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Assessment from Drought Perspective for Bundelkhand Region, India

ABSTRACT

The Bundelkhand region in Madhya Pradesh state poses many issues related to water resource availability and is under grip of frequent drought like situation. The drought condition in the region is continuously worst than before due to climate change which intimate increased drought intensity and magnitude. The region mainly consists of 7 district of Uttar Pradesh and 6 district of Madhya Pradesh. The present study aims to investigate drought characteristics in Bundelkhand region of Madhya Pradesh using departure analysis and prioritization of which is carried out using Relative Departure Index (RDI) for planning immediate mitigation strategies. The impact of climate change was assessing using Mann-Kendell test and its magnitude of change using Sen's slope estimator. For assessment of drought characteristics and evaluation of climate change 45 years (1970-2014) monthly rainfall data is analyzed. The average annual rainfall in Bundelkhand region in M.P is computed as 1071.1 mm. In 1970, 1974, 2002, 2006, 2007, and 2010 the region was under grip of widespread drought condition. Prioritization using RDI indicated that Sagar district is at the highest priority and was followed by Chhatarpur and Panna. The trend analysis reveals the decrement of seasonal rainfall patterns except in Damoh and Chhatarpur districts. The annual rainfall trends assessment showed quite similar changing patterns among the districts, except in Chhatarpur and Panna district.

Keywords: Drought area, drought years, trend analysis, Bundelkhand region

INTRODUCTION

Drought is a complex and multivariate phenomenon influenced by diverse physical and biological processes resulting shortage of water over an extended period which badly affects the production of agriculture, livestock, and the environment (Rhee et al. 2018). As per the India Meteorological Department (IMD) if total seasonal rainfall received less than 75% of its normal value than it is considered as drought. The frequency and intensity of drought are exacerbated due to climate change which acts as a driver that causes variability in rainfall patterns. Many studies have shown that greenhouse gas (GHG)-induced global warming may lead to an increase in drought occurrence in the twenty-first century due to decreased precipitation and increased evaporative demand associated with higher vapor pressure deficit under warmer temperatures (Dai et al. 2018). Climate change has influenced the hydrological processes and renders its performance causing extreme drought conditions and inadequate water availability. The influence of climate change due to its impact on the pattern of precipitation, temperature, and evapotranspiration has diverted the attention of many researchers worldwide to investigate factors that help to render its effects which causes increase drought severity and frequency.

The problem of water shortage attribute to climate change scenario in the long term causes natural variability in the different phenomenon and resulting in incrementing extreme drought conditions imparted as decrease soil moisture, runoff, and streamflow. For water management strategies adaptation, the study of effects of climate change on hydrological, ecological, and socioeconomic regimes is necessary. The hydrology of a region i.e. changes in the timing, amount, and form of precipitation, evaporation and transpiration rates, and soil moisture are important to assess the impact of climate change. Though drought is a long-term phenomenon affecting large regions causing significant damages its evaluation coupled with climate change considerably helps in water resources management and socio-economic development in the region. The threat that droughts pose to the different sectors has necessitated the assessment of the potential impacts of climate change at various scales to reduce their vulnerability (Loukas et al. 2007). Few studies on climate change impacts on droughts have employed meteorological drought indices, which require considerably fewer input data when compared to the weather, soil and land use information needed by meteorological, hydrologic, geohydrologic and water management models as the tools for assessing drought responses (i.e., Kothavala, 1999; Blenkinsop and Fowler, 2007; Mavromatis, 2007: Loukas et al.2007).

The present study mainly focuses to evaluate drought characteristics in the Bundelkhand region along with climate change detection. Water stress condition is not new to the Bundelkhand region which is home to 18 million people spread over 7 districts of Uttar Pradesh and 6 districts of Madhya Pradesh. Over 75% of the Bundelkhand population continues to depend on agriculture, while 96% of the total income in the region is raised from agriculture and livestock together. The region experienced drought events in every 16 years during the 18th and 19th centuries. The drought frequency, intensity, and magnitude have further escalated due to climate change over a long period of time. Due to such unprecedented uncertainties associated with drought and climate change scenarios, it is quite critical to examine the drought situations in the region.

MATERIAL AND METHODS

Description of Study Area

The Bundelkhand region lies in a semi-arid plateau which encompasses six districts of Madhya Pradesh (M.P) viz., Chhatarpur, Tikamgarh, Damoh, Sagar, Datia and Panna. The region is located between fertile Gangetic plain stretching across southern UP and the highlands of central MP. The Bundelkhand region lies between 23°08′N and 26°30′N latitude and 78°11′E and 81°30′E longitude. Agriculture is the major occupation in that region and the majority of which is rain-fed. The major rivers in that region include Sindh, Betwa, Ken, Bagahin, Tons, Pahuj, Dhasan, and Chambal. They are the major sources of drinking and irrigation water in the Bundelkhand region and in the neighboring districts of Uttar Pradesh. The major soils include alluvial, medium black, and mixed red and black soils. The base map of the study area is shown in Figure 1.

