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Identification of Drought Prone Areas and Trend Analysis of Rainfall Phenomenon in Dhasan Basin

Saswat Kumar Kar[1], T. Thomas[2] and R.M. Singh[1]

[1]*Department of Farm Engineering, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi-221 005, Uttar Pradesh*
[2]*Ganga Plains South Regional Centre, National Institute of Hydrology, Bhopal-462 016, Madhya Pradesh*

Email: saswatkumarkar@gmail.com

ABSTRACT: The present study has been focussed to recognize and quantify the drought condition in Dhasan basin which falls in drought prone region of Bundelkhand (Madhya Pradesh). The area is under frequent occurrence of droughts since decades due to irregularity in arrival of rainfall. The high variability of the annual rainfall is one of the primary causes of the drought prevailing in the Dhasan basin on a regular basis. The decreasing trend of rainfall may further aid to drought severity. The rainfall departure analysis indicated that, the study area is under the grip of regular and continuous droughts with the drought frequency varying between once in 2 years to once in 3 years, which is rather very high. Sagar and Banda areas were identified to be most drought prone followed by Khurai.

Key words: Drought area, drought years, trend analysis

Introduction

Drought is a natural hazard and is one of the major threats to livelihood affecting socio-economic development. The parameters indicating drought impacts include soil moisture depletion, reduction in stream flow, reservoir storage, lake levels and groundwater level (Dracup *et al.,* 1980). However, when it occurs, it generally affects a broad region for a season or a year or for consecutive years. The arid areas are more prone to drought because the rainfall amount critically depends on a few rainfall events (Sun *et al.,* 2006). The severity drought affected areas change gradually and regions of maximum intensity shift from season to season (Wilhite, 2000). Although several indexes were proposed for the analysis of propagation drought for assisting policy makers to address this phenomenon in advance, drought severity is considered as key factor as compared to others. Drought area and drought development identification is useful for monitoring drought events and acts as an early warning system. Drought monitoring and forecasting are important tools for implementing appropriate drought mitigation strategies in order to reduce the impact of drought. As the area under consideration is completely rainfed so variation in rainfall during monsoon period affects crop growth severely. Trend analysis has been done to study significant change in rainfall amount in past which may lead to occurrence of drought. For the purpose of trend analysis, Mann–Kendall test has been extensively used by several researchers on climatic variables *viz.,* temperature, precipitation and stream flow (Taylor and Loftis, 1989; Burn, 1994 and Burn *et al.,* 2004). Similarly, Thomas *et al.* (2014) had studied the trend of critical dry spell for Bearma basin in Bundelkhand region and found an increasing trend in drought severity with increasing drought intensity. This study has been carried out in Dhasan basin which falls in drought prone region of Bundelkhand (Madhya Pradesh) to understand and quantify the drought scenario. The area is totally rainfed and the south-west monsoon is the only big contributor of rainfall, so deficit monsoon rainfall is responsible for the regular occurrence of drought and subsequent water stress in the study area. As the area is under the grip of frequent occurrence of droughts since decades due to irregularity in onset of monsoon, early withdrawal of monsoon, scanty rainfall, may ultimately affect the livelihoods.

Materials and Methods

Description of study area

The study area has been limited to Dhasan basin in Madhya Pradesh up to Patan village, with a catchment area of 2054.39 sq. km. It falls completely in Sagar district and is located at the southern eastern edge of Malwa Plateau. The index map of the study area is given in Figure 1. River Dhasan originates from the Jashrathi hill (msl of 714 m) near the Bhaisa village (23°26′00′′N latitude to $78^0$33′00′′E longitude) located at the north-east part of Raisen district (Madhya Pradesh) and subsequently joins River Betwa which is a tributary of the Yamuna river system. The average maximum, minimum and mean daily temperatures for Sagar district are 45.6^0C, 1.1^0C and 23.3^0C, respectively. Eight soil groups have been identified in the study area namely, deep clayey soils, deep calcareous clayey soils, moderately deep calcareous clayey soils, slightly deep clayey soils, very shallow clayey skeletal soils, deep loamy soils, slightly deep loamy soils and very shallow loamy soils. Most of the area is covered by deep calcareous clayey type soils. The soil classes are based on the classification system of ICAR- NBSS & LUP, Nagpur. Generally, the monsoon commences between 15^{th} and 30^{th} June and the monsoon season lasts for 3 to 4 consecutive months. The maximum rainfall is obtained during the month of August followed by July. More than 90% of the annual rainfall is provided by the south-west monsoon during the months of June to September and the rest during winter and summer seasons. The average annual rainfall of Dhasan basin is around 1117 mm and seasonal rain fall is about 1020 mm. Rainfed agriculture is the main livelihood of the farmers in this region. Maize, paddy, oil seeds, sorghum etc. are the major crops cultivated during *kharif* season and wheat, pulses, chickpeas etc. are cultivated during *rabi* season. Hydrologically, the entire study area is comprised of hard rock formations. The scarcity of water for drinking as well as irrigation purpose is the main problem in the Dhasan basin.

