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RAINFALL TREND ANALYSIS BY MANN-KENDALL TEST: A CASE STUDY OF NORTH-EASTERN PART OF CUTTACK DISTRICT, ORISSA

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ABSTRACT

The present study is mainly concerned with the changing trend of rainfall of a river basin of Orissa near the coastal region. It is facing adverse effects of flood almost every year. This is 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 40 years from 1971 to 2010 has been processed in the study to find out the monthly variability of rainfall for which Mann-Kendall (MK) Test, Modified Mann-Kendall Test have been used together with the Sen's Slope Estimator for the determination of trend and slope magnitude. Monthly precipitation trend has been identified here to achieve the objective which has been shown with 40 years of data. There are rising rates of precipitation in some months and 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 effective 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)*. Impact of climate change in future is quite severe as given by IPCC reports which signify that there will be reduction in the freshwater availability because of climate change. This has also been revealed that by the middle of 21st century, 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. Study of different time series data have 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 landuse 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 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 average temperature of India during the last half of 20th century *(Arora et al., 2005)*. Central Water Commission (*CWC, 2005)* reported that annual average precipitation received by India is about 4000 billion cubic metres (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 ground water is estimated to be about 690 BCM and 433 BCM correspondingly. Therefore, it is apparent from the report that there is reduction in the annual average rainfall over the country signifying decreasing trend in the precipitation. So there will be fluctuation in the availability of water and due to irregularity of rainfall in most areas, difficulty in availability of water is rising.

Some researchers have also studied the availability of quality freshwater which is of 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 more flimsy in India and China where population is very high and posing continuous threat to the fresh water. According to *Gleick, (2000),* these two countries use about 40% of global freshwater for the purpose of irrigation. Some parts of the French Mediterranean area have been studied by *Chaouche et*

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al., (2010), which is sensitive to the 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 significance in case of rainfall and temperature.

CUSUM (Cumulative Summation) test and 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 the landuse are the cause of adverse impact on environment resulting in extreme weather conditions and change in climatic parameters for short term period.

The prime objective of this study is to analyse the trend of precipitation in Birupa river basin of Orissa.

STUDY AREA

The study area is located in the north-eastern part of Cuttack district in Orissa state of India. Geographically, it is situated at 20°37´ N latitude and 86°9´ E longitude and it is a part of Mahanadi basin area. The area falls under monsoon climatic regain and annual temperature differs from 13ºC to 37ºC and annual rainfall is around 120 cm. Maximum amount of rainfall occurs during monsoon period ie. June to October. The economy of the study area is comprised of agriculture and more than 90 per cent population is practicing agriculture here. Agricultural activities are often affected by floods and droughts. Cyclones are also occasionally responsible for causing damages (Fig.1.).