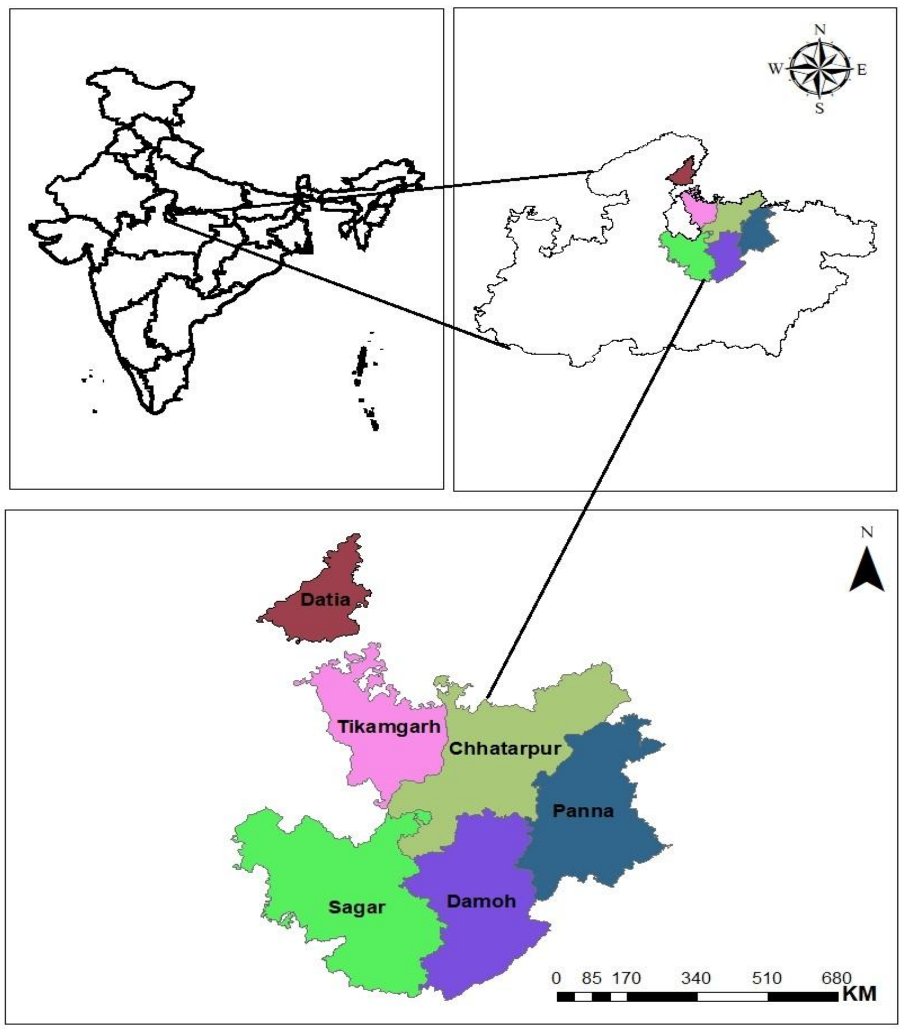

Fig.1. Location map of the study area

Data Availability

For the assessment of drought characteristics rainfall data is mainly used and were obtained from the India water portal sites, IMD, Pune. The data pertaining to the Bundelkhand region in Madhya Pradesh consists of monthly rainfall data of 45 years (1970-2014).

Identification of Drought Prone Areas

The drought prone areas were identified using the probability analysis of annual rainfall. The region was considered to be drought affected if the probability of occurrence of 75% of average annual rainfall less than 80% (CWC, 1982; Sharma et al. 2019). The probability of exceedance computed using Weibull's plotting position formula in which annual rainfall series were sorted in the descending order and ranks were assigned from 1, 2, ……N. The computing formula for probability of exceedance is provided in equation 1.

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

Where,

P = Probability of Exceedance of annual rainfall,

m = Rank of the particular record,

N = Total number of observations,

Identification of Drought Years

Drought years were identified using departure analysis of seasonal and annual rainfall. For assessing drought year seasonal rainfall was considered as it provides results that are oriented to monsoon and which largely affecting marginal and small farmers. Departure analysis of seasonal rainfall was used to compute drought years using criteria which implies seasonal rainfall departure less than -20%. The criteria used were area-specific because in most of the literature the minimum criteria for drought years were less than -25%. The departure was further classified into different categories for assessing the drought severity and its frequency that prevails in the region (Appa Rao, 1986; Thomas et al. 2014). The seasonal rainfall departure was computed using equation 2. Chart 1 enlists the drought classes which were evaluated using departure analysis.

$$D\ \% = \frac{Di}{Xm} X100 \qquad (2)$$

Table 1: classification of drought severity based on the rainfall departure

No.	Seasonal rainfall departure (%)	Drought Class
1.	-20 to -25	Mild drought
2.	-25 to -35	Moderate Drought
3.	-35 to -50	Severe Drought
4.	>-50	Extreme Drought

If the value of seasonal departure is less than -20 then no drought condition, if the value of departure lies between -20 to -25% then moderate drought, and if it lies between -35 to -50% then severe drought and less than -50% implies extreme drought condition.

Relative Departure Index

During drought conditions, it is important to identify the most critical area in the drought-affected region. The worst affected area can be prioritized in the region and accordingly mitigation strategies will be implemented. Prioritization of blocks using relative departure index is a simple and most widely used method and is based on assigning weights to different drought severity classes as (1) for mild drought, (2) moderate drought, (3) severe drought, and (4) extreme drought. The weighted are decided by the impact caused by the type of drought, which emphasis that extreme drought which has greater impact will be allotted with a higher weighted number and vice-versa. Summation of weights multiplied with the number of drought events with different severity divided by the total number of years under consideration implies rank or RDI (Kar et al. 2016; Kumar et al. 2020). The computation of RDI was carried out using equation 3.

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

Where,

N= Total number of a year under consideration

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

Mann-Kendell (MK) Test

To detect monotonic trends in a series of rainfall data non-parametric Mann-Kendell (MK) test was used (Thorsten Pohlert, 2018). The MK test involves two sets of hypotheses viz., the null hypothesis (Ho) which implies no trend i.e., the data in a set of series is independent and do not show any realizations and the alternative hypothesis (Ha) that is data follow a monotonic trend. The Mann-Kendall test statistic is calculated using equation 4 (Mann 1945).

