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RAINFALL CHARACTERISTICS AND METEOROLOGICAL DROUGHT IN HANUMANGARH DISTRICT OF ARID RAJASTHAN

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ABSTRACT

The rainfall characteristics and meteorological drought conditions in Hanumangarh district of arid Rajasthan were studied using seven tehsil-wise rainfall data (1960-2012). The district experiences 225 to 371 mm of annual rainfall in 12 to 19 rainy days. The resultant standard deviation of annual rainfall was 104 to 171 with a coefficient of variation of 39 to 48 per cent. The seasonal rainfall (June-Sept.) varied from 170 to 309 mm in 10 to 15 rainy days. The highest annual rainfall recorded in the district was between 460 mm at Pilibanga and 887 mm at Bhadra. Similarly, the lowest rainfall record varied between 22 mm at Hanumangarh and 111 mm at Bhadra. The extreme rainfall events recorded in the Hanumangarh district showed that 1-day highest rainfall varied from 122 mm at Bhadra to 175 mm at Pilibanga. The 1-day rainfall was lowest at Sangaria (72.7, 88.3, 107.8, 122.3 and 137.1 mm) and highest at Nohar (90.6, 107.9, 129.4, 145.4 and 161.8 mm) for all return periods (5, 10, 25, 50 and 100 years). The long-term annual rainfall trends showed that there was a increase at a rate 1.12 mm year^{-1} at Hanumangarh, 2.24 mm year^{-1}at Tibi, 2.42 mm year^{-1}at Sangaria, 0.60 mm year^{-1} at Nohar, 1.00 mm year^{-1} at Bhadra and 1.41 mm year^{-1} at Pilibanga. The meteorological droughts prevailed in 17 years out of 53 years (1960-2012) with lowest frequency of 16 years with drought at Bhadra, Sangaria and Nohar to a highest frequency of 18 years drought at Hanumangarh. The decade 1960-69 experienced highest (5 out of 10 years) number of moderate to severe droughts, whereas the 2001-2012 recorded least frequency (2 out of 10 years) of droughts. Similarly using Standardized Precipitation Index (SPI), an analysis on incidence and severity of drought occurred in Hanumangarh district during the period 1960-1969 (7 out of 10 years) and 1980-1989 (5 out of 10 years) experienced highest number of moderate and severe droughts.

Keywords: Rainfall characteristics, meteorological drought, Standardized precipitation index.

INTRODUCTION

Hanumangarh district located in the north east of arid western Rajasthan is highly vulnerable to extreme climatic conditions and drought compared to other arid regions of the country. Hanumangarh district experiences mainly an arid climate with mean moisture of -83.0. The average annual rainfall of the district is 295.0 mm occurring in about 15 rainy days. The southwest monsoon normally sets over the Hanumangarh region earliest by 20th June, but normally by 10th of July and it withdraws from the area by end of September or early October. Rainfall records at Hanumangarh show that the onset of southwest monsoon rainfall was timely (before 15th July) in 67 per cent of the years, whereas it was late in 33 per cent of the years. The potential evapotranspiration rates are quite high, especially during May and June. The estimated annual potential evapotranspiration of the area is 1736 mm compared to average rainfall of 295 mm, thus leaving a larger water deficit in the area. May and June are the months with very high PET due to intense heat, low humidity and strong wind regime. During major cropping season of monsoon period (July to September) the normal daily PET at Hanumangarh varied from 5.4 to 7.6 mm/day and in winter (December to February) the normal daily PET varied from 1.6 to 3.2 mm/day (Rao and Poonia, 2011). Out of the total (1.18 million ha) cropped area in the district during 1997-98 about 58% goes to *rabi* crops and rest 42% to *kharif* crops. Of the total cropped area 47 % is irrigated while 53% goes rain fed. Cotton, wheat, mustard, guar, bajra and gram are most dominant crops of the total cropped area. Gram is mainly taken on the conserved moisture. Other important crops are moth, barley, rice, taramira, moong and fodder crops (Balak Ram *et al.*, 2002). An attempt is made in this paper, to analyze the rainfall characteristics for identifying the meteorological droughts characterization based on IMD and Standardized Precipitation Index (SPI).

