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Analysis of Rainfall Trends and Variability Barkot of Uttarakhand

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ABSTRACT

The present study is an effort to collect detailed and authentic information about the climate change and rainfall trend, variations in, mid-Himalaya region, Barkot of Uttarakhand. Precipitation is an important climatic parameter for analysis of rainfall pattern, to detect trend and variability of a region, which may have impacts of changing climate patterns, extreme weather conditions, increasing rainfall events and floods. Rainfall time series over a period of 28 years (1985-2012), from limited observational evidence has been processed to detect statistically significant trend and variability, annually, seasonally and monthly, by parametric and non parametric statistical test, in relationship between rainfall and time, regression analysis and coefficient of determination. Non parametric study of Mann-Kendal test and Sen's Slope estimator are applied for detection of trend and slope magnitude. Annually monthly, parametric and non parametric trend and seasonal parametric trends of rainfall and variability are identified; significant and non significant increasing and decreasing monotonic trend and variation in the rainfall time series, to achieve the objective of this research, and concludes that there are fluctuations, significant and insignificant changes in the region.

Keywords *Rainfall trend, variability, Himalayan region, Climate change, Precipitation, Mann-Kendal test, Sen's Slope.*

INTRODUCTION

The heavy rainfall during the period $16^{th} - 18^{th}$ June 2013 in Uttarakhand region, caused loss of lives at large scale, landslides and damages of properties, agriculture production, seasonal crops and economy of farmers. The climatic parameters are physical parameters which are uncertain, risky and unavoidable. The rainfall is a random variable has significant spatial and temporal variations. Study of rainfall pattern and other forms of precipitation is an important weather parameter and is difficult to predict in comparison to other climatic parameters, but the continuous research work by the Scientist about the climatic parameters have developed a confidence about the future and future forecast .The distribution of precipitation, annually, monthly and seasonally is an important to evaluate its impact on hydrology, ecology, agriculture or in water use. Other kind of precipitation, fresh water, the world largest supplies of fresh water is Himalayan mountain system, most of the critical factors are to determine the impact of climate changes, every stage of growth and development of crops, floriculture, agro forestry and livestock. Increased temperature and increase of CO_2 in the atmosphere are the major climate factors, which are affecting crop production due to loss of soil moisture, changed precipitation conditions are increasing demand of water for the crops. Climate is important for living things and weather events immediate respond on the human welfare.

Intergovernmental Panel on Climate Change (IPCC, 2007a) has projected that increase in temperature is expected to be in the range of 1.8 to 4.0°C by the end of 21st Century, for the Indian region (South Asia), the IPCC projected rise in temperature will be 0.5 to 1.2°C by 2020, 0.88 to 3.16°C by 2050 and 1.56 to 5.44°C by 2080, depending on the future human activities (IPCC, 2007b) and the rise in temperature will be higher during the winter season than in the rainy season. Various studies indicated that significant climatic changes are observed over different regions (Sinha *et al*., 1998a). Climate change threatens to reverse the gains achieved in human development as droughts, floods, intermittent rainfall and extremes of temperature, among other variables induced by climate change, compromise potential food and income security (Dervis, 2007). Global warming is likely to cause major changes in various weather variables such as temperature, absolute humidity, precipitation and global solar radiation *etc*. (Mimi *et al*., 2010).

In the perspective of climate change, it is significant to establish whether, the characteristics of regional weather conditions are also changing. Climate change is affecting the temperature, as well as rainfall patterns in the densely populated regions that would have enormous significance for livelihood and wellbeing of the people of the region. Climate change will have environmental and social impacts that will likely increase uncertainty in water supplies and agricultural production for people across India. The cascading effects of rising temperatures are already affecting water availability, biodiversity, ecosystem boundaries, and global feedbacks (Amin, *et al*., 2004).