Data availability

The daily rainfall data required were aquired from three rain gauge stations *viz.,* Sagar, Banda and Khurai, located in and around the basin. The rainfall data was collected from Superintendent of Land Records (SLR), Sagar, Madhya Pradesh for the period from 1981 to 2009. The average aerial rainfall for the study area has been computed using the Thiessen Polygon method in ILWIS 3.0, a Geographic Information System (GIS) software. In order to derive the basin average rainfall, initially a base map of the basin, as well as a point map showing the location of the three rain gauge stations were prepared. The nearest point algorithm was used for interpolation and the resultant map has then been crossed with the base map in raster operation to obtain the Thiessen polygon map of the study area. The corresponding histogram has been used to compute the Thiessen weights of the influencing rain gauge stations.

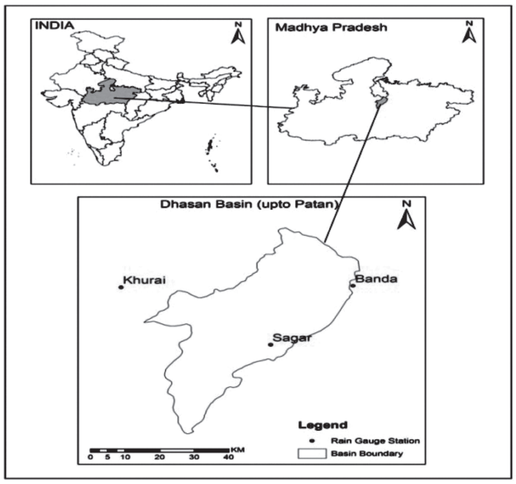

Fig. 1 : The index map of the study area

Identification of drought prone areas

The probability analysis of annual rainfall is done with an aim to identify the drought prone regions in the basin which are experiencing frequent droughts and to predict the return period of annual rainfall so that drought mitigation activities can be implemented on priority basis. The probability distribution of annual rainfall has been calculated using Weibull's plotting position formula and thereafter the plots between the probability of exceedence and the corresponding magnitude of annual rainfall were prepared. For this purpose, the annual rainfall series has been arranged in the descending order of magnitude and an order from 1 for first entry upto N for last entry were assigned and Weibull's plotting position formula was fitted to the ordered data. The probability of exceedance is given by Equation 1.

$$P = \frac{m}{n+1} * 100 \qquad \text{------------- (1)}$$

where, P = Probability of exceedance (%)

m = Order of rainfall in the series

N = Total number of rainfall events in the series

The probability of occurrence for rainfall equal to 75% of mean annual rainfall as well as the 75% dependable annual rainfall was estimated. An area was considered to be drought prone if the probability of occurrence of 75% of mean annual rainfall is less than 80% otherwise the area is not considered as drought prone (CWC, 1982).

Identification of drought years and meteorological drought characteristics

The rainfall departure is an ideal indicator of dry or wet conditions for a given time over specified areas. The assessment of drought severity due to meteorological drought was carried out by employing IMD method (Report of Irrigation Commission, 1972). 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 (Appa Rao, 1986). The drought years have been identified based on the departure analysis study of annual and seasonal rainfall for the study period. The annual or seasonal rainfall departure was computed by subtracting the mean of annual or seasonal rainfall (R_m) from the annual or seasonal rainfall (R_i) for that year respectively. The percentage departure (D_i) is subsequently computed by dividing the mean rainfall for the station by the rainfall departure as given by Equation 2.

$$D_i(\%) = \frac{(Ri\text{-}Rm)}{R_m} * 100 \qquad \text{---------- (2)}$$

where, D_i = Annual or seasonal rainfall departure for the i^{th} year

R_i = Annual or seasonal rain fall for i^{th} year

R_m =Average annual or seasonal rainfall for the period of study

The year having annual or seasonal rainfall departure more than or equal to 25% is considered to be a drought year. In this study, the severity of drought has been categorised according to percentage deviations from the normal rainfall and grouped into four severity classes as given in Table 1. The departure analysis of annual and seasonal rainfall has been performed for the influencing rain gauges *viz.,* Sagar, Banda and Khurai and subsequently the drought years have been identified.

