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Assessment of drought in Ahmednagar district using standardized precipitation index (SPI)

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Abstract
To mitigate natural disaster such as drought long term data can be useful for prediction of drought condition in any region, so that appropriate mitigation practices can be followed to minimize the losses. For assessment of drought condition standardized precipitation Index (SPI) is one of the indices used worldwide to predict drought condition in region at different time scale. The present study target to assess drought condition for using standardized precipitation index (SPI) of 12 months time scale for Ahmednagar district of Maharashtra by using daily rainfall data collected from India meteorological department and Dept. of Agricultural meteorology Pune. Results from analysis showed that year 1972 and 2018 was the year of severe drought condition.

Keywords: Drought, standardized precipitation index (SPI), SPI value

1. Introduction

As According to NARP (National Agriculture Research Project), Ahmednagar district falls under the western Maharashtra scarcity zone, where rainfall is low which is main hinderance in crop production along with-it variation in distribution, long dry spell, early withdrawal, late onset like aberrant weather conditions can be seen which causes water stress in plants and ultimately yield losses hence, there is a need to study the frequency of occurrence of these contingency events so that a suitable cropping pattern can be suggested to the farmers of this region for sustainable production and to reduce crop losses as much as possible.

Indices are indicators that are used to determine certain conditions quantitatively as well as qualitatively. Drought can be determined using various indicators, which help to indicate drought conditions regarding geographical area, time of occurrence, duration, etc. From the various indices which are used for drought monitoring, standardize precipitation index used world over, for this research work Standardized precipitation index is used to characterize drought in Ahmednagar district of Maharashtra.

2. Materials and Methods

2.1 Study area

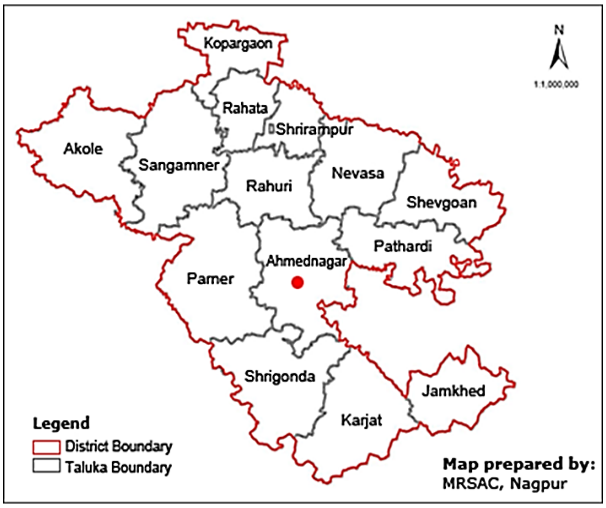

Fig 1: Map of Tehsils of Ahmednagar district

Ahmednagar District is a district of Maharashtra state in west-central India. It is situated between the latitude 19º09'N and longitudinal of 74º74'East. It is bounded by Nashik and Aurangabad district to the North, Beed district to the East, Osmanabad and Solapur district to the South, Pune and Thane district to the West. There are 14 tehsils in Ahmednagar district *viz.*, (1) Ahmednagar (2) Akole (3) Jamkhed (4) Karjat (5) Kopergaon (6) Newasa (7) Parner (8) Pathardi (9) Rahata (10) Rahuri (11) Sangamner (12) Shevgaon (13) Shrigonda and (14) Shrirampur.

2.2 Climate and Rainfall
The climate of the Ahmednagar district is hot and dry. During the year there is little rainfall. The winter is pleasant from December to February. The summer season starts from mid-February to the end of May. June to September are the months of the rainy season. The district receives rain mostly from the South-West monsoons. The rainfall in the western part of the district near the Western Ghats is higher than in the rest of the district. The rainfall is comparatively less as we go from the Western Ghats to the eastern part of the district.

2.3 Data Acquisition
The daily rainfall data of all tahsils in Ahmednagar district was collected from

1. Department of Agricultural Meteorology, College of Agriculture, Pune.
2. India Meteorological Department, Pune.
3. Downloaded from www.maharain.gov.in (www.krishi.maharashtra.gov.in) from January to December. Rain gauges are located at the headquarters of tahsils.

Collected data was used for analysis of Standardized Precipitation Index (SPI).

