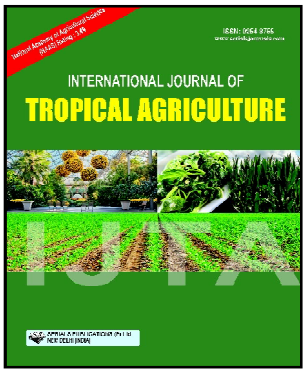

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Recent Rainfall Trend and Drought Behavioural Assessment in the Pantnagar Region of Uttarakhand

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Abstract: The present study is carried out to investigate the long-term variation and distribution of rainfall at monthly, seasonal and annual time scale for the last 48 years (1970–2017) in the Pantnagar region of Uttarakhand state**.** The daily rainfall data from January, 1970 to October, 2017 were collected from meteorological observatory of G. B. Pant University of Agriculture and Technology, Pantnagar. The commonly used non-parametric Mann-Kendall (MK) test was employed to identify the trends; and the Sen's slope estimator was applied to detect the magnitude of rainfall time series trend. The drought behavioural assessment was carried out using the two different drought indices viz. Standard precipitation index (SPI) and Rainfall departure (RD). In the study region, the maximum and minimum rainfall values of annual data series were respectively 3218.6 mm and 831.2 mm. The rainy season rainfall was found to vary from 59.51 to 96.27 % of the total annual rainfall. No significant (at 5% level) monthly, annual and monsoon season rainfall trend could be found in the study region. However, both annual and rainy season data analysis showed a non-significant incremental trend. The drought analysis through SPI shows that the months of October, November and December had never suffered any kind of drought. The results from SPI analysis show that extreme and exceptional drought rarely occurs in the Pantnagar region. Similar to SPI, the RD method also showed that most of the years exhibited no drought. Notably, the rainy season of the year 2017 was not under any kind of drought.

Keywords: Drought; Rainfall Trend; Rainfall departure; Mann-Kendall; Sen's slope.

1. INTRODUCTION

The determination of rainfall amount and its behaviour over time and space has many practical applications in engineering and agriculture. To utilize available rainfall effectively, crop planning and management practices must be followed based on

amount and distribution of rainfall at a place. In our country, rainfall distribution is very erratic in nature and varies from region to region and year to year though adequate rainfall is received through four different types of weather phenomenon. Many researchers have carried out the trend analysis on meteorological variables, particularly precipitation. For this purpose, many parametric and non-parametric tests have been used for the detection of the trend in meteorological variables time series data. The Mann-Kendall (MK) and Sen's slope (SS) estimator tests are the non-parametric tests which have been widely used in many studies for the detection of climatic trends. Furthermore, there was great attention in the study of the existence of these trends in the meteorological variable (i.e. precipitation) and drought is directly linked with these climatic variables variations. Drought occurs due to the less availability of water than those of normal water conditions in the region. Primary causes of drought are amount and timing of precipitation and use according to the water demand of region. The occurrences of droughts often lead to problems such as agricultural crop failure, lowering of water table, depletion of water storage in reservoirs, reduced fodder availability and shortage of drinking water. These problems are the indications to make a significant research and operational efforts for monitoring drought. In India, droughts occur frequently and about 1.07 million km^2 of total geographical area is subjected to different degrees of water stress and drought conditions [1]. The drought prone area spread over 300 districts and about 60% of the population of the country gets affected by drought at one or other time in the country.

There are three types of drought (i) meteorological (ii) hydrological (iii) agricultural droughts. Meteorological drought occurs due to precipitations which occur below normal levels for several months. A wide range of indexes has been introduced for the assessment of different types of droughts. Standardized Precipitation Index (SPI) and Rainfall Departure (RD) have been widely used for the identification of meteorological drought [2, 3]. Further, it is also essential to analyse the characteristics of meteorological variables and drought analysis using different types of indices at various times scales (1-month, 3-month, seasonal, and annual), which is a necessary for forecasting and mitigation. These analyses can improve the management of water resources.

Keeping all the aforesaid arguments in view, following objectives have been put forward for this study:

1. To conduct a trend analysis of precipitation data on monthly, seasonal and annual time scale.
2. To assess the frequency and severity of drought behaviour in the last 48 years (1970-2017).