MATERIALS AND METHODS

Hanumangarh, the northern most district of Rajasthan with a total geographical area of 9,70,315 ha, is located between 28°46′30″ to 29°57′20″ north latitudes and between 73°49′55″ to 75°31′32″ east longitudes. It is surrounded by Ganganagar district in the west, Bikaner and Churu districts towards south west and south, Sirsa district of Haryana in the east and Firozepur district of Punjab in the north. For the present meteorological drought study, *tehsil*-wise rainfall data for seven stations for the period 1960 to 2012 was collected from Water Resource Department, Government of Rajastahn, Sinchai Bhawan, Jaipur.

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Meteorological drought characterization based on IMD: The frequencies of different categories of meteorological drought are made according to a classification by the India Meteorological Department (Koteswaram, 1976 and 1978; Subrahmanyam, 1967, Rao *et al.*, 2007 and 2012).

Classification of meteorological drought based on IMD is as below:

Drought category	Percentage departure from normal
Excess or flood	More than 51%
Above normal	+26% to +50%
Normal	+25 % to –25%
Below normal	-26% to –50%
Drought	Less than –51%

Hershfield (1961 and 1965) technique suggested by Chow (1964) was used to find out the 1-day maximum rainfall for different return periods based on daily rainfall events at seven *tehsil* locations of Hanumangarh district. Such technique was earlier used by Samra *et al.* (1975) to calculate probable maximum precipitation (PMP) over coastal Andhra Pradesh for 93 stations and by Rao *et al.* (2007 and 2012) to calculate 1-day maximum rainfall for different return periods for locations in Churu and Sirohi districts of arid Rajasthan. The following equation was used to estimate the probable maximum precipitation;

$X_m = X_{mean} + \sigma K_m$

Where X_m =estimate of PMP

X_{mean}=mean of rainfall

σ =standard deviation of rainfall

K_m= frequency factor

Where, $K_m = X_L - (X_{meanN-1})/\sigma_{N-1}$

X_L is the largest value of the rainfall series

$X_{meanN-1}$ =Mean of the rainfall excluding X_L value

σ_{N-1} =Standard deviation of rainfall excluding X_L value

Meteorological drought characterization based on SPI

Among the several proposed indices for meteorological drought monitoring, the Standardized Precipitation Index (SPI) developed by McKee *et al.* (1993, 1995) to quantify precipitation deficit at different time scales has found widespread application (Komuscu, 1999). This index compares very favorably against several other indices and has been adopted by US National Drought Mitigation Centre for operational use. Although SPI is a comparatively new index, it has been used in India for real time monitoring or retrospective analysis of droughts (Patel *et al.*, 2007). In this study an attempt has been made to analyze frequency and temporal trend of drought occurred in Hanumangarh district of arid Rajasthan during 53 years period (1960-2012) was carried out using the SPI of McKee *et al.* (1993 and 1995).

$$SPI = \frac{X - \overline{X}}{\sigma}$$

Where, X = Precipitation for the station; $\overline{X}$ = Mean precipitation; σ = Standardized deviation

The drought classification of SPI is as below

SPI	Category
≤ -2.00 and less	Extreme drought
-1.50 to -1.99	Severe drought
-1.00 to -1.49	Moderate drought
-0.99 to 0.00	Mild drought

The annual rainfall trends were obtained by using linear regression technique based on the annual rainfall totals for Hanumangarh, Tibi, Bhadra, Sangaria, Nohar and Pilibanga *tehsils* of Hanumangarh district of arid Rajasthan.