Table 1: The location of rain gauge station, Geographical area, location and availability of data

Sr. No.	Name of tehsils	Geographical Area (Km^2)	Latitude	Longitude	Period of Year	No. of Years
1.	Ahmednagar	1605.74	19.09ºN	73.74ºE	1961-2021	61
2.	Akole	1505.08	19.85ºN	74.0ºE	1961-2021	61
3.	Jamkhed	878.62	19.69ºN	73.56ºE	1961-2021	61
4.	Karjat	1503.61	19.56ºN	73.32ºE	1961-2021	61
5.	Kopergaon	725.16	20.08ºN	74.11ºE	1961-2021	61
6.	Newasa	1343.43	20.04ºN	74.48ºE	1961-2021	61
7.	Parner	1930.28	18.93ºN	73.92ºE	1961-2021	61
8.	Pathardi	1214.1	20.20ºN	73.83ºE	1961-2021	61
9.	Rahata	759.19	20.32ºN	74.25ºE	1998-2021	24
10.	Rahuri	1035.11	20.58ºN	74.22ºE	1961-2021	61
11.	Sangamner	1705.06	20.46ºN	74.18ºE	1961-2021	61
12.	Shevgaon	1031.85	20.47ºN	74.02ºE	1998-2021	24
13.	Shrigonda	1605.61	20.54ºN	74.32ºE	1961-2021	61
14.	Shrirampur	569.87	20.30ºN	74.65ºE	1961-2021	61

2.4 Software used for study
The SPI_SL_6.exe software developed by T.B. McKee, N.J. Doesken and J. Kleist, Colorado State University, 1993 is used for analysis of drought by calculating standardized precipitation index (SPI).

2.5 Statistical characteristics of climatological data
The statistical behaviour or characteristics of series of any climatological variables can be described on the basis of several parameters. These parameters are mean, standard deviation, coefficient of variation. All these parameters were used to describe the variability of climatological variables (rainfall) in this study. The statistical characteristics of rainfall of stations will be determined on a weekly, monthly, seasonal and annual basis. *Viz*. Ahmednagar, Akole, Jamkhed, Karjat, Kopergaon, Newasa, Parner, Pathardi, Rahata, Rahuri, Sangamner, Shevgaon, Shrigonda and Shrirampur. (www.maharain.gov.in).

2.5.1 Mean
Mean represents the measure of central tendency. It is the average of given values and given by,

$$X = \frac{\sum_{(i=1)}^{n} Xi}{n} \quad \ldots (3.1)$$

Where,
X = Mean
i = Variables.
n = Total number of variables.

2.5.2 Standard deviation
Standard deviation is the best measure of dispersion. It gives more weight to extreme items and less to those which are near the mean. It is defined as the positive square root of the arithmetic mean of the squares of the deviations of the given values from the arithmetic mean.

$$\sigma = \sqrt{\frac{(\Sigma x_i - x)^2}{n-1}} \quad \ldots (3.2)$$

Where,
σ = Standard deviation.
X_i= Variables.
X= Mean.
n= Total number of variables.

2.5.3 Coefficient of variation
The coefficient of variation is the percentage of variation in the mean, the standard deviation being treated as the total variation in the mean. The coefficient of variation (CV) is a statistical measure of how the individual data points vary about the mean value.

$$CV = \frac{\sigma}{x} 100 \quad \ldots (3.3)$$

Where,
CV = Coefficient of variation
X = Mean
σ= Standard deviation

This measure is indicative of dependability of variable expressed in percentage. The threshold levels for CV for any interpretation are <25, <50, <100, <150 and <250 per cent for yearly, seasonal, monthly, weekly and daily rainfall respectively Manorama *et al.*, (2007) [9].

2.6 Methodology

Meteorological drought by standardized precipitation index

Meteorological drought was analyzed by using Standardized Precipitation Index (SPI) for Ahmednagar district.