2. MATERIALS AND METHODS

2.1. Study area description and data collection

The present study is carried out at Pantnagar which is located in Udham Singh Nagar district of Uttarakhand state. Pantnagar is situated at latitude of 28º 97' N and longitude of 79º 41' E and it has an elevation of 243.8 m above mean sea level. The area lies in the foothills of Himalayas in the Tarai region of state. The climate of Pantnagar is sub-humid sub-tropical type. The average annual temperature is about 24.1 ºC and average annual rainfall is 1545.44 mm for last 47 years (1970-2016).

The daily rainfall data for 48 years from January, 1970 to October, 2017 were collected from meteorological observatory of Govind Ballabh Pant University of Agriculture and Technology, Pantnagar. The observatory is located at Crop Research Center (CRC), Pantnagar.

2.2. Statistical tests for trend analysis

If the trend can be assumed to be linear, trend analysis can be undertaken within a formal regression

analysis but if the trends have other shapes than linear, trend testing can be done by non-parametric methods. In present study, the non-parametric Mann-Kendall test was used for detecting the trend in rainfall data series. The analysis for the trend detection was performed on the monthly and annual data series for the period of 47 years (1970–2016). In contrast to it, 48 years (i.e. 1970-2017) data were used for rainy season trend analysis.

The Mann-Kendall test statistic (S) [4, 5] is calculated by using the formula given below:

$$s = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}(x_j - x_i) \quad (1)$$

Where,

x_j & x_i = values of i and j ($j > i$) in time series, sgn (x_j-x_i) is the sign function, and n = number of data points.

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

If sample size $n > 10$, the mean and variance are given by:

$$\mu(s) = 0$$

$$\sigma^2(s) = n(n-1)(2n+5) \sum_{i=1}^{m} \frac{t_i(t_i-1)(2t_i+5)}{18} \quad (3)$$

Where,

t_i = number of ties of extent i, m = number of tied group.

A set of data containing the same values is called tied group. If ties values are absent between the observations, then

$$\sigma^2(s) = \frac{n(n-1)(2n+5)}{18} \quad (4)$$

The standard normal test statistic Z_s is computed as:

$$Z_s = \begin{cases} \frac{s-1}{\sqrt{\sigma^2(S)}} & if\ s > 0 \\ 0 & if\ s = 0 \\ \frac{s+1}{\sqrt{\sigma^2(s)}} & if\ s < 0 \end{cases} \quad (5)$$

Here, the positive and negative values of Z_s represent the increasing and decreasing trend, respectively. Z_s is the value read from a standard normal distribution table with α being the significance level of the test. At the 99% significance level, the null hypothesis of no trend is rejected if $|Z_s| > 2.575$; at 95% significance level, the null hypothesis of no trend is rejected if $|Z_s| > 1.96$; and at 90% significance level, the null hypothesis of no trend is rejected if $|Z_s| > 1.645$.

Further, Sen's slope estimator was used to calculate the magnitude of slope in the time series data [6].

$$T_i = \frac{x_j - x_k}{j - k} \quad (6)$$

Where,

x_j = data value at time j, x_k = data value at time k

$$Q_i = \begin{cases} T_{(N+1/2)} & N\ if\ odd \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) & N\ if\ even \end{cases} \quad (7)$$

Here, the positive and negative values of Qi show the increasing and decreasing trends, respectively.

2.3. Change magnitude as percentage of mean

Some trends may not be evaluated to be statistically significant while they might be of practical interest, and vice versa [7]. Even if a climate change component is present, it does not need to be detected by statistical tests at a satisfactory significance level [8]. For the present study, change percentages have been computed by approximating it with a linear trend, estimating its magnitude by Sen's median slope and assessing the change over the period as percentage of mean of the period concerned, following Yue and Hashino, 2003 [7].

2.4. Drought analysis

In the present study, the meteorological drought was examined through Standardized Precipitation Index (SPI) and Rainfall Departure (RD). The drought categorization was done on the basis of their SPI values following Mckee *et al.,* 1993 criterion [9] (Table 1). In RD method, the difference between the actual value for the day and the normal is known as the departure from mean rainfall. Here, only the rainy season and annual time scale drought was analysed employing the rainfall departure method. The following Table 2 shows rainfall departure values and its drought category. Due to limitation of space, details about SPI and RD methods cannot be given in paper. The stepwise procedure for finding drought through the SPI and RD methods can be found in Kumar *et al.,* 2009 [10].

