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Rainfall Characteristics and Incidence of Meteorological Droughts in Sirohi District of Rajasthan

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Abstract: The rainfall characteristics and meteorological drought conditions in Sirohi District of Rajasthan were studied by analyzing the rainfall data (1901-2012) of three tehsils namely Reodar, Sirohi and Sheoganj. Three tehsils experience 520 to 621 mm of average annual rainfall in 24 to 27 days, out of which 482 to 580 mm occurs during June to September. The lowest annual rainfall in Sirohi was 140 mm in 1901 and highest of 1578 mm in 1973, whereas at Sheoganj, it varied from 157 mm in 1918 to 1689 mm in 1973 mm and at Reodar from 54 mm in 1987 to 1495 mm in 1973. The 1-day rainfall for return periods of 5, 10, 25, 50 and 100 years was 139.1, 168.8, 205.8, 233.4 and 261.6 mm at Sheoganj, 156.1, 192.7, 238.3, 272.3 and 307.0 mm at Reodar and 169.7, 209.5, 259.0, 296.0 and 333.7 mm at Sirohi. The long-term annual rainfall trends showed that there was an increase at a rate 0.62 mm year^{-1} at Sirohi, 0.24 mm year^{-1} at Sheoganj and 0.85 mm year^{-1} at Reodar. The severe meteorological droughts occurred in 11-12% years at Sirohi and Sheoganj and in 19% years at Reodar, whereas, mild drought in 23-29% and moderate drought in 19% years at all the locations.

Key words: Rainfall characteristics, meteorological drought, Sirohi District.

There is a large variation in rainfall distribution observed from time to time and year to year on same place and place to place in India (Dhar *et al.,* 1979). In India nearly 75% of the annual rainfall is received during monsoon season (June to September). Kharif crops depend upon the rainfall during the monsoon season.

Rainfall characteristics of arid Rajasthan are not only influenced by monsoon circulations, but also from projected global climate changes by the Inter-governmental Panel on Climate Change (IPCC, 2007). Rainfall and its variability continues to govern crop production from the fragile eco-regions like Indian hot arid zone, which has a high human and livestock density and people largely depend on climate sensitive sectors like agriculture and animal husbandry (Rao and Roy, 2012). There are many methods available which can be applied for analysis of meteorological drought using rainfall data (Erol Keskin *et al.,* 2011; Asati, 2012; Lala *et al.,* 2012). Very recently Rajpoot and Kumar (2013) studied meteorological drought using rainfall data in Satna District of Madhya Pradesh.

The arid part of Sirohi District of Rajasthan is one of the most disadvantageous districts so far identified by the Planning Commission. Out of its total 5136 km^2 area nearly 40% is arid. Of this nearly 43% area is occupied by barren hills, rock outcrops and rocky/gravelly pediment and nearly 5% by settlement and water bodies. Thus only 52% area is available for agriculture, out of this 26.6% area has irrigation facility aggregating drought impact on crop production in the district (Anon., 2007). The average annual potential evapotranspiration of the area is 1449 mm compared to average rainfall of 579 mm, thus leaving a larger water deficit in the area. Bajra, guar, castor and mung are most dominant rainfed crops, and mustard, wheat, groundnut and cotton are important irrigated crops (Anon., 2008). Out of the gross cropped area during 2007-08 kharif cropped area constituted 59%, rabi 35% and summer 6%. Castor, mustard, wheat, guar and bajra are dominant crops of the region constituting 16.9%, 12.7%, 14.7%, 10.6% and 8.9% of the total cropped area (Anon., 2008). An attempt is made in this paper, to analyze the rainfall characteristics for identifying the meteorological droughts.

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Materials and Methods

Study area

The arid part of Sirohi District, Rajasthan, occupies 3,15,934 ha area comprising Sheoganj, Sirohi and Reodar tehsils (Fig. 1). The region is located between 24º24′25″ to 25º17′07″ north latitudes and between 72º15′00″ to 73º07′47″ east longitudes. It is bounded by Pindwara and Abu Road tehsils of Sirohi District towards east, Jalore towards west, Pali District towards north, and Banaskantha District of Gujarat towards south. For the present meteorological drought study, tehsil-wise rainfall data for three stations for the period 1901 to 2012 were collected from Water Resource Department, Government of Rajastahn, Sinchai Bhawan, Jaipur. Hershfield technique was used to find the probable maximum precipitation and Gumbel's method was used to compute one day maximum rainfall for return period 5, 10, 25, 50 and 100 years for the Sirohi District.