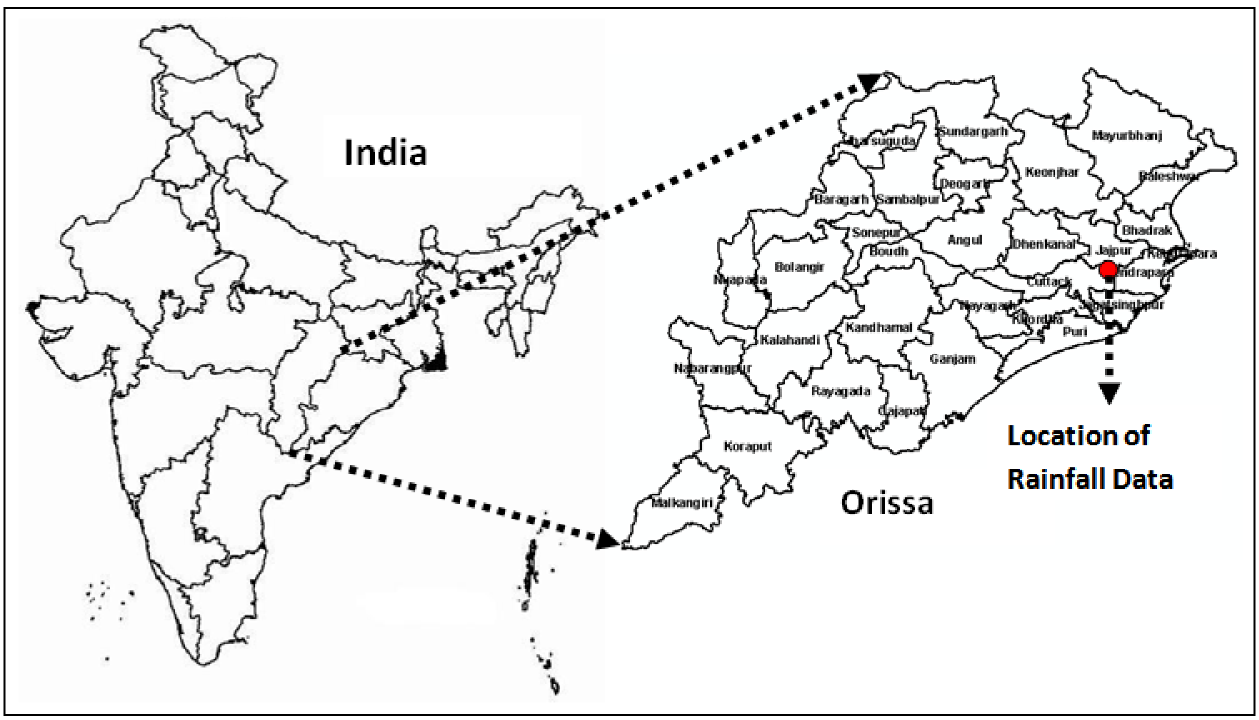

Fig.1. Study Area

MATERIALS AND METHODS

Trend Analysis

In the present study, trend analysis has been done by using non-parametric Man- Kendall test. This is a statistical method which is being used for studying the spatial variation and temporal trends of hydro-climatic series. A non parametric test is taken into consideration over the parametric one since it can

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evade the problem roused by data skew (*Smith, 2000)*. Man-Kendall test is preferred when various stations are tested in a single study *(Hirsch et al., 1991)*. Mann-Kendall test had been formulated by *Mann (1945)* as non-parametric test for trend detection and the test statistic distribution had been given by *Kendall (1975)* for testing non-linear trend and turning point.

Autocorrelation: Trend detection in a series is largely affected by the presence of a positive or negative autocorrelation *(Hamed and Rao, 1998; Serrano et al., 1999; Yue et al., 2003; Novotny and Stefan, 2007)*. With a positive autocorrelation in the series, possibility for a series of being detected as having trend is more, which may not be always true. On the other hand, this is reverse for negative autocorrelation in a series, where a trend is not detected. The coefficient of autocorrelation ρk of a discrete time series for lag-k is projected as

$$\rho_k = \frac{\sum_{t=1}^{n-k}(x_t - \bar{x}_t)(x_{t+k} - \bar{x}_{t+k})}{\left[\sum_{t=1}^{n-k}(x_t - \bar{x}_t)^2 \times \sum_{t=1}^{n-k}(x_{t+k} - \bar{x}_{t+k})^2 \times\right]^{1/2}} \qquad (1)$$

where, $\bar{x}_t$ and *Var* (x_t) are considered as the sample mean and sample variance of the first $(n - k)$ terms respectively, and $\bar{x}_{t+k}$ and *Var* (x_t+k) are the sample mean and sample variance of the last $(n - k)$ terms respectively. Further, the hypothesis of serial independence is tested by the lag-1 autocorrelation coefficient as $H_0 : \rho_1 = 0$ against $H_1 : |\rho_1| > 0$ using

$$t = |\rho_1|\sqrt{\frac{n-2}{1-\rho_1^2}} \qquad (2)$$

where the t test statistic has a Student's t-distribution with $(n - 2)$ degrees of freedom *(Cunderlik and Burn, 2004)*. If $|t| \geq t_{\alpha/2}$, then the null hypothesis about serial independence is rejected at the significance level α.