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

Where x_i and x_j are the annual values in years i and j, respectively, (i > j) and n is the number of data points. The value of sign(x_i - x_j) is computed as follows:

$$sign(x_i - x_j) = \begin{cases} 1 & \text{if } x_i - x_j > 0 \\ 0 & \text{if } x_i - x_j = 0 \\ -1 & \text{if } x_i - x_j < 0 \end{cases} \quad \text{......... (5)}$$

This statistic represents the number of positive differences minus the number of negative differences for all the differences considered.

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

$$\sigma^2(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18} \quad \text{......... (6)}$$

Where m is the number of tied groups and ti is the number of ties of extent i(Afouda, 2017).

If there are no ties between the observations, the variance is computed as:

$$\sigma^2(S) = \frac{n(n-1)(2n+5)}{18} \qquad \text{……… (7)}$$

The standard normal test statistic Z is computed using equation stated below as per the condition satisfied:

$$Z = \frac{S-1}{\sqrt{Var(S)}} \qquad \text{If, S > 0} \qquad \text{……… (8)}$$

$$Z = \frac{S-1}{\sqrt{Var(S)}} \qquad \text{If, S= 0} \qquad \text{……… (9)}$$

$$Z = \frac{S+1}{\sqrt{Var(S)}} \qquad \text{If, S < 0} \qquad \text{……… (10)}$$

The presence of a statistically significant trend is evaluated using the Z value. A positive value of Z indicates an upward trend and its negative value a downward trend(Adarsh & Reddy, 2015). The Z values were tested at 0.05 level of significance.

Sen's Slope Estimator

Non-parametric method (Sen, 1968) is used to estimate the magnitude of change in trends in time series data. The slope of 'n' pairs of data can be first estimated by using the following equation 11:

$$N = \frac{x_j - x_i}{j - i} \qquad \text{……… (11)}$$

Where *xj* and *xi* are considered as data values at time *j* and *i*(*j*>*i*) correspondingly.

The median of these n values of Q is represented as Sen's estimator of slope (Prayas Rath, 2016)

$$Q = T_{\frac{N+1}{2}} \qquad \text{If N is odd} \qquad \text{……… (12)}$$

$$Q = \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+1}{2}}\right)$$

If N is even ……… (13)

Sen's slope is computed using equation 12, if N appears odd, and equation 13, if N appears even. In the end, Q is computed by a two-sided test at 100 (1-α) % confidence interval and then a true slope can be obtained by the non-parametric test. The positive value of Q indicates an upward or increasing trend and a negative value of Q gives a downward or decreasing trend in the time series (Begum, 2006).

RESULT AND DISCUSSION

Statistical Analysis

The statistical approach was mainly considered for assessing the general information for the study area based on which the blocks within the region can be compared. The Bundelkhand region in Madhya Pradesh comprises of 6 districts. The assessment of monthly rainfall data of 45 years (1970 -2014) revealed that the region receives an average annual rainfall of 1071.1 mm. Out of 6 districts; Datia receives the minimum average annual rainfall of 802 mm and a maximum of 1203 mm received by Sagar. The rainfall variability in the region was assessed using the coefficient of variance (CV %). The region shows high variability in annual rainfall and that value correspond to 30%, such high variability in rainfall influence to drought-like situation when substantially low rainfall occurred in any particular years. Almost all districts show high CV% value but were maximum in Sagar with 36% and minimum in Datia with 26 %. Bundelkhand regions have high rainfall variability which acts as a constraint for agricultural activities and thus affecting the livelihood of largely rainfall dependent population. The mean and coefficient of variance for different districts in Bundelkhand region are shown in Table 1. Figure 2 and Figure 3 show the variation in annual rainfall and CV% in the Bundelkhand region.

Table 1: Mean and coefficient of variance in Bundelkhand region of M.P

No.	District	Mean	CV (%)
1.	Chhatarpur	935	28.9
2.	Damoh	1174	28.6
3.	Datia	802	26.8
4.	Panna	1179	29.7
5.	Sagar	1203	36.2
6.	Tikamgarh	999	28.1

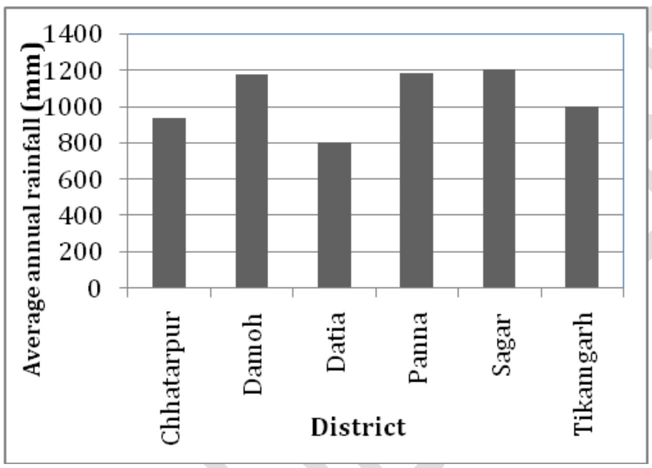

Fig.2. Average annual rainfall in Bundelkhand region (M.P)

Fig.3. coefficient of variance of annual rainfall

Computation of Drought years

Drought years were evaluated using a departure analysis of seasonal rainfall. The seasonal rainfall depicts the drought scenario which prevails during the most critical stage where farmers are highly dependent on monsoon for their crop productivity. The assessment of drought years helps to get the extent as well as the severity of drought in the region. Mainly four types of droughts occurred at different years viz. mild, moderate, severe, and extreme. In the present study, the year is considered drought years when rainfall departure is less than -20%. The drought years as computed by departure analysis in the series of 1970-2014 rainfall data are tabulated in 2. Maximum drought severity at various district: Chhatarpur (-44 % in 2014), Damoh (-38 % in 2002), Datia (-44% in 2002), Panna (-47% in 1970), Sagar (-62% in 1972), Tikamgarh (-46% in 1979).