The meteorological drought over an area for a year has been defined by the India Meteorological Department as a situation when annual rainfall over an area or place is less than 75% of the normal (Table 1). The frequencies of different categories of meteorological drought are made according to a classification by the India Meteorological Department (Koteswaram, 1976, 1978; Subrahmanyam, 1967; Singh *et al.*, 1991; Rao *et al.*, 2007, 2013; Poonia *et al.*, 2014).

Table 1. Classification of meteorological drought based on IMD

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%

Return period of one day heavy falls

Return period or recurrence interval is the average interval of time within which any extreme event of given magnitude will be equalled or exceeded at least once (Patra, 2001). The probability of occurrence of intense falls of rain is reflected in the length of the return period of the fall considered. Chow (1951) derived specific relationship of K and the return period (T) for different probability distributions. The theoretical value of annual maximum daily rainfall for different return periods was computed by Gumbel's method. In case of Gumbel's extreme value distribution (Gumbel, 1958), it was computed by the following equation:

$$f(x) = 1/\sigma \exp [-x-\mu/\sigma - \exp (-x-\mu/\alpha)]$$

where, $\alpha = \sigma\sqrt{6}/\pi$ and $\mu = \bar{x} - 0.5772\alpha$

Now, Chow (1951) derived the following equation for return periods from 5 to 100 years:

$$X_t = \bar{X} + \sigma K_t \quad \text{..............................(1)}$$

where, X_t = Magnitude of item with return period

$\bar{X}$ = Mean of the extreme values

s = Standard deviation of the series of extreme values (one day rainfall)

K= Frequency factor depending on return period and length of record.

K_t = 1.00-1.75 log log [T/(T-1)]

t = Return period

Weiss (1955) had also developed a table to know K values for various return periods for the length of the observed record of N years. By using K values from the table and incorporating it in the equation (1), expected 1-day rainfall for different return periods were calculated.

Hershfield technique

Hershfield (1961, 1965) was a pioneer who developed a statistical method for estimating probable maximum precipitation (PMP) values for small area around the world. Hershfield (1961, 1965) technique for estimating PMP is based on Chow's (1951) general frequency equation and was used to find out the 1-day maximum rainfall for different return periods based on daily rainfall events at three tehsil locations of Sirohi District. Such technique was earlier used by Samra *et al.* (1975) to calculate PMP over coastal Andhra Pradesh for 93 stations, Singh *et al.* (1991) for Kutch region of India, Rao *et al.* (2007 and 2013) and Poonia *et al.* (2014) to calculate 1-day maximum rainfall for different return periods for locations in Churu, Jhunjhunu and Hanumangarh districts of arid