Worldwide, there are several studies have been focused on trend detection of mean rainfall and its possible effects on variability in water resources, desertification, loss of biodiversity and agriculture productivity (Delitala *et al*., 2000, Lazaro *et al*., 2001; Burlando and Rosso, 2002). The study of precipitation trend is important for a country like India, whose food security and economy depends on timely availability of water, and changing pattern of rainfall over India, observed that there is no clear trend of increase or decrease in average rainfall over the country (Kumar *et al*., 2010). Trend detection of rainfall for the period 1901-1984 at 11 stations in Himachal Pradesh indicating an increasing trend in annual rainfall at eight stations(Kumar *et al*.,2005).(Kumar and Jain 2010)studied trend detection in seasonal and annual rainfall and rainy days using Mann-Kendal test, in Kashmir valley and result indicates the upward trend of rainfall and rainy days in one station where as other stations indicates decreasing trend for both rainfall and rainy days .Existence of significant trend in a time series of rainfall alone cannot be conclusive evidence of the occurrence of climate change in the region, but also to reinforce, the assumption that event (Serrano *etal*.,1999).Several studies on precipitation process are performed using non parametric method (Yue and Hashino 2003) to examine the monthly and annual rainfall of Japan and majority stations showed a significant negative trend.

(Zahedi *et al*., 2007) using the linear regression method and Mann-Kendall, North West began to study the temperature changes. Modarresi (2007), Rainfall trends in the arid and semi-arid country on M-K way reviewed. Research showed that a seasonal shift in the focus of a major climate change in total precipitation occurred but has been not done in the area.

The aim of the present research is to study climate change and local variations, the analysis of rainfall trends and variability for water utilization and agriculture planning in mid-Himalayan region, data over a period of 28 years (1985-2012) were processed and analyzed. This is an effort to detect the possible, trend and variability, annually, monthly and seasonally.

METHODOLOGY

Study Area

Figure-1

The Barkot is situated in District Uttarkashi, Garhwal, Uttarakhand, in the mid-Himalayan region, located 30°82" North latitude and 78°2"East longitude, its altitude above the sea level is 1324 meters, due to variation in altitude provide a great diversity of land cape and micro habitats. The most striking aspect of Barkot is its natural setting a back drop of magnificent Bander punch range and verdant hills and terraced fields in the fore ground. Climate of Barkot, average maximum temperature is 36°C and minimum temperature 20°C and perception 3.2 mm to fall and cloud of land cape and microhabitats. Rainfall time series data over a period of 28 years (1985-2012), were collected from Agro-meteorology Division, Hill campus Ranichaur-243199, processed and analyzed, in the present study to detect annually, monthly and seasonally rainfall trend and variability. Statistical analysis was carried out, by parametric, regression analysis, coefficient of determination R^2, and nonparametric, Mann-Kendal trend test and Sen’s Slope were applied to study the rainfall time series pattern.

The Mann-Kendal trend test

The Mann-Kendal trend test is a non parametric test to detect the trend in time series data. The test was suggested Mann-Kendal, 1945 and has been extensively used in environmental time series (Hipel and McLeod 2005).The test compares the relative magnitudes of sample data rather than the data values themselves.

Let $x_1, x_2 \ldots x_n$, represents ‘n’ data points where x_j represents the data point at time j. Then the Mann Kendal statistics S is given by

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

Application of trend test is done to the 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 point's x_j so that

$$sgn\,(x_j - x_i) \begin{cases} +1, > (x_j - x_i) \\ 0, = (x_j - x_i) \\ -1, > (x_j - x_i) \end{cases} \quad \rightarrow (2)$$

When n ≥ 8, the statistic S is approximately normally distributed with mean E(S) = 0 and

$$V(S) = [n\,(n-1)\,(2n+5) - \sum_{t=i}^{m} t_i\,(t_i - 1)\,(2\,t_i + 5)]/18 \quad \rightarrow (3)$$

Where t_i is considered as the number of ties up to sample i. The test statistic Z_C is calculated as

$$Z_C = \begin{cases} S - 1/\sqrt{Var\,(S)},\ S > 0 \\ 0,\ S = 0 \\ S + 1/\sqrt{Var\,(S)},\ S < 0 \end{cases} \quad \rightarrow (4)$$

Z_C follows a standard normal distribution. A positive (negative) value of Z signifies an upward trend (downward) trend and negative value of Z signifies the negative trend, or downward trend, testing of monotonic trend (a two tailed test), at α /2% level of significance, if $Z_C \geq Z_{\alpha/2}$ or if $-Z_C \leq -Z_{\alpha/2}$ then trend is considered as significant. Null hypothesis H_o: There is no trend, against the alternative hypothesis H_1: There is increasing or decreasing monotonic trend.

