Assessment of meteorological droughts over Hoshangabad district, India

Sabyasachi Swain\textsuperscript{1,}\textsuperscript{*}, Surendra Kumar Mishra\textsuperscript{1} and Ashish Pandey\textsuperscript{1}

\textsuperscript{1}Department of Water Resources Development and Management, Indian Institute of Technology Roorkee, Roorkee-247667, India

Corresponding author - Email: sabyasachiswain16@gmail.com

Abstract. In this study, the meteorological drought characteristics (severity, frequency, and persistence) over the Hoshangabad district, Madhya Pradesh, India are analyzed. The percent departure from mean (PDM) is employed to describe the drought characteristics, considering the monthly rainfall data for the duration of 62 years (1951-2012). Rainfall during monsoon season contributes over 95% of the annual rainfall and thus, only monsoon season is considered for identifying the drought years. The entire duration of 62 years was divided into two epochs of 31 years i.e. 1951-1981 and 1982-2012. The results revealed that the rainfall over the district possesses remarkable inter-annual variability. The district is prone to droughts with a frequency of once in four years. More importantly, the comparative assessment of two epochs indicates an increase in frequency, severity, and persistence of droughts in the latter epoch. The frequency of droughts has tripled in 1982-2012 as compared to 1951-1981. Since Hoshangabad is a monsoon-dominated district with high agricultural importance, proper management strategies need to be devised to minimize the harmful consequences of droughts.

1. Introduction
Drought is a creeping natural calamity, which propagates slowly [1]. Therefore, it becomes very difficult to recognize a drought event and its characteristics. No systematic method has yet been developed to comprehensively understand and predict them. The broad classes of drought are meteorological, agricultural, hydrological and socio-economic [2], [3]. Among these, the meteorological drought, typically defined as an abnormal shortage of precipitation, is taken as the root cause for all other types of droughts. Though several investigations to determine a suitable approach for the drought modeling and assessment have been carried out, the simplest technique is to compute the deviation from the long-term average rainfall. The hydroclimatic variables associated with meteorological drought are rainfall and evapotranspiration [4]-[6]. However, most of the prior studies on meteorological droughts are based on rainfall only [7]-[9]. If these characteristics are known for a particular region, the planning and management of droughts become relatively easy [10], [11]. In general, the timescales associated with meteorological droughts are monthly, seasonal, annual or multi-annual [12]. In tropical regions, due to a clear seasonality in the pattern of rainfall, droughts are assessed on a seasonal or annual basis [13]. Since the dry and wet seasons are well known for tropical regions, the assessment of only wet seasons may provide sufficient idea about whether the particular year can be regarded as a drought year or not. The frequency of droughts is expected to increase under the influence of climate change, due to the increase of anomalies in the rainfall pattern [14]-[19].
In the present study, the Hoshangabad district (located in Central Indian region) is considered for assessment of meteorological droughts. The following section provides the details of the study area. The data and methodology used in this study, the results and discussions, and the conclusions drawn from the study are presented in the subsequent sections.

2. Study area

The Hoshangabad district lies in the state of Madhya Pradesh, Central India. It is located between 22° 12’ to 22° 59’ North latitudes and 77° 10’ to 78° 42’ East longitudes, as shown in Figure 1. It has six neighboring districts namely, Betul, Chhindwara, Harda, Narsinghpur, Raisen, and Sehore. The areal extent of the Hoshangabad district is 5400 km². The population of the district is about 1.3 million, one-third of which lies in urban areas. Regarding climatological characteristics, the mean annual rainfall over the district is about 1340 mm. The majority of rainfall amount is received during the southwest monsoon season (June to mid-October). The temperature conditions are moderate throughout the year. However, during the months of April and May, the maximum temperature rises up to 42 °C. In contrast, the minimum temperature may fall up to 9 °C during the months of December and January [20]. The district is one of the most agriculturally productive districts of the state owing to its very fertile lands, as it lies in the Narmada River Valley. Hoshangabad is the highest Wheat producing district and one of the highest Soya Bean producing districts in the whole country. The crop rotation strategy is commonly adopted by farmers and thus, Paddy, Sugarcane, Mung Bean and Gram are also largely produced in the district [21]. Therefore, the rainfall anomalies, especially during the monsoon
season, may have significant impacts on crop production. Therefore, the assessment of droughts over the study area is crucial.