RESULTS AND DISCUSSION

Climatic characteristics

The most characteristics feature of the climate of arid region of Rajasthan is the great variation in temperature. The average minimum temperature ranging between 5.7 to 27.8^{0}C and average maximum temperature ranges between 20.8 to 41.6^{0}C. May and June are the hottest months with mean monthly air temperatures around 41-42^{0}C. December and January are the coldest months with mean temperature 5-7^{0}C. The air temperature slowly recede with the onset of monsoon by 1st week of July and further drop down in winter with values ranging from 20.5^{0}C during day and 4.7^{0}C during night. However, the extreme air temperatures recorded in the region were as high as 49.4^{0}C during summer and as low as –2.8^{0}C during winter. The mean annual temperature at Hanumangarh is about 25.2^{0}C. The relative humidity is often less than 25% during summer months, but gradually increases up to 80% by monsoon season and then again decreases from October onwards following withdrawal of the monsoon. Low humidity combined with strong wind regime leads to advection, a phenomenon which causes evaporation losses more than the energy actually available through solar radiation. The winds over Hanumangarh district blow in southwesterly during monsoon and northeasterly during winter season. Though winds during winter are low, a strong wind regime builds up along with the temperature regime from April onwards. Strong winds of the rate

7 to 8 *kmph* are observed during June but the average winds during summer vary from 4 to 6 *kmph*. Strong wind regime during May and June cause wind erosion depleting soil fertility particularly during drought years. The estimated potential evapotranspiration (PET) for the region was 1736 mm in a year against the annual rainfall of 295 mm. The PET was 4 times higher than the annual rainfall received in the area. Such high evapotranspiration is due to high temperatures, low humidity and high wind conditions prevailing in the district for most of the time expect during the monsoon period. Solar radiation is generally high in district throughout the year. The daily duration of bright sunshine hours in the area remains above 10 hr/day in May and reduces to 8.0 hr/ day in July and August and is above 9.1 hr/day in the winter season.

Rainfall characteristics

The normal annual rainfall of the district varied from 225 mm in 13 rainy days at Pilibanga to 371 mm in 19 rainy days at Bhadara (Table 1). The southwest monsoon rainfall had contributed for 85-90% to the annual total, whereas the winter rains 4-5% and summer rains 6-7% to the total. The coefficient of variation in annual rainfall for these locations varied from 39% at Nohar to 48% at Hanumangarh, which indicates high inter-annual variability in the rainfall of the region. The long term rainfall data of the district reveals that the district experienced very poor rainfall between the period 1979 to 1991 with the exception of few years in between. Thereafter, the district was fortunate to have very good spell of rainfall continuously for a period of 7 years from 1992 to 1997. The years 1976, 1997 and 2010 was the best with annual rainfall exceeding mean annual rainfall by 107.4%, 97.9% and 128.9%. The district again experienced drought conditions from 1999 to 2003. The year 2002 was the worst drought year with rainfall being 60% less than mean annual rainfall. The extreme annual rainfall records of the district shows that the highest annual rainfall was between 887 mm (263% of normal) at Bhadara in 1978 and 460 mm (151% of normal) at Pillibanga in 1997. On the other hand, the lowest annual rainfall was between 22 mm (9.6% of normal) at Hanumangarh and 111 mm (70% of normal) at Bhadara.

Table 1: *Tehsil*-wise rainfall characteristics of Hanumangarh district

Station	Annual rainfall (mm)	Annual rainy days	Standard deviation (mm)	CV (%)	Seasonal rainfall (mm)	Seasonal rainy days	Highest rainfall (mm)	Lowest rainfall (mm)
Hanumangarh	239	14	115	48	193	12	547 (2010)	22 (1994)
Tibi	288	14	124	43	224	11	625 (1997)	37 (1965)
Sangaria	314	16	146	47	249	13	688 (1960)	54 (1969)
Nohar	354	18	137	39	297	14	679 (1975)	106 (2000)
Bhadara	371	19	171	46	309	15	887 (1978)	111 (1961)
Rawatsar	277	12	111	41	195	10	497 (1997)	109 (2002)
Pillibanga	225	13	104	46	170	11	460 (1997)	55 (1972)