Table 1 : Drought severity classification based on percentage of rainfall departure

Drought severity classes	Rainfall departure (%)
Mild drought	-10 to -20
Moderate drought	-20 and -25
Severe drought	-25 and -50
Extreme drought	Less than -50

Relative departure index

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

$$RDI = \frac{\sum_{i=1}^{N} W_i}{N} \quad \text{---------- (3)}$$

where, N = Number of years of data under consideration

W_i = Weight for the i^{th} drought years

An attempt was made to analyze the existence of trends in the recurrent droughts in Bundelkhand in the last decade. Trends in the rainfall data and drought severity can be detected by using either parametric or non-parametric methods. The most popularly used non-parametric tests for identifying trend in the time series is the Mann-Kendall (MK) test at 5% significance level and can be used for the data which are not normally distributed. The Mann-Kendall (MK) non-parametric method (Mann, 1945 and Kendall, 1975) was applied to observe trends in precipitation over three rain gauging sites for the present analysis. The daily rainfall data has been converted to four seasons and annual data series as per definitions used by Jhajharia *et al.* (2009) as follows: monsoon (June-September), post monsoon (October-December),winter (January-February), pre-monsoon (March-May), annual (June-May). The Mann-Kendall statistic (S) is as given by Salas (1993) is as follows

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_i) \quad \text{---------- (4)}$$

$$\text{where, } sign(x_j - x_i) = \begin{bmatrix} +1 & if(x_j - x_i) > 1 \\ 0 & if(x_j - x_i) = 1 \\ -1 & if(x_j - x_i) < 1 \end{bmatrix} \quad \text{---------- (5)}$$

And n is the number of data points. For large samples (n >10), the test follows normal distribution (Helsel and Hirsch, 1992) with the mean (= 0) and the variance as follows:

$$E(S) = 0 \text{ and } Var(S) = \frac{n(n-1)(2n+5) - \sum_{k=1}^{n} t_k (t_k - 1)(2t_k + 5)}{18} \quad \text{---------- (6)}$$

where, n is the number of tied groups, and t_k is the number of data points in the k^{th} tied group. The standard normal deviate (Z statistic) is then estimated as (Hirsch *et al.,* 1993):

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if, S > 0 \\ 0 & if, S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if, S < 0 \end{cases} \quad \text{---------- (7)}$$

A positive value of Z indicates increasing trend and negative value indicates decreasing trend. If Z> +1.96 or Z< -1.96, the null hypothesis (Ho) of no trend in the time series is rejected at 5 % significance level and if the computed test statistic value lies within limits -1.96 and +1.96, the null hypothesis (Ho) of no trend in the time series is accepted at the 5% level of significance using a two-tailed test. In this study, trend analyses were also carried out using simple linear regression method (parametric). The linear trend is expressed as $y(t) = at + b$, where t is the time and a and b are constants.

Results and Discussion

Statistical analysis of rainfall data

The processing and analysis of the rainfall data have been carried out for the rain gauge stations located in and around the study area, *viz.,* Sagar, Banda and Khurai and the missing rainfall gaps filled and consistency checks were performed. The mean annual rainfall varies between 999.5 mm at Banda to 1182.4 mm at Khurai with the average value of rainfall for the basin being 1117.2 mm. The coefficient of variation (Cv) for rainfall ranging between 23.7% at Khurai and 33.4% at Banda with the average value of Cv for the basin being 29.4%. The high variability of the annual rainfall is also one of the primary causes of the drought prevailing in the basin on a regular basis. The average rainfall for the basin has been computed using the Thiessen polygon method (Figure 2). The area under influence of various rain gauge stations in the study area is given in Table 2. The Thiessen weights for the Dhasan basin are 0.60, 0.33 and 0.07 for Sagar, Bandaand Khurai, respectively.