2.6.1 Standardized Precipitation Index (SPI)

The SPI index was designed by McKee *et al.*, to quantify the precipitation deficit in 1993 in University of Colorado. The calculation of the SPI index in any place is based on the precipitation history over a long period corresponding to the period of time studied. This effort was accomplished by quantifying the rainfall deficit at multiple time scales. More specifically, McKee *et al.*, (1993) [10] estimated the SPI for the time scales of 1, 3, 6, 12, 24 and 48 months. Drought at time scales 1-, 3-, and 6-month is relevant for agriculture, 12-month for hydrology and 24-month for socioeconomic impact. Any drought including meteorological and agriculture is a result of deficient rainfall. The SPI has been used widely to quantify the deficit of precipitation. It could be computed at different time scales from less than 1 month to 48 months or more. The calculation time period depends on the user's application. Short-term SPI is used to detect agricultural drought, and long-term SPI can be used for water supply management. In addition, the 1-month SPI reflects a short-term condition; the 3-month SPI provides a seasonal estimation of precipitation; the 12-month SPI also reflects medium-term trends in precipitation patterns and may provide an annual estimation of water condition. Therefore, this study used the SPI values at 1, 3 and 6-month scales to discover the drought discrepancy. The advantage of SPI is, it needed only precipitation data and can be used for both dry and rainy seasons while some indices using specific data as per designed. It can describe drought conditions that are important for a range of meteorological, agricultural, and hydrological applications. Studies have shown that the SPI is suitable for quantifying most types of drought events (Guenang and Kamga, 2014). To calculate the SPI, a long-term precipitation record at the desired station is first fitted to a probability distribution (e.g., gamma distribution), which is then transformed into a normal distribution so that the mean SPI is zero (McKee *et al.*, 1993, McKee *et al.*, 1995, Edwards and McKee, 1997) [10, 11, 12]. The SPI value is derived from the inverse value of the cumulative probability function of the observed precipitation distribution. Standardized precipitation index was calculated according to the following formula Edwards and McKee, (1997) [12].

$$\text{SPI} = \text{Z score} = \frac{X_i - X}{\sigma} \quad \ldots (3.4)$$

The SPI is equivalent to Z-score which is often used in statistics *i.e.*, SPI=Z-score.

Where,
X_i = Precipitation of the specified time scale for i^{th} year (*i.e.*, for annual SPI is the precipitation of ith year; for monthly SPI, it is the precipitation of particular month in ith year; and for two-month time scale, it is the sum of the precipitation of the particular month and the month preceding to this particular month).
X= Long-term average precipitation of the specified time scale
σ = Standard deviation of the precipitation of the specified time scale

To adjust for this empirical fact, the precipitation data is transformed to a more normal or Gaussian symmetrical distribution by applying the gamma function. After the precipitation data have been transformed, the SPI is calculated in a manner that mirrors the Z-score formula Edwards and Mckee, (1997) [12]. Procedure and formulae adopted for computation of SPI is;

1. The transformation of the precipitation value in to standardized precipitation index (SPI) with the purpose of:
   a) Transforming the mean of the precipitation value adjusted to 0;
   b) Standard deviation of the precipitation is adjusted to 1.0; and
   c) Skewness of the existing data is readjusted to 0.
2. When these goals are achieved the standardized precipitation, index is interpreted as mean 0 and standard deviation of 1.0.

The precipitation needs to convert to lognormal values and the statistics, U shape and β scale parameters of gamma distribution are computed as:

$$\text{Log mean} = X_{ln} = \ln(\overline{X}) \quad \ldots (3.5)$$

$$U = X_{ln} - \frac{\Sigma \ln(X)}{N}$$

$$\text{Shape parameter} = \beta = \frac{1+\sqrt{1+\frac{4U}{3}}}{4U} \quad \ldots (3.6)$$

$$\text{Scale factor} = \alpha = \frac{\bar{x}}{\beta} \quad \ldots (3.7)$$

The resulting parameters are then used to find the cumulative probability of an observed precipitation event. The cumulative probability is given by:

$$G(X) = \frac{\int_0^x x^{\alpha-1} e^{\frac{-x}{\beta}}\, dx}{\beta^{\alpha} r(a)} \quad \ldots (3.8)$$

Since the gamma function is undefined for x=0 and a precipitation distribution may contain zeros, the cumulative probability is becoming:

$$H\,x = q + 1 - q\,G\,x \quad \ldots (3.9)$$

Where q = the probability of zero.
The cumulative probability H(x) is then transformed to the standard normal random variable Z with mean zero and variance of one, which is the value of the SPI (Edwards and McKee, 1997) [12]. Abramowitz and Stegun (1965) [13] provide the approximate conversion as an alternative:

$$Z = SPI = -\left(t - \frac{c0+c1t+c2t2}{1+d1t+d2t2+d3t3}\right) \quad 0 < H(x) \leq 0.5 \qquad \dots (3.10)$$

$$Z = SPI = +\left(t - \frac{c0+c1t+c2t2}{1+d1t+d2t2+d3t3}\right) \quad 0.5 < H(x) \leq 01 \qquad \dots (3.11)$$