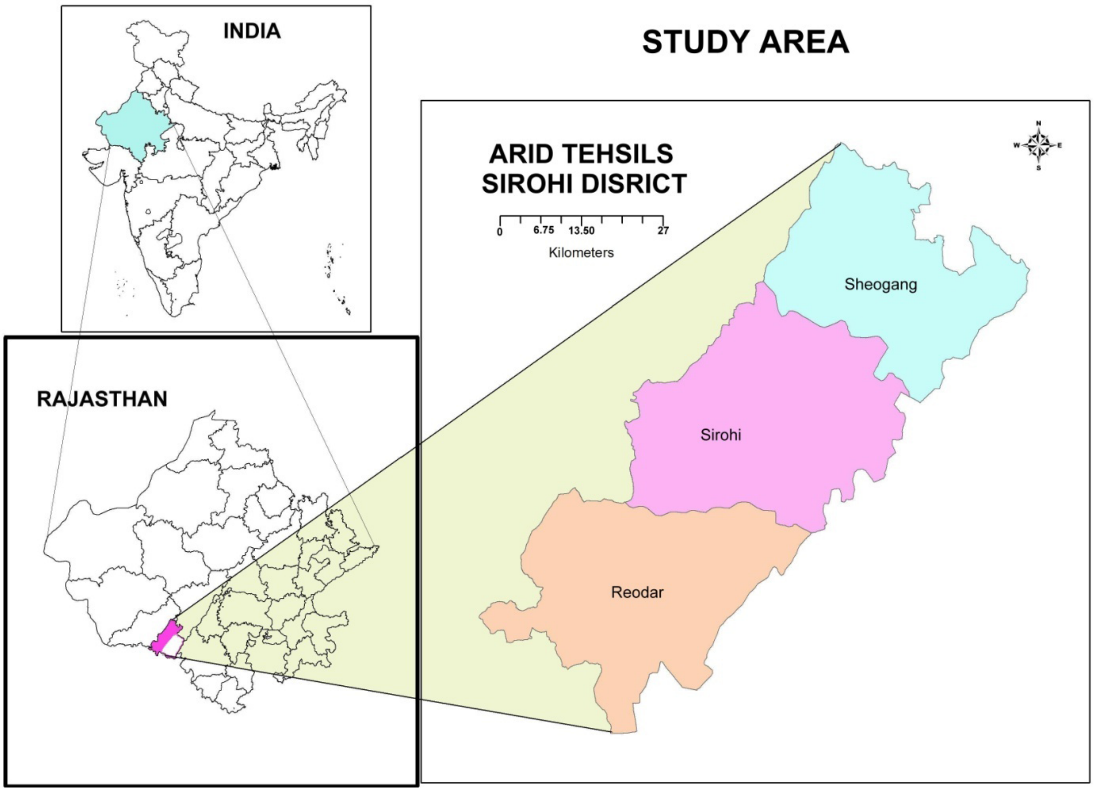

Fig. 1. Tehsil map of Sirohi District of Rajasthan.

Rajasthan. The following equation was used to estimate the probable maximum precipitation:

$PMP = X_{mean} + s K_m$ -----------------------------(2)

where, X_{mean}= Mean of events (1 day rainfall)

s = Standard deviation of the series of extreme values

K_m = Frequency factor

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

X_L = Largest value of the 1 day rainfall series

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

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

The annual rainfall trends were obtained by using linear regression technique based on the annual rainfall totals for each tehsil.

Results and Discussion

Rainfall characteristics

The normal annual rainfall at Sirohi varied from 140 mm in 1901 to 1578 mm in 1973 with a mean of 594 mm occurring in 26 rainy days, whereas at Sheoganj, it varied from 157 mm in 1918 to 1689 mm in 1973 with a mean of 520 mm occurring in 24 rainy days and in Reodar,

Table 2. Tehsil-wise rainfall characteristics of Sirohi District

Station	Annual rainfall (mm)	Annual rainy days (nos.)	CV of annual rainfall (%)	Seasonal rainfall (June-Sept.) (mm)	Seasonal rainy days (nos.)	Highest rainfall (mm)	Lowest rainfall (mm)
Sirohi (1901-2012)	594	26	48	551	23	1578 (1973)	140 (1901)
Sheoganj (1911-2012)	520	24	46	482	21	1689 (1973)	157 (1918)
Reodar (1957-2012)	621	27	56	580	25	1495 (1973)	54 (1987)

Table 3. Maximum 1-day rainfall at different stations in Sirohi District

Stations	Maximum one-day rainfall (mm.)	Date	Probable maximum precipitation values (PMP) (K=6)
Sirohi	362.7	14 August, 1941	379.7
Sheoganj	315.4	2 September, 1973	338.9
Reodar	317.0	8 September, 1992	347.7

it varied from 54 mm in 1987 to 1495 mm in 1973 with a mean of 621 mm occurring in 27 rainy days (Table 2). The south-west monsoon rainfall had contributed for 93% to the annual total, whereas the winter rains contributed 1% and summer rains 3% to the total. The coefficient of variation in annual rainfall for these locations varied from 46% at Sheoganj to 56% at Reodar, which indicates high inter-annual variability in the rainfall of the region. The long term rainfall data of the district reveal that the district experienced very poor rainfall between the period 1981 to 1991 with few exceptions in between. Thereafter, the district was fortunate to have very good spell of rainfall for consecutive 7 years from 1992 to 1998. The district experienced severe drought during 1901, 1918, 1987 and 2002, when rainfall was 76, 73, 72 and 68% less than mean annual rainfall. Very recently the years 2008 and 2009 were the drought years with rainfall being 51% less than mean annual rainfall. The years 1917, 1973 and 1990 were the best with annual rainfall exceeding mean annual rainfall by 114, 168 and 140%.

