ASSESSMENT OF METEOROLOGICAL DROUGHT USING SPI FOR SATNA AND TIKAMGARH OF MADHYA PRADESH

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Abstract : Drought is a serious natural hazard that affects all climatic regions in so much that more than half of the world is under the threat of drought each year. Lack of precipitation is the principal reason for all types of drought. The causes for this phenomenon to occur may be sub-normal rainfall, uneven rainfall distribution, greater requirement of water than availability or the combinations of all the three. Meteorological drought is usually defined on the basis of the degree of dryness (in comparison to some "normal" or average amount) and the duration of the dry period. Some widely used and advanced meteorological drought indices are Rainfall Anomaly Index, Palmer Drought Severity Index, Bhalme and Mooley Drought Index, Drought Severity Index, Standardized Precipitation Index (SPI), Effective Drought Index and Reconnaissance Drought Index. Standard Precipitation Index (SPI) overcomes the traditional drought indices. In the present study, meteorological drought assessment has been carried out at Satna and Tikamgarh districts of Madhya Pradesh using Standard Precipitation Index (SPI). The SPI values have been calculated on 3 month and 12 month time scales for the duration of 1981-2017 and then drought classification of the study area has been done using the SPI values. Mann Kendall Non Parametric Test has also been applied on the calculated SPI values to detect the presence of trend in the SPI values. The results from SPI values show that Tikamgarh district has extreme drought condition and there is severe drought condition in Satna district. The trend analysis of the SPI values show that there is no trend present in the SPI values in any of the studied districts. The results of the present drought assessment study will thus help the water managers & policymakers to take further adaptation steps to eradicate and mitigate the chances and effects of future expected droughts.

***Index Terms* – Standard Precipitation Index, World Meteorological Organization, Meteorological Drought .**

I. INTRODUCTION

Drought is very less understood and complex phenomenon (Hisdal and Tallaksen,2003). It is a serious natural hazard that affect all climatic regions (Wilhite, 2000) in so much that more than half of the world is under threat of drought each year (Kogan, 1997). The causes for this phenomenon to occur may be sub-normal rainfall, uneven rainfall distribution, greater requirement of water than availability or the combinations of all the three. As a result, the demand on water resources increases which can lead to inconsistency in supply to users .It is slow and gradual process due to which the degree of this particular calamity varies from place to place. The severity of drought is also difficult to determine. The most serious outcome of drought, associated with social, economic and political factors, is famine. Its severity thus not only depends on the duration, intensity and geographical extent of water shortage conditions, but also on the degree of vegetation and human activities depend on water. McKee et al. (1993) proposed a new definition of explicitly specifies time scales and utilizes a standardized precipitation index. Palchaudhuri et al.(2013) in this study severity and spatial pattern of meteorological drought was analyzed in the Puruliya District, West Bengal, India using multi-temporal SPI. Daily gridded data for the period 1971-2005 from 4 rainfall stations surrounding the study area were collected from IMD, Pune, and used in the analysis.

SPI overcomes the traditional drought indices like PDSI for the purpose of drought assessment (Rahmat, 2012). It can be also applied for any location by using a transformation of precipitation from a skewed distribution to the normal distribution, which makes it a suitable indicator accepted around the world. Guttman (1997) explained the advantages of SPI being probabilistic in nature and thus, its usability in risk and decision analysis over other drought assessment indices. The identification of extreme drought with SPI presents a better spatial standardization as compared to the PDSI (Hughes and Saunders, 2002). The use of SPI is standardized to a variety of time scales i.e. 1, 2, 3, 6, 12 24, 26, 48 months.

