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Comparative Study of Meteorological Drought Indices in Amravati District

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ABSTRACT: Water is increasingly becoming scarce resource in many parts of the world. Precipitation deficiency due to natural climatic variability in space and time is the primary cause of drought. Drought is a complex phenomenon that is difficult to accurately describe. The most common tool used to monitor drought is a drought index. Drought characterization is one of the important aspects in crop planning and resource development in rainfed farming areas. In this study, monthly rainfall at nine tehasils in Amravati district of Maharashtra was analyzed to estimate and compare decile drought index, effective drought index (EDI) and standardized precipitation index (SPI) for identifying drought years using 22 years rainfall data (1991-2012). Decile drought index identified maximum number of years in moderate drought category and widespread drought during 11 years. Effective drought index identified maximum number of years in normal condition and only one year 1995 as widespread drought year. SPI identified maximum number of years in mild wet condition and widespread drought was observed in four years in Amravati district. The three indices were compared using seven assessment criterion adopted by Ntale and Gan (2003). The SPI was found to be superior over that of decile index and EDI because it describes all the major droughts occurred in Amravati district, it has higher positive values of Spearman rank correlation coefficient between year wise crop yield data and climatic severity, it shows more consistency with historical drought events, it is easily adapted to the local climate, it can be computed at almost any time scale, it has no theoretical upper or lower bounds and it fulfills the criteria of data requirement and availability for its assessment. SPI can be considered as the most suitable index for drought assessment in Amravati district.

Key words: Amaravati, drought index, EDI, meteorological drought, SPI

Introduction

Drought is a climatic anomaly, characterized by deficient supply of moisture, resulting either from sub-normal rainfall, erratic rainfall distribution, higher water need or a combination of the entire factors (Bhalme and Mooley, 1980). Drought affects very large areas for months and years and thus has a serious impact on regional food production, life expectancy for entire populations and economic performance of large regions or several countries. Precipitation deficiency due to natural climatic variability in space and time, is the primary cause of drought. Drought is a complex phenomenon that is difficult to accurately describe, detect and monitor (Wilhite, 2000).

Several users including farmers, suppliers, traders and water managers are interested in reliable and accurate drought information for effective management. There are large number of tools that have been developed to monitor moisture conditions. The most common tool for monitoring drought conditions is a drought index. A drought index can be used to quantify the moisture condition of a region, to detect the onset of drought, to measure the severity of a drought event, to quantify the spatial extent of a drought event, thereby allowing a comparison of moisture supply conditions between regions (Alley, 1984). Precipitation is the primary factor controlling the formation and persistence of drought conditions. The drought indices can be used to provide an early drought warning system (Lohani and Loganathan, 1997; Lohani *et al.,* 1998), to calculate the probability of drought termination (Karl *et al.,* 1987), to determine drought assistance (Wilhite *et al.,* 1986), to assess forest fire hazard and dust storm frequency (Cohen *et al.,* 1992), to predict crop yield (Kumar and Panu, 1997), to examine the spatial and temporal characteristics of drought, the severity of drought and to make comparisons between different regions (Alley, 1984; Soule, 1992; Kumar and Panu 1997; Quiring *et al.,* 2007). Dabare and Satpute (2008) quantified and categorized agricultural droughts in Nagpur district by using decile drought index. They evaluated the widespread drought years by compairing average crop yield of different crops and found that decile drought index can also be used for agricultural drought charecterisation. For proper crop planning and management there is an urgent need of analysis of droughts occurred in this region by quantifying and categorizing them using suitable drought index. Standardized precipitation index (SPI), decile drought index (DI) and effective drought index (EDI) are some of the widely used meteorological drought indices for drought quantification. These indices are solely based on precipitation data. Kim *et al.* (2009) compared the performances of the effective drought index (EDI) and standardized precipitation indices for drought monitoring for Seoul, Korea. McKee *et al.* (1993) used SPI for Fort Collins, CO., Bordi *et al.* (2001) for Italy, Oza *et al.* (2002) used SPI for North-West India, West Rajasthan and Saurashtra-Kutch. Morid *et al.* (2006) compared the performance of seven indices for drought monitoring in the Tehran province of Iran. The SPI and EDI was found to be able to detect the onset of drought, its spatial and temporal variation consistently, and it may be recommended for operational drought monitoring in the Province. The meteorological drought study has been carried out by different researchers by using three drought indices such as decile index (DI), effective drought index (EDI) and standardized precipitation index (SPI) at different locations. The

present study was undertaken for comparative assessment of meteorological drought indices *i.e.,* decile index (DI), effective drought index (EDI) and standardized precipitation index (SPI) for assessment of meteorological drought in nine tehasils of Amravati district using 22 years rainfall data (1991 - 2012).