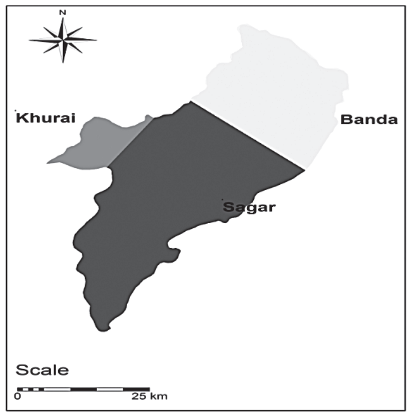

Fig. 2 : Thiessen polygon map for the study area

Table 2 : Area under the influencing rain gauge stations

Rain gauge station	Area (sq. km.)	Thiessen weights	Mean seasonal rainfall (mm)	Mean annual rainfall (mm)	Coefficient of variation (Cv)
Sagar	1234.9	0.6	1091	1174.3	31.3
Banda	677.7	0.33	938.5	999.5	33.4
Khurai	141.8	0.07	1097.6	1182.4	23.7
Total area	2054.4		1027.2	1117.2	

Identification of drought years

The percentage departure from annual and seasonal rainfall have been carried out to identify the drought years based on the data for the period from 1980-81 to 2009-10. Several other drought characteristics like drought frequency, drought severity and drought intensity are also studied for the respective study area. The positive rainfall departure indicates wet conditions whereas the negative rainfall departure indicates drought condition. It shows that maximum annual rainfall departure of -47.51% was observed during the year 2007-2008 and also having seasonal rainfall departure of -43.62%. The highest annual rainfall deviation of -51.6 % was recorded in Banda district in 2007-08 with Sagar also facing annual rainfall deficit of more than

-48.4% in the same year, indicative of the severe drought conditions. However, the highest seasonal (monsoon) rainfall deviation of -58.7% occurred at Sagar during 1981-82. The plots of annual rainfall departure for Sagar, Banda and Khurai are given in Figure 3, Figure 4 and Figure 5, respectively. It can be concluded from the Table 3, that the years with seasonal (June-Sept) drought generally corresponds to the annual drought also since the magnitude of annual rainfall departure is analogous to seasonal rainfall departure. Maximum of thirteen numbers of drought years are experienced at Banda during the study period with a maximum return period of once in 2.23 years which is same for basin followed by Sagar and Khurai having return period 2.42 and 2.9, respectively. As the south-west monsoon is the only big contributor of rainfall, the deficit south-west monsoon is primarily responsible for the regular occurrence of drought and subsequent water stress in the study area, thereby adversely affecting the major agricultural operations. From the analysis for annual and seasonal rainfall departure, it has been observed that the occurrence of drought takes place once in every two to three years in the study area.

Table 3 : Summary of annual and seasonal rainfall departures analysis

Name of station	No. of years of data for analysis	No. of drought years	Avg. return period (year)	Maximum recorded annual deficit (%)	Maximum recorded seasonal deficit (%)
Sagar	29	12	2.42	-48.4 (2007-08)	-58.70 (1981-82)
Khurai	29	10	2.9	-43.57 (2002-03)	-48.84 (2002-03)
Banda	29	13	2.23	-51.58 (2007-08)	-47.90 (2007-08)
Study area	29	13	2.23	-47.52 (2007-08)	-50.31(1981-82)