Table 1
Different drought conditions based on their SPI values

Drought conditions	*SPI values*
Abnormally Dry	-0.79 to -0.5
Moderate drought	-1.29 to -0.8
Severe drought	-1.59 to -1.3
Extreme drought	-1.99 to -1.6
Exceptional drought	-2.0 or less

Table 2
Classification of drought based on the percentage departure of rainfall from mean [11]

Percentage departure of rainfall from normal	*Intensity of drought*
>-25.0	No drought condition
-25.0 to -50.0	Moderate drought condition
<-50.0	Severe drought condition

3. RESULTS AND DISCUSSION

3.1. Descriptive statistics of rainfall for the last 47 (1970-2016) years of data

The minimum and maximum rainfall with different statistical parameters viz., mean, median, standard deviation, coefficient of variation, skewness and kurtosis are calculated for each month, annual and rainy season and results are shown in Table 3. The maximum rainfall value of annual data series was 3218.6 mm. On the other hand, minimum value went down to 831.2 mm which is almost 4 times less than that of maximum. In rainy season the minimum rainfall occurred was 647.8 while the maximum went 4 times higher (i.e. 2652 mm). As seen from Table 3, the rainy season in the study region received most of the rainfall. In the year 2008 the 96.27% of the annual rainfall occurred in rainy season only.

3.2. Trend analysis

The results of trend analysis using Mann-Kendall method and Sen's slope estimator are given in Table 4. As seen, the values of standard normal test static Z_S varied from -1.33 to 1.29 on a monthly timescale analysis. The Sen's slope was varied from 1.411 to -0.385. The percentage change with a value of 35.78 was maximum in April month and minimum with a value of -29.73 in month of May. As per the monthly trend analysis, no months were found to show either increasing or decreasing rainfall trend significantly (at 5% level). The both annual and rainy season data analysis also showed a non-significant incremental trend.

Table 3
Descriptive statistics of rainfall (mm) at Pantnagar for last 47 (1970-2016) years of data

Statistic	*Jan*	*Feb*	*March*	*April*	*May*	*June*	*July*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Annual*	*RS*	*A*
Maximum	112.4	184.8	66.6	130.8	328	666	768.8	1076.0	746.6	354	29.2	94	3218.6	2652	96.27
Minimum	0	0	0	0.0	0	21.2	112.0	62.60	27	0	0	0	831.2	647.8	59.51
Mean	28.9	41.6	15.67	23.1	60.9	201.8	489.7	379.66	234.6	37.73	3.77	14.30	1531.9	1305.87	85.07
Median	23.0	20.6	8.70	17.6	40.0	159	509.8	350.60	184	11.60	0	9	1442.8	1276.4	85.96
SD	29.5	49.1	17.88	26.9	71.4	146.3	167.6	185.05	174.5	73.27	7.88	20.69	528.75	469.98	7.52
CV	101.7	118	114.2	116.3	117.4	72.49	34.21	48.74	74.38	194.2	209.1	144.6	34.52	35.99	8.84
Skewness	1.15	1.56	1.5	1.98	2.24	1.53	-0.26	1.14	1.23	3.03	2.31	2.2	0.98	0.81	-1.45
Kurtosis	0.61	1.73	1.54	4.84	5.54	2.11	-0.46	2.89	1.09	9.64	4.25	5.47	1.17	0.37	3.36

(*Note:* SD= Standard Deviation; CV= coefficient of variation (%); RS= Rainy Season; A= Percentage of annual rainfall occurred in rainy season)

Table 4
Results of Mann-Kendall (MK) test, Sen's slope estimator and percentage change for different timescales

Period	*Zs*	*Sen's Slope (mm/year)*	*Percentage change*	*Trend*
Jan	-0.92	-0.145	-23.51	Decreasing
Feb	0.45	0.111	12.54	Increasing
Mar	-0.42	-0.036	-10.80	Decreasing
Apr	1.29	0.176	35.78	Increasing
May	-0.84	-0.385	-29.73	Decreasing
Jun	0.20	0.318	7.41	Increasing
Jul	0.13	0.305	2.93	Increasing
Aug	0.72	1.411	17.47	Increasing
Sep	0.61	1.000	20.03	Increasing
Oct	-1.33	-0.075	-9.34	Decreasing
Nov	-0.61	0.000	0.00	Decreasing
Dec	-0.85	0.000	0.00	Decreasing
Annual	0.59	3.327	10.21	Increasing
RS	0.83	3.408	12.49	Increasing