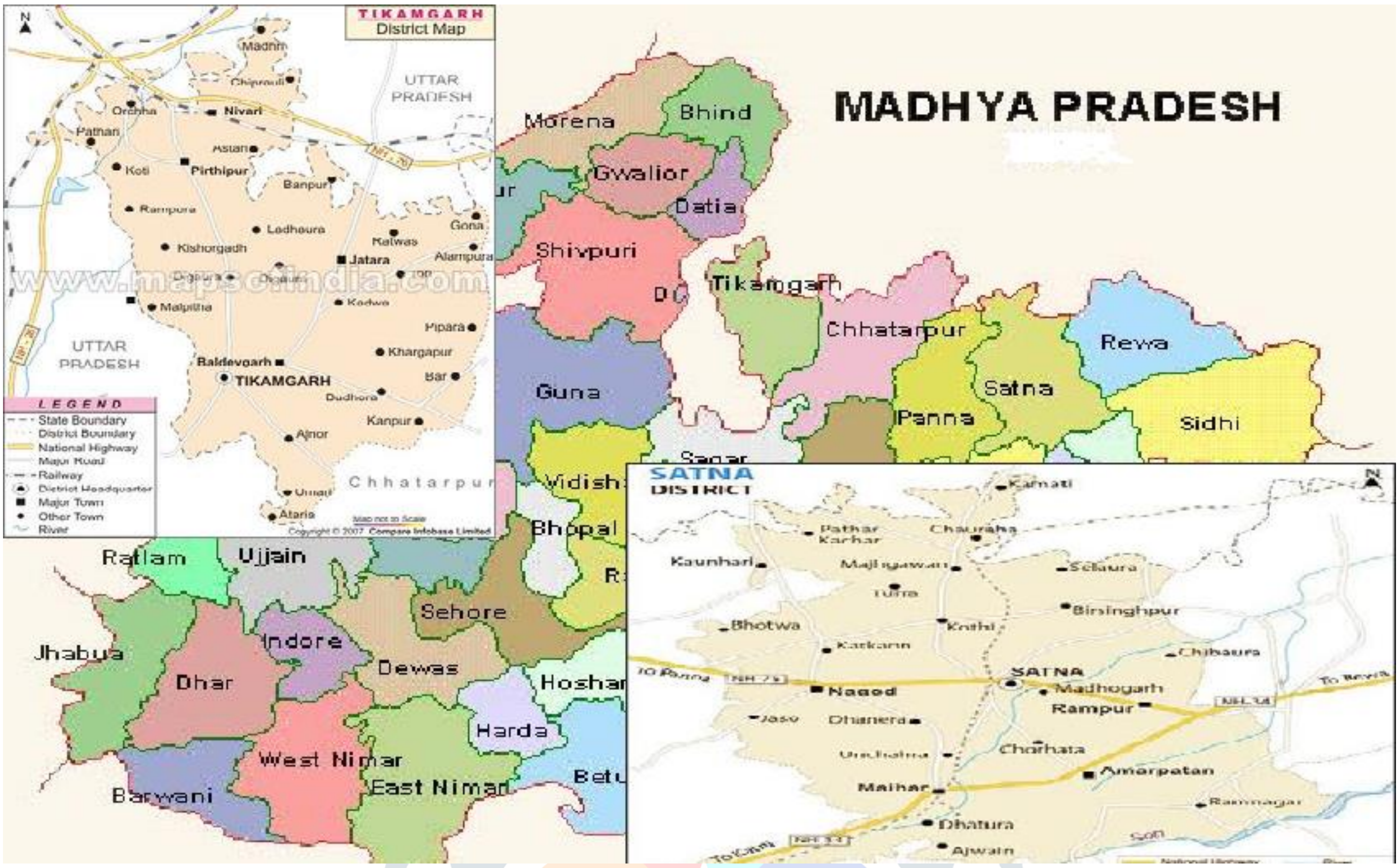
Thus, considering the work of Rahmat (2012), the use of Standard Precipitation Index (SPI) has been preferred in the present study for the assessment of drought with the application of trend analysis using non-parametric Mann Kendall Test.

2 Research Methodology

2.1 Description of Study Area

Satna: Is a city in central Madhya Pradesh, with the population approaching to 300,000 people. Satna is located at 24.34°N 80.49°E with an average elevation of 315 meters (1,352 feet) and its area is187 km^2 (72 sq mi). The location is renowned for dolomite mines and limestone.

Tikamgarh: Is a small city in the state of Madhya Pradesh, Central India. The population of the city is about 80,000 people and its Area is 21 km^2 (8 sq mi).Latitude and longitude coordinates are: **24.756807, 78.839264.**



2.2 Data and Sources of Data

Monthly Rainfall data of 37 Years for four districts of Madhya Pradesh viz. Satna, Tikamgarh has been collected from IMD (http://www.imd.gov.in) & Indian Water Portal (http://www.indiawaterportal.org). The monthly rainfall data for the duration 1981-2017 has been taken for Satna and Tikamgarh.