3. Data used and methodology

In this study, the monthly rainfall data for the Hoshangabad district for a period of 62 years (1951-2012) was obtained from India Meteorological Department (IMD), Pune. A vast majority of the annual rainfall over the district is received during June to October, which is typically regarded as monsoon rainfall in Indian context. The statistical properties of the annual rainfall, as well as monsoon rainfall, are presented in Table 1. It can be observed that all the statistical properties are quite similar for annual and monsoon rainfall. The ratio of mean monsoon rainfall (1278.8 mm) to mean annual rainfall (1343.2 mm) is 0.952, which implies, above 95% of annual rainfall is contributed by monsoon rainfall. As the rainfall during non-monsoon seasons is very scanty, the monsoon season can be fairly assumed to identify the annual drought conditions.

Table 1. Statistical properties of annual and monsoon rainfall over Hoshangabad district

| Statistical Measures     | Annual Rainfall | Monsoon Rainfall |
|--------------------------|-----------------|-----------------|
| Mean                     | 1343.2          | 1278.8          |
| Standard Deviation       | 343.29          | 343.15          |
| Maximum                  | 2183.5          | 2145.7          |
| Minimum                  | 743.3           | 716.8           |
| Coefficient of Variation | 0.256           | 0.268           |
| Standard Error           | 43.25           | 43.233          |

The percentage departure from the mean (PDM) has been used as an index to identify the drought years. PDM is computed as the ratio of difference of rainfall in a particular year from long term mean, with respect to the long term mean rainfall. As PDM is expressed in terms of percentage, the ratio is multiplied by 100. The formula to calculate PDM is given by Equation 1.

\[ \text{Percent departure from mean, } PDM = \frac{P_i - P_m}{P_m} \times 100 \]  

where, \( P_i \) represents monsoon rainfall in a particular \( i^{th} \) year and \( P_m \) represents long-term mean monsoon rainfall.

The PDM-based classification is provided in Table 2. It is to be noted that, a drought is said to be initiated when the PDM falls less than -20. Hence, based on severity, there are three kinds of droughts i.e., moderate, severe and extreme.

Table 2. Classification of PDM into different classes

| Condition | Classes       |
|-----------|---------------|
| PDM > 10  | Wet           |
| -10 < PDM < 10 | Near Normal   |
| -20 < PDM < -10 | Mild Dry    |
| -40 < PDM < -20 | Moderate Drought |
| -50 < PDM < -40 | Severe drought |
| PDM < -50  | Extreme Drought |
4. Results and discussions

Table 3. Percentage departure from mean rainfall over Hoshangabad district for 1951-2012