Table 2: Drought year during the span of 1970-2014

District	**Drought year**
Chhatarpur	1970, 1973, 1974, 1994, 1995, 1998, 2006, 2007, 2010
Damoh	1970, 1972, 1974, 1976, 1989, 2002, 2006, 2007, 2014
Datia	1978, 1979, 1980, 1981, 1989, 2000, 2005, 2006, 2007, 2009, 2010
Panna	1970, 1973, 1977, 1979, 1986, 1998, 2000, 2006, 2007, 2009, 2010
Sagar	1970, 1974, 1981, 1984, 1986, 1988, 1992, 2000, 2002, 2007, 2008, 2010, 2012
Tikamgarh	1977, 1979, 1986, 1988, 1989, 1991, 1995, 2000, 2002, 2004, 2010

The region was under grip of widespread drought condition in 1970, 1974, 2002, 2006, 2007, and 2010. Due to acute water shortage the agriculture sector in region was adversely affected and resulted in loss of livelihood and inadequate crop growth. Figure 4 to 9 depicts seasonal rainfall departure in different districts of Bundelkhand region falling in Madhya Pradesh. The severity of drought was much more intense in Sagar district as compared with another district in Bundelkhand region.

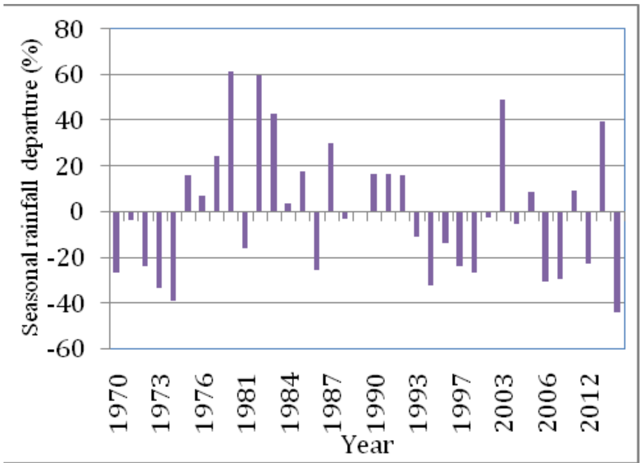

Fig.4: Seasonal rainfall departure at Chhatarpur

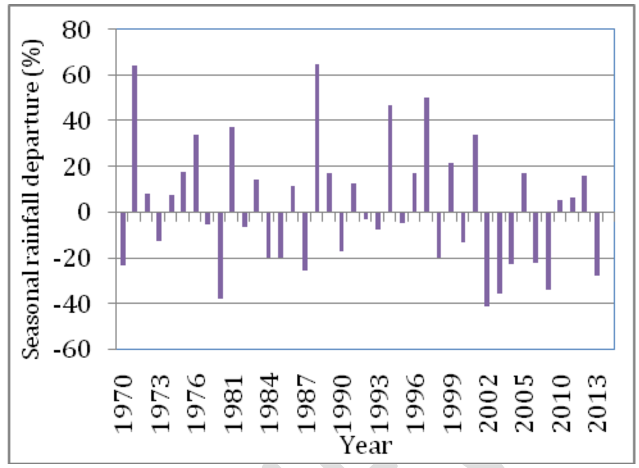

Fig.5: Seasonal rainfall departure at Damoh

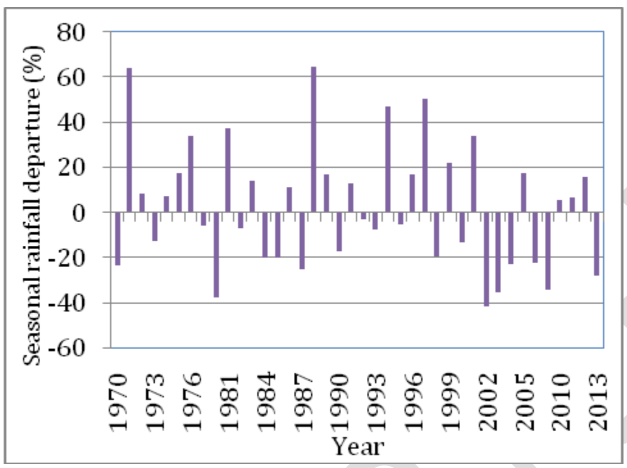

Fig.6: Seasonal rainfall departure at Datia

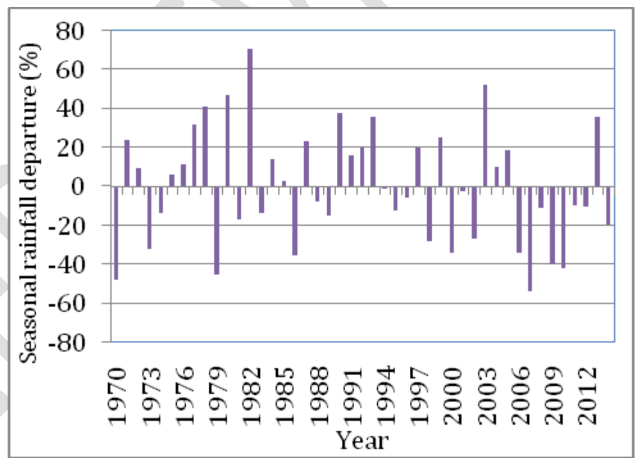

Fig.7: Seasonal rainfall departure at Panna

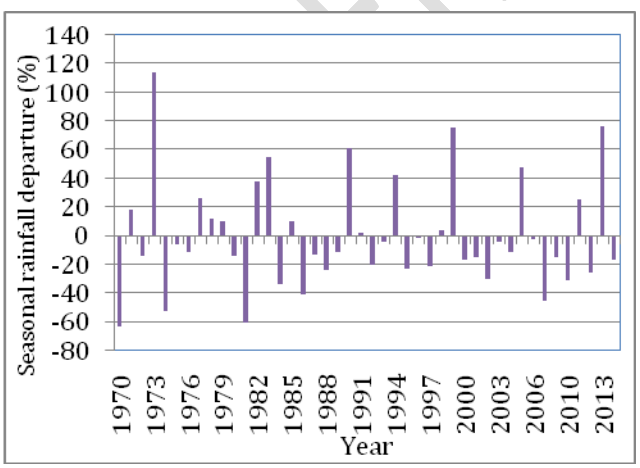

Fig.8: Seasonal rainfall departure at Sagar

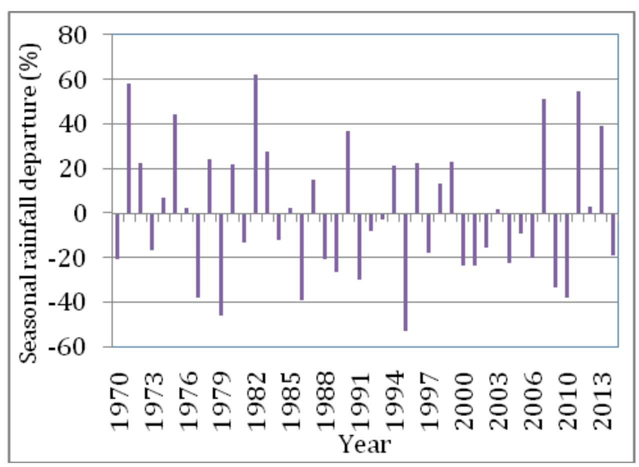

Fig.9: Seasonal rainfall departure at Tikamgarh

Evaluation of Drought Characteristics

