

Identification of Meteorological Drought Characteristics and Drought Year Based on Rainfall Departure Analysis

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Authors' contributions

This work was carried out in collaboration among all authors. Author AK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors KCP and MN managed the analyses of the study. Author GS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Dholpur district is located in the semi-arid regions of Rajasthan. The region is affected due to unreliable rainfall pattern, which resulted in the development of a drought-like situation. The mean annual rainfall in the district is 596.76 mm. The present study has been conducted to identify drought-prone station, drought year and drought characteristics. Departure analysis of seasonal and annual rainfall helps to determine drought year and drought characteristics. The study shows that the region is under widespread drought condition in 1986, 1987, 1989, 1991, 2002, 2006, and 2007. The drought severity in the region was classified into four categories, namely extreme, severe, moderate and mild. Maximum extreme drought events occur in Baseri and Dholpur station. Urmilsagar station faced severe drought events 4 times followed by Rajakhera station with three times. Occurrences of moderate and mild drought events are frequent in the region. All the stations are drought-prone based on probability analysis of annual rainfall. Relative departure index (RDI) has been used to decide the relative drought proneness of the various station and based on which

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Dholpur station (RDI= 1.04) followed by Baseri station (RDI=1.0) are relatively higher drought-prone. The region faces natural water scarcity and droughts. Therefore effort is needed for drought preparedness, mitigation and management measures.

Keywords: Drought; drought severity; a drought year; rainfall departure; relative departure index.

1. INTRODUCTION

Drought is a complex natural hazard which is defined by the awful water shortage which directly affects social and economic development which increases the risk of livelihood. Some parameters indicate the effects of drought among them groundwater level, Soil moisture depletion, reduction in streamflow, reservoir storage, lake levels [1]. The prolonged low precipitation denotes the arrival of meteorological drought. The meteorological drought turns into hydrological drought as groundwater and surface water levels reduce further [2]. Hydrological drought directly impacts the crops and results in agricultural drought [3,4,5]. Drought effects can be seen worldwide on the livelihood, environment, economy, and overall human well-being. Globally, around 11 million people lost their lives because of drought, and 2 billion people were adversely affected by drought since 1900 [6]. Food Security Information Network reports show that about 108 million people from all over the world were affected by food shortage, caused by El-Nino induced drought [7]. India had been severely affected by drought events in the past. Drought area identification is useful for monitoring drought events and acts as an early warning system. Drought monitoring and forecasting are essential tools for implementing appropriate drought mitigation strategies to reduce the impact of drought. Several indexes were proposed for the analysis of propagation of drought for assisting policymakers to address this phenomenon in advance, drought severity is considered as key factor as compared to others. As the area under consideration is completely rainfed so variation in rainfall during monsoon period affects crop growth severely [8]. This study has been carried out in Dholpur district, Rajasthan which falls in drought-prone region. The area receives inadequate rainfall and is responsible for the regular occurrence of drought and subsequent unavailability of water to meet the demands. The area is under the grip of the frequent occurrence of droughts due to irregularity in onset of monsoon, early withdrawal of monsoon, scanty rainfall, may ultimately affect the livelihoods. The present study aims to compute drought-prone region in the study area

and prioritization of which is implemented based on which mitigation will be provided to render the impact of drought. The evaluation of drought characteristics helps to understand the pattern of drought severity and its frequency so that suitable strategies will be adopted to cope under such hazardous situation.

2. MATERIALS AND METHODS

2.1 Description of Study Area

The areal extent of Dholpur District is 3084 km². The Chambal River forms the southern boundary of the district, across which lies the state of Madhya Pradesh. The geographical coordinates of Dholpur are 26° 42' 0" N, 77° 54' 0" East. All along the bank of the Chambal River, the district is deeply intersected by ravines; low ranges of hills in the western portion of the district supply quarries of fine-grained and easily worked red sandstone. Temperatures in summers usually are higher than 40°C. Coldest months are December and January where temperatures sometimes reach near-zero and subzero levels. The climate of the district can be classified as semi-arid type. The mean annual rainfall of the district is 563.94 mm (2001-2011). The long term normal annual rainfall (1951-2000) is 722.1mm. Soils of the district have been classified into six categories, namely- Sandy soil, Loamy, sandy soil, Sandy loamy soil, Clayey soil, Sandy clayey loam soil, Sandy clayey soil.

2.2 Data Availability

The daily rainfall data of different rain gauge station located in Dholpur district, Rajasthan were obtained from the State data center, water resources department, Rajasthan. The location of different rain gauge station is shown in Fig. 1.