| Year | Monsoon Rainfall | Percent Departure from Mean | Year | Monsoon Rainfall | Percent Departure from Mean |
|------|------------------|-----------------------------|------|------------------|-----------------------------|
| 1951 | 925.7            | -27.61                      | 1982 | 1012.8           | -20.80                      |
| 1952 | 1037.9           | -18.84                      | 1983 | 1278.1           | -0.05                       |
| 1953 | 1404.0           | 9.79                        | 1984 | 1262.9           | -1.24                       |
| 1954 | 1466.7           | 14.69                       | 1985 | 926.3            | -27.56                      |
| 1955 | 1713.1           | 33.96                       | 1986 | 1364.9           | 6.73                        |
| 1956 | 1281.5           | 0.21                        | 1987 | 939.4            | -26.54                      |
| 1957 | 1108.8           | -13.29                      | 1988 | 1128.3           | -11.77                      |
| 1958 | 1271.7           | -0.56                       | 1989 | 1059.8           | -17.13                      |
| 1959 | 1733.3           | 35.54                       | 1990 | 1515.4           | 18.50                       |
| 1960 | 1031.9           | -19.31                      | 1991 | 772.8            | -39.57                      |
| 1961 | 2145.7           | 67.79                       | 1992 | 952.9            | -25.48                      |
| 1962 | 1266.9           | -0.93                       | 1993 | 1549.5           | 21.17                       |
| 1963 | 1241.9           | -2.89                       | 1994 | 1723.4           | 34.77                       |
| 1964 | 1434.7           | 12.19                       | 1995 | 1103.3           | -13.72                      |
| 1965 | 926.4            | -27.56                      | 1996 | 839.1            | -34.38                      |
| 1966 | 966.9            | -24.39                      | 1997 | 955.4            | -25.29                      |
| 1967 | 1376.9           | 7.67                        | 1998 | 914              | -28.53                      |
| 1968 | 1398.5           | 9.36                        | 1999 | 1686.2           | 31.86                       |
| 1969 | 1833.0           | 43.34                       | 2000 | 743.3            | -41.88                      |
| 1970 | 1793.4           | 40.24                       | 2001 | 772.0            | -39.63                      |
| 1971 | 1589.6           | 24.30                       | 2002 | 796.0            | -37.76                      |
| 1972 | 1378.9           | 7.83                        | 2003 | 1333.4           | 4.27                        |
| 1973 | 2066.6           | 61.60                       | 2004 | 1202.9           | -5.94                       |
| 1974 | 1299.8           | 1.64                        | 2005 | 1353.1           | 5.81                        |
| 1975 | 1403.5           | 9.75                        | 2006 | 1773.9           | 38.72                       |
| 1976 | 1188.7           | -7.05                       | 2007 | 1055.5           | -17.46                      |
| 1977 | 1394.5           | 9.05                        | 2008 | 797.9            | -37.61                      |
| 1978 | 1550.0           | 21.21                       | 2009 | 1419.3           | 10.99                       |
| 1979 | 716.8            | -43.95                      | 2010 | 1027.6           | -19.64                      |
| 1980 | 1147.1           | -10.30                      | 2011 | 1326.6           | 3.74                        |
| 1981 | 1186.3           | -7.23                       | 2012 | 1694.4           | 32.50                      |

- Black: Wet or near-normal condition; Pink: Mild dry condition; Orange: Moderate Drought; Red: Severe Drought

The PDM-based results for each individual year considering the monsoon rainfall are presented in Table 3. The wet or near-normal conditions, mild dry conditions, moderate drought, and severe drought are represented in black, pink, orange and red colours respectively. It can be observed that the Hoshangabad district has undergone significant inter-annual variation. The monsoon rainfall over years varied from 2145.7 mm (PDM of 67.79) in the year 1961 to 716.8 mm (PDM of -43.95) in the year 1979. It is worth noticing that the district has been in dry conditions (including mild dry,
moderate and severe droughts) 24 times in 62 years. This shows that the district is prone to frequent droughts.
To analyze the temporal changes in the meteorological droughts over the district, the entire time duration considered was divided into two equal halves, thereby forming two epochs of 31 years i.e. 1951-1981 and 1982-2012. From Table 3, it is evident that the frequency of dryness or droughts has significantly increased in the latter half of the time series. However, as mentioned earlier, a PDM value of -20 or lesser can only be regarded as drought condition. So, only the meteorological droughts (moderate, severe and extreme) are compared for their frequency during different epochs. The frequencies of drought under different drought severity classes for 1951-1981, 1982-2012 and the entire duration are presented in Table 4.

