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Analysis of rainfall for drought using standardized precipitation index (SPI) for various tehsils in Nandurbar district

Arti B Kubade, SV Bagade, VA Sthool, JD Jadhav, PB Pawar, SK Upadhye and SK Rahase

Abstract
One of the key elements in *rainfed* farming, water management, and water distribution for protective irrigation is having the proper knowledge of the nature of the emergence of drought and its distinguishing features. There is a lack of information about the characteristics of the drought among the various developmental organizations and groups trying to resolve the issues in the area. As a result, sometimes in years with normal precipitation, crops fail due to a lack of proper use of rainfall and water resources. Hence, the present study entitled, "Analysis of rainfall for drought in Nandurbar district using standardized precipitation index (SPI)", was conducted with the objectives; to analyze rainfall for drought using precipitation deciles (PD) and standardized precipitation index (SPI), to determine the onset and withdrawal of monsoon to determine probabilities of dry and wet weeks by using Markov-chain model and to suggest tehsil wise suitable cropping pattern.
The Study area of Nandurbar district comprises 6 tehsils *viz.*, Nandurbar, Akkalkuwa, Akrani, Navapur, Shahada, and Taloda.
In selected tehsils of the Nandurbar and Dhule district, a drought analysis was conducted using the Standardized Precipitation Index (SPI) over a 12-month period. It is observed that in a decade, there are typically two or three wet years, two or three dry years, and four or five normal years, depending on the trend and frequency of drought in the decade. It was concluded that the frequency of drought increased in recent decade (2011-2019) in Akrani, Navapur.

Keywords: Standardized precipitation index, decades, drought, frequency, rainfall

1. Introduction
A drought is a period of time when an area or region experiences below normal precipitation. The lack of adequate precipitation, either rain or snow, can cause reduced soil moisture or groundwater, diminished stream flow, crop damage, and a general water storage. Rainfall in India is highly uneven over a period of time in a year. The western coasts & North East India receives rainfall of over 400cm average. It is less up to 60 cms in western Rajasthan and adjoining parts of Gujarat, Punjab, and Haryana &Maharashtra. Variation of rainfall can be influenced by many factors like for instance elevation, slope and prevailing wind directions. This depends on the geographical and climatological characteristics of specific area. Therefore the drought events are also different for different states of India, and different districts of Maharashtra.
Scope of the study is the appropriate knowledge of nature of occurrence of drought and its characteristic features is one of the important aspects in the *rainfed* farming, water resource planning and management, and allocation of water for protective irrigation. These studies provide basic information for evaluating climatic potential of an area for agricultural development, for evolving suitable cropping patterns, protective irrigation and for implementing cultural and conservation practices done to rainfall distribution in the area.
The standardized precipitation index (SPI) is a probability-based indicator that depicts the degree to which the accumulative precipitation of a specific period departs from the average state. SPI is easy to calculate and convenient to apply. It requires only precipitation as input data and escapes the problem of parameter calibration, thus is particularly suitable for drought/flood monitoring in areas where hydrological data is scarce (Yuan and Zhou 2004). As a result, SPI has already been widely used to characterize dry and wet conditions in many countries and regions. Drought Assessment tools enables an assessment of drought related hazards, the associated impact & the risk towards different vulnerable areas or sectors.

2. Materials and Methods

2.1 Study Area

In July 1998 Dhule district was bifurcate and Nandurbar district formed. The district covers geographical area of 5,955 sq. kms. which is 1.62 % of Maharashtra state Nandurbar located between 21°74′69″ North latitude and 74°12′40″ east longitude. It is the north east district of Maharashtra. It is surrounded by Gujrat, MP. Dhule. This district is one of the part of western Ghats and satpura hills. Nandurbar and Shahada has Tapi river along with and Gomai rivers for agriculture and industrial requirement of water. Nandurbar district has 6 tehsils, viz. Nandurbar, Akkalkuwa, Akrani, Navapur, Taloda, and Shahada

2.2 Data and Methods

The daily rainfall data of all tahsils in Nandurbar district will be collected from Department of Agricultural Meteorology, College of Agriculture, Pune, State Agriculture Department, Pune, India Meteorological Department, Pune, Downloaded from www.maharain.gov.in (www.krishi.maharashtra.gov.in) from January to December. Rain gauges are located at the headquarters of tahsils.