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 are computed as (Sen, 1968)

$$T_i = (x_j - x_k)\,/\,j-k,\ \text{for } i= 1, 2\ldots N \quad \rightarrow (5)$$

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

$$Q_i = \begin{cases} T_{(N+1)/2},\ \text{where, N is odd} \\ 1/2\,[T_{(N/2)} + T_{(N+2)/2}],\ \text{where N is even} \end{cases} \quad \rightarrow (6)$$

Sen's estimator is computed, Q med $=T_{(N+1)/2}$ if N is odd, and it is considered as Q med = $[T_{(N/2)} + T_{(N+2)/2)}]$ if N is even. At the end Q med is computed by a two tailed test at 100 (1− α) % the confidence interval and then a true slope which can be obtained by the non parametric test. Positive values of Q_i indicates an upward or increasing trend and negative values of Q_i indicates a downward or decreasing trend in the time series.

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RESULTS AND DISCUSSIONS

In the present study of Barkot, rainfall trend and variability is analyzed, by parametric, trend detection, through statistical methods in relationship between rainfall and time, regression analysis, coefficient of determination $R^2$and non parametric study of Mann-Kendal test and Sen's Slope estimator are applied for detection of trend and slope magnitude. Table-1and Figure-1, shows variation in annual rainfall pattern with maximum mean rainfall 175.30 mm in the year1988 and minimum mean rainfall 10.40 mm in the year 2012, and the average rainfall is 100.793 mm, the coefficient of variation minimum in the year 1997 is75.920% and maximum in the year 2012 is 345.410%, decreasing rate of rain fall is 3.93 mm per annum. Annual Rainfall data did not follow normal distribution because the skewness =1.936, i.e. $\gamma_1 \neq 0$ and the kurtosis = 4.460, i.e. $\beta_2 \neq 3$. Regression analysis,indicates a trend line for annual mean rainfall agaist time is decreasing, $\beta = -1.3403$,indicates a negative linear relationship between annual mean rainfall and time,the coefficient of determination $R^2 = 0.1246$,indicating only 12.46% variation in rainfall yearly time series within the period of 28 years (1985-2012).

The Mann-Kendal trend test was applied to the annual rainfall time series, the value of S is − 6242.00, a very high negative value, and tested at 5% level of significance, H_o: There is no trend in the time series against alternative hypothesis H_1: There is a trend in the time series, Z-value is – 3.0372 and p-value is 0.002, magnitude of trend, Sen's Slope is − 0.098, indicating statistically significant, decreasing monotonic trend of rainfall time series within the period of 28 years (1985-2012).

Table-1 Statistical analysis of Annual rainfall time series in Barkot (1985-2012)

Max.	Mean	C.V.%	Skew.	Kurt.	β	R^2	Z-Value	p-value
641.50	100.79	115.22	1.936	4.460	− 1.3403*	0.1246	-3.0372*	0.002

* indicates significant values.