A study of the intensity of rainfall and its variability would be of extreme importance both for the purpose of assessing the water harvesting potential of a district as well as for planning soil conservation measures. From the daily rainfall data (1960-2012), the highest rainfall intensities in a day during each year at all stations were taken to calculate probable maximum precipitation (PMP) values using Hershfield (1965) technique as adopted by Samra *et al*. (1975) of extreme values. The extreme rainfall events recorded in the Hanumangarh district showed that 1-day highest was between 122.0 mm at Bhadara during 2 July 1990 to 163.0 mm at Rawatsar during 13 September, 2007. The probable maxiumum 1-day rainfall was between 128 mm at Bhadara to 402 mm at Pillibanga (Table 2). The one day rainfall indicates that even though the district receives less annual rainfall, occasional cloud bursts associated with monsoon depression and trough movements occur over the district. Such intensive short period rainfall causes excessive runoff and damages to agricultural crops. Knowledge on probable maximum precipitation (PMP) values is very useful for planning in constructional works like roads, bridges, buildings and dams etc.

The probability of occurrence of intense falls is reflected on the length of the return period of the fall considered. In order to work out the 1-day rainfall values for different return periods from 5-100 years calculated by the formula given by Chow (1964). The 1-day rainfall was lowest at Sangaria and highest at Pilibanga for all return periods of 5, 10, 25, 50 and 100 years. Once in 10 years, most of the stations receive rainfall equivalent to half the quantity of

Table 2: Maximum 1-day rainfall at different stations in Hanumangarh district

Station	Maximum one day rainfall (mm.)	Date	Probable Maximum precipitation values (PMP)
Hanumangarh	160.0	10 July, 1968	177
Tibi	125.0	15 June, 1989	132
Sangaria	147.0	18 July, 2001	170
Nohar	130.3	3 October, 1955	134
Bhadara	122.0	2 July, 1990	128
Rawatsar	163.0	13 September, 2007	180
Pillibanga	175.0	21 July, 1999	402

annual rainfall in a single day. Further most of the stations had recorded highest observed one-day rainfall values nearer to the estimated rainfall of 100 years return periods. These return period rainfall values also showed that there is plenty of scope for water harvesting and re-use for cultivation of crops

Table 3: Estimated 1-day rainfall (mm) for different return periods in Hanumangarh district

Station	Return Period (Years)				
	5	10	25	50	100
Hanumangarh	81.7	100.3	123.4	140.7	158.2
Tibi	85.4	103.0	124.8	141.0	157.6
Sangaria	72.7	88.3	107.8	122.3	136.4
Nohar	90.6	107.9	129.4	145.4	161.8
Bhadara	85.8	100.4	118.5	132.1	145.9
Rawatsar	79.1	93.0	110.3	123.2	137.1
Pillibanga	115.9	144.9	180.9	207.9	235.3

(Table 3). These values show a substantial increase on the 100 year return period values and must therefore have a very low probability of occurrence. It is very difficult to judge how realistic these values are, but they are of course the estimated upper limits to the likely samples of rainfalls. The percentage probability for occurrence of different amounts of rainfall ranging from 100 mm to more than 600 mm annual rainfall (mm) at different locations of Hanumangarh district are given in Table 4. Most of the stations showed about 92 to 100 per cent probability to get 200 mm of annual rainfall. The probability decreased to 60-100 per cent for 300 mm to 25-56 per cent probability to get an annual rainfall of 400 mm. Only 6-31 per cent chance was shown to get an annual rainfall of 500 mm, 0-13 per cent chance to get 600 mm of annual rainfall and 0-3 per cent chance for getting above 600 mm. (Table 4).