The drought severity and its frequency were assessed using seasonal departure. The region was experiencing a drought of varying severity during the span of 1970-2014 and it is shown in Table 3. The occurrences of extreme drought events were maximum in Sagar district followed by Panna, Chhatarpur, and Damoh. Due to frequent drought occurrences with more widespread aerial extent i.e., 1 in 4 years and inadequate rainfall, the region experiencing poor groundwater availability and even existence of disastrous conditions during the monsoon period. From the analysis, it has been observed that the occurrence of drought is predominant in the region and thus required area-oriented strategies to mitigate and render its impacts. Monitoring of drought and associated agricultural production deficit can be considered as an essential component for drought preparedness in the region.

Table 3: drought characteristics based on departure analysis

No	Stations	Mild	Moderate	Severe	Extreme	Total	Frequency
1	Chhatarpur	1	5	1	2	9	1 in 5
2	Damoh	1	5	1	2	9	1 in 5
3	Datia	3	6	2	0	11	1 in 4
4	Panna	3	3	3	2	11	1 in 4
5	Sagar	2	6	1	4	13	1 in 3
6	Tikamgarh	2	5	3	1	11	1 in 4

Computation of Drought prone districts

Identification of drought prone district involves assessment using the probability analysis of annual rainfall. The probability of occurrence of rainfall equivalent to 75% of normal is obtained from probability distribution graph. From the probability analysis, it is indicated that the district are no drought prone (probability of 75% mean rainfall being less than 80%) but faced regular water shortage and water stress condition due to inadequate water resources management. So, efforts should be focused for drought preparedness, mitigation and management measures to cope and render drought impact. The graph depicting the probability distribution of the annual rainfall at Sagar and Tikamgarh district is given in Figure 10 and Figure 11.