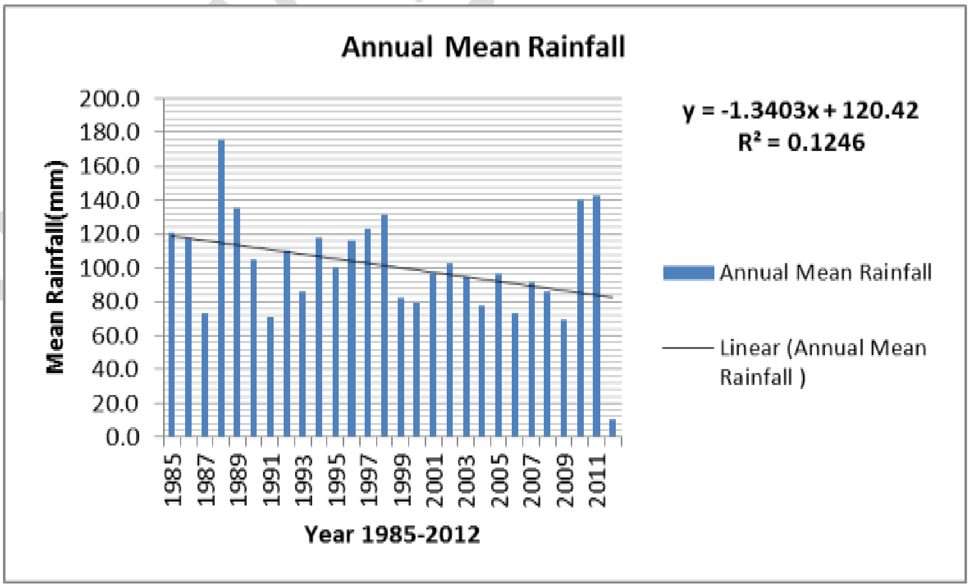

Figure-1 Annual Mean Rainfall (1985-2012)

Table-2 andFigure-2, shows variation in monthly rainfall pattern with maximum mean rainfall in the month of July is 276.40 mm and minimum mean rainfall in the month of November is 9.96 mm, the minimum coefficient of variation in the month of August is 50.94 % and maximum in the month of October is 193.04 %, decreasing rate of rainfall is 2.00 mm per month within 28 years. Monthly distribution of Rainfall January to December, with in months did not follow normal distribution because of the Coefficient of skewness lies between (0.057to 3.211), i.e. $\gamma_1 \neq 0$ and the kurtosis lies between (−1.50 to10.870), i.e. $\beta_2 \neq 3$. Regression analysis,indicates a trend line for monthly mean rainfall agaist time is an increasing trend in the month of January and September and decreasing trend in the months February, March, April, May, June, July, August, October, November and observed significant decreasing trend in the month of December.

The Mann-Kendal trend test was applied to the monthly rainfall time series,(January to December), for the period (1985-2012), have been calculated individually for each month and estimated Sen's magnitude of Slope, and tested at 5% level of significance, H_o: There is no trend in the time series against alternative hypothesis H_1: There is a trend in the time series, Z-value, p-value and magnitude of trend, Sen's Slope are presented in Table-2, indicating statistically in- significant increasing monotonic trend in the months January is 0.5736 and September, is 0.1580,indicating statistically in-significant decreasing monotonic trend in the months, February, March, April, May, June, July, August, October, November are – 0.3567, −1.857, −0.7110, −1.9175, −0.3573, −0.9680, −0.6124, −0.6204, −0.0215 and indicating statistically significant decreasing monotonic trend in the month, December is −2.1644.

Table -2. Statistical analysis of monthly rainfall time series in Barkot (1985-2012)

Parametric								**Non Parametric**		
Month	Max.	Mean	C.V.%	Skew.	Kurt.	β	R^2	Z-value	p-value	Sen's Slope
Jan.	146.00	55.578	71.00	0.501	− 0.474	0.5951	0.0154	0.5736	0.567	0.798
Feb.	157.00	73.633	62.81	0.057	− 1.058	− 0.5568	0.0098	− 0.35671	0.722	− 0.387
Mar.	168.00	68.258	77.23	0.296	− 1.50	− 2.2541	0.1237	−1.857	0.063	− 2.764
Apr.	215.10	57.118	91.09	1.365	1.566	− 1.0926	0.0298	− 0.7110	0.441	− 0.583
May	188.40	63.882	60.96	1.507	2.879	− 2.2635	0.2285	− 1.91750	0.058	− 1.523
Jun.	294.10	116.246	66.67	0.469	− 0.621	− 0.0375	2E-05	− 0.3573	0.707	− 0.798
Jul.	606.00	276.400	57.28	0.464	− 0.121	− 5.7981	0.0907	− 0.9680	0.333	− 4.017
Aug.	641.50	257.650	50.94	0.667	1.086	− 0.5912	0.0014	− 0.6124	0.540	− 1.845
Sept.	582.00	167.428	70.86	1.652	3.655	0.7944	0.003	0.1580	0.874	0.363
Oct.	298.00	31.823	193.04	3.211	10.87	− 1.6505	0.0488	− 0.62041	0.535	− 0.101
Nov.	50.000	9.964	158.62	1.449	0.726	− 0.0096	2E-05	− 0.02155	0.983	0
Dec.	163.10	31.539	143.58	1.480	1.154	− 3.1494*	0.3273	− 2.6144*	0.009	− 1.592