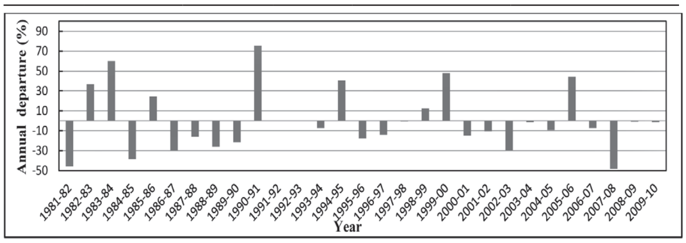

Fig. 3 : Annual rainfall departure at Sagar station

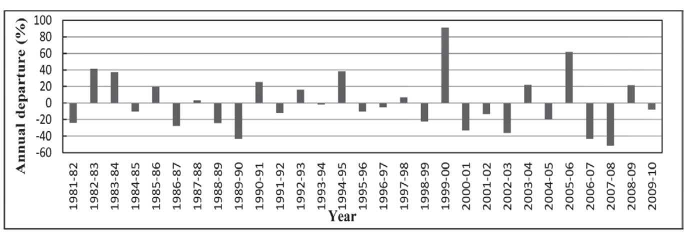

Fig. 4 : Annual rainfall departure at Banda station

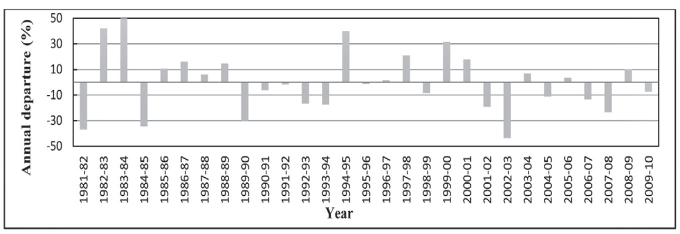

Fig. 5 : Annual rainfall departure at Khurai station

Identification of drought prone areas

The probability analysis of rainfall for three raingauge 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 the three influencing rain gauge stations are given in Table 4. It has been observed that there is considerable variation in the 75% dependable rainfall values from maximum of 979.4 mm at Khurai to minimum of 758.2 mm at Banda. This indicates that rainfall distribution at neighbouring stations have 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, which varies from 77.4% at Banda to 84.1% at Khurai. From the probability analysis, it is indicative of the fact that the areas of the basin influenced by Sagar and Banda are drought prone (probability of 75% mean rainfall being less than 80%) and faced regular water scarcity and droughts. So efforts should be focused on Sagar and Banda for drought preparedness, mitigation and management measures. The graph depicting the probability distribution of the annual rainfall at Sagar, Banda and Khurai is given in Figure 6, Figure 7 and Figure 8, respectively.

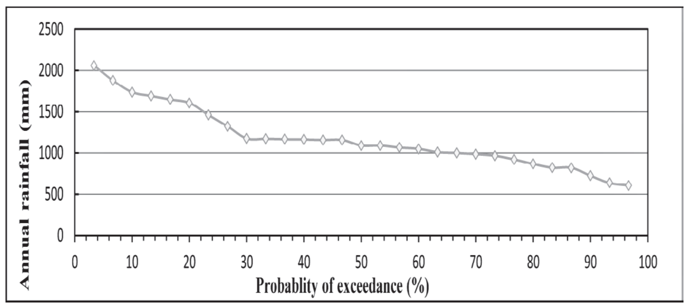

Fig. 6 : Probability distribution of annual rainfall at Sagar

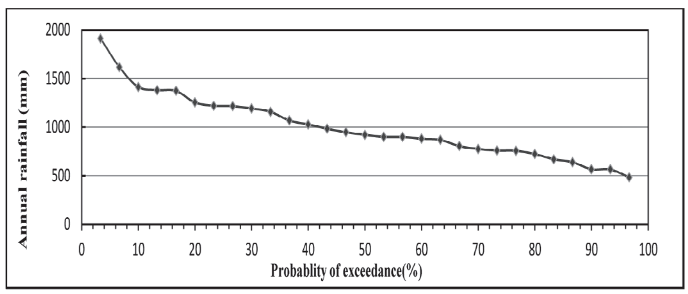

Fig. 7 : Probability distribution of annual rainfall at Banda

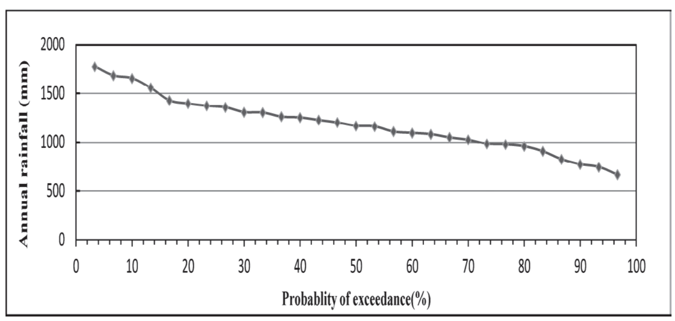

Fig. 8 : Probability distribution of annual rainfall at Khurai

Table 4 : Probability distribution of annual rainfall

Station	Mean rainfall (mm)	75% dependable rainfall (mm)	Probability of occurrence of rainfall equivalent to 75% of mean rainfall	Drought condition
Sagar	1174.3	944.2	1174.3 (79.17%)	Drought prone
Khurai	1182.4	979.4	1182.4 (84.09%)	Normal
Banda	999.5	758.2	999.5 (77.38%)	Drought prone
Study area	1117.2	888.9	837.9 (78.99%)	Drought prone

Relative departure index

The relative departure index (RDI) study for three raingauge stations of the Dhasan basin also indicates that the area of the basin influenced by Banda and Sagar are severely drought prone compared to Khurai as given in Table 5. So drought mitigation measures should be carried out for Banda and Sagar on priority basis followed by Khurai.