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 (1901-2012), the highest rainfall intensities in a day during each year at all stations were taken to calculate PMP values using Hershfield (1961, 1965) technique as adopted by Samra *et al.* (1975) of extreme values. The extreme rainfall events recorded in Sirohi District showed that 1-day highest was between 317.0 mm at Reodar on 8th September 1992 to 362.7 mm at Sirohi on 14th August, 1941 and the probable maxiumum 1-day rainfall was between 338.9 mm at Sheoganj to 379.7 mm at Sirohi (Table 3).

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 damage to agricultural crops. Knowledge on PMP values is very useful for planning in constructional civil works like roads, bridges, buildings and dams, etc.

The probability of the 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 in Sirohi District for different return periods of 5, 10, 25, 50 and 100 years are presented in Table 4. These return periods of rainfall amounts can be used to design capacity of water harvesting structures. The 1-day rainfall was lowest at Sheoganj (139.1 mm, 168.8 mm, 205.8 mm, 233.4 mm and 261.6 mm) and highest at Sirohi (169.7 mm, 209.5 mm, 259.0 mm, 296.0 mm and 333.7 mm) and at Reodar (156.1 mm, 192.7 mm, 238.3 mm, 272.3 mm and 307.0 mm) for all return periods (5, 10, 25, 50 and 100 years). The extreme rainfall records at these three locations showed higher rainfall (Table 3) than that computed values for all return periods (Table 4). These return period rainfall values also showed that there is plenty of scope for water harvesting and re-use for cultivation of crops. 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.

Table 4. Return period of 1-day rainfall (mm) in Sirohi District

Station	Return period (years)				
	5	10	25	50	100
Sirohi	169.7	209.5	259.0	296.0	333.7
Sheoganj	139.1	168.8	205.8	233.4	261.6
Reodar	156.1	192.7	238.3	272.3	307.0