2.3 Identification of Drought Prone Areas

The drought-prone areas have been identified based on probability analysis of annual rainfall. An area has been considered to be drought-prone if the probability of occurrence of 75% of mean annual rainfall is less than 80% [9,10,8].

The annual rainfall series has been sorted in the descending order and ranks assigned from 1, 2 ...N, up to the last record and Weibull's distribution is fitted to the ranked data. The probability of exceedance is given equation 1.

$$P = \frac{m}{N+1} * 100 \quad (1)$$

Where,

P = Probability of Exceedance of annual rainfall,
 m = Rank of the particular record,
 N = Total number of observation

2.4 Identification of Drought Years

The drought years can be identified based on the departure analysis of annual and seasonal rainfall time series. Since more than 90% of the annual rainfall is received during the monsoon season, the seasonal rainfall departure analysis better represents the drought conditions in the study area. To compute the seasonal rainfall departure (Di) the mean seasonal rainfall (Xm) is

subtracted from the seasonal rainfall series (Xi) given by equation 2.

$$D_i = X_i - X_m \quad (2)$$

The percentage departure (D %) is subsequently computed as given by Equation 3.

$$D\% = D_i / X_m * 100 \quad (3)$$

An area or region is considered to be drought-affected if it receives seasonal rainfall less than 75% of its normal value, as per the classification given by India Meteorological Department [11]. The year having annual or seasonal rainfall departure more than or equal to -20% is considered to be a drought year. In this study, the severity of the drought has been categorized according to percentage deviations from the normal rainfall and grouped into four severity classes [12,13,14,15], as given in Table 1. The departure analysis of annual and seasonal rainfall has been performed for different rain gauge station and subsequently, the drought years have been identified.

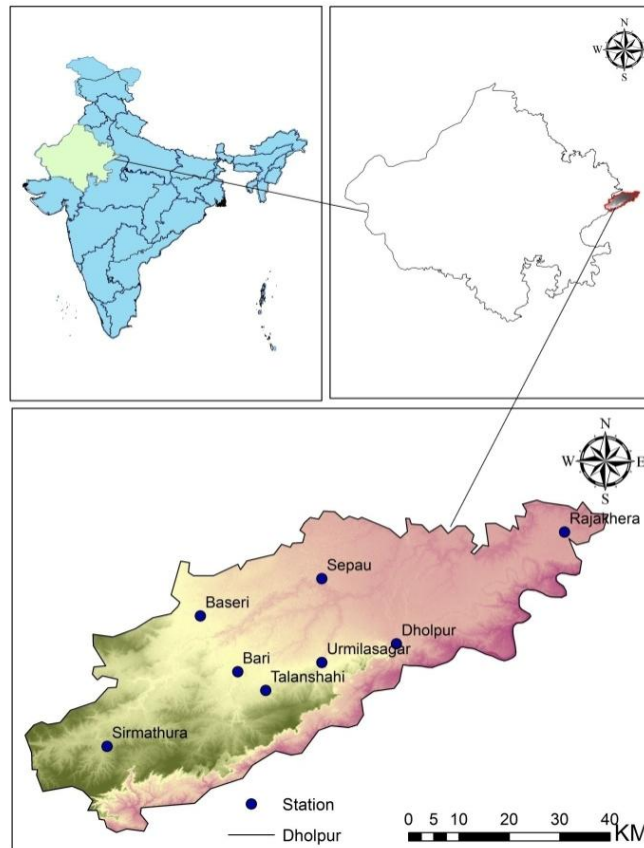


Fig. 1. Location of study area

Table 1. Drought severity classification based on the percentage of rainfall departure

S. no.	Drought Classes	Range (%)
1.	Mild Drought	-20 % < D < -25%
2.	Moderate Drought	-25 % < D < -35%
3.	Severe Drought	-35 % < D < -50%
4.	Extreme Drought	D > -50%

2.5 Relative Departure Index

Relative departure index (RDI) is a ranking system, used to decide the relative drought proneness of various areas under the Dholpur district based on rainfall departure analysis [16,17]. For this purpose, weights have been assigned to several drought years as follows, (1) mild drought, (2) moderate drought, (3) severe drought and (4) extreme drought. The relative departure index for the rain gauge stations has been decided by dividing the total cumulative weights obtained for the study period during drought years with the total number of years under consideration [18] as given in equation 4.

$$RDI = \frac{\sum_{i=1}^n W_i}{N} \quad (4)$$

Where

N= Total number of a year under consideration

W_i= Weight for the ith drought years

Higher the values of RDI more will be the severity of drought and based on that prioritization of stations is being carried out for the mitigation process.