Materials and Methods

Location of study area

The study was conducted for nine tehasils of Amravati district Vidharbha region in Maharashtra *viz.,* Achalpur, Anjangaon, Amravati, Chandur Bazaar, Chandur Railway, Chikhaldara, Dharani, Morshi and Warud. The average seasonal rainfall (1991-2012) of the selected tehasils is 733.55, 624.3, 799.0, 673.8, 699.4, 1313.6, 908.6, 646.1 and 712.4 mm, respectively.

Meteorological data and yield data

The 22 years (1991-2012) rainfall data and yield data of dry land crops *viz.,* soybean, sorghum, cotton and pigeonpea in selected places in Amravati district was used.

Determination of decile drought index

The decile value for each monsoon month from June to September has been calculated and compared with actual rainfall of that month to identify the severity of drought according to the classification given by Gibbs and Maher (1967). After categorizing the months, the drought years were computed by critically analyzing the growing period using the criteria given by George and Kalyansundaram (1969).

Determination of effective drought index

Effective drought index (EDI) was developed by Byun and Wilhite (1999) and monthly EDI values were estimated for the study period (1991-2012) by running 'EDI.exe' program. EDI values are standardized which allows drought severity at two or more locations to be compared with each other regardless of climatic differences between them. EDI roughly varies in the range from -2 to 2. It has thresholds indicating the range of wetness from extremely dry to extremely wet conditions.

Determination of standardized precipitation index

SPI was developed by McKee *et al*. (1993) in Colorado State University is based on the probability distribution of precipitation. The standardized precipitation index (SPI) was estimated by running the 'SPI_SL_6.exe' program using monthly rainfall data. The 3-month time scale SPI for September values were used to represent SPI index for *kharif* season of the year according to Patel (2007), which uses the monthly rainfall data of July, August and September for estimating the 3-month SPI index. Drought classification by SPI value and corresponding event probabilities as given by McKee *et al.* (1993) is used to categorize the drought.

Comparison of drought indices

This study is planned to identify the most suitable index for characterizing drought in Amravati district. The three drought indices were compared according to the procedure suggested by Ntale and Gan (2003) and Dabare (2007) by following seven assessment criteria to determine most appropriate drought index for monitoring meteorological drought in Amravati District.

Drought years identified by different indices

The drought years identified by different indices were analyzed according to their severity class. The index, which is having more consistency with historical drought events, was characterized as good indicator of drought for this region. The three indices were checked with the well-known historic drought event in 1991, 1995, 2000 and 2002 in Amravati district.

Widespread drought years indicated by different drought indices

The years during which a drought of higher severity (moderate and above) occurred at more than 50% of talukas under study in Amravati district are considered as a widespread drought year. Such drought years of moderate to severe and extremely severe category identified by the three drought indices at different taluka places in Amravati district during 1991-2012 are sorted out and presented in Table 4.

Spearman rank correlation coefficient

Due to the discrete variation of two variables (*i.e.* yield and drought year), Spearman rank correlation was chosen as a measure of how well years ranked by drought index value are compared to years ranked by yield of the area. For all drought indices, a positive index value indicates wetter than normal condition and negative index value imply dryer than normal conditions. Correlation between the drought years and yield of the year can range between -1 and 1 (Chandel, 1965). A positive correlation indicates a direct relationship between two variables.

Results and Discussion

Drought years identified by different indices and comparison of drought indices

The drought years identified by three drought indices *i.e.*, DI, EDI and SPI at nine tehasils in Amravati district during 1991-2012 are sorted out according to drought severity and presented in Table 1, 2 and 3, respectively.

The climatic condition identified by DI during 1991-2012 was determined and presented in Table 1. From Table 1, it is revealed that maximum number of years at most of the taluka places falls under mild to moderate drought category and very few years falls under severe drought to above normal conditions. The overall average climatic conditions under moderate drought for Amravati district was found to be 40.9% years followed by 24.2% years under mild drought, 20.7% years under normal climatic conditions, 9.1% years under severe drought and 5.1% years under above normal (wet) conditions.