* indicates significant values.

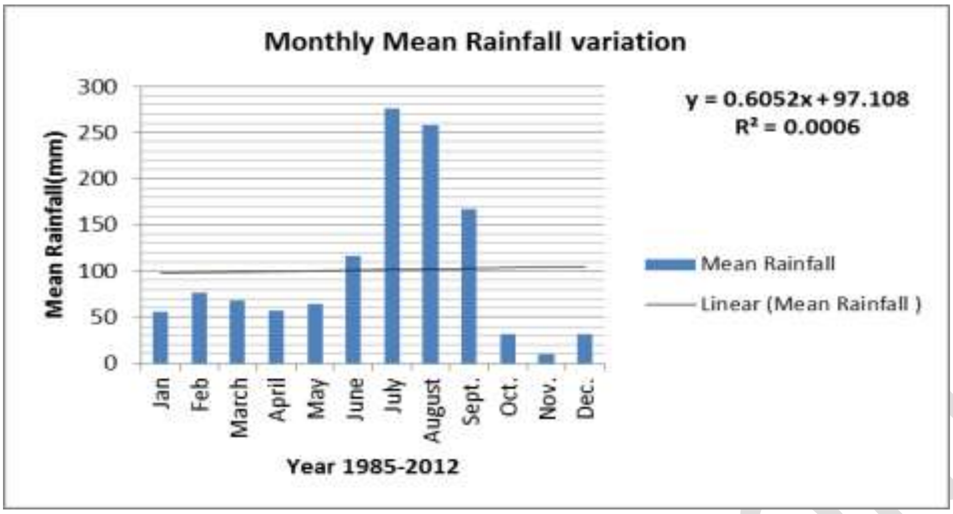

Figure-2 Monthly Rainfall (1985-2012)

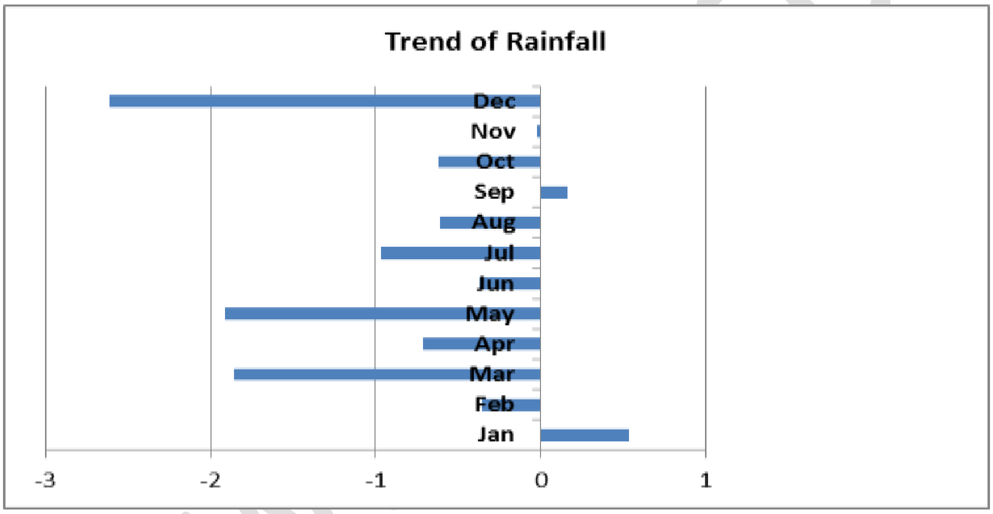

Figure-3 Individual Month Rainfall Trend test by Mann-Kendal

The Figure-3 shows estimated Sen'Slope for the months January to December have been calculated,indicating non significant increasing slope for the months January and September. The decreasing non-significant slopes of months, Feb., Mar., April, May, June, July, August, October and indicating no change in Sen's slope for the month November, the only month December, indicates significant decreasing Sen's slope.