Where,

$$t = \sqrt{ln\left(\frac{1}{H(x)^2}\right)} \quad 0 < H(x) \leq 0.5 \qquad \dots (3.12)$$

$$t = \sqrt{ln\left(\frac{1}{1-H(x)^2}\right)} \quad 0.5 < H(x) \leq 01 \qquad \dots (3.13)$$

C_0= 2.515517
C_1= 0.802583
C_2= 0.010328
d_1= 1.432788
d_2= 0.189269
d_3= 0.001308

The values of c_0, c_1, c_2, d_1, d_2 and d_3 given in equation are constants widely employed for SPI computation Edwards and McKee, (1997) [12]. Anomalous behavior of rainfall can be identified from SPI values as extraordinary heavy rainfall indicates more positive SPI while scanty rainfall shows deviation towards more negative SPI. Drought event is considered commencing when SPI goes below -1 and is said offsetting when SPI becomes positive (i.e., rainfall just above the mean rainfall). The region is said to have continuous drought when several consecutive months show negative SPI values. According to the SPI method the severity of a drought is determined. The negative value from zero shows the severity of dryness. The SPI value normally ranges from (-2) to (+ 2). The SPI is grouped into seven classes as presented in Table 2. In this study SPI value will be computed for four different time scale *i.e.*, 3-month,6 months, 9 month and 12 months for all the 14 stations in Ahmednagar districts of Maharashtra. The software SPI_SL_6.exe is used for analysis.

Table 2: Classification of Drought condition according to SPI Class

Index Class	Description
+2	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
(0.99) to (-0.99)	Near normal
(-1.0) to (-1.49)	Moderately dry
(-1.5) to (-1.99)	Severely dry
(-2.0) or less	Extremely dry

3. Results and Discussion

SPI_SL_6.exe software was used for the assessment of meteorological drought in all tehsils of Ahmednagar district, in which 12-month timescales (SPI-12) are used. Positive value indicated wet conditions and a negative value of SPI indicated a drought (dry) condition.

As per the data of the last 61 years, it was observed that Ahmednagar tehsil has 4 wet years, 52 near normal years, and the remaining 5 years showed dry or extreme drought conditions similarly Akole tehsil has 10 wet years, 41 near normal years, and the remaining 10 years showed dry or extreme drought conditions. Jamkhed tehsil has 7 wet years, 44 near normal years, and the remaining 9 years showed dry or extreme drought conditions. Karjat tehsil has 13 wet years, 39 near normal years, and the remaining 9 years showed dry or extreme drought conditions. Kopergaon tehsil has 9 wet years, 45 near normal years, and the remaining 7 years showed dry or extreme drought conditions. Newasa tehsil has 8 wet years, 42 near normal years, and the remaining 11 years showed dry or extreme drought conditions. Parner tehsil has 8 wet years, 42 near normal years, and the remaining 11 years showed dry or extreme drought conditions. Pathardi tehsil has 10 wet years, 44 near normal years and the remaining 7 years showed dry or extreme drought conditions. The Rahuri tehsil has 11 wet years, 42 near normal years, and the remaining 8 years showed dry or extreme drought conditions. Sangamner tehsil has 9 wet years, 42 near normal years, and the remaining 10 years showed dry or extreme drought conditions. Shrirampur tehsil has 10 wet years, 41 near normal years, and the remaining 10 years showed dry or extreme drought conditions. As per the data of the last 24 years, it was observed that the Rahata tehsil has 5 wet years, 15 near normal years, and the remaining 4 years showed dry or extreme drought conditions. Shevgaon tehsil has 4 wet years, 15 near normal years, and the remaining 5 years showed dry or extreme drought conditions.

According to the above observations, it was observed that in decade the two or three wet years, three or four dry years and two or three normal years happened. In tehsils like Ahmednagar, Karjat, Newasa frequency of drought increased in last two decades. In case of all other tehsils of Ahmednagar district, the 2011-2020 decade showed much below normal and below normal condition for maximum times with two to three near normal years. For all tehsils Recent decade (2011-2020) showed frequent rise in number of drought years.