Mann-Kendall Test: The Mann-Kendall statistic S is given as

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\text{sgn}(x_j - x_i) \qquad (3)$$

The application of trend test is done to a time series x_i that is ranked from i = 1,2,………n-1 and x_j, which is ranked from j = i+1,2,……….n. Each of the data point x_i is taken as a reference point which is compared with the rest of the data points x_j so that,

$$Sgn(x_j - x_i) = \begin{cases} +1, > (x_j - x_i) \\ 0, = (x_j - x_i) \\ -1, < (x_j - x_i) \end{cases} \qquad (4)$$

It has been documented that when n ≥ 8, the statistic S is approximately normally distributed with the mean.

$$E(S) = 0 \qquad (5)$$

The variance statistic is given as

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(i)(i-1)(2i+5)}{18} \qquad (6)$$

where t_i is considered as the number of ties up to sample i. The test statistics Z_c is computed as

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} \\ 0, S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, S < 0 \end{cases} \quad (7)$$

Z_c here follows a standard normal distribution. A positive (negative) value of Z signifies an upward (downward) trend. A significance level α is also utilised for testing either an upward or downward monotone trend (a two-tailed test). If Z_c appears greater than $Z_{\alpha/2}$ where α depicts the significance level, then the trend is considered as significant.

Modified Mann–Kendall test: Pre-whitening is being used for detecting a trend in a time series in the presence of autocorrelation *(Cunderlik and Burn, 2004)*. Nonetheless, pre-whitening is stated to reduce the rate of detection of significant trend in the MK test *(Yue et al., 2003)*. Thus, the Modified MK test *(Rao et al., 2003)* has been used for trend detection of an autocorrelated series. In the present study, the autocorrelation between ranks of the observations ρk has been estimated after subtracting an estimate of a non-parametric trend such as Sen's median slope from the data. Significant values of ρk have only been used for calculating the variance correction factor n/n^*_S, as the variance of S is underestimated for the positively autocorrelated data:

$$\frac{n}{n_s^*} = 1 + \frac{2}{n(n-1)(n-2)} \times \sum_{k=1}^{n-1} (n-k)(n-k-1)(n-k-2)\rho_k \quad (8)$$

where n represents the actual number of observations, n^*_s is represented as an effective number of observations to account for the autocorrelation in the data and ρk is considered as the autocorrelation function for the ranks of the observations. The corrected variance is then calculated as *(Rao et al., 2003)*

$$V^*(S) = V(S) \times \frac{n}{n_s^*} \quad (9)$$

where $V(S)$ is from Equation (6). The rest is same as in the MK test.

Sen's Slope Estimator Test: The magnitude of trend is predicted by the Sen's estimator. Here, the slope (T_i) of all data pairs is computed as *(Sen, 1968)*

$$T_i = \frac{x_j - x_k}{j-k} \qquad \text{for i = 1,2,……..,N} \quad (10)$$

where x_j and x_k are considered as data values at time j and k (j>k) correspondingly. The median of these N values of T_i is represented as Sen's estimator of slope which is given as:

$$Qi = \begin{cases} T_{\frac{N+1}{2}} & N \text{ is odd} \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) & N \text{ is even} \end{cases} \quad (11)$$

Sen's estimator is computed as Q_{med}=T(N+1)/2 if N appears odd, and it is considered as $Q_{med}=[T_{N/2}+T_{(N+2)/2}]/2$ if N appears even. At the end, Q_{med} is computed by a two sided test at 100 (1-α)% confidence interval and then a true slope can be obtained by the non-parametric test.

Positive value of Q_i indicates an upward or increasing trend and a negative value of Q_i gives a downward or decreasing trend in the time series.