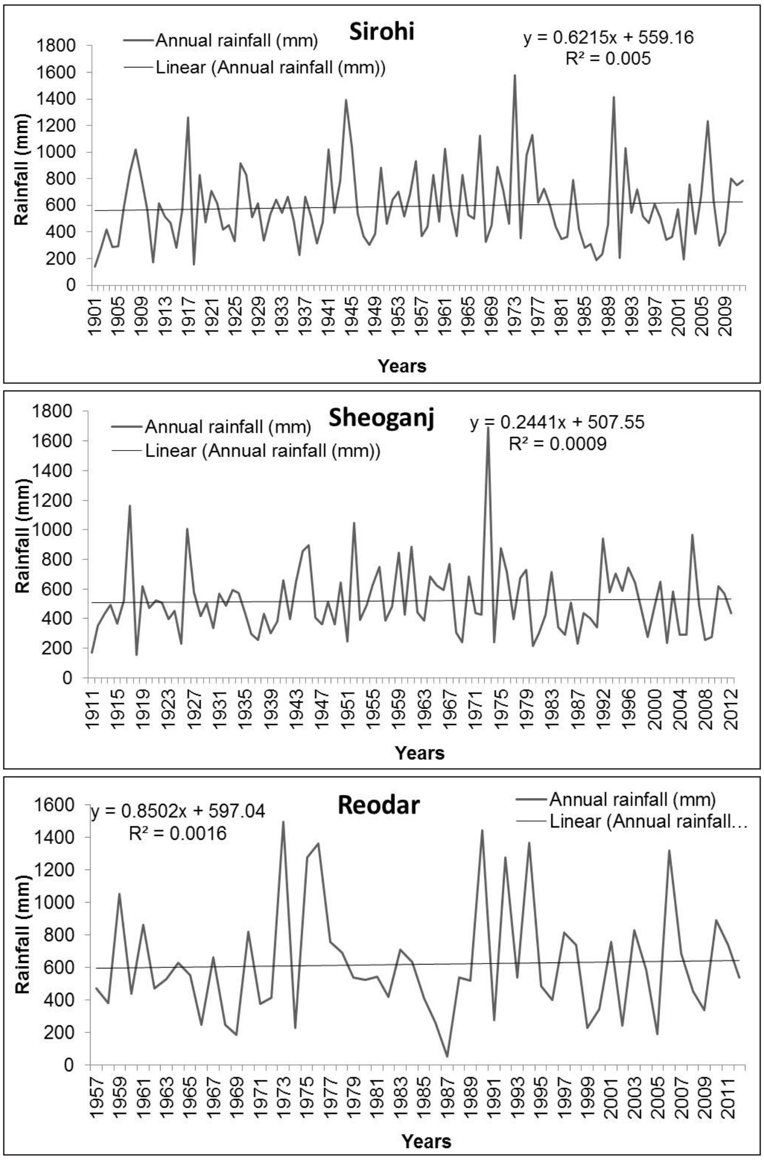

Fig. 2. Annual rainfall recorded at different locations in Sirohi District.

The long-term trends in the annual rainfall (1901-2012) of three tehsil locations of Sirohi District (Fig. 2) have shown that there is a marginal increase in annual rainfall of the district. The rate of increase in the annual rainfall was 0.62 mm year^{-1} at Sirohi, 0.24 mm year^{-1} at Sheoganj and 0.85 mm year^{-1}at Reodar.

Meteorological droughts

The frequency of years with meteorological drought (severe, moderate and mild), normal rainfall, above averege and excess rainfall at Sirohi, Sheoganj and Reodar during 1901 to 2012 are shown in Fig. 3. Severe drought occurred in 12% years at Sirohi, 11% at Sheoganj and 18% years at Reodar, whereas, moderate drought in 19% years at Sirohi, 19% at Sheoganj and 18% years at Reodar. The mild drought in 26% years at Sirohi, 28% at Sheoganj and 21% years at Reodar. Normal rainfall in 18% years at Sirohi, 21% years at Sheoganj and 20% years at Reodar, and above normal to excessive rainfall leading to flood occurred in 26% years at Sirohi compared to 22% years at Sheoganj and 23% years at Reodar (Fig. 3).

The drought frequency was highest during the decade 1981-1990 with 6 out of 10 years recording moderate to severe drought and no drought was recorded during 1941-50 at Sirohi and Sheoganj. The excessive rainfall

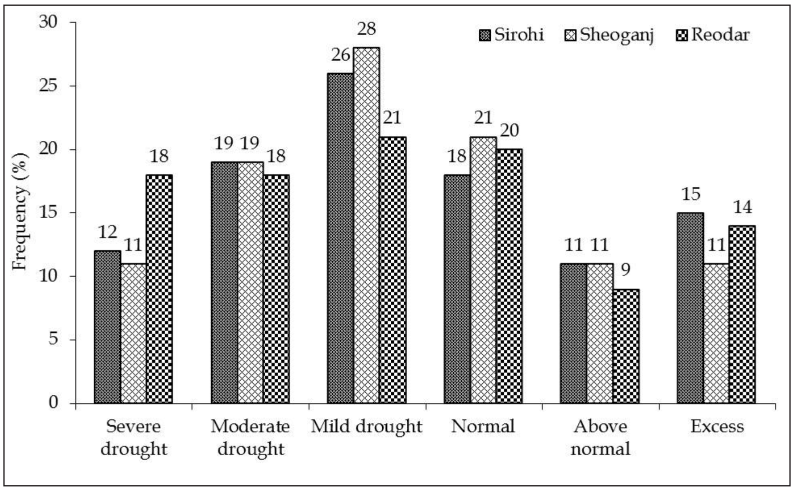

Fig. 3. Per cent years with drought, normal and excessive rainfall conditions at Sirohi, Sheoganj and Reodar (1901-2012).

conditions occurred leading to flood during 1941, 1944, 1975 and 1950, when rainfall was 73, 137, 77 and 50% above mean annual rainfall. Similarly during decade 1971-80, the years 1973, 1975, 1976 and 1979 were the best with rainfall exceeded mean annual rainfall by 168, 66, 91 and 40%, respectively. Comparing the average rainfall during the periods 1901-90 and 1991-2012, it is observed that the rainfall has decreased from 597 mm to 572 mm at Sirohi whereas; it has increased from 520 mm to 523 mm at Sheoganj.

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