Table 4. Frequency of droughts in different severity classes for 1951-2012

| Drought severity | 1951-1981 | 1982-2012 | 1951-2012 |
|------------------|-----------|-----------|-----------|
| Moderate         | 3         | 11        | 14        |
| Severe           | 1         | 1         | 2         |
| Extreme          | 0         | 0         | 0         |
| Total            | 4         | 12        | 16        |

From Table 4, it can be noticed that there have been 14 moderate droughts, 2 severe droughts and no extreme droughts over the district during 1951-2012. Therefore, there are 16 droughts on aggregate in 62 years which implies, the frequency of droughts is almost once in 4 years. However, there have been 4 droughts during 1951-1981 and 12 droughts during 1982-2012. Hence, the frequency of droughts in last 3 decades is once in every 2.5 years. Regarding persistence, there was only one occurrence during 1951-1981 where drought persisted for two consecutive years i.e. 1965-66. However, during 1982-2012, droughts persisting for consecutive three years have been observed twice (1995-97, 2000-02) and that for consecutive two years have been observed once (1991-92). Further, three out of five most severe yearly droughts over the district occurred during 2000-02. From the comparison of the frequency of droughts in both the epochs, it is found that the frequency has tripled in latter as compared to the former. Such an increase in frequency of droughts may be primarily attributed to climate change, which results in erratic rainfall behavior. Pandey and Khare (2017) carried out trend analysis of climatic parameters over the district using Mann-Kendall test and found the trend of rainfall to be decreasing at 1% significance level, which implies an increased probability of droughts. The details of Mann-Kendall test are available in literature [22]-[25]. The population explosion has already posed a challenge for food security all around the globe. In such circumstances, it is highly undesirable for to witness frequent droughts over a district with remarkable agricultural importance. Therefore, maximum attention should be given to devise robust management and coping strategies to combat the damaging consequences.

5. Conclusion

The percent departure from mean (PDM) is used to assess the meteorological droughts over Hoshangabad district, Madhya Pradesh, India using monsoon rainfall data for 1951-2012. The results reveal that the monsoon rainfall over the district possesses significant inter-annual variation. There have been 16 droughts (14 moderate and 2 severe) over the district during the considered period. A comparative assessment of droughts during 1951-1981 and 1982-2012 reveals an increase in frequency, severity and persistence of droughts in the latter epoch. The frequency of droughts has tripled in 1982-2012 as compared to 1951-1981. As Hoshangabad is a district known for high agricultural productivity, significant attention should be given to combat the impacts of droughts.
References

[1] Wilhite, D. A., and Glantz, M. H. (1985). Understanding: the drought phenomenon: the role of definitions. Water international, 10(3), 111-120.

[2] Swain, S., Patel, P., and Nandi, S. (2017). Application of SPI, EDI and PNPI using MSWEP precipitation data over Marathwada, India. In 2017 IEEE International geoscience and remote sensing symposium (IGARSS) (pp. 5505-5507). IEEE.

[3] Swain, S., Nandi, S. and Patel, P. (2018). Development of an ARIMA model for monthly rainfall forecasting over Khordha district, Odisha, India. In Recent Findings in Intelligent Computing Techniques (pp. 325-331). Springer, Singapore.

[4] Adarsh, S., Kumar, D. N., Deepthi, B., Gayathri, G., Aswathy, S. S., and Bhagyasree, S. (2019). Multifractal characterization of meteorological drought in India using detrended fluctuation analysis, International Journal of Climatology, 39(11), 4234-4255.

[5] Jamshidi, S., Zand-Parsa, S., Naghdzyadegan Jahromi, M., and Niyogi, D. (2019). Application of a simple Landsat-MODIS fusion model to estimate evapotranspiration over a heterogeneous sparse vegetation region. Remote Sensing, 11(7), 741.

[6] Jamshidi, Zand-parsa, S., Pakparvar, M., and Niyogi, D. (2019). Evaluation of Evapotranspiration over a Semi-arid Region Using Multiresolution Data Sources. Journal of Hydrometeorology, 20(5), 947-964.

[7] Mishra, A. K., and Singh, V. P. (2010). A review of drought concepts. Journal of hydrology, 391(1-2), 202-216.

[8] Amrit, K., Pandey, R. P., and Mishra, S. K. (2018). Characteristics of meteorological droughts in northwestern India. Natural Hazards, 94(2), 561-582.

[9] Swain, S., Mishra, S.K., and Pandey, A. (2019). Spatiotemporal Characterization of Meteorological Droughts and Its Linkage with Environmental Flow Conditions. In AGU Fall Meeting 2019. AGU.