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RESULTS AND DISCUSSION

Trend analysis of Birupa river basin has been done in the present study with 40 years of precipitation data from 1971 to 2010. Mann-Kendall and Sen's Slope Estimator has been used for the determination of the trend. Fig.2. represents the annual rainfall for 40 years with maximum rainfall occurrence in the years 1983 with the total precipitation of 2810 mm approximately and minimum rainfall has occurred in the year 1996 with the total of around 1118 mm. Average rainfall for these 40 years is 1693.709 mm.

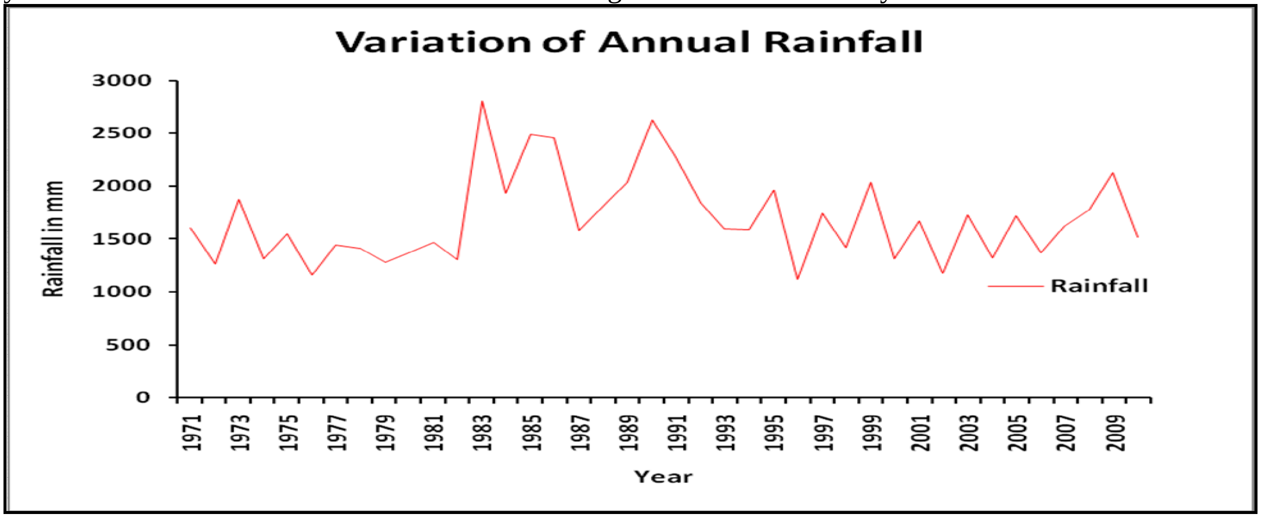

Figure 2: Annual Rainfall of 40 Years

Annual average is least for the month of December for all these 40 years (6.14 mm) followed by January (8.29 mm) and February (22.63 mm) while maximum rainfall occurs in the month of August (397.86 mm) followed by July (344.83 mm) and September (292.56 mm). Fig.3,, 4. and 5 show the rainfall distribution of 40 years of individual months.

