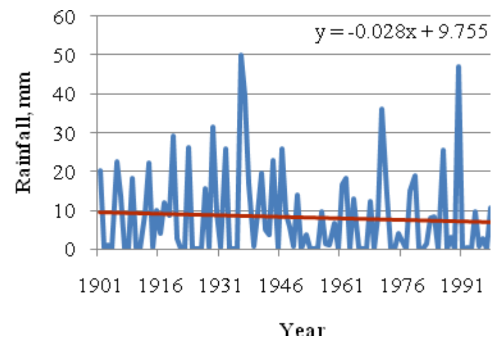


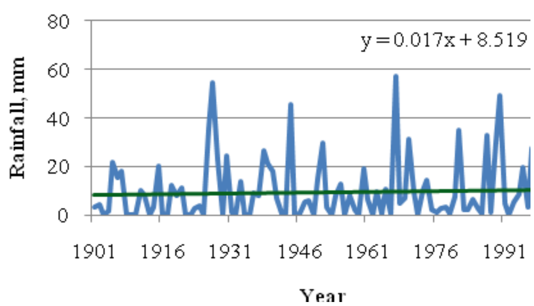
Fig.2 Monthly, seasonal and annual graphs showing the temporal variation of rainfall in Malkangiri



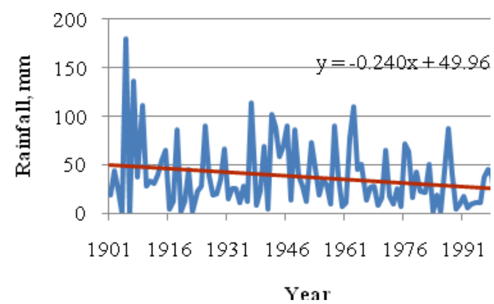
Rainfall variation for January month for Malkangiri



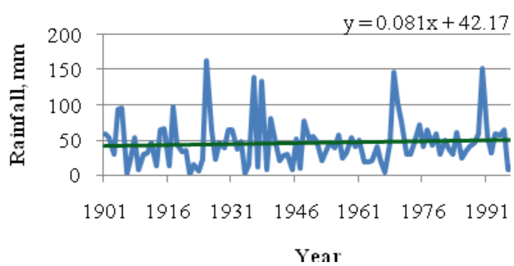
Rainfall variation for February month for Malkangiri



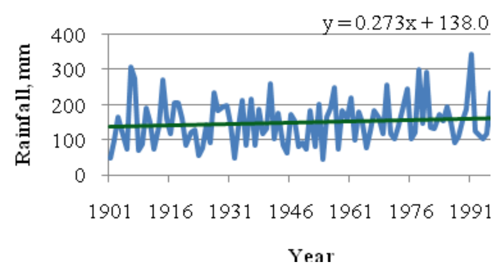
Rainfall variation for March month for Malkangiri



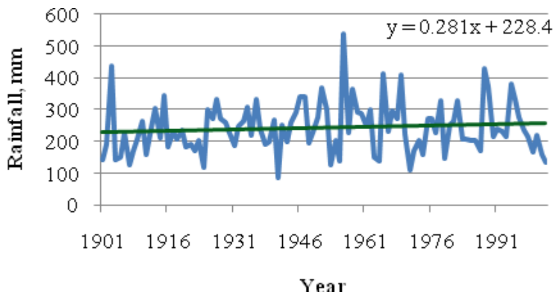
Rainfall variation for April month for Malkangiri



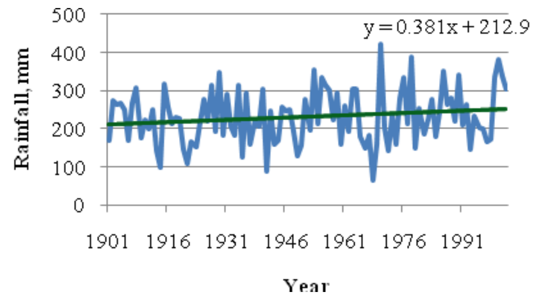
Rainfall variation for May month for Malkangiri



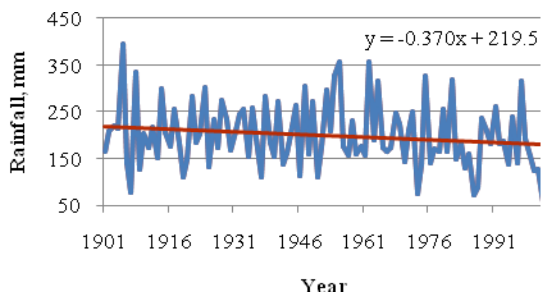
Rainfall variation for June month for Malkangiri



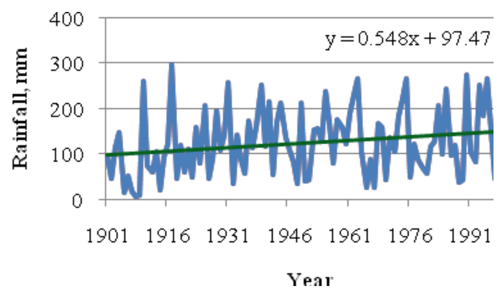
Rainfall variation for July month for Malkangiri