Table 3: Annual frequency of drought condition in different tehsils of Ahmednagar District

Annual Frequency								
Tehsil	**Extremely wet**	**Very wet**	**Moderately wet**	**Near normal**	**Moderately dry**	**Severely dry**	**Extremely dry**	**Year**
Ahmednagar	1	0	3	52	2	3	0	61
Akole	3	3	4	41	8	1	1	61
Jamkhed	3	1	4	44	5	2	2	61
Karjat	0	2	11	39	2	5	2	61
Kopergaon	1	3	5	45	3	1	3	61
Newasa	1	1	6	42	5	5	1	61
Parner	0	3	5	42	5	3	3	61
Pathardi	0	6	4	44	3	1	3	61
Rahata	1	1	3	15	2	2	0	24
Rahuri	1	2	8	42	4	2	2	61
Sangamner	0	3	6	42	7	1	2	61
Shevgaon	1	0	3	15	3	2	0	24
Shrigonda	1	1	9	43	2	3	2	61
Shrirampur	2	2	6	41	6	2	2	61

Table 4: Annual probability of drought condition in different tehsils of Ahmednagar District

Annual Probability								
Tehsil	**Extremely wet**	**Very wet**	**Moderately wet**	**Near normal**	**Moderately dry**	**Severely dry**	**Extremely dry**	**Year**
Ahmednagar	2	0	5	85	3	5	0	100
Akole	5	5	7	67	13	2	2	100
Jamkhed	5	2	7	72	8	3	3	100
Karjat	0	3	18	64	3	8	3	100
Kopergaon	2	5	8	74	5	2	5	100
Newasa	2	2	10	69	8	8	2	100
Parner	0	5	8	69	8	5	5	100
Pathardi	0	10	7	72	5	2	5	100
Rahata	4	4	13	63	8	8	0	100
Rahuri	2	3	13	69	7	3	3	100
Sangamner	0	5	10	69	11	2	3	100
Shevgaon	4	0	13	63	13	8	0	100
Shrigonda	2	2	15	70	3	5	3	100
Shrirampur	3	3	10	67	10	3	3	100

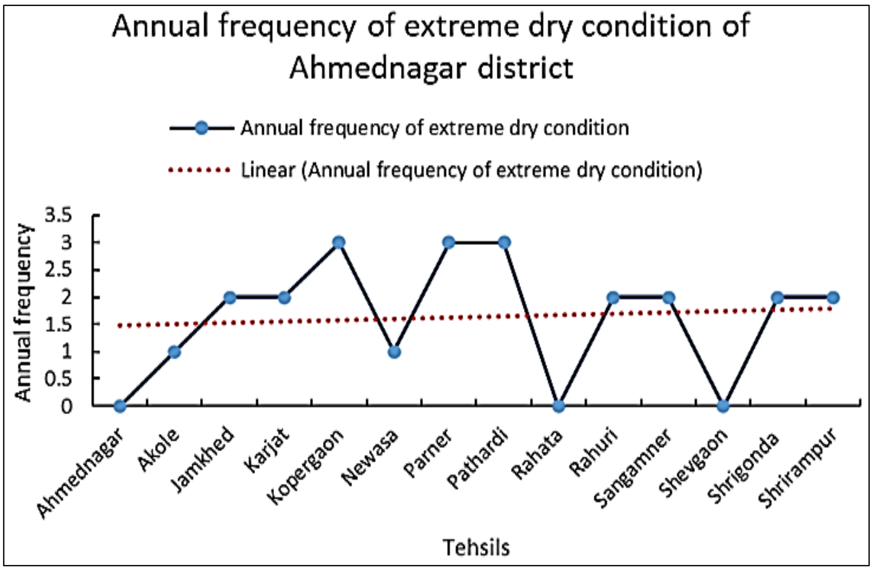

Fig 1: Annual frequency of drought condition in different tehsils of Ahmednagar District