Table 5 : Ranking based on RDI

Station name	RDI	Rank
Banda	0.98	1
Sagar	0.862	2
Khurai	0.655	3

Trend analysis of rainfall

The trend analysis has been carried out for identification and interpretation of existing rainfall pattern in the Dhasan basin which leads to recurrent drought situation in Dhasan basin. Annual and seasonal rainfall variability leads to climate change which may be possible reason for frequent drought and also greatly affects water availability thus causes failure in crop production. Long term rainfall over study area, was analyzed using Mann-Kendall (MK) test for identification of any statistical significance of temporal trend at seasonal and annual basis. Ahead of applying the Mann-Kendall test, the data series was tested for serial correlation and Standard Normal Homogeneity Test (SNHT) was carried out to check presence of any shift point in data series. The Man-Kendall test result of rainfall data analysis has been presented in the Table 6. Significant trend (5% significance level) has not been observed at any of the rain gauging stations. The investigation showed a long term insignificant declining trend of annual as well as monsoon, post-monsoon and winter rainfall, was observed for Khurai and Banda whereas insignificant decreasing trend for annual, post-monsoon and winter season were observed at Sagar. Though the analyzed trends found to be statistically insignificant in nature, but it has high practically significant effects in emerging drought like situation in the basin over a long time period.

Table 6 : Trend analysis of rainfall for Dhasan basin

Pre-monsoon (March-May)			
Station name	**Z (Test statistics)**	**Sen's slope (Magnitude of trend)**	**Remark**
Sagar	1.55	0.952	Increasing
Khurai	1.93	0.873	Increasing
Banda	0.14	0.000	Increasing
Study area	1.34	0.637	Increasing
Monsoon (June-September)			
Sagar	0.14	1.215	Increasing
Khurai	-0.53	-3.944	Decreasing
Banda	-0.85	-6.032	Decreasing
Study area	0.14	0.422	Increasing
Post-monsoon (October-December)			
Sagar	-0.38	-0.033	Decreasing
Khurai	-0.76	-0.086	Decreasing
Banda	-1.71	-0.251	Decreasing
Study area	-1.05	-0.302	Decreasing
Winter (January-February)			
Sagar	-1.55	-1.033	Decreasing
Khurai	-0.99	-0.500	Decreasing
Banda	-1.38	-0.488	Decreasing
Study area	-1.54	-0.853	Decreasing
Annual			
Sagar	0.14	2.271	Increasing
Khurai	-0.81	-6.608	Decreasing
Banda	-0.81	-7.038	Decreasing
Study area	-0.06	-1.700	Decreasing

The variability of the mean annual precipitation data for the entire period of study is studied using MS Excel software. A decline in annual mean precipitation in the period 1981-2008 is observed. The highest average change rate of annual rainfall data is 5mm/yr, for Khurai followed by basin average 2.41 mm/yr as given in Table 7.

Table 7 : Change rate and trend detection for study area

Station name	Average change rate (mm/yr)	Linear regression equation	Coefficient of determination (R^2)	Trend of annual rainfall
Sagar	2.41	y = -2.5464 x + 1206	$R^2 = 0.0029$	Decreasing
Khurai	5.00	y = -5.326 x + 1259.9	$R^2 = 0.0223$	Decreasing
Banda	3.10	y = -2.9452 x + 1041.9	$R^2 = 0.0049$	Decreasing
Study area	2.41	y = -2.8726 x + 6843.3	$R^2 = 0.0047$	Decreasing

Conclusion

The departure analysis of rainfall data indicated that, the study area is under the grip of regular and continuous droughts with the drought frequency varying between once in 2 years to once in 3 years, which is rather very high. The high variability of the annual rainfall ranging between 23.7% at Khurai and 33.4% at Banda with the average value of Cv for the basin being 29.4%, is also one of the primary causes of the drought prevailing in the basin on a regular basis. From the probability analysis, it is indicative of the fact that areas of the basin under Sagar and Banda are drought prone and face regular water scarcity. So attempts should be focused on Sagar and Banda for drought preparedness, alleviation and management measures. The trend analysis depicts an insignificant but decreasing rainfall pattern for Khurai and Banda during monsoon, post-monsoon and winter season, which may further magnify the drought condition.

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