2.3 Theoretical framework

Standard Precipitation Index (SPI) is probabilistic in nature and thus it is more suitable drought assessment index among all the drought assessment indices. The SPI calculation for any location is based on the long term precipitation record for a desired period. This long term record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero. Thus, SPI has been used in the present study to assess the Meteorological Drought. The SPI values have been evaluated with the help of a program SPI_SL_6. The trend analysis on a given set of data is helpful in the determination of trends in the data, if present. The determination of presence or absence of trend in the given set of data is helpful is estimation of the traits of that data and also assists in providing an idea of how the variable is going to vary in the upcoming future. Thus, trend analysis has been applied on the SPI values using Mann Kendall Non Parametric Test. The details of the Standard Precipitation Index, Mann Kendall Test and detailed methodology have been discussed in the next sub-sections of this chapter.

2.3.1 Standard Precipitation Index (SPI)

Daily gridded precipitation data for the period of (1981 – 2017) at the two District of Madhya Pradesh data were collected from IMD and Indian water portal. The monthly precipitation data were used as input for the calculation of SPI. The SPI is computed by fitting an appropriate probability density function to the frequency distribution of precipitation summed over the time scale of interest (usually 3, 6, 12, and 24 months). This is performed separately for each time scale and for each location in space. Computation of the SPI involves fitting a gamma probability density function to a given time series of precipitation, whose probability density function is represented in Eq. 2.1

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{\frac{-x}{\beta}} \qquad \text{.....Eq. 2. 1}$$

Where, $\alpha > 0$ is a shape parameter, $\beta > 0$ is a scale parameter, and $x > 0$ is the amount of precipitation. $\Gamma(\alpha)$ is the gamma function, as shown in Eq.2.2

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y} dy \qquad \text{.....Eq. 2. 2}$$

Fitting the distribution to the data requires α and β to be estimated as in Eq.2.3. Edwards & Mckee in 1997 suggest estimating these parameters using the approximation for maximum likelihood as follows:

$$\alpha = \frac{1}{4A}\left[1+\sqrt{\left(1+\frac{4A}{3}\right)}\right], \beta = \frac{\bar{x}}{\alpha}, with\ A = \ln\bar{x} - \frac{\sum \ln x}{n} \qquad .....Eq.\ 2.\ 3$$

Where, n is the number of observations. Integrating the probability density function with respect to x yields the following expression G (x) for the cumulative probability can be calculated by using Eq.2.4

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)}\int_0^x x^{\alpha-1}e^{\frac{-x}{\beta}}$$

Substituting $t = \frac{x}{\beta}$, is reduced to:

$$G(x) = \frac{1}{\Gamma(\alpha)}\int_0^x t^{\alpha-1}e^{-t}dt \qquad .....Eq.\ 2.\ 4$$

It is possible to have several zero values in a sample set. In order to account for zero value probability, since the gamma distribution is undefined for x = 0, the cumulative probability function for gamma distribution is modified as in Eq.2.5

$$H(x) = q + (1-q)G(x) \qquad .....Eq.\ 2.\ 5$$

Drought intensity classification into various categories with different values of SPI is given in the following Table 2.1. Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation.
SPI program developed by the National Drought Mitigation Centre, University of Nebraska-Lincoln (http://drought.unl.edu/MonitoringTools/DownloadableSPIPr ogram.aspx), is used is used to compute time series of drought indices (SPI) for each station in the basin and for each month of the year at different time scales (1,3, 6,9, and 12 months).