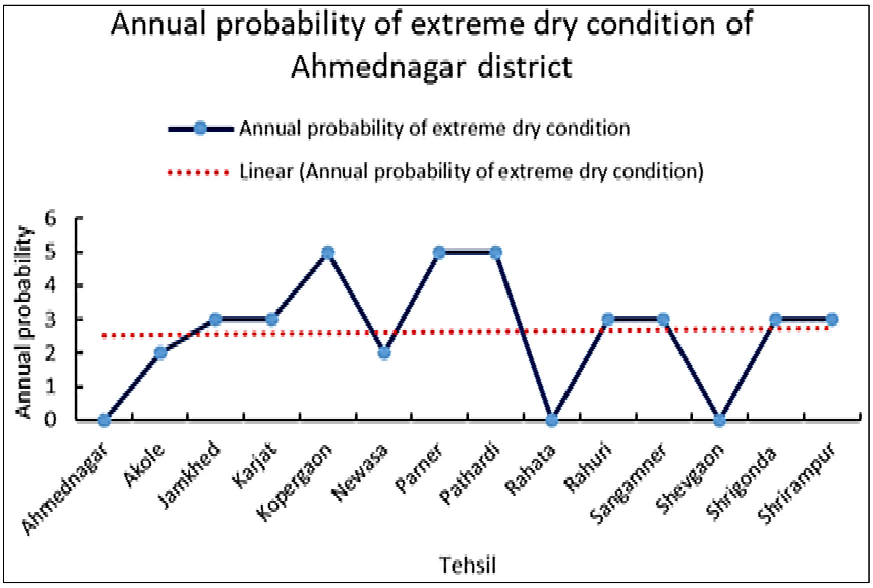

Fig 2: Annual probability of drought condition in different tehsils of Ahmednagar District

Table 5: Annual SPI values (12 months basis) of different tehsils of Ahmednagar district

Annual SPI Probability of tehsils							
Years	**Ahmednagar**	**Akole**	**Jamkhed**	**Karjat**	**Kopergaon**	**Newasa**	**Parner**
1961	-0.26	-0.56	-0.58	-0.66	0.72	0.95	-0.23
1962	0.47	-0.44	0.57	0.11	0.74	1.2	0.94
1963	-0.6	-1.25	0.06	0.7	-0.84	0.57	-0.39
1964	-0.24	-0.41	0.74	1.19	0.31	-0.28	-0.11
1965	-0.29	-0.47	-1.18	-0.04	1.14	-0.2	-0.04
1966	-0.83	-1.14	-0.68	0.21	0.95	0.16	-0.29
1967	0.07	-0.02	0.54	-0.28	0.9	-0.24	0.64
1968	-0.14	-0.29	-0.75	-2.14	-0.81	0.51	-2.2
1969	0.33	0.29	0.46	1.82	0.71	1.32	-0.22
1970	0.35	0.32	0.19	0.9	-2.37	0.17	0.81
1971	-0.34	-0.54	-0.27	-0.57	-0.24	0.05	0.28
1972	-1.85	-2.4	-2.68	-1.75	-2.69	-0.8	-2.36
1973	-0.44	-0.65	0.18	-0.5	-0.39	0.72	0.46
1974	0.72	0.78	-0.31	0.41	1.15	0	0.64
1975	0.54	0.56	1.49	0.44	0.36	0.31	0.15
1976	-0.49	-0.72	-1.05	-2.11	-0.93	-1.65	0.35
1977	-1.16	-1.55	0.34	-0.05	-0.17	-0.93	0.53
1978	-0.69	-0.97	-0.16	-0.72	-0.66	-0.68	-0.48
1979	0.29	0.25	1.29	0.28	0.87	1.15	1.75
1980	-0.73	-1.02	0.53	-0.68	-0.1	-1.79	0.93
1981	0.15	0.32	-0.93	-0.03	-0.43	-1.32	0.58
1982	-0.88	-1.49	-0.85	-0.93	-0.75	-1.73	-1.83
1983	0.6	-0.81	2.12	1.12	0.54	0.96	0.23
1984	-0.39	-1.2	0.43	-0.07	-1.24	-1.17	0.43
1985	-0.87	-0.37	-0.48	-0.46	-1.29	-1.78	-0.64
1986	-0.12	-0.33	1.62	-1.81	1.14	1.01	0.54
1987	-0.78	-1.04	-2.49	-0.8	0.02	0	-1
1988	0.6	-0.81	2.12	1.12	0.54	0.96	0.23
1989	0.38	-1.25	0.86	1.48	0.93	0.17	1.23
1990	1.34	-0.11	-0.68	0.16	0.05	0.92	0.57
1991	1.13	-0.01	-0.63	0.91	-1.12	0.3	-0.39
1992	-0.04	-1.03	-0.33	-1.11	-0.27	-1.12	0.29
1993	0.51	-0.66	0.8	1.15	-2.12	-0.97	1.48
1994	-0.7	-0.45	-1.06	-0.7	0.21	-1.29	-1.45
1995	0.42	0	-0.48	-0.22	-0.87	0.93	-1.39
1996	0.46	0.16	0.92	-0.15	0.67	0.53	0.9
1997	0.8	-0.82	-0.31	-0.74	-0.13	-0.14	0.37
1998	0.66	0.83	2	1.9	1.71	0.77	1.02
1999	5.47	-0.49	1.16	0.46	0.67	0.67	-1.08
2000	0.24	0.27	-0.04	-0.37	-0.04	0.21	0.23
2001	-0.42	-0.25	-1.13	0.73	-0.68	-0.68	-0.09