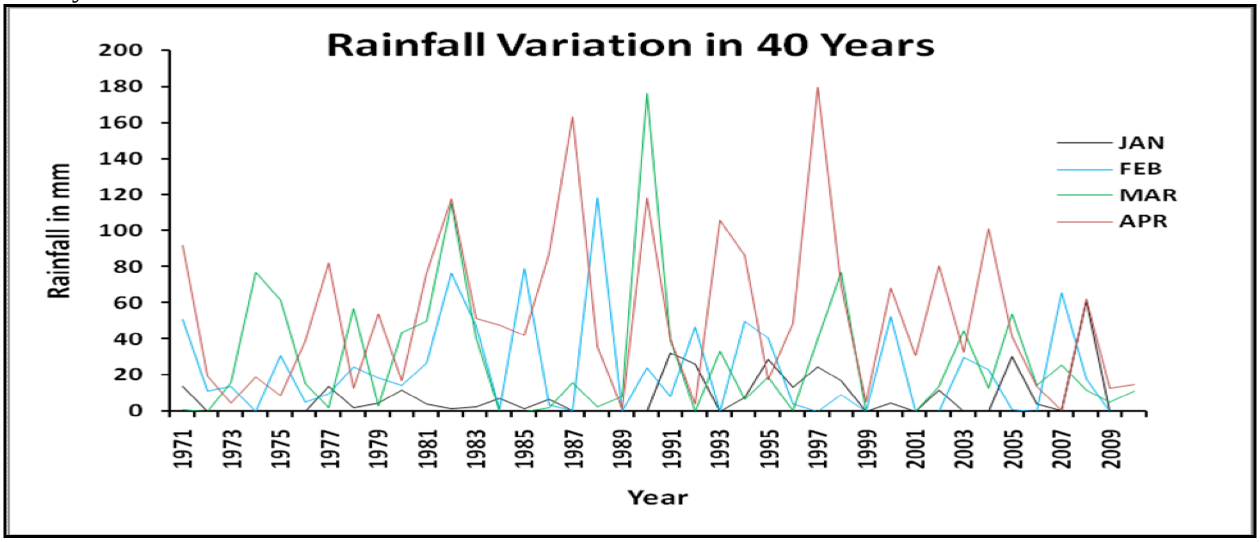

Figure 3: Rainfall of January, February, March and April months for 40 Years

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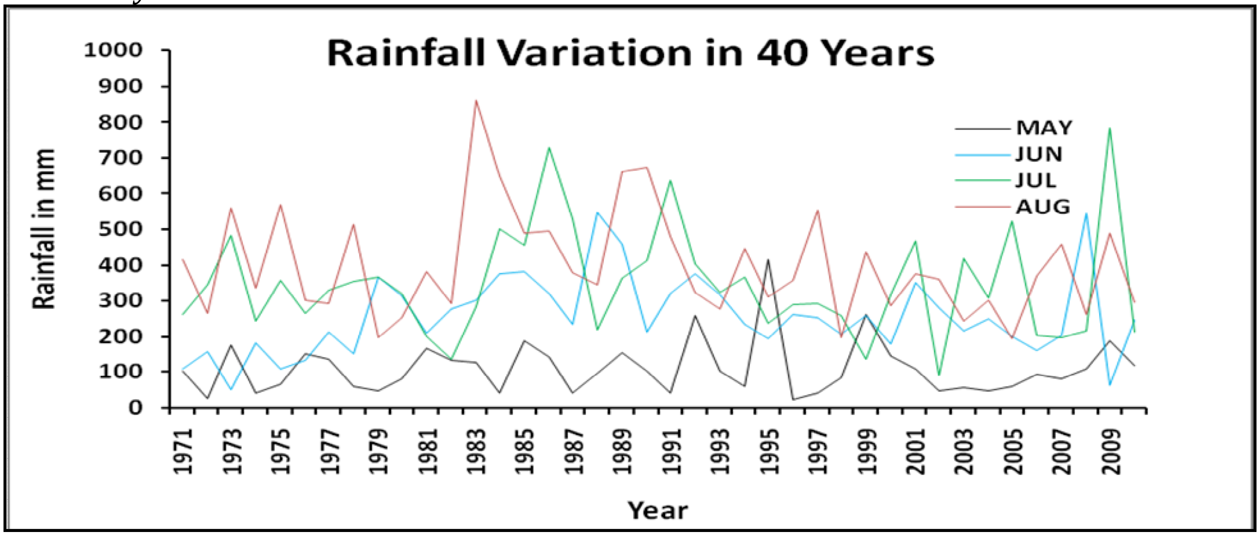