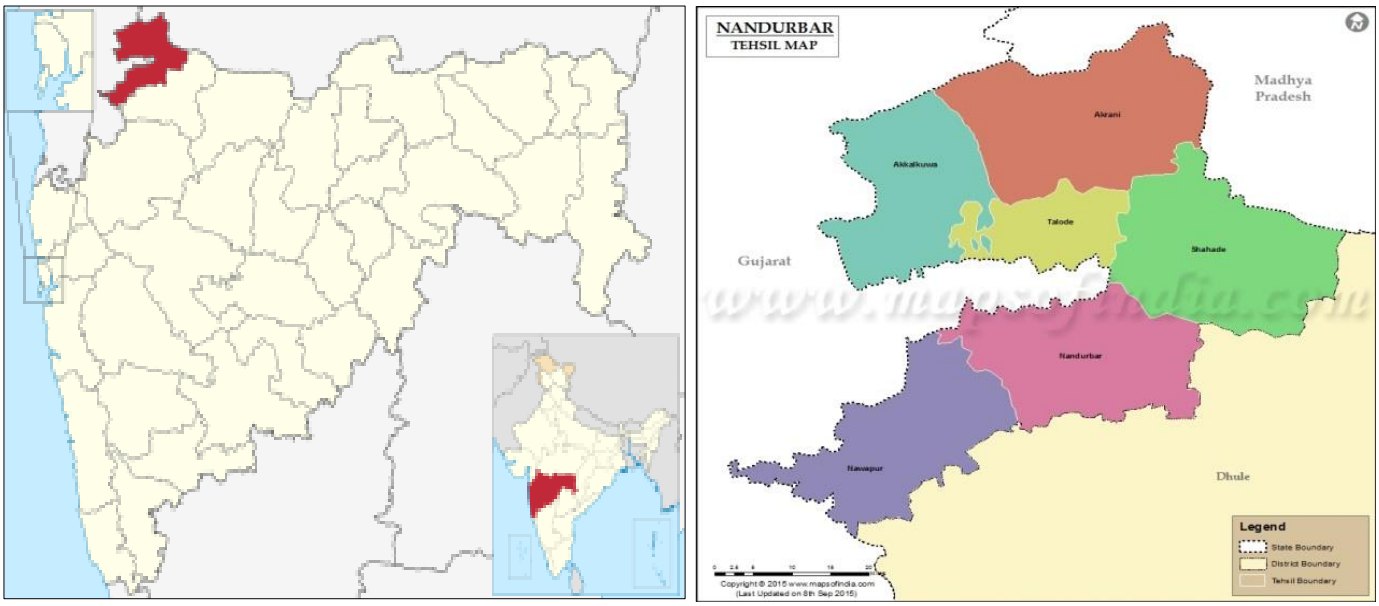


Fig 1: Location map of Nandurbar district

Microsoft office sub-module Microsoft-Excel-2010 is used for data analysis. The formulation and conditional statements were also executed in MS-excel. The SPI_SL_6.exe Svoboda *et al.*, (2012) [9] software developed at Edwards and McKee (1993) [1] is used for analysis of drought using Standardized Precipitation Index (SPI).

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

Sr. No	Name of tehsils	Area km^2	latitude	longitude	Period of year		No. of years
					From	To	
1	Nandurbar	1022.12	21.370°'N	74.250°'E	1961	2021	61
2	Akkalkuwa	936.02	21.550°'N	74.020°'E	1961	2021	61
3	Akrani	1282.31	21.824°'N	74.216°'E	1991	2021	31
4	Navapur	1030.23	21.101°'N	73.464°'E	1961	2021	61
5	Shahada	1181.27	21.542°'N	74.469°'E	1961	2021	61
6	Taloda	452.94	21.560°'N	74.830°'E	1961	2021	61

2.2.1 Computation of Precipitation Deciles

The SPI index was designed by McKee *et al.*, to quantify the precipitation deficit in 1993 [1] 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. 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. The advantage of SPI is less data requirement 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. Standardized precipitation index was calculated according to the following formula Edwards and McKee, (1993) [1].

$$\text{SPI} = \text{Z score} = \frac{x_i - x}{\sigma}$$

The Indices are grouped into seven classes as presented in Table 2.