2002	-0.76	-0.66	-0.81	-0.05	-0.96	-1.4	0.1
2003	-1.73	0.45	-0.69	-1.53	-0.71	-2.02	-1.91
2004	-0.14	2.28	0.02	0.49	0.18	0.2	1.35
2005	-0.35	1.56	-0.19	0.35	-0.37	-0.37	0.18
2006	0.66	1.69	1.21	1.15	0.8	0.56	1.76
2007	0.4	0.96	0.42	-0.06	1.07	-0.89	-0.39
2008	0.32	1.33	0.19	1.19	-0.41	0.41	-0.73
2009	0.1	0.77	0.14	1.11	0.28	-0.05	0.46
2010	0.72	1.44	0.61	1.01	1.9	1.96	0.95
2011	-0.88	-0.54	0.13	-0.7	0.01	-0.41	-0.88
2012	-1.72	0.1	-1.69	-1.95	-0.4	-0.21	-1.88
2013	-0.16	0.92	-0.48	-0.02	-0.48	-0.01	0.23
2014	-0.46	0.75	-0.78	-0.39	-1.72	-0.14	-1.43
2015	-0.69	0.84	-1.14	-1.25	-0.62	-0.52	-0.42
2016	-0.07	1.4	0.63	0.47	0.18	0.49	-0.39
2017	0.42	2.05	0.71	1.26	0.47	1.4	0.5
2018	-1.47	1.2	-1.5	-1.78	-0.57	-1.53	-2.03
2019	0.26	2.05	0.17	0.27	1.63	0.78	0.49
2020	1.07	-0.39	0.94	1.44	2.11	2.93	1.74
2021	0.52	1.51	0.82	0.86	1.45	1.05	1.03

Annual SPI Probability of tehsils							
Years	**Pathardi**	**Rahata**	**Rahuri**	**Sangamner**	**Shevgaon**	**Shrigonda**	**Shrirampur**
1961	0.28	NA	-0.75	-0.46	NA	-0.82	-0.37
1962	0.84	NA	-1.21	0.08	NA	0.51	-1.54
1963	0.98	NA	-0.72	-0.58	NA	-0.46	-1.06
1964	0.55	NA	0.25	-0.48	NA	1.37	-1.28
1965	0.2	NA	-0.08	-2.2	NA	-0.77	-0.6
1966	0.02	NA	-0.41	-0.69	NA	-1.07	1.98
1967	0.12	NA	0.04	-0.68	NA	-0.11	-0.16
1968	-0.35	NA	0.55	-0.87	NA	-0.94	0.24
1969	-0.35	NA	1.11	0.39	NA	-0.06	-1.26
1970	-0.27	NA	-0.39	-0.57	NA	-0.97	-0.47
1971	-1.31	NA	0.24	-0.73	NA	-0.24	-2.1
1972	-2.56	NA	-2.83	-3.56	NA	-1.77	-2.2
1973	0.02	NA	1.44	-1.28	NA	0.89	0.11
1974	0.24	NA	2.4	1.11	NA	1.48	0.18
1975	1	NA	0.53	0.78	NA	0.24	0.85
1976	-0.46	NA	-0.75	1.51	NA	-0.69	-0.17
1977	-0.44	NA	0.19	0.11	NA	0.3	0.01
1978	-1.12	NA	-1.21	-0.5	NA	-0.28	-0.57
1979	-0.6	NA	0.95	0.71	NA	0.96	0.24
1980	-0.67	NA	-0.43	1.13	NA	0.04	0.4
1981	-0.54	NA	0.58	0.11	NA	0.56	1.09
1982	-1.45	NA	-0.78	-1.05	NA	-0.76	-1.08
1983	1.67	NA	1.06	-0.87	NA	1.03	0.39
1984	-0.55	NA	-0.47	0.63	NA	-0.07	-1.03
1985	1.08	NA	-1.35	-0.18	NA	-0.97	-0.73
1986	-0.44	NA	-1.51	0.95	NA	-0.38	-0.14
1987	-0.49	NA	-0.99	-1.06	NA	0.19	2.88
1988	1.67	NA	1.06	-0.87	NA	1.03	0.39
1989	0.6	NA	-0.07	0.89	NA	0.63	0.32
1990	0.67	NA	1.17	0.02	NA	0.83	0.98
1991	-0.28	NA	-0.08	0.54	NA	-0.12	-0.42
1992	-0.77	NA	-0.64	-1.09	NA	-0.83	-0.39
1993	-2.79	NA	-2.42	-0.52	NA	0.23	0.07
1994	-0.66	NA	-0.84	-1.25	NA	-1.58	-0.77
1995	0.2	NA	0.24	-1.33	NA	1.24	0.03
1996	1.53	NA	0.22	0.8	NA	0.54	0.35
1997	0.16	NA	-0.39	0.74	NA	0.03	-0.54
1998	1.91	0.2	0.43	1.27	1.1	2.05	1.11
1999	-0.55	0.2	1.38	0.21	0.21	1.29	-0.54
2000	-0.41	-0.92	0.46	1.43	-0.05	-0.66	0.23
2001	0.68	-0.15	0.28	-0.02	-0.43	0.59	0.09
2002	-0.09	-0.3	-1.18	0.35	-0.61	-0.54	-1.33
2003	-0.07	-1.61	-0.98	0.1	-1.12	-2.94	-1.7
2004	0.48	0.24	0.26	1.34	0.88	0.36	0.15