Figure 4: Rainfall of May, June, July and August months for 40 Years

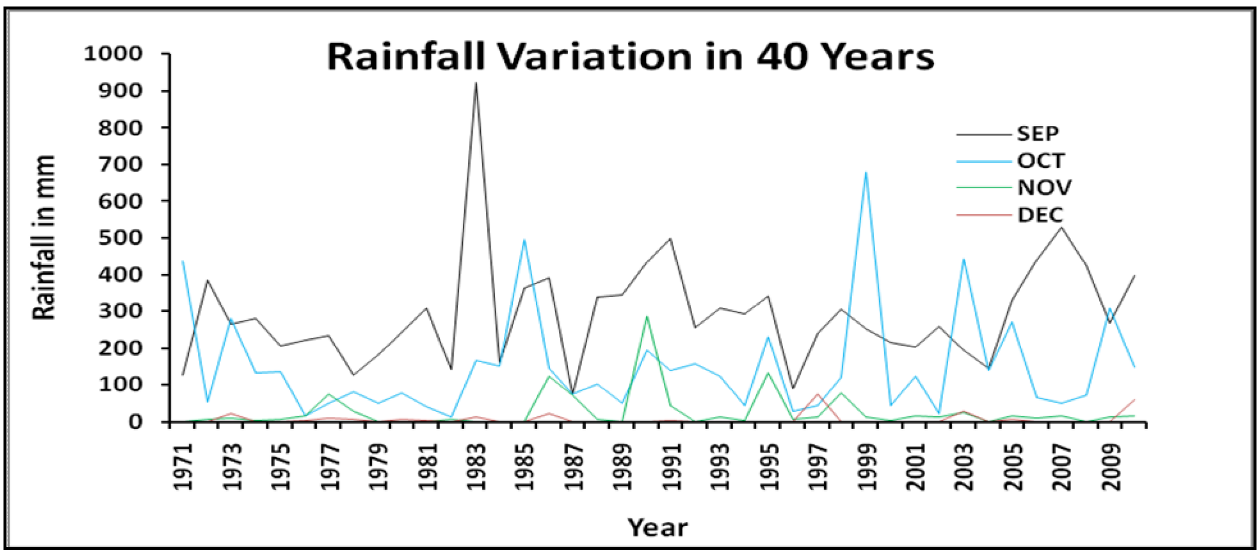

Figure 5: Rainfall of September, October, November and December months for 40 Years

In the non parametric Mann-Kendall test, trend of rainfall for 40 years from January to December has been calculated for each month individually together with the Sen's magnitude of slope (Q) and calculation of percentage (β). In the Mann-Kendall test the Z_c statistics revealed the trend of the series for 40 years for individual 12 months from January to December which are 0.652, -1.56, -0.594, -0.315, 0.198, 0.804, -0.711, -1.247, 1.34, 0.408, 1.363 and -0.827 respectively. For January, May, June, September, October and November there is an evidence of rising trend while Z_c value is showing negative trend in February, March, April, July, August and December. Thus Z_c values for six months show a positive trend and for other six months it shows negative trend representing almost non-significant condition (Fig.6.).