The climatic condition identified by EDI during 1991-2012 was determined and presented in Table 2. From Table 2, it is revealed that maximum number of years at most of the taluka places falls under normal climatic category followed by mild drought category and very few years falls under moderate to extreme dry and mild wet to extreme wet condition. The overall average climatic conditions in Amravati district was found to be 44.4%

Table 1 : Climatic condition during as identified by decile drought index during 1991-2012

	Climatic condition				
Taluka	**Above normal**	**Normal**	**Mild drought**	**Moderate drought**	**Severe drought**
Achalpur	--	1998, 2006, 2007, 2010, 2012	1992, 1994, 1999, 2011	1991, 1993, 1996, 1997, 2000, 2001, 2002, 2003, 2004, 2005	1995, 2008, 2009
Anjangaon	2006 2007	1994, 1998, 2012	1996, 1997, 1999, 2002, 2004, 2005, 2008, 2010	1992, 1993, 1995, 2000, 2001, 2003, 2009, 2011	1991
Amravati	--	1998, 2007, 2010, 2011, 2012	1992, 1994, 1996, 1999, 2001, 2005, 2006, 2008	1991, 1993, 1997, 2000, 2002, 2003, 2009	1995, 2004
Chandur Bazar	2007	1994, 2006, 2011, 2012	1992, 1997, 1998, 2005, 2010	1991, 1993, 1996, 1999, 2001, 2002, 2003, 2004, 2008, 2009	1995, 2000
Chandur Railway	2010	1999, 2003, 2005, 2006, 2007	1996, 2011	1991, 1992, 1994, 1995, 1997, 1998, 2000, 2001, 2002, 2004, 2008, 2009, 2012	1993
Chikhaldara	1994, 2007, 2012	1993, 1996, 2006, 2011	1997, 1998, 2008, 2010	1991, 1992, 1999, 2002, 2003, 2004, 2005, 2009	1995, 2000, 2001
Dharani	1994, 2012	1999, 2006, 2007, 2011	1992, 1993, 1996, 1998, 2002, 2003, 2005	1997, 2000, 2001, 2004, 2008, 2009, 2010	1991, 1995
Morshi	2007	2005, 2006, 2010, 2012	1992, 1994, 1999, 2003, 2004, 2011	1991, 1993, 1996, 1997, 1998, 2001, 2002, 2008, 2009	1995, 2000
Warud	--	1993, 1994, 1995, 2007, 2010, 2011, 2012	1992, 1999, 2005, 2006	1996, 1997, 1998, 2001, 2002, 2003, 2004, 2008, 2009	1991, 2000
Overall avearage	5.1	20.7	24.2	40.9	9.1

Table 2 : Climatic condition during different years as identified by effective drought index during 1991-2012

	Climatic Condition								
Taluka	**Extremely wet**	**Severe wet**	**Moderate wet**	**Mild wet**	**Normal condition**	**Mild drought**	**Moderate drought**	**Severe drought**	**Extremely dry**
Achalpur	--	--	2007 2010	1991, 1994	1992, 1993, 1998, 1999, 2006, 2011, 2012	1997, 2000	1995, 1996, 2001, 2002, 2003	2004, 2008, 2009	2005
Anjangaon	2006, 2007	2012	2001	2005, 2010	1993, 1994, 1995, 1997, 1998, 1999, 2002, 2003, 2004, 2008, 2009, 2011	1991, 1992, 1996, 2000	--	--	--
Amravati	2010	--	1998, 2000, 2001	2005, 2007	1991, 1992, 1993, 1994, 1999, 2003, 2006, 2011, 2012	2008, 2009	2002	1995, 1997, 2004	1996
Chandur Bazar	2007	--	--	1994, 2006, 2010	1992, 1993, 1997, 1998, 1999, 2003, 2004, 2009, 2011, 2012	1991, 2000, 2005, 2008	1995, 2001, 2002	1996	--
Chandur Railway	2010	1994	2006	2005	1999, 2000, 2003, 2007, 2011	1991, 1992, 1993, 1997, 1998, 2001, 2002, 2004, 2012	1995, 1996, 2008	2009	--
Chikhaldara	--	2007	2012	--	1991, 1993, 1994, 1996, 1997 1998, 2003, 2005, 2006, 2010, 2011	1992, 1999, 2002, 2004, 2008, 2009	2000	1995, 2001	--
Dharani	--	--	--	1993, 1994, 1996, 2007	1991, 1995, 1999, 2001, 2003, 2005, 2006, 2008, 2010, 2011, 2012	1992, 1997, 1998, 2002, 2004	2000	2009	--
Morshi	--	2001 2007 2010	--	--	1991, 1992, 1998, 1999, 2003, 2004, 2005, 2006, 2011, 2012	1993, 1994, 1995, 2002, 2009	1997, 2000, 2008	1996	--
Warud	--	--	1993, 1994, 1995, 2007	--	1992, 1999, 2000, 2001, 2003, 2004, 2005, 2006, 2008, 2009, 2010, 2011, 2012	1991, 1996, 1997, 1998	2002	--	--
Overall avearage	2.52	3.03	6.06	7.07	44.44	20.70	9.09	6.06	1.01