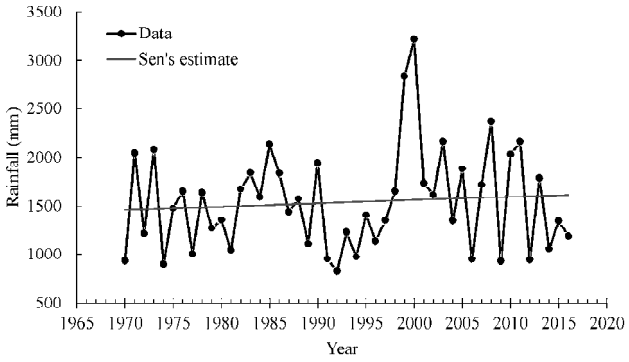

Figure 1: Plot of trend of annual rainfall for the 47 (1970-2016) years' time series

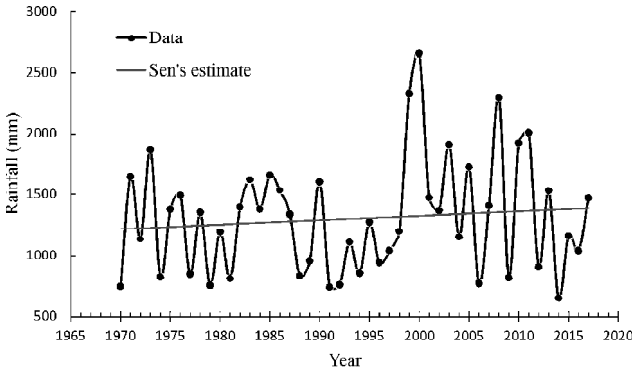

Figure 2: Plot of trend of rainy seasonal time series of the 48 (1970-2017) year

The Sen's slope for both annual and rainy season was as 3.327 and 3.408 mm per year, respectively. The annual rainfall percentage change over the 47 years was as 10.21. On the other hand, it was found to be 12.49% for the rainy season over a period of 48 years. The graph plots of annual and rainfall data series are also quite similar as shown in Figure 1 and Figure 2, respectively.

3.3. Drought analysis of monthly, annual and rainy season data series through SPI

Out of 47 years of monthly data series analysis, January month experienced 14 years under drought conditions. It is worth to note that the January witnessed the four continuous droughts during the years 1991, 1992, 1993 and 1994. The February month never experienced severe, extreme and exceptional drought as the SPI values did never fall below -1.3. Similar to the February month, the March, April and May months did not experience the any severe, extreme and exceptional drought. In March month, 61% of the total years did never experienced any kind of drought; whereas the remaining 39% (i.e. 18 years) found to fall under abnormal and moderate drought conditions. The April month faced abnormal drought in the years 1972, 1974, 2006 and 2011. In contrast, the years 1970, 1973, 1975, 1976, 1979, 1980, 1989, 1993 and 1995 were under moderate drought conditions. The June month witnessed abnormal drought in the years 1971, 1988, 1993, 1997 and 2009; and the years 1977, 1985, 1986, 1992, 1994, 2005 and 2014 were under moderate drought conditions. On the other hand, each year 1987, 2006 and 2012 were under severe, extreme and exceptional drought conditions, respectively. The severe and extreme drought was not found in July month, but the years 1970, 1991

and 2009 witnessed exceptional drought. The year 2014 experienced exceptional drought, and the year 1981 was extremely dry during the August. The 15 out of 47 years were found experienced drought in the September month. In these 15 drought years, 1981 and 1994 were severe, while 1979, 1982 and 2014 were extremely dry. Notably, the October, November and December months never witnessed drought conditions over the last 47 year of study period.

For the rainfall data analysed through SPI, there were 16 years under drought condition for both annually and rainy seasons. The abnormal drought occurred in the rainy seasons of 1997 and 2016. Similarly, the years 1972, 1993, 1996 and 2016 on annual data series basis were also abnormally dry. Notably, the year 2014 was extremely dry in rainy seasons, while on annual basis it was found to be as severely dry. On annual basis, no year experienced exceptional drought in the past 47 years. Annually, the 1992 was extremely dry year, but it fell under severe drought on the rainy seasons basis. 1970 was severely dry for both annual and rainy season whereas 1974, 2009, 2012 were on severe dry condition on annual time scale. The rainy season of the current year 2017 had a SPI value of 0.43 which doesn't fall under any drought conditions as shown in Figure 3. As seen, the minimum annual and rainy season SPI values were -1.67 and -1.77, respectively. On the other hand, the maximum SPI values were respectively 2.70 and 2.44 for annual and rainy season.