3. RESULTS AND DISCUSSION

3.1 Statistical Analysis

The statistical analysis was conducted for the different station of Dholpur district for 23 years

(1983-2008). Average annual rainfall varies between 503.20 mm in Baseri station to 710.36 mm for Bari station. The mean annual rainfall in district was 596.76 mm. Fig. 2 shows the average annual rainfall for different station. There was a high deviation in annual rainfall from its average. The maximum deviation occurs in Rajakhera station (278.86) and minimum in Sepau (169.82). The variability in annual rainfall was computed using the coefficient of variance (CV %), and maximum variability prevails in Talanshahi station (44.71%) and minimum in Bari station (27.86%). Fig. 3 show variability in rainfall pattern. The variability in annual rainfall was high (37.23%) in Dholpur district, which is responsible for the frequent occurrence of drought and inadequate water to fulfill the demand for irrigation. Table 2 represents the statistical parameter computed for different station.

3.2 Identification of Drought Year

Drought year are computed using departure analysis of seasonal and annual rainfall based on the data for the period from 1983-2008. A positive value of rainfall departure indicates wet condition and a negative value indicates drought condition. The region is facing persistent drought condition, and it shows the maximum seasonal departure of -66.5% in 2002 for Sirmathura station and maximum annual departure of -64.63% in 1989 for Baseri station. Table 3 shows the number of droughts occurred in the different year during the span of study and which was computed based on seasonal departure.

Table 2. Mean, standard deviation and coefficient of variance at a different station

Station	Mean	SD	CV
Bari	710.36	197.93	27.86
Baseri	503.20	201.74	40.09
Dholpur	681.27	258.27	37.91
Rajakhera	663.61	278.86	42.02
Sepau	577.91	169.82	29.39
Sirmathura	541.11	209.41	38.70
Talanshahi	543.63	243.07	44.71
Urmilasagar	552.96	205.65	37.19

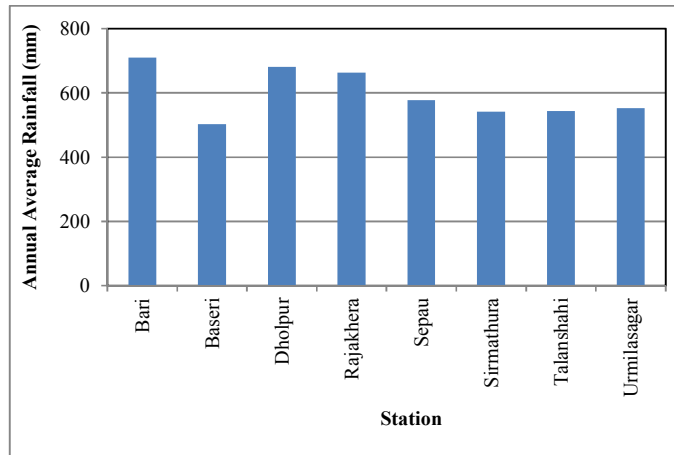


Fig. 2. Average annual rainfall for a different station in Dholpur district

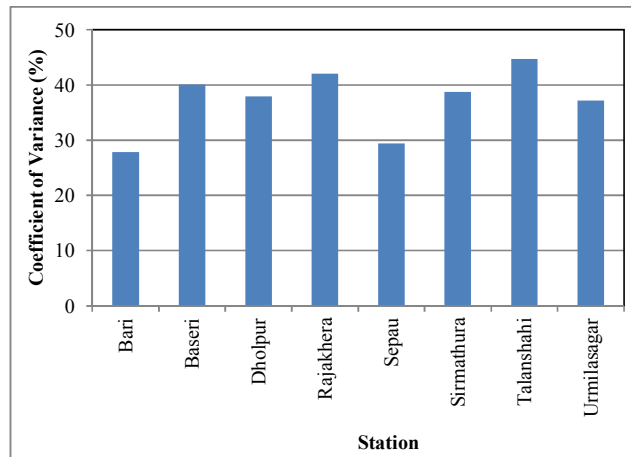


Fig. 3. Variability in annual rainfall at a different station in Dholpur district