Table 2.1: Classification of SPI values

SPI values	Drought Category
0 to -0.99	Mild Drought
-1 to-1.49	Moderate Drought
-1.5 to -1.99	Severe Drought
≤-2	Extreme Drought

2.4 Trend Analysis

The trend analysis of hydrological and meteorological data is one of the important aspects to determine a time dependent variation in the time series. For the analysis of trends parametric and non-parametric tests are very common. Following is the list of the commonly adopted tests for trend analysis:

1. Linear Regression Analysis Test
2. Mann-Kendall Test
3. Sen's Test

2.4.1 Mann-Kendall analysis

The Mann-Kendall test was performed to evaluate the trend, which is usually known as Kendall's z statistic, has been widely used to test for randomness against trend in hydrology and climatology (Khambhammettu, 2005).
The Mann-Kendall test is a non-parametric test for identifying trends in time series data. The test compares the relative magnitudes of sample data rather than the data values themselves (Gilbert, 1987). One benefit of this test is that the data need not conform to any particular distribution. Moreover, data reported as non-detects can be included by assigning them a common value that is smaller than the smallest measured value in the data set. When multiple data points exist for a single time period, the median value is used.
The data values are evaluated as an ordered time series. Each data value is compared to all subsequent data values. The initial value of the Mann-Kendall statistic, S, is assumed to be 0 (e.g., no trend). If a data value from a later time period is higher than a data value from an earlier time period, S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S can be solved by Eq.2.6. (Khambhammettu, 2005)

$$S = \sum_{k=1}^{n-1}\sum_{j=k+1}^{n} sgn(x_j - x_k) \qquad .....Eq.\ 2.\ 6$$

$$sgn(x_j - x_k) = \begin{cases} +1 & if\ \ x_j - x_k > 0 \\ 0 & if\ \ x_j - x_k = 0 \\ -1 & if\ \ x_j - x_k < 0 \end{cases}$$

Where, x_j and x_k are the annual values in the years j and k (j > k) respectively.

If n < 10, the value of |S| is compared directly to the theoretical distribution of S derived by Mann and Kendall (Gilbert, 1987).A very high positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend.

However, it is necessary to compute the probability associated with S and the sample size, n, to statistically quantify the significance of the trend. Variance S can be calculated by Eq. 2.7

E(s) =0

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)\right] \quad \text{.....Eq. 2. 7}$$

Where, q is the number of tied groups t_p is the number of data values in the pth group.
The standard test statistic Z is computed as described in Eq. 2.8

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if\ S < 0 \end{cases} \quad \text{.....Eq. 2. 8}$$

The presence of a statistically significant trend is evaluated using the Z value. A positive value of Z indicates an upward trend and negative trend indicate downward trend. To test for either an upward or downward monotone trend (a two-tailed test) at α level of significance, H0 is rejected if the |Z| > Z1-α/2, where Z1-α/2 is obtained from the standard normal cumulative distribution tables.

III. RESULTS AND DISCUSSION

3.1 Results for the Standard Precipitation Index

Table 3.1: Yearly Classification of Drought Based on SPI Values for Satna

Year	12-Month SPI	Classification	Year	12 Month SPI	Classification
1981	1.12	No Drought	2000	-0.22	Mild Drought
1982	1.43	No Drought	2001	-0.23	Mild Drought
1983	-0.03	Mild Drought	2002	-0.49	Mild Drought
1984	-0.19	Mild Drought	2003	1.96	No Drought
1985	0.45	No Drought	2004	0.21	No Drought
1986	0.31	No Drought	2005	1.38	No Drought
1987	-1.41	Mod Drought	2006	-0.89	Mild Drought
1988	-0.09	Mild Drought	2007	-1.06	Mod Drought
1989	-0.55	Mild Drought	2008	-1	Mod Drought
1990	1.42	No Drought	2009	-0.44	Mod Drought
1991	**-1.76**	**Severe Drought**	2010	-1.4	Mod Drought
1992	-1.35	Mod Drought	2011	-0.09	Mild Drought
1993	**-1.52**	**Severe Drought**	2012	-0.2	Mild Drought
1994	1.45	No Drought	2013	1.05	No Drought
1995	0.14	No Drought	2014	-0.77	Mild Drought
1996	0.49	No Drought	2015	0.22	No Drought
1997	-0.46	Mild Drought	2016	1.98	No Drought
1998	0.9	No Drought	2017	-1.05	Mod Drought
1999	0.66	No Drought			

Table 3.1 Yearly Classification of the drought based on SPI values for the duration 1981-2017 for Satna is shown . The results of the Standard Precipitation Index values are helpful in determining the drought classification. Positive SPI values indicate greater than median precipitation and negative values indicate less than median precipitation.