The percentage of occurrence was 25 in both severe and abnormal conditions of annual drought. Similarly, the moderate drought had a highest percent occurrence of 43.75 in the annual data analysis. Both annual abnormal and severe drought occurred once in 11.75 years. As seen from the analysis, the annually extreme drought severity was 1 in 47 years. In rainy season abnormal drought occurred once in 23.5 years, moderate drought-the most frequent one

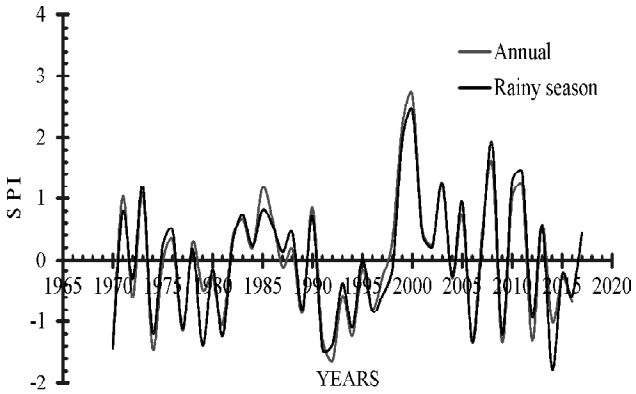

Figure 3: Plot of SPI values against corresponding year

occurred once in 5.9 years. Further, extreme drought occurred only a single time in past 48 years. Exceptional drought was never found till date in rainy season.

3.4. Drought analysis of rainy season and annual data through rainfall departure

For the rainfall data analysed by departure method, there were 13 and 14 years under drought conditions for both annual and rainy season data series, respectively. As there were no severe droughts recorded on annual basis, but the year 2014 with rainfall of 647.8 mm was under severe drought condition on rainy season. Also, the annual rainfall for the year 2014 was 1057.1 mm, and 2014 was also the nearest year categorized under drought; and no year is recorded under drought condition since 2014. As per departure method, 1992 was the year with moderate annual drought but no rainy season drought. That means that there was less rainfall for the first 6 months in 1992 as compared to second half of the year. Similarly, as seen from the Figure 4, the year 1979 was under moderate seasonal drought but with no annual drought. It was observed due to the less rainfall in the rainy season as compared to entire year. Notably, the rainy season of current year 2017 was not dry.

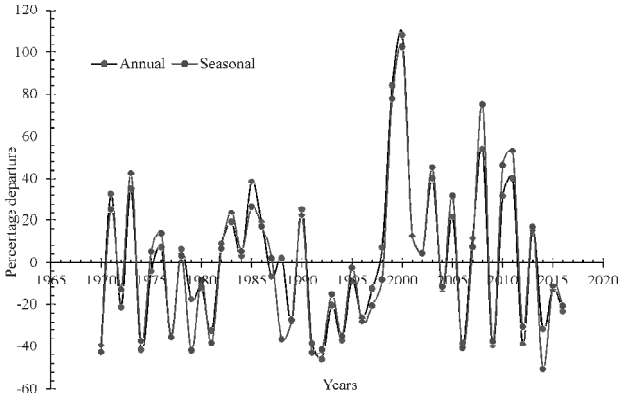

Figure 4: Plot of annual and seasonal percentage departure values against corresponding year

3.5. Conclusions

Based on the analysed data, the following specific conclusions were drawn from the present investigation:

1. In the past 47 years, the rainy season rainfall was found to vary from 59.51 to 96.27 % of annual rainfall.
2. No significant (at 5% level) monthly, annual and monsoon rainfall trend could be found in the study region. However, both annual and rainy season data analysis showed a non-significant incremental trend.
3. The 16 out of 47 years fell under various drought categories on annual basis. The majority of the drought years were under the abnormal and moderate drought conditions. Thus, it can be inferred from the SPI analysis that extreme and exceptional drought rarely occurs in Pantnagar region. Notable, the rainy season of the current year was not under any kind of drought.
4. The drought analysis through RD method showed that most of the years exhibited no drought conditions while few of them fell under moderate condition. Exceptionally, the year 2014 faced severe drought during rainy season; however, annually it fell under moderate condition.

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