Table 3. Drought year which occurred in the study area

Stations	Drought year
Bari	1986, 1987, 1989, 1994, 2002, 2006, 2007
Baseri	1986, 1987, 1988, 1989, 1991, 1993, 2002, 2007
Dholpur	1986, 1987, 1991, 1993, 2001, 2002, 2006
Rajakhera	1986, 1987, 1988, 1989, 1994, 2000, 2006, 2007
Sepau	1987, 1989, 1991, 2000, 2002, 2006, 2007
Sirmathura	1986, 1987, 1989, 1991, 1994, 2002, 2004, 2006, 2007
Talanshahi	1986, 1987, 1989, 1991, 1992, 1993, 2001, 2002, 2006, 2007
Urmilasagar	1986, 1987, 1989, 1991, 2002, 2005, 2006, 2007

The region is under widespread drought condition in 1986, 1987, 1989, 1991, 2002, 2006, and 2007 as most of the area is under the grip of drought in those years. South-west monsoon is the only primary source of rainfall and the deficit of which is primarily responsible for the regular

occurrence of drought and subsequent water stress, thereby adversely affecting the primary agricultural operations. The plots of seasonal rainfall departure for Baseri and Dholpur station are given in Fig. 4 and Fig. 5 respectively.

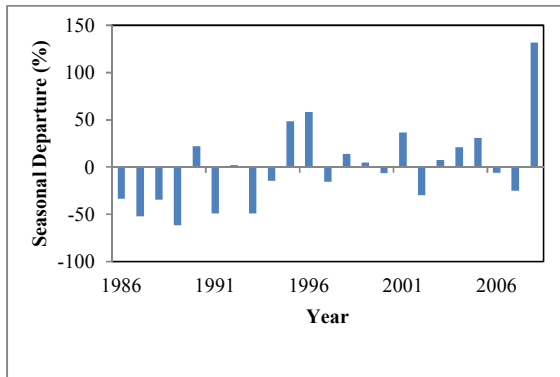


Fig. 4. Seasonal rainfall departure at Baseri station

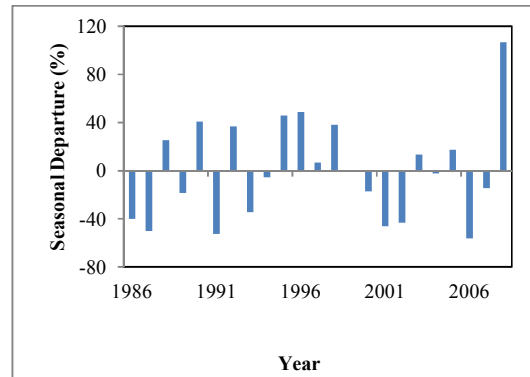


Fig. 5. Seasonal rainfall departure at Dholpur station

Table 4. Drought characteristics based on departure analysis

S. no	Stations	Mild	Moderate	Severe	Extreme	Total	Frequency
1	Bari	3	2	2	0	7	3.29
2	Baseri	1	3	0	4	8	2.87
3	Dholpur	0	1	2	4	7	3.29
4	Rajakhera	1	2	3	2	8	2.9
5	Sepau	1	3	2	1	7	3.3
6	Sirmathura	5	0	1	3	9	2.6
7	Talanshahi	5	3	1	1	10	2.3
8	Urmilasagar	2	1	4	1	8	2.9

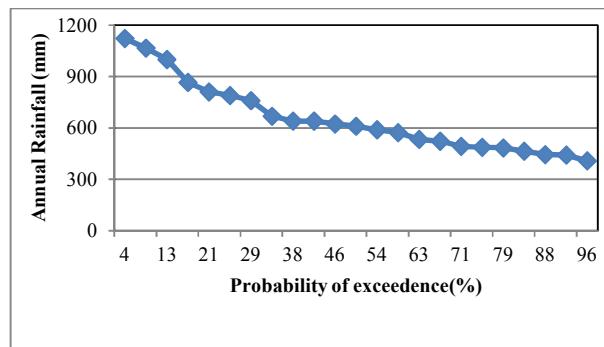


Fig. 6. Probability distribution of annual rainfall at Sirmathura station

3.3 Evaluation of Drought Characteristics Based on Departure Analysis

The departure analysis of annual rainfall was used to determine the drought characteristics, including drought severity and frequency. The drought severity in the region was classified into four categories, namely extreme, severe, moderate and mild. The drought events are classified as extreme drought event when annual departure greater than -45%, severe drought event (-45 < D < -35), moderate drought event (-35 < D < -25), and mild drought event (-25 < D

< -20) occurs in the region. Table 4 shows the drought characteristics based on annual rainfall departure. Maximum extreme drought events occur in Baseri and Dholpur station. Urmilasagar station faced severe drought events four times followed by Rajakhera station with three times. Occurrences of moderate and mild drought events are frequent in the region. From the analysis for annual rainfall departure, it has been observed that the occurrence of drought takes place once in every two to three years in the study area.