2005	-0.67	0.51	-0.31	0.6	-0.67	-0.15	0.13
2006	1	1.02	1.2	0.98	0.77	0.08	1.19
2007	0.09	-0.11	1.27	0.56	-0.29	1.46	1.07
2008	0.51	-0.98	0.69	0.32	-0.36	-0.36	-0.02
2009	0.68	-0.5	0.76	0.07	0.65	0.75	0.61
2010	1.48	2.19	1.54	1.58	1.04	1.16	1.73
2011	0.18	-0.9	0.32	-1.81	0.7	-1.21	0.54
2012	-2.09	0.18	-0.05	0.38	-1.98	-1.78	-0.65
2013	-0.19	0.18	-0.1	0.19	-0.3	0.63	-0.19
2014	-0.8	-1.15	-0.52	-0.22	-1.18	-0.94	-0.46
2015	-0.73	-1.12	-0.8	-0.43	-1.03	-0.7	-0.8
2016	0.51	-0.17	0.08	0.39	0.51	0.08	0.46
2017	0.17	1.15	0.48	0.92	0.25	0.52	1.21
2018	-1.78	-1.71	-1.85	-1.15	-1.84	-2.31	-0.82
2019	0.41	1.15	0.33	1.56	0.19	0.72	0.7
2020	1.77	1.86	1.76	0.63	2.16	1.59	2.41
2021	1.82	0.72	0.93	1.18	1.41	1.19	1.2

4. Conclusions

For the assessment of meteorological drought in all tehsils of Ahmednagar district, 12-month timescales (SPI-12) are used. A positive value indicated wet condition and a negative value of SPI indicated drought (dry) conditions. In tehsils like Ahmednagar, Karjat, Newasa frequency of drought increase in last two decades. In case of all other tehsils of Ahmednagar district, the 2011-2020 decade showed much below normal and below normal condition for maximum times with two to three near normal years. The recent decade (2011-2020) showed a frequent rise in the number of drought years for all tehsils. Tehsils like Ahmednagar, Akole, Jamkhed, Karjat, Kopergaon, Newasa, Parner, Pathardi, Rahuri, Shrigonda and Shrirampur had drought years observed for 24 years; in the case of Sangamner tehsils, out of 61 years, it was observed for 25 years. whereas for tehsils like Rahata and Shevgaon, for which only 24 years of data are available, it shows nine drought years. In tehsils such as Ahmednagar, Jamkhed, Karjat, Kopergaon, Newasa, Parner, Pathardi, Rahuri and Shrigonda, the frequency of drought has increased as compared to the last decade. Overall, the frequency of drought events has increased over the last two decades, which was a serious concern for crop production in this region, which needs rainwater harvesting and conservation programmed to be implemented.

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6. References

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