Table 3 : Climatic condition during different years as identified by standardized precipitation index during 1991-2012

Taluka	Extremely wet	Severe wet	Moderate wet	Mild wet	Mild drought	Moderate drought	Severe drought	Extremely dry
Achalpur	--	2007, 2010	1998, 2012	1991, 1994, 2006, 2011	1992, 1993, 1996, 1997, 1999, 2003, 2004, 2005	2000, 2001, 2009	1995, 2008	2002
Anjangaon	2006, 2007	1998	--	1994, 1997, 1999, 2005, 2009, 2010, 2011, 2012	1992, 1993, 1995, 1996, 2001, 2002, 2003, 2004, 2008	1991, 2000	--	--
Amravati	--	2010	1994, 2006, 2007, 2012	1992, 1993, 1998, 1999, 2000, 2005, 2008, 2011	1991, 1996, 1997, 2001, 2003, 2004, 2009	--	2002	1995
Chandur Bazar	2007	--	1994, 2006	1992, 1996, 1997, 1998, 2010, 2011, 2012	1993, 1999, 2000, 2002, 2003, 2004, 2005, 2008, 2009	2001	1991	1995
Chandur Railway	2010	1992, 2006	1994, 2005, 2007	1996, 1999, 2003, 2011, 2012	1997, 1998, 2000, 2004, 2009	1991, 1993, 1995, 2002	2001, 2008	--
Chikhaldara	--	--	1994, 2007, 2012	1992, 1993, 1996, 1997, 1998, 2003, 2005, 2006, 2010, 2011	1999, 2004, 2008, 2009	1991, 2000, 2002	1995	2001
Dharani	--	--	1994	1992, 1993, 1996, 1998, 2005, 2006, 2007, 2011, 2012	1991, 1995, 1999, 2001, 2002, 2003, 2004, 2008, 2009, 2010	1997, 2000	--	--
Morshi	2010	2007	2012	1992, 1994, 1998, 1999, 2001, 2003, 2004, 2005, 2006, 2011	1991, 1996, 1997, 2008, 2009	1993, 1995	2000	2002
Warud	1993	--	1992, 2007	1994, 2005, 2006, 2009, 2010, 2011, 2012	1995, 1996, 1997, 1998, 1999, 2003, 2004, 2008	2000, 2001, 2002	1991	--
Overall avearage	3.03	3.53	9.09	34.34	32.82	10.10	4.54	2.52

year under normal condition followed by 20.7% under mild drought, 9.09 per under moderate drought, 7.07 under severe drought, 13.67 under moderate wet condition and 5.55 under severe wet condition.

The seasonal climatic condition for different years was decided by considering the 3-months SPI for September and is summarized in Table 3. From Table 3, it is revealed that maximum number of years at most of the taluka places falls under moderate wet and moderate dry climatic category. The overall average climatic condition in Amravati district was found to be under mild wet for 34.34% year followed by 32.82% year under mild drought, 10.10% year under moderate drought, 7.06% year under severe drought, 9.09% year under moderate wet and 6.56% year under severe wet condition.