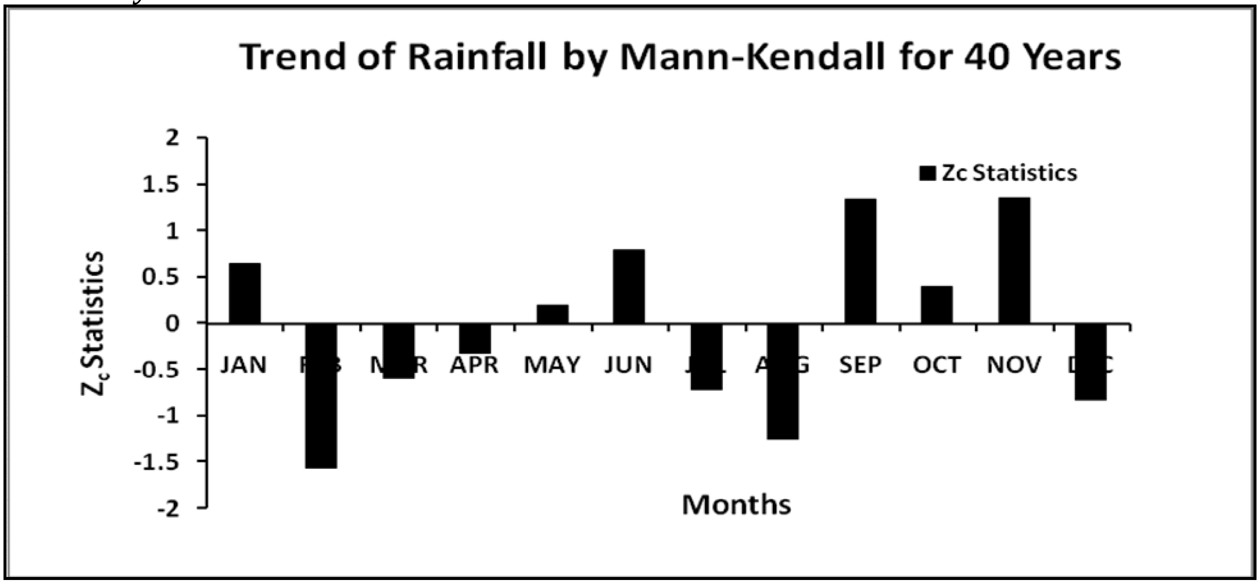

Figure 6: Trend of Z_c for Individual Months for 40 Years

The estimated Sen's slope (Q) for 40 years has been calculated for 12 months showing rising slope magnitude from January to September although a non-significant one. Only the month of December shows non-significant decreasing trend and β value is computed from 1971 to 2010 for 12 months.

Table 1. Estimated Sen's Slope from 1971 to 2010

Months	*Variance*	*Mean*	*Median*	*Standard Deviation*	*Sen's Slope*	*Beta (β)*
JAN	57	8.29	2.37	12.78	0	0
FEB	-135	22.63	12.72	27.54	-0.21	-37.28
MAR	-52	27.44	14.20	36.19	-0.07	-9.88
APR	-28	52.62	42.01	44.06	-0.15	-11.33
MAY	18	109.78	99.07	76.81	0.19	6.87
JUN	70	255.55	240.94	113.06	1.53	24.06
JUL	-62	344.83	321.46	151.80	-1.53	-17.77
AUG	-108	397.86	363.11	148.90	-2.09	-20.96
SEP	116	292.56	265.39	148.87	2.40	32.82
OCT	36	149.47	121.36	146.50	0.37	9.99
NOV	118	26.57	8.69	52.85	0.17	25.04
DEC	-72	6.15	0	15.30	0	0

Table1 is demonstrating the Sen's Slope which is also indicating slope magnitude for each month from January to December for 40 years. But the months of January and December show no change in the Sen's Slope while others are depicting either increasing or decreasing trend. This result is quite significant as the months where Mann-Kendall trend analysis has shown negative trend, similar negative slope has been observed for the Sen's Slope and vice versa.

CONCLUSION

The present study analyzed the rainfall data for 40 years from 1971 to 2010 of a river basin in Orissa for the determination of the trend of precipitation. The area is rural and thus represents more of agricultural

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land and cultivation zones. The Z_c value of MK Test represents both positive and negative trend in the area although not much significant. Individually months of January, May, June, September, October and November are showing positive trend and months of February, March, April, July, August and December are depicting negative trend in the Z_c value. Rainfall varies in different months for different years which are evident in the graphs. Sen's Slope is also indicating increasing and decreasing magnitude of slope in correspondence with the MK Test values. There are six months with increasing trend and Z_c value along with the increasing slope magnitude, and six months with decreasing or negative Z_c value and Sen's Slope. Therefore it can be concluded that there is evidence of some change in the trend of precipitation of the region in these 40 years in different months. Further, study of the area may reveal other aspects which will be helpful in controlling flood causing havoc in this particular area.

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