[10] Rossi, G., Benedini, M., Tsakiris, G., and Giakoumakis, S. (1992). On regional drought estimation and analysis. Water resources management, 6(4), 249-277.

[11] Swain, S. (2017). Hydrological modeling through soil and water assessment tool in a climate change perspective a brief review. In 2017 2nd International Conference for Convergence in Technology (I2CT) (pp. 358-361). IEEE.

[12] Prabhakar, S. V. R. K., and Shaw, R. (2008). Climate change adaptation implications for drought risk mitigation: a perspective for India. Climatic Change, 88(2), 113-130.

[13] Thorthwaite, C. W. (1948). An approach toward a rational classification of climate. Geographical review, 38(1), 55-94.

[14] Swain, S., Patel, P., and Nandi, S. (2017). A multiple linear regression model for precipitation forecasting over Cuttack district, Odisha, India. In 2017 2nd International Conference for Convergence in Technology (I2CT) (pp. 355-357). IEEE.

[15] Gosain, A. K., Rao, S., and Basuray, D. (2006). Climate change impact assessment on hydrology of Indian river basins. Current science, 90(3), 346-353.

[16] Kumar, K. N., Rajeevan, M., Pai, D. S., Srivastava, A. K., and Preethi, B. (2013). On the observed variability of monsoon droughts over India. Weather and Climate Extremes, 1, 42-50.

[17] Swain, S., Verma, M. K., and Verma, M. K. (2018). Streamflow estimation using SWAT model over Seonath river basin, Chhattisgarh, India. In Hydrologic Modeling (pp. 659-665). Springer, Singapore.

[18] Dayal, D., Swain, S., Gautam, A. K., Palmate, S. S., Pandey, A., and Mishra, S. K. (2019). Development of ARIMA Model for Monthly Rainfall Forecasting over an Indian River Basin. In World Environmental and Water Resources Congress 2019: Watershed Management, Irrigation and Drainage, and Water Resources Planning and Management (pp. 264-271). Reston, VA: American Society of Civil Engineers.

[19] Aadhar, S., Swain, S., and Rath, D. R. (2019). Application and performance assessment of SWAT hydrological model over Kharun river basin, Chhattisgarh, India. In World
Environmental and Water Resources Congress 2019: Watershed Management, Irrigation and Drainage, and Water Resources Planning and Management, pp. 272-280. Reston, VA: American Society of Civil Engineers (2019).

[20] Quamar, M. F., and Chauhan, M. S. (2012). Late Quaternary vegetation, climate as well as lake-level changes and human occupation from Nitaya area in Hoshangabad District, southwestern Madhya Pradesh (India), based on pollen evidence. Quaternary International, 263, 104-113.

[21] Pandey B.K., and Khare D. (2017). Assessment of Reference Evapotranspiration in the Context of Climate Change for Central India (Madhya Pradesh). In: Garg V., Singh V., Raj V. (eds) Development of Water Resources in India. Water Science and Technology Library, Vol. 75, 245-253.

[22] Adarsh, S., and Janga Reddy, M. (2015). Trend analysis of rainfall in four meteorological subdivisions of southern India using nonparametric methods and discrete wavelet transforms. International Journal of Climatology, 35(6), 1107-1124.

[23] Sonali, P., and Kumar, D. N. (2013). Review of trend detection methods and their application to detect temperature changes in India. Journal of Hydrology, 476, 212-227.

[24] Pandey, B. K., and Khare, D. (2018). Identification of trend in long term precipitation and reference evapotranspiration over Narmada river basin (India). Global and planetary change, 161, 172-182.

[25] Swain, S., Dayal, D., Pandey, A., and Mishra, S. K. (2019). Trend Analysis of Precipitation and Temperature for Bilaspur District, Chhattisgarh, India. In World Environmental and Water Resources Congress 2019: Groundwater, Sustainability, Hydro-Climate/Climate Change, and Environmental Engineering (pp. 193-204). Reston, VA: American Society of Civil Engineers.