Table 4: Percentage probability for occurrence of different annual rainfall (mm) amounts in Hanumangarh district

Station	Annual Rainfall (mm)						
	100	200	300	400	500	600	>600
Hanumangarh	100	92	60	25	6	-	-
Tibi	100	89	61	34	16	5	3
Sangaria	100	92	71	39	18	11	-
Nohar	100	100	79	54	31	10	2
Bhadara	100	98	71	56	31	13	2
Rawatsar	100	100	83	50	17	-	-
Pillibanga	100	100	100	50	17	-	-

The long-term trends in the annual rainfall (1960-2012) of six *tehsil* locations of Hanumangarh district have showed that there was an increase in the annual rainfall of the district. The rate of increase in the annual rainfall was 1.21 mm $year^{-1}$at Hanumangarh, 2.24 mm $year^{-1}$at Tibi, 1.00 mm $year^{-1}$at Bhadara, 2.42 mm $year^{-1}$at Sangaria, 0.60 mm $year^{-1}$at Nohar and 1.41mm $year^{-1}$at Pillibanga.

Meteorological drought characterization based on IMD

The frequency of meteorological droughts occurred in Hanumangarh district are given in Table 5. Nohar *tehsil* experienced highest number of normal to above normal rainfall years of 34 out of 53 years with minimum number of 10 years with below normal conditions. Hanumangarh *tehsil* experienced highest number of years with below or severe drought conditions in 18 out of 53 years.

Table 5: Frequency of meteorological droughts occurred in Hanumangarh district (1960-2012)

Category	Hanumangarh (1960-2012)	Tibi (1960-2012)	Sangaria (1960-2012)	Nohar (1960-2012)	Bhadara (1960-2012)
Excess	6	6	8	3	5
Above normal	9	8	6	13	10
Normal	20	21	23	21	22
Below normal	10	12	8	10	4
Severe	8	5	8	6	12
Total	**53**	**53**	**53**	**53**	**53**

Thus, the frequency of occurrence of drought in the Hanumangarh district varied from once in 3.5 years at Hanumangarh to 3.0 years at Nohar. The other locations in the district experienced in 17 years at Tibi and 16 years out of 53 years at Sangaria, Nohar and Bhadara. The drought frequency was highest during the decade 1960-70 and 1981-90 with 4 out of 10 years recording moderate to severe drought and least frequency recording during 2001-12 with 2 out of 10 years as drought years (Fig.1).