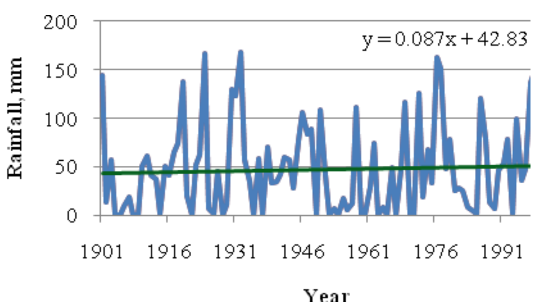
Rainfall variation for August month for Malkangiri



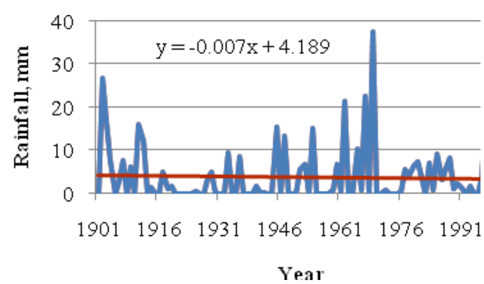
Rainfall variation for September month for Malkangiri



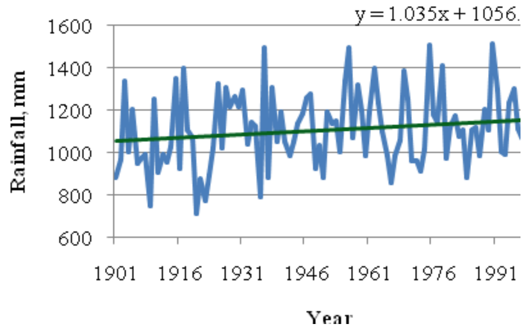
Rainfall variation for October month for Malkangiri



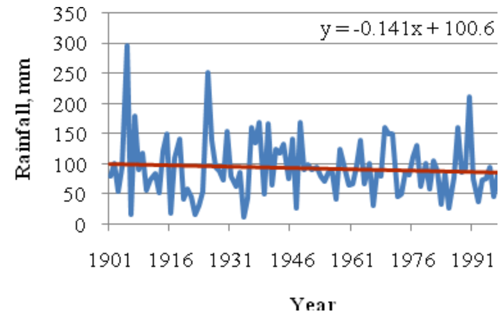
Rainfall variation for November month for Malkangiri



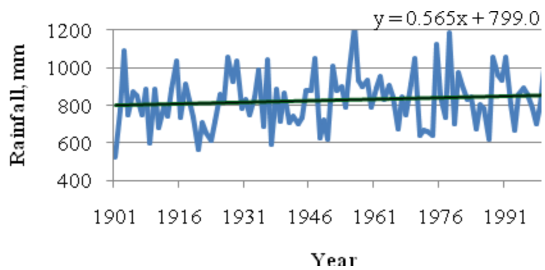
Rainfall variation for December month for Malkangiri



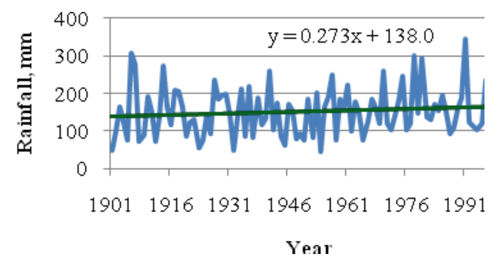
Annual Rainfall variation for Malkangiri



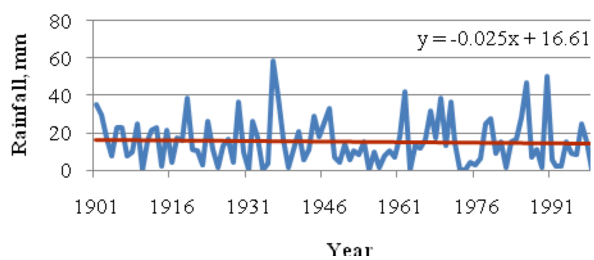
Pre-monsoon Rainfall variation for Malkangiri



Monsoon Rainfall variation for Malkangiri



Post-monsoon Rainfall variation for Malkangiri



Winter Rainfall variation for Malkangiri

In conclusion, the present study analyzed the rainfall data for 102 years from 1901 to 2002 of Malkangiri district of Odisha for the determination of the trend of precipitation. The area is rural and thus represents more of agricultural land and cultivation zones. The Z value of the MK Test represents both positive and negative trends in the area, although not much significant. Individually months of January, March, May, June, July, August, October, and November are showing positive trend and months of February, April, September, and December are depicting negative trends in both parametric tests and the Z value found in nonparametric test. Similarly, monsoon and post-monsoon seasons show a positive trend while pre-monsoon and winter seasons show a negative trend. Finally, the annual rainfall trend is positive. Among all months and seasons, only

October month shows a significant change in trend. Therefore it can be concluded that there is evidence of some change in the trend of precipitation of the region in these 102 years in different months and seasons. Further, the study of the area may reveal other aspects that will help control flood causing havoc in this particular area.

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