Figure 3.1 Bar Graph for the duration 1981-2017 for Satna.

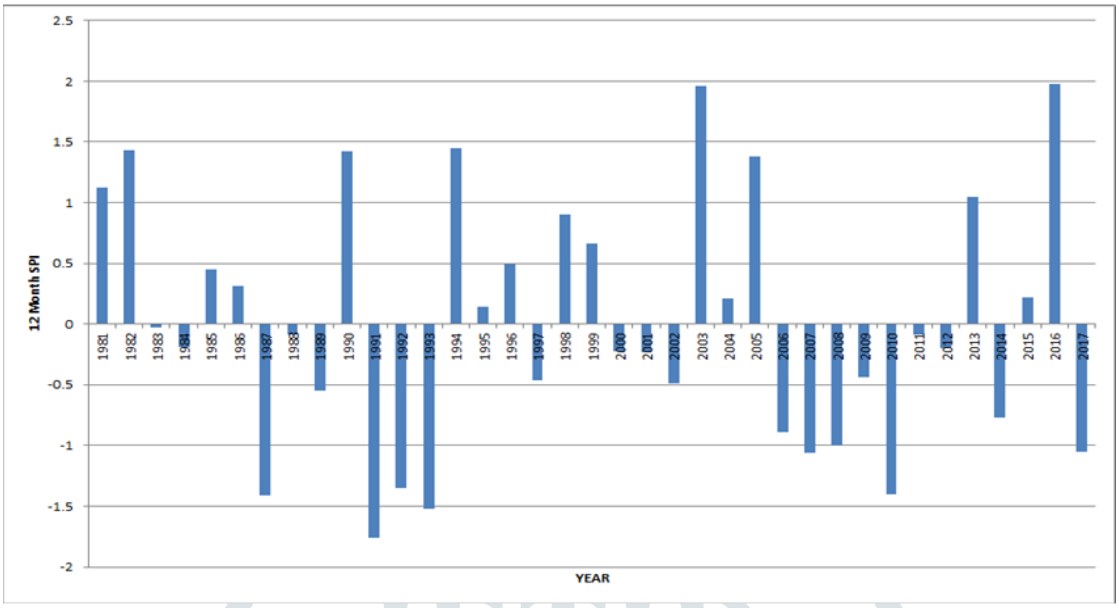


Figure 3.2 Pie Chart has been developed for the Percentage Classification of Drought for Satna. The analysis of the obtained data with the help of the given Pie Chart shows that Satna has faced a Severe Drought Condition of 5% in the study duration. There has been no case of Extreme Drought in Satna during the past 37 years.