Table -3 Statistical analysis of Seasonal rainfall time series in Barkot (1985-2012)

Seasons	Maximum	Mean	C.V.%	Skew.	Kurt.	β	R^2
Winter	163.100	53.583	86.9454	0.551	− 0.785	0.553	0.839
Pre-Monsoon	215.100	63.086	76.0121	0.941	0.535	− 0.227	0.199
Monsoon	641.500	204.431	68.3125	0.987	0.999	0.3635	0.0071
Post-Monsoon	298.00	20.984	219.1633	4.397	22.616	−0.793	0.0798

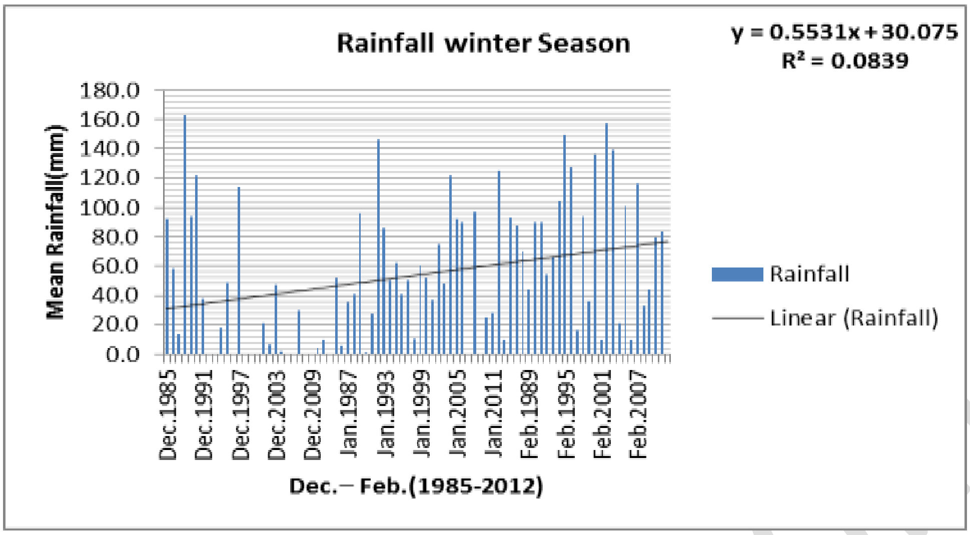

Figure-4 Rainfall Winter Season (1985-2012)

Table-3 and Figure-4 shows the rainfall variation in winter season,(December to Feburary), The maximum rainfall is 163.100 mm in the month December 1988,the mean rainfall is 53.83 mm, and coefficient of variation is 86.9454%,winter season rainfall distribution did not follow normal distribution, because of coefficient of skewness = 0.551, i.e. $\gamma_1 \neq 0$ and the kurtosis = − 0.785, i.e. $\beta_2 \neq 3$.The regression analysis,indicates a trend line for winter season, mean rainfall agaist time is increasing, $\beta = 0.553$,indicates a positive linear relationship between mean rainfall and time,the coefficient of determination $R^2 = 0.0839$,indicating only 8.39% variation in,seasonal rainfall time series within the period of 28 years (1985-2012).