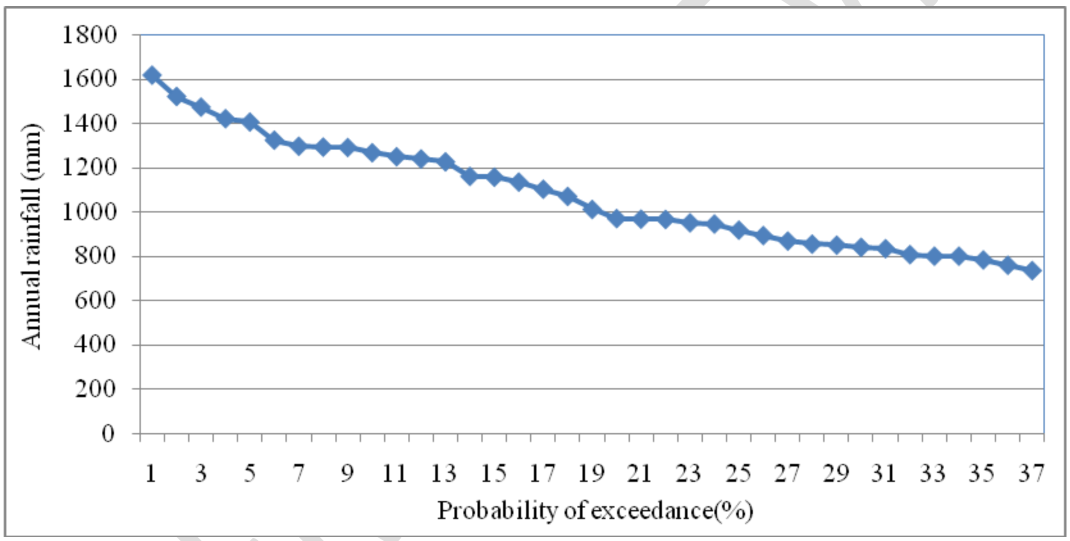

Fig. 10: Probability distribution of annual rainfall at Sagar

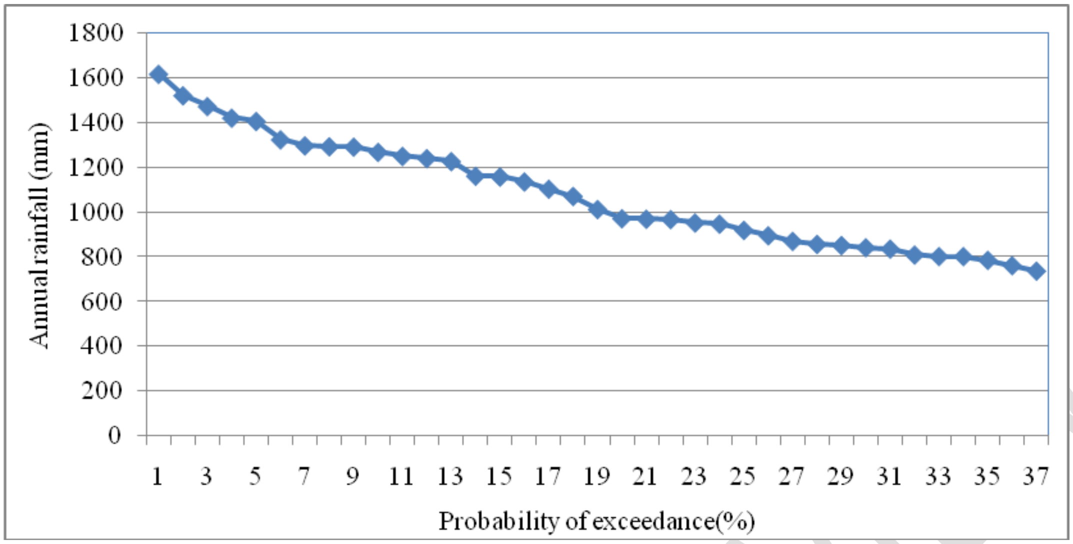

Fig. 11: Probability distribution of annual rainfall at Tikamgarh

Relative departure index (RDI)

Drought in any particular region cannot be avoided but some remedial measures can be pursued before its occurrences based on indices that prioritize district which is most vulnerable to drought. For prioritization, the relative departure index was computed and Table 4 enlists the ranking of different districts of the Bundelkhand region in M.P. Sagar district is at highest priority followed by Chhatarpur and Panna. Thus, using prioritization technique drought mitigation strategies and preparedness plans can be implemented as area-oriented and can help best to cope under drought situations.

Table 4: ranking based on RDI

No	**Stations**	**RDI**
1	Chhatarpur	0.59
2	Damoh	0.48
3	Datia	0.48
4	Panna	0.58

5	Sagar	0.74
6	Tikamgarh	0.56

Trend analysis of seasonal and annual rainfall

Non-parametric Mann-Kendell test was employed to identify the impact of climate change in the region by assessing change in seasonal and annual rainfall patterns. The trend assessment help to interpret the existing rainfall pattern which leads to frequent drought occurrence and thus affecting water availability in the region which causes failure in crop production. The Mann-Kendall test result of seasonal rainfall and annual rainfall has been presented in the Table 5.

Table 5: Trend analysis of seasonal rainfall and annual rainfall

Seasonal rainfall

No.	District	Test-Z	Trend	Slope
1	Chhatarpur	0.38	Rising	1.33
2	Damoh	0	No change	0.05
3	Datia	-0.01	Falling	-0.06
4	Panna	-0.09	Falling	-0.34
5	Sagar	-1.11	Falling	-5.17
6	Tikamgarh	-0.28	Falling	-0.81

Annual rainfall

No.	District	Test-Z	Trend	Slope
1	Chhatarpur	-1.23	Falling	-4.313
2	Damoh	0.43	Rising	2.235

3	Datia	-0.54	Falling	-1.372
4	Panna	0.85	Rising	4.54
5	Sagar	-1.03	Falling	-4.654
6	Tikamgarh	-0.17	Falling	-0.593

The investigation of seasonal rainfall pattern which is the most critical period for agriculture showed declining trend in most of the district except in Damoh and Chhatarpur district. The assessment of long-term data showed insignificant decreasing trend except in Sagar district (-5.17) at 1% level of significance. Overall, the annual rainfall trends showed quite similar changing patterns among the districts, except in Chhatarpur and Panna district. The insignificance of change in analyzed trend implies high practically significant effects in emerging drought like situation over a long time period. The variability in seasonal and annual rainfall suggesting an urgent need for contingency planning to overcome the disastrous effects caused due to climate change scenario.