Fig. 3.2 Pie Chart Showing Percentage of Various Types of Drought for Satna

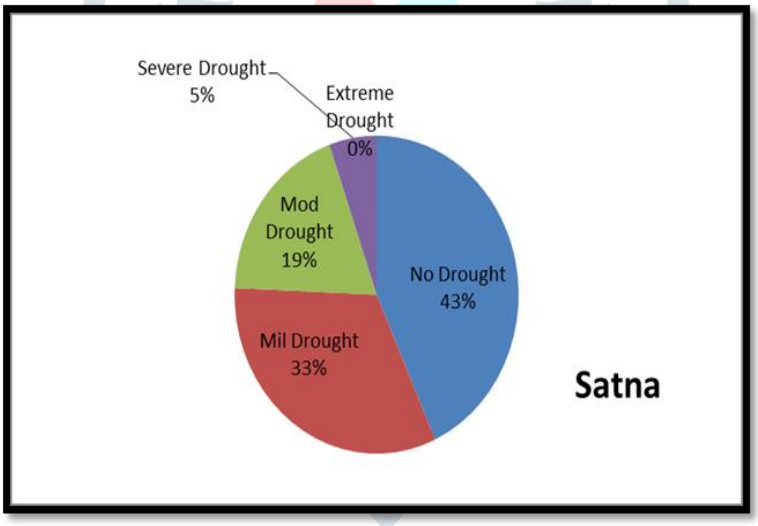


Table 3.2 Yearly Classification of Drought Based on SPI Values for Tikamgarh

Year	12-Month SPI	Classification	Year	12-Month SPI	Classification
1981	-0.11	Mild Drought	2000	-0.03	Mild Drought
1982	1.57	No Drought	2001	-0.04	Mild Drought
1983	1.39	No Drought	2002	-0.62	Mild Drought
1984	-0.31	Mild Drought	2003	0.18	No Drought
1985	1.31	No Drought	2004	-1.33	Mod Drought
1986	-0.4	Mild Drought	2005	-0.7	Mild Drought
1987	-0.64	Mild Drought	2006	-1.21	Mod Drought
1988	0.26	No Drought	**2007**	**-2.31**	**Extreme Drought**
1989	-0.31	Mild Drought	2008	1.28	No Drought
1990	2.2	No Drought	2009	-0.44	Mild Drought

1991	-0.88	Mild Drought	2010	-1.31	Mod Drought
1992	-0.7	Mild Drought	2011	1.55	No Drought
1993	-0.8	Mild Drought	2012	-0.28	Mild Drought
1994	1.53	No Drought	2013	1.28	No Drought
1995	0	Mild Drought	2014	-0.1	Mild Drought
1996	0.53	No Drought	2015	-0.81	Mild Drought
1997	0.25	No Drought	2016	-0.21	Mild Drought
1998	0.26	No Drought	2017	-1.18	Mod Drought
1999	1.13	No Drought			

Figure 3.3 Bar Graph showing Yearly SPI values for Tikamgarh

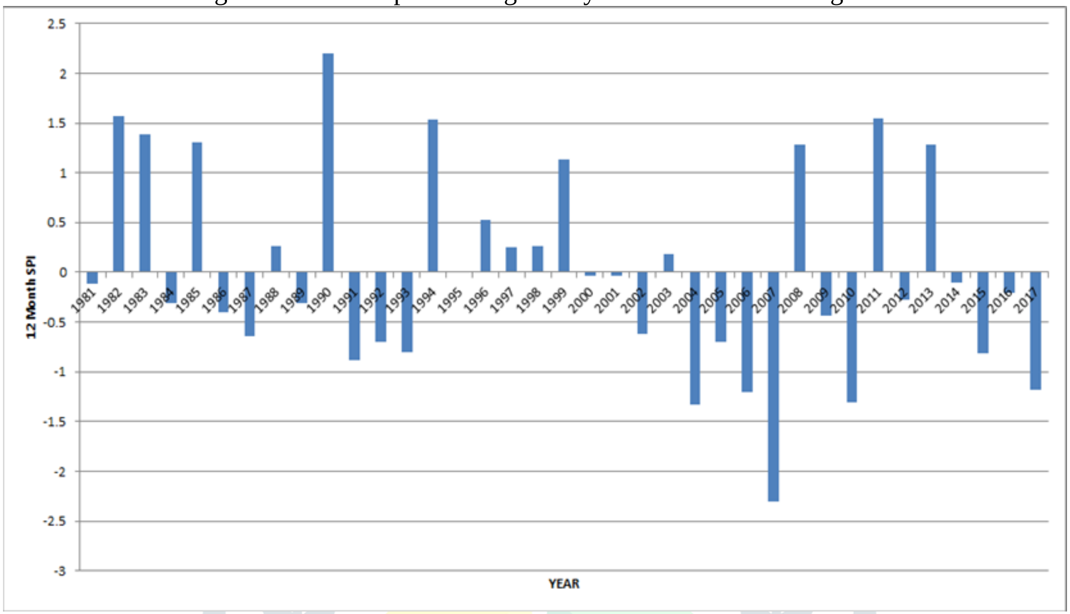
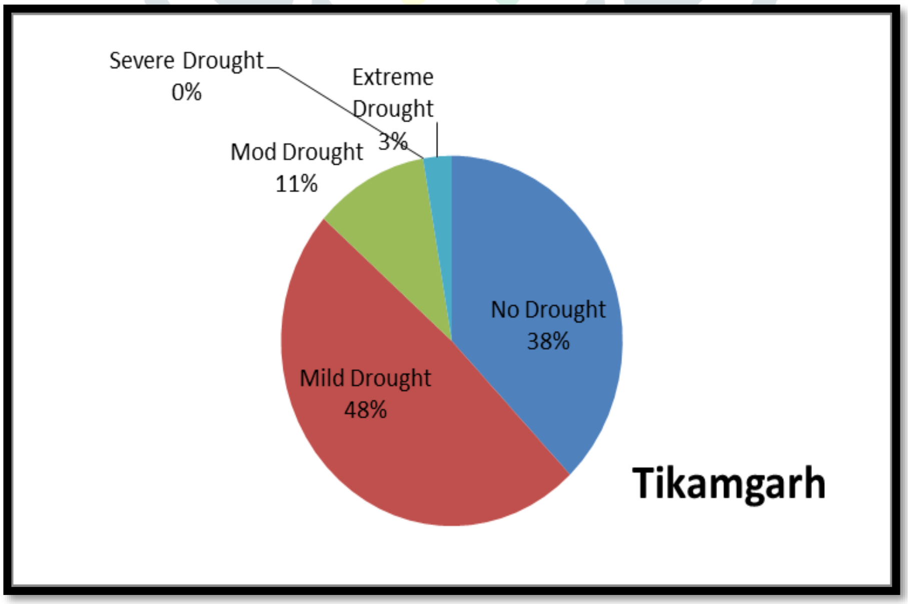