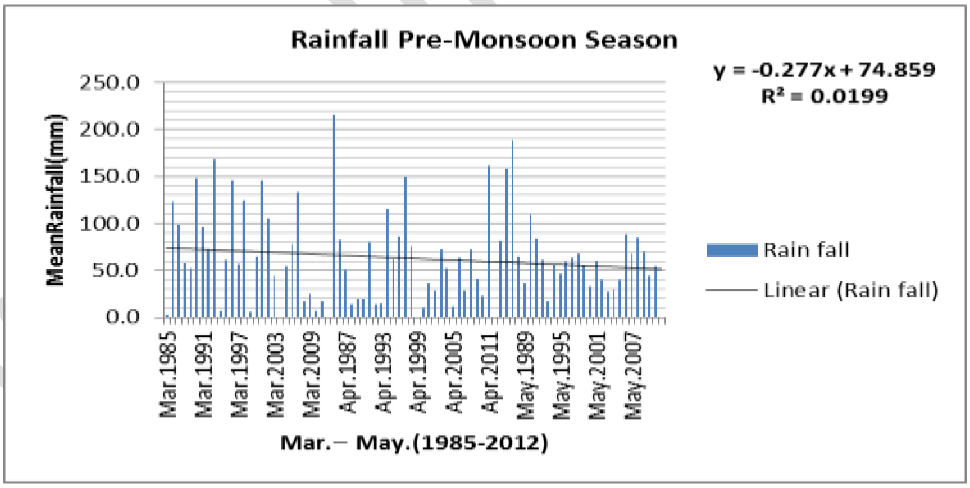

Figure- 5 Rainfall Pre-Monsoon Season (1985-2012)

Table-3 and Figure- 5 shows the rainfall variation in ,Pre monsoon season,(March to May). The maximum rainfall is 215.100 mm in the month April 1985, the mean rainfall is 63.086 mm, and coefficient of variation is 76.0121%. Rainfall distribution did not follow normal distribution, because of coefficient of skewness = 0.941 i.e. $\gamma_1 \neq 0$ and the kurtosis = 0.535 i.e. $\beta_2 \neq 3$. The regression analysis,indicates a trend line for Pre-monsoon season, mean rainfall agaist time is decreasing, $\beta = -0.277$,indicates a negative linear relationship between mean rainfall and time,the coefficient of determination R^2 = 0.0199,indicating only 1.99% variation in,seasonal rainfall time series within the period of 28 years (1985-2012).

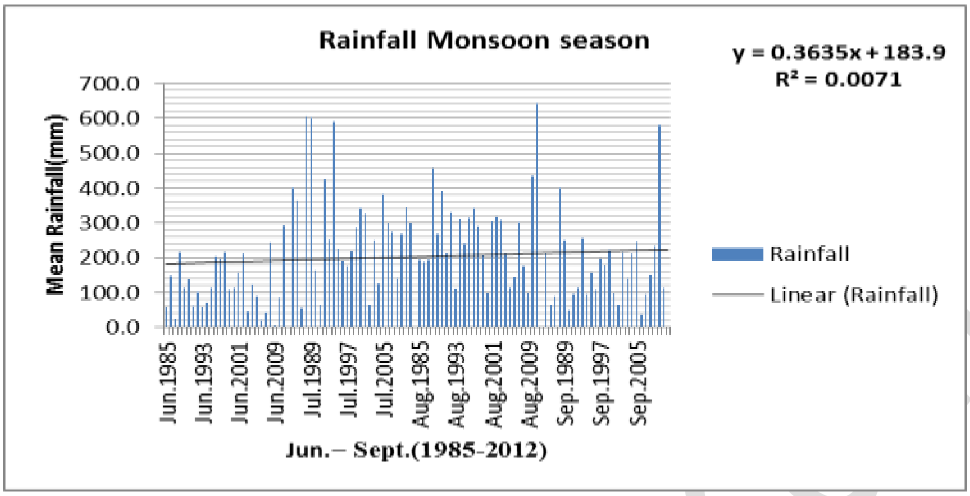

Figure- 6 Rainfall Monsoon Season (1985-2012)

Table-3 and Figure-6 shows the rainfall variation in monsoon season,(June to September).The maximum mean rainfall is 641.500 mm, in the month of August 2011, the mean rainfall is 204.431mm, and coefficient of variation is 68.3125%. Rainfall distribution did not follow normal distribution, because of the coefficient of skewness = 0.987 i.e. $\gamma_1 \neq 0$ and the kurtosis = 0.999 i.e. $\beta_2 \neq 3$. The regression analysis,indicates a trend line for monsoon season, mean rainfall agaist time is increasing, β = 0.3635 ,indicates a positive linear relationship between mean rainfall and time,the coefficient of determination R^2 = 0.0071,indicating only 0.71% variation in seasonal rainfall time series within the period of 28 years (1985-2012).