Numerical climate forecasts as well as historical data analysis studies for the purpose of characterizing meteorological drought support the management of climatic emergencies, as demonstrated by the studies developed by Olivares (2018), Olivares et al. (2016), also in the mitigation of impacts and prevention of economic losses produced by extreme events such as droughts (Olivares et al. 2017; Parra et al. 2018; Cortez et al. 2018) and floods (Olivares et al. 2018; Olivares and Hernandez, 2019). For example, irrigation systems are deficient in dry seasons and irrigation is commonly carried out at night (Olivares et al. 2021), so a climate forecast will be able to quantify the amount of rainfall entering the system and thus cover the irrigation demand users. In recent years, the greatest efforts in predictions (forecasts), projections and simulations have focused on the precipitation component, since if there is a bad representation of rainfall there will be a poor characterization of other meteorological variables (Casana and Olivares, 2020; Cortez et al. 2019). Precipitation variability is due to topography (orientation, elevation, and slope) and climatic influences (prevailing wind, distance from the sea) altered by moist air blocking the mountains (Olivares et al. 2017).

In addition, Olivares et al. (2013); Olivares et al. (2012) and (Urdiales Flores & Célleri, 2018) establish that there is a need to know the characteristics of drought management in each context and to develop specific methodologies for its evaluation (Olivares and Hernández, 2020; Olivares et al. 2018a). This would help to better understand how we are addressing the problem of drought (Olivares and Hernández, 2019; Olivares et al. 2018; Olivares and Zingaretti, 2018), determining the degree of adoption of the risk approach and the factors that facilitate or hinder its implementation would be very useful for improve drought management (Casana and Olivares, 2020; Olivares, 2018; Olivares et al. 2017b) and make concrete recommendations on the design of related public policies in rural territories (Olivares et al. 2017a, Olivares et al. 2016c; Olivares et al. 2017c) .

CONCLUSION

The statistical analysis for Bundelkhand regions showed high rainfall variability which ranging between 36% at Sagar and 26 % at Datia district whereas the average CV% is 30%. Departure analysis of seasonal rainfall indicated that the area was under widespread drought conditions in 1970, 1974, 2002, 2006, 2007, and 2010 with return period which varying between once in 3 years to once in 4 years. From the probability analysis, it is indicated that the districts are no drought-prone but faced regular water shortage and water stress conditions due to inadequate water resources management. Prioritization of districts using the relative departure index indicates that Sagar district is at the highest priority and was followed by Chhatarpur and Panna. Drought mitigation strategies and preparedness plans must be implemented for districts based on ranking. The trend analysis reveals the decrement of seasonal rainfall patterns except in Damoh and Chhatarpur districts where there is an increasing trend. The change is not significant except at the Sagar district. The annual rainfall trends assessment showed quite similar changing patterns among the districts, except in Chhatarpur and Panna district. The variability in seasonal and annual rainfall signifies the impact of climate change and thus suggesting an urgent need for comprehensive adaptation and mitigation strategies to overcome the effects of extreme weather events.

REFERENCES

Adarsh, S., & Reddy, M. J. (2015). Trend analysis of rainfall in four meteorological subdivisions of southern India using nonparametric methods and discrete wavelet transforms, *1124*(May 2014), 1107–1124. https://doi.org/10.1002/joc.4042

Afouda, A. (2017). Trends and Changes in Recent and Future Penman-Monteith Potential Evapotranspiration in, 7–16. https://doi.org/10.3390/hydrology4030038

Appa R. 1986. Drought climatology, Jal Vigyan Samiksha. High Level Technical Committee on Hydrology, National Institute of Hydrology, Roorkee.

Begum, M. A. R. M. (2006). Application of non parametric test for trend detection of rainfall in the largest Island of Bangladesh.

Central Water Commission (CWC). 1982. Report on identification of drought prone areas for 99 districts. New Delhi, India.

Casana, S., Olivares, B. 2020. Evolution and trend of surface temperature and windspeed (1994 - 2014) at the Parque Nacional Doñana, Spain. Rev. Fac. Agron. (LUZ). 37(1):1-25. https://n9.cl/c815e

Cortez, A., Olivares, B., Parra, M., Lobo, D., Rey, JC., Rodriguez, MF. 2019. Systematization of the calculation of the Standardized Precipitation Index as a methodology to generate meteorological drought information. Rev. Fac. Agron. (LUZ). 36(2):209-223. https://n9.cl/4spjp

Cortez, A., Olivares, B., Parra, R., Lobo, D., Rodríguez, M.F. & Rey, J.C. 2018. Descripción de los eventos de sequía meteorológica en localidades de la cordillera central, Venezuela. Ciencia, Ingenierías y Aplicaciones. I (1):22-44. http://dx.doi.org/10.22206/cyap.2018.vlil.pp23-45.

Dai, A., Zhao, T., & Chen, J. (2018). Climate Change and Drought: a Precipitation and Evaporation Perspective. Current Climate Change Reports, 4, 301-312.

Kar, S. K., Thomas, T., & Singh, R. M. (2016). Identification of drought prone areas and trend analysis of rainfall phenomenon in Dhasan basin. Indian Journal of Dryland Agricultural Research and Development, 31(2), 9-14.

Kumar, A., Panda, K. C., Nafil, M., & Sharma, G. (2020). Identification of Meteorological Drought Characteristics and Drought Year Based on Rainfall Departure Analysis. Current Journal of Applied Science and Technology, 51-59.

Loukas, A., Vasiliades L., and Tzabiras J. (2007). Evaluation of Climate Change on Drought Impulses in Thessaly, Greece. European Water, 17/18: 17-28.

Mann H.B. 1945. Non-parametric Test against Trend, Econometrika. 13: 245-259.