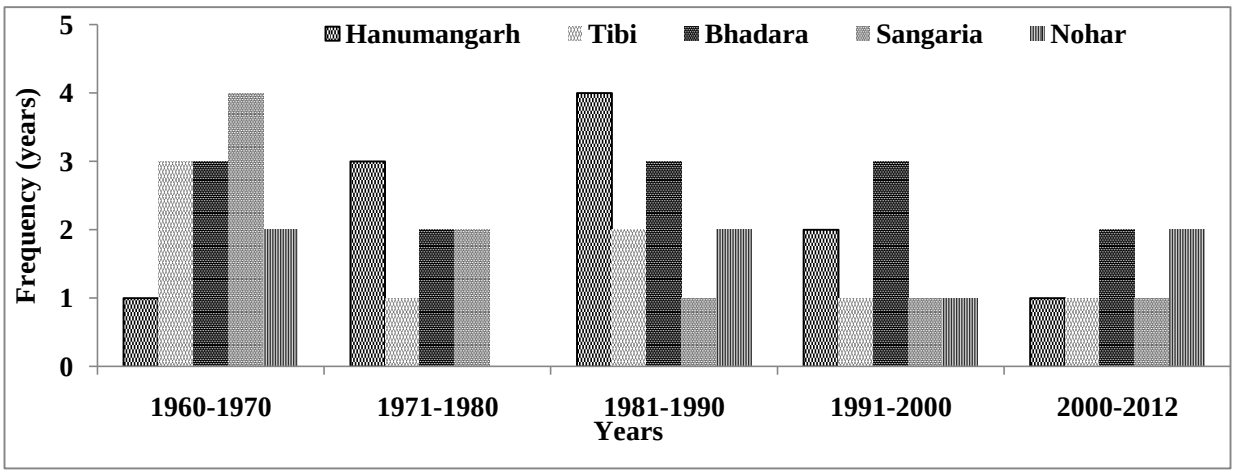

Fig.1: Decadal-wise drought situation in Hanumangarh district

Meteorological drought characterization based on SPI

In this study and attempt has been made to analyze the temporal and spatial variability of drought using SPI at Hanumangarh district of arid Rajasthan during 53 years period (1960-2012). For this SPI was calculated and analyzed at two time scales, namely tri-monthly (June-August) and four monthly (June-September). The SPI values for both time scales are summarized in Table 6. Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation. In the 53 years of study, there were four year with severe drought (1979, 1986, 1987, 1994) during trimonthly and four monthly time scale. During tri-monthly, eight years experienced moderate drought (1967, 1969, 1971, 1974, 1988, 1898, 1991, 2002) and in four monthly time scale also experience different moderate drought years (1967, 1969, 1974, 1989, 1990, 1991, 2000, 2002). It could be concluded that meteorological drought has nearly same frequency for tri and four monthly time scale at Hanumangarh and on an average it is experiencing one drought year in every four years.

Table 6: Minimum, maximum and frequency of SPI values for different intensity of meteorological drought in two time scale during 1960-2012

Particulars	Trimonthly (June-August)	Four monthly (June-September)
Minimum SPI Value	-1.80	-1.71
Maximum SPI Value	3.00	3.04
Frequency of –ve SPI value	26	29
Frequency of +ve SPI value	27	24
Severe drought years	1979, 1986, 1987, 1994	1979, 1986, 1987, 1994
Moderate drought years	1967, 1969, 1971, 1974, 1988, 1989, 1991, 2002	1967, 1969, 1974, 1989, 1990, 1991, 2000, 2002
Total drought years	12	12

The present study showed that the Hanumangarh district of arid Rajasthan experiences 225 to 371 mm of annual rainfall in 12 to 19 rainy days. The seasonal rainfall varied from 170 to 309 mm in 10 to 15 rainy days. The highest annual rainfall recorded in the district was between 460 mm at Pilibanga and 887 mm at Bhadra. Similarly, the lowest rainfall record varied between 22 mm at Hanumangarh and 111 mm at Bhadra. The extreme rainfall events recorded in the Hanumangarh district showed that 1-day highest rainfall varied from 122 at Bhadra to 175 mm at Pilibanga. The 1-day rainfall was lowest at Sangaria and highest at Nohar for all return periods (5, 10, 25, 50 and 100 years). These return period rainfall values also showed that there is plenty of scope for water harvesting and re-use for cultivation of crops. The long-term annual rainfall trends showed that there was a increase at a rate 1.12 mm $year^{-1}$ at Hanumangarh, 2.24 mm $year^{-1}$at Tibi, 2.42 mm $year^{-1}$at Sangaria, 0.60 mm $year^{-1}$ at Nohar, 1.00 mm $year^{-1}$ at Bhadra and 1.41 mm $year^{-1}$ at Pilibanga. The meteorological droughts prevailed in 17 years out of 53 years with lowest frequency of 16 years with drought at Bhadra, Sangaria and Nohar to a highest frequency of 18 years drought at Hanumangarh. The decade 1960-69 experienced highest (5 out of 10 years) number of moderate to severe droughts, whereas the 2001-2012 recorded least frequency (2 out of 10 years) of droughts. Similarly using Standardized Precipitation Index, an analysis on incidence and severity of drought occurred in Hanumangarh district during the period 1960-1969 (7 out of 10 years) and 1980-1989 (5 out of 10 years) experienced highest number of moderate and severe droughts.

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