Fig.3.4 Pie Chart Showing Percentage of Various Types of Drought for Tikamgarh



3.2 Results for the Trend Analysis using Mann-Kendall Test

The trend analysis techniques were applied to the SPI values calculated from the 3-month and 12month time scales. The z statistics obtained from both MK test for all two districts are presented in Table 3.3 and Table 3.4 for 12 Month SPI and 3 Month SPI respectively. Positive value indicates an increasing trend and vice versa. At the 5% significance level, z values cannot be rejected (-1.96>z>1.96). If z values lies between -1.96 and +1.96, then there is No Trend. For comparison, the data series is split into different sets of data series i.e 1981-2017, 1981-2005 & 1993-2017 in order to compare one time period to the other and examine changes of the precipitation.

Table 3.3: Z Statistics for 12 Month SPI data for Satna and Tikamgarh.

	12 MONTH SPI		
District	**z value**	**z-value**	**z-value**
	1981-2017	1981-2005	1993-2017
Satna	-0.045213	-0.080914	-0.026729
Tikamgarh	-0.075888	-0.026729	-0.080914

Table 3.4: Z Statistics for 3 Month SPI data for Satna and Tikamgarh.

	3 MONTH SPI (6-9)		
District	**z value**	**z-value**	**z-value**
	1981-2017	1981-2005	1993-2017
Satna	-0.029696785	-0.106612979	0
Tikamgarh	0	0.080913792	-0.026729306

3.3 Conclusions and future scopes

The analysis of spatial pattern of drought using SPI from rainfall data is useful to determine the characteristics of drought in the different District of Madhya Pradesh, India. SPI helps to generate drought severity values for the different time scales and months of the year.

On the basis of SPI calculation for two districts, extreme drought is found in Tikamgarh District in 2007 the SPI value is -2.31. Severe drought found in other district. In 1993 severe drought found in Satna the spi values are -1.76 and -1.52. The most positive SPI value in Tikamgarh is found in 1982 and the SPI value is +1.57, in Satna the most positive SPI value is found in 2016 and the spi value is +1.98. It is found that SPI is a good indicator of the drought characteristics like severity and spatial extent. There exists no relation between the droughts of short and longer time scales as well as among the severity classes of each time period.

The trend analysis techniques were applied to the SPI values calculated from the 3-month and 12-month time scales. The z statistics obtained from MK test for all two districts. Positive value indicates an increasing trend and vice versa. At the 5% significance level, z values cannot be rejected (-1.96>z>1.96). Since, z values lies between -1.96 and +1.96 hence there is No Trend in the SPI values in the present study area. Thus, the determination of pattern of future drought is not possible in the present study area. An identification of presence or absence of trend is thus helpful in assessing traits of drought conditions for the study area.

The results of the drought assessment study will thus help the water managers & policymakers to identify the drought prone regions so that they can take further adaptation steps to eradicate and mitigate the chances and effects of future expected droughts for the districts under study.

Drought studies using hydro-meteorological indices could help in designing early warning systems for policymakers and water resource managers.

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