From Table 1 to 3, it is observed that SPI and decile index methods had identified most of the drought years which were not observed by EDI method. However, decile index method has identified more years in moderate and severe category at different taluka places compared to SPI and EDI methods. From the above results, it can be concluded that SPI method identifies all the drought years consistently and distinctly over DI and EDI method which proves the superiority of SPI method over the latter two drought indices.

Widespread drought years indicated by different drought indices

From Table 4, it is observed that, decile index had identified maximum number of drought years followed by SPI and least by EDI at different taluka places in Amravati district. Decile index identified 11 number of drought years, whereas EDI identified only one drought year and SPI identified 4 drought years. The years 1991, 1995, 2000 and 2002 were identified as most widespread disastrous years since these years are shown by all the indices at most of the taluka places in Amravati district. From Table 4, it is revealed that, SPI has identified all the drought years which were also traced by other two indices. EDI finds only one (1995) drought year. Compared to EDI and SPI, decile index gives more number of drought years at different taluka places in Amravati district. From above discussion on identification of drought years, it is observed that SPI and decile index methods had identified most of the drought years which were not observed by EDI method in required numbers in different taluka places. However, decile index method had identified extra large number of year at different taluka places compared to SPI method. From the above results, it can be concluded that decile index has over estimated the droughts, EDI method has under estimated and SPI identifies all the drought years consistently and distinctly over decile index and EDI, which proves the superiority of SPI over the latter two drought indices.

Table 4 : Widespread drought years (moderate to severe) indicated by different drought indices in Amravati district during 1991 to 2012

Taluka	DI	EDI	SPI
Achalpur	1991, 1993, 1995, 1997, 2000, 2001, 2002, 2003, 2004, 2008, 2009	1995	1995, 2000, 2002
Anjangaon	1991, 1993, 1995, 2000, 2001, 2003, 2009	--	1991, 2000
Amravati	1991, 1993, 1995, 1997, 2000, 2002, 2003, 2004, 2009	1995	1995, 2002
Chandur Bajar	1991, 1993, 1995, 1997, 2000, 2001, 2002, 2003, 2004, 2008, 2009	1995	1991, 1995
Chandur Railway	1991, 1993, 1995, 1997, 2000, 2001, 2002, 2004, 2008, 2009	1995	1991, 1995, 2002
Chikhaldara	1991, 1995, 2000, 2001, 2002, 2003, 2004, 2009	1995	1991, 1995, 2000, 2002
Dharani	1991, 1995, 1997, 2000, 2001, 2004, 2008, 2009	--	2000
Morshi	1991, 1993, 1995, 1997, 2000, 2001, 2002, 2008, 2009	1995	1995, 2000, 2002
Warud	1991, 1997, 2000, 2001, 2002, 2003, 2004, 2008, 2009	--	1991, 2000, 2002

Analysis of major historical droughts

The three indices used for drought characterization have identified four major historical droughts in Amaravati district *viz.,* 1991, 1995, 2000 and 2002. Decile index and SPI are showing more consistency with historical drought events indicating the superiority of these two indices over EDI in identifying proper severity of drought in the region (Table 5).

Table 5 : Drought severity indicated by various indices in historical drought years

Taluka	1991			1995			2000			2002		
	DI	EDI	SPI	DI	EDI	SPI	DI	EDI	SPI	DI	EDI	SPI
Achalpur	MoD	MIW	MIW	SD	MoD	SD	MoD	MID	MoD	MoD	MoD	ED
Anjangaon	SD	MID	MoD	MoD	Nor	MID	MoD	MID	MoD	MID	Nor	MID
Amravati	MoD	Nor	MID	SD	SD	ED	MoD	MoW	MIW	MoD	MoD	SD
Chandur Bazaar	MoD	MID	SD	SD	MoD	ED	SD	MID	MID	MoD	MoD	MID
Chandur Railway	MoD	MID	MoD	MoD	MoD	MoD	MoD	Nor	MID	MoD	MID	MoD
Chikhaldara	MoD	Nor	MoD	SD	SD	SD	SD	MoD	MoD	MoD	MID	MoD
Dharani	SD	Nor	MID	SD	Nor	MID	MoD	MoD	MoD	MID	MID	MID
Morshi	MoD	Nor	MID	SD	MID	MoD	SD	MoD	SD	MoD	MID	ED
Warud	SD	MID	SD	Nor	MoW	MID	SD	Nor	MoD	MoD	MoD	MoD