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

3.1 Variation of Annual Rainfall in Nandurbar District

Table 3 shows that average annual rainfall in Nandurbar district was 882.17 mm. It ranged between 681.1 mm in Shahada and 1114.28 mm at Navapur. The large standard deviation was found at Akkalkuwa (395.77 mm) with 39percent variation, while the lowest was found at Nandurbar (252.45 mm) with 33.77 percent variation.

Table 3: Tehsil wise annual rainfall variation in Nandurbar district

Tehsil	Maximum Rainfall		Minimum Rainfall		Mean Rainfall (mm)	S.D.	C.V. (percent)
	Rainfall (mm)	Year	Rainfall (mm)	Year			
Nandurbar	1386	2006	306.3	1987	747.58	252.45	33.77
Akkalkuwa	2097.9	2013	355.1	1968	1014.91	395.77	39
Akrani	2003	2006	306.3	2000	908.41	316.15	34.8
Navapur	2244	1976	619.56	2021	1114.28	380.06	34.11
Shahada	2166	1981	324.1	1999	681.1	276.79	40.64
Taloda	1653	2006	415.2	1986	826.75	266.59	32.25
Nandurbar District average					882.1	314.6	35.7

3.2 Standardized Precipitation Index (SPI)

3.2.1 SPI of Nandurbar Tehsil

Indices were calculated for the Nandurbar Tehsil using long-term historical rainfall data spanning 61 years (1961–2021), tehsil has 9 wet years, 44 near normal years, while the remaining 8 years show drought or extreme drought conditions. The probability of recurrence of mild drought is 28 percent, which means once every four years, the probability of recurrence of moderate drought is 5 percent, which means once every 20 years, the probability of recurrence of severe drought is 1 percent, which means once every 100 years, and the probability of recurrence of extreme drought is 1 percent, which means once every 100 years over Nandurbar tehsil (table 4) However, between 1990 to 2000 and 2008 to 2021, the frequency and intensity of drought years increased, and negatively impacting the farming system.

3.2.2 SPI of Akkalkuwa Tehsil

Indices were calculated for the Akkalkuwa Tehsil using long-term historical rainfall data spanning 61 years (1961–2021). tehsil have 9 wet years, 42 near normal years and remaining 8 years shows dry or extreme drought condition. The probability of recurrence of mild drought is 23 percent, which means once every 4 years, 5percent means once every 20 years, 2 percent means once every 50 years, and 2 percent means once every 50 years throughout Akkalkuwa tehsil (table 4). However, between 1990 to 2005, and from 2009 to 2021, the frequency and intensity of drought years increased quickly, negatively impacting the cropping system.

3.2.3 SPI of Akrani Tehsil

Indices were calculated for the Akrani Tehsil using long-term historical rainfall data spanning 31 years (1991–2021), tehsil have 4 wet years, 21 near normal years and remaining 6 years shows dry or extreme drought condition. In Akrani tehsil, the probability of recurrence of mild drought is 8 percent, which means once every 12 years, the probability of recurrence of moderate drought is 3 percent, which means once every 33 years, the probability of recurrence of severe drought is 1 percent, which means once every 100 years, and the probability of recurrence of extreme drought is 2 percent, which means once every 50 years (table 4). However, from 1991-2003, 2009-2021 the frequency and intensity of drought years increased quickly, negatively impacting the farming system.

3.2.4 SPI of Navapur Tehsil

Indices were calculated for the Navapur Tehsil using long-term historical rainfall data spanning 61 years (1961–2021), tehsil had 9 wet years, 42 near average years, and the remaining 10 years indicate dry or high drought conditions. The probability of recurrence of mild drought is 21 percent, which means that it occurs once every 5 years, the probability of recurrence of moderate drought is 8 percent, which means that it occurs once every 12 years, the probability of recurrence of severe drought is 1 percent, which means that it occurs once every 100 years, and the probability of recurrence of extreme drought condition is not observed in 100 years over Navapur tehsil (table 4). However, between 1990-2002 and 2006 to 2021, the frequency and intensity of drought years increased quickly, negatively impacting the farming system.

3.2.5 SPI of Shahada Tehsil

Indices were calculated for the Shahada Tehsil using long-term historical rainfall data spanning 61 years (1961–2021), tehsil have 8 wet years, 43 near normal years and remaining 10 years shows dry or extreme drought condition.