3.4 Identification of Drought-Prone Areas

The probability analysis of rainfall for eight rain gauge stations has been carried out to identify the drought-prone areas in the study area. The statistics based on the probability distribution of annual rainfall at different influencing rain gauge stations are given in Table 5. It has been observed that there is considerable variation in the 75% dependable rainfall values from 503.20 mm at Baseri station to 710.36 mm at Bari station. This indicates that rainfall distribution at neighbouring stations have a wide variation, where one station receiving more than its normal

rainfall and at the same time other station may experience rainfall deficiency. The probability of occurrence of rainfall equivalent to 75% of normal is obtained from probability distribution graph. From the probability analysis, was computed that most of the areas are drought-prone (probability of 75% mean rainfall is less than 80%) and faced regular water scarcity and droughts. So efforts are required for drought preparedness, mitigation and management measures. The graph depicting the probability distribution of the annual rainfall at Sirmathura, and Talanshahi station is given in Fig. 6 and Fig. 7 respectively.

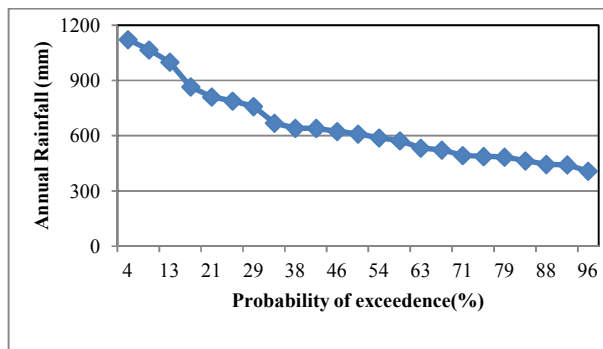


Fig. 7. The probability distribution of annual rainfall at Talanshahi station

Table 5. Probability distribution of annual rainfall

S. no.	Station	Mean rainfall (mm)	75% dependable rainfall (mm)	Probability of occurrence of rainfall equivalent to 75% of mean rainfall	Drought condition
1	Bari	653.9	490.4	72.8	Drought Prone
2	Baseri	464.5	348.4	66.1	Drought Prone
3	Dholpur	634.3	475.7	67.8	Drought Prone
4	Rajakehra	602.4	451.8	66.3	Drought Prone
5	Sepau	540.0	405.0	73.6	Drought Prone
6	Sirmathura	485.8	364.4	75.5	Drought Prone
7	Talanshahi	543.6	407.7	65.1	Drought Prone
8	Urmilasagar	553.0	414.7	70.6	Drought Prone

Table 6. Ranking based on RDI

S. no	Stations	RDI
1	Dholpur	1.04
2	Baseri	1.00
3	Rajakhera	0.96
4	Sirmathura	0.87
5	Urmilasagar	0.87
6	Talanshahi	0.78
7	Sepau	0.74
8	Bari	0.57

3.5 Relative Departure Index

The relative departure index (RDI) was computed for eight rain gauge stations of Dholpur district. RDI help in prioritization of station based on which drought mitigation measures should be provided to those which are at the first position in the ranking. Table 6 shows the ranking based on RDI. Dholpur station (RDI= 1.04) followed by Baseri station (RDI=1.0) are relatively higher drought-prone. Drought mitigation activities need to be implemented in the station based on prioritization.

4. CONCLUSION

This study provides a broad knowledge about temporal variations of meteorological droughts in Dholpur district, Rajasthan during the period 1983-2008. Drought year and drought characteristics for the different station were computed based on rainfall departure analysis. Probability analysis of annual rainfall helps to reveal drought-prone station in the study area. From the study, it was found that all the station is drought-prone. The occurrence of Moderate, severe and extreme drought events are common. The region was under widespread drought condition in 1986, 1987, 1989, 1991, 2002, 2006, and 2007. Based on relative departure index Dholpur and Baseri rain gauge station are at the highest priority for immediate implementation of drought mitigation activities. The deficit in rainfall is primarily responsible for the regular occurrence of drought and subsequent water stress, thereby adversely affecting the major agricultural operation, which is also responsible for the loss of crop productivity. Therefore, it is crucial to have proper management's strategies against drought conditions. Based on the assessment, agricultural planners and irrigation engineers can take necessary steps to mitigate drought scenario prevails in the region.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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