Mow - Moderate wet, MIW - Mild wet, Nor - Normal condition, MID - Mild drought, MoD - Moderate drought, SD - Severe drought, ED - Extremely dry

Table 6 : Spearman rank correlation between various crop yield and drought severity by different drought indices for different talukas in Amravati district

Taluka	Decile				EDI				SPI			
	Soybean	Sorghum	Cotton	Pigeon pea	Soybean	Sorghum	Cotton	Pigeon pea	Soybean	Sorghum	Cotton	Pigeon pea
Achalpur	0.70	0.16	-0.03	0.32	0.42	-0.09	-0.004	0.02	0.7	0.09	-0.17	-0.02
Anjangaon	0.30	0.24	-0.29	0.28	0.46	0.045	0.048	0.37	0.3	0.3	-0.02	0.23
Amravati	0.71	-0.15	-0.10	-0.07	0.49	-0.13	-0.13	-0.03	0.58	-0.30	0.1	-0.2
Chandur Bazar	0.47	-0.04	0.05	0.33	0.49	-0.29	0.08	0.15	0.47	0.01	0.12	0.20
Chandur Railway	0.46	-0.08	-0.08	-0.14	0.36	-0.18	-0.44	-0.36	0.49	-0.16	-0.14	-0.25
Chikhaldara	0.57	0.41	-0.01	0.28	0.59	0.41	-0.04	0.11	0.49	0.47	-0.12	0.18
Dharani	0.37	0.39	0.23	0.13	0.26	0.45	0.14	0.24	0.35	0.38	0.10	0.20
Morshi	0.58	-0.15	0.05	-0.03	0.37	-0.28	0.07	-0.09	0.40	-0.18	0.18	-0.13
Warud	0.47	-0.007	0.35	0.25	0.37	-0.01	0.34	0.30	0.47	0.17	0.28	0.32

Spearman rank correlation coefficient

From Table 6, it can be revealed that for soybean crop, decile index gives highest positive correlation followed by SPI and EDI, for different taluka places in Amravati district. For sorghum, SPI gives highest positive correlation at six taluka places followed by decile index (4 taluka places) and EDI (3 taluka places) in Amravati district. For cotton, the EDI and SPI gives same positive correlation followed by decile index. For pigeon pea, the decile and EDI shows positive correlation at six taluka places followed by SPI at five taluka places. From the above results of correlation between different rainfed crops yield data and drought years severity obtained by different indices, it can be concluded that the performance of decile index and SPI can be considered as better in identification of drought over EDI.

The three indices were compared using seven assessment criterion adopted by Ntale and Gan (2003) and Dabare (2007). The SPI was found to be superior over that of decile index and EDI because it describes all the major droughts occurred in Amravati district, more consistency with historical drought events, easily adapted to the local climate, can be computed at almost any time scale, has no theoretical upper or lower bounds and it fulfills the criteria of data requirement and availability for its assessment. Since Standardized precipitation index (SPI) satisfies all the assessment criterion followed by decile index which fulfills only four criteria, SPI can be considered as the most suitable index for drought assessment in Amravati district.

Conclusion

The monthly rainfall at nine taluka places in Amravati district of Maharashtra was analyzed to estimate and compare decile index (DI), effective drought index (EDI) and standardized precipitation index (SPI) for identifying drought years in Amravati district using 22 years rainfall data (1991-2012). The decile drought index identified maximum number of years in moderate drought category. Effective drought index identified maximum number of years in normal condition. SPI identified maximum number of years in mild wet and mild drought condition. In case of wide spread drought years, it can be concluded that decile index has over estimated the droughts, EDI method has under estimated and SPI identifies all the drought years consistently and distinctly over decile index and EDI, which proves the superiority of SPI over the other two drought indices. Decile index and SPI are showing more consistency with historical drought events indicating the superiority of these two indices over EDI in identifying proper severity of drought in the region. From the correlation between different rainfed crops yield data and drought years severity obtained by different indices, it can be concluded that the performance of decile index and SPI can be considered as better in identification of drought over EDI. The three indices were compared using seven assessment criterion adopted by Ntale and Gan (2003) and Dabare (2007). Standardized precipitation index (SPI) satisfies all the seven assessment criterion followed by decile index which fulfills only four criteria, SPI can be considered as the most suitable index for drought assessment in Amravati district.

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