Olivares B, Cortez A, Muñetones A, Casana S. Strategic Elements of Organizational Knowledge Management for Innovation. Case: Agrometeorology Network. Revista Digital de Investigación en Docencia Universitaria. 2016c;10(1):68-81. http://dx.doi.org/10.19083/ridu.10.446

Olivares, B. 2018. Tropical conditions of seasonal rain in the dry-land agriculture of Carabobo, Venezuela. La Granja: Journal of Life Sciences. 27(1):86-102. http://doi.org/10.17163/lgr.n27.2018.07

Olivares, B. Parra, R y Cortez, A. 2017b. Characterization of precipitation patterns in Anzoátegui state, Venezuela. Ería. 3 (3): 353-365. https://doi.org/10.17811/er.3.2017.353-365

Olivares, B., Cortez, A., Parra, R., Lobo, D., Rodríguez, M.F & Rey, J.C 2017a. Evaluation of agricultural vulnerability to drought weather in different locations of Venezuela. Rev. Fac. Agron. (LUZ) 34 (1): 103-129. https://n9.cl/d827w

Olivares, B., Cortez, A., Rodríguez, M.F, Rey, J.C. y Lobo, D. 2016. Information system development of an alternative raingauge network in rural areas. Case state Anzoategui, Venezuela. Acta Universitaria 26 (4):65-76. https://doi.org/10.15174/au.2016.961

Olivares, B., Hernández, R. 2019. Regional analysis of homogeneous precipitation zones in Carabobo, Venezuela. Revista Lasallista de Investigación. 16(2):90-105. https://doi.org/10.22507/rli.v16n2a9

Olivares, B., Hernández, R. 2020. Application of multivariate techniques in the agricultural land's aptitude in Carabobo, Venezuela. Tropical and Subtropical Agroecosystems, 23(2):1-12. https://n9.cl/zeedh

Olivares, B., Hernández, R; Coelho, R., Molina, JC., Pereira, Y. 2018. Spatial analysis of the water index: advances in sustainable decision-making in Carabobo agricultural territories, Venezuela. Revista Geográfica de América Central. 60 (1): 277-299. https://doi.org/10.15359/rgac.60-1.10

Olivares, B., Hernández, R; Coelho, R., Molina, JC., Pereira, Y. 2018a. Analysis of climate types: Main strategies for sustainable decisions in agricultural areas of Carabobo, Venezuela. Scientia Agropecuaria. 9(3): 359 – 369. https://doi.org/10.17268/sci.agropecu.2018.03.07

Olivares, B., Paredes, F., Rey, J., Lobo, D., Galvis-Causil, S. 2021. The relationship between the normalized difference vegetation index, rainfall, and potential evapotranspiration in a banana plantation of Venezuela. SAINS TANAH - Journal of Soil Science and Agroclimatology, 18(1), 58-64. http://dx.doi.org/10.20961/stjssa.v18i1.50379

Olivares, B., Parra, R., Cortez, A. & Rodríguez, M.F. 2012. Patterns of pluviometric homogeneity in climatic stations of Anzoátegui state, Venezuela. Revista Multiciencias. 12 (Extraordinario): 11-17. https://n9.cl/e6pjz

Olivares, B., Torrealba, J. & Caraballo, L. 2013. Variability of the precipitation regime in the period 1990-2009 in the location of El Tigre, Anzoátegui state, Venezuela. Rev. Fac. Agron. (LUZ). 30 (1): 19-32. https://n9.cl/mic0l

Olivares, B., Zingaretti, M.L., Demey Zambrano, J.A. y Demey, J.R. 2017c. Application of the STATIS-ACT method to the rain regime in the Venezuelan Oriental Region. UNED Research Journal 9(1): 97-106. https://n9.cl/3mls7

Olivares, B. & M.L. Zingaretti. 2018. Analysis of the meteorological drought in four agricultural locations of Venezuela by the combination of multivariate methods. UNED Research Journal. 10 (1):181-192. http://dx.doi.org/10.22458/urj.v10i1.2026

Parra, R., Olivares, B., Cortez, A., Lobo, D., Rodríguez, M.F. & Rey, J.C. 2018. Characteristics of drought weather (1980-2014) in two towns of Venezuelan Andes agricultural. Revista de Investigación. 42(95):38-55. https://n9.cl/mm6d

Pohlert, T. (2018). Trend: non-parametric trend tests and change-point detection. R package version, 1(0).

Rath, P. (2016). Assessing the Impact of Climate Change on the Hydrological Parameters Using Statistical Downscaling (Doctoral dissertation).

Rhee, G., Salazar, J., & Grigg, C. (2018). How Long Does a Fifteen Year Drought Last? On the Correlation of Rare Events. Journal of Climate. doi:10.1175/jcli-d-18-0326.1

Sharma, G., Kishor Kumar, C., & Singh, B. P. (2019). Assessment of Meteorological Drought for Ujjain District of Madhya Pradesh, India using Effective Drought Index and ArcGIS. International Journal of Current Microbiology and Applied Sciences, 8(05), 604–612. https://doi.org/10.20546/ijcmas.2019.805.070

Thomas T., Jaiswal R.K., Nayak P.C., and Ghosh N.C. (2014). Comprehensive evaluation of the changing drought characteristics in Bundelkhand region of Central India. Meteorol. and Atmos. Phys., 127(2): 163-182.

Urdiales Flores, D. H., & Célleri, R. 2018. Forecasting of daily precipitation occurrence in an altitudinal gradient in southern Ecuador using a weather generator. *Enfoque UTE*, *9*(3), 29 - 41. https://doi.org/10.29019/enfoqueute.v9n3.209