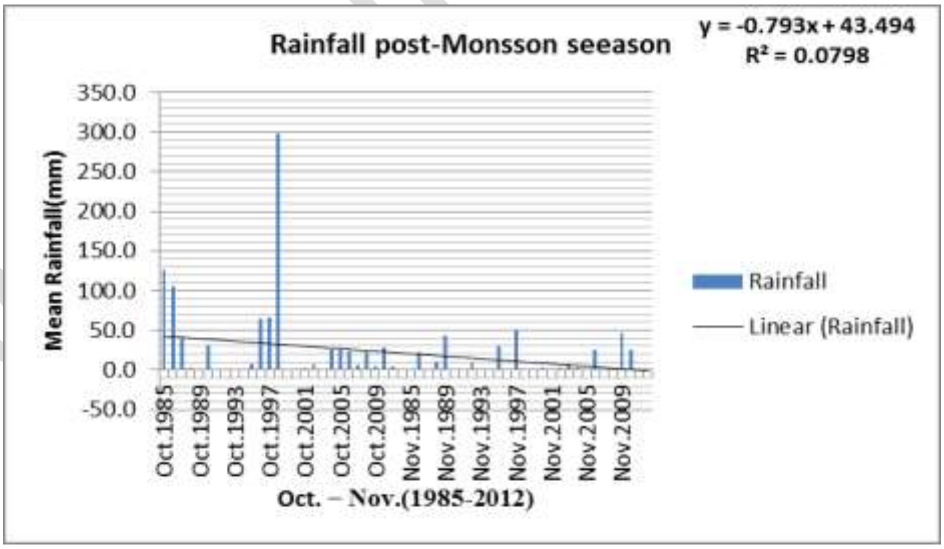

Figure-7 Rainfall Post-monsoon season (1985-2012)

Table-3and Figure-7, shows the rainfall variation in , Post-monsoon season,(October to November).The maximum mean rainfall is 298.00 mm,in the month of October 1988,the mean rainfall is 53.83mm, coefficient of variation is 86.9454% .Rain fall did not follow normal distribution because of coefficient of skewness =1.936, i.e. $\gamma_1 \neq 0$ and the kurtosis = 4.460, i.e. $\beta_2 \neq 3$. The regression analysis,indicates a trend line for Post-monsoon season, mean rainfall agaist time is decreasing, $\beta = -0.793$,indicates a negaitive linear relationship between mean rainfall and time,the coefficient of determination $R^2 = 0.0798$, indicating only 7.98% variation in seasonal rainfall time series within the period of 28 years (1985-2012).

CONCLUSIONS

The parametric and non-parametric statistical trend test analysis shows significant and non-significant decreasing and increasing trend annually, monthly and seasonally. Annual rainfall time series regression analysis indicates the decreasing trend line, and non-parametric Mann-Kendal test also confirms significant decreasing monotonic trend. Monthly rainfall time series regression analysis indicates an increasing trend in the month of January and September,and decreasing trend in the months ,February, March, April, May, June, July, August, October, November and significant decreasing trend in the month of December and non-parametric Mann-Kendal test also confirms indicating insignificant ,increasing monotonic trend for the month January and September and decreasing insignificant monotonic trend of months, February, March, April, May, June, July, August, October, November, but the month December, indicates, significant monotonic decreasing trend. Estimated Sen'Slope for the months January to December,indicating non significant increasing slope for the months January and September and decreasing non-significant slopes of months, February, March, April, May, June, July, August, October and indicating no change in Sen's slope for the month November, but the month December, indicates significant decreasing Sen's slope. The seasonal trend of rainfall trend and variation was analyzed by parametric statistical trend test, the winter season and monsoon season indicates an increasing trend, but the Pre-monsoon season and Post-monsoon season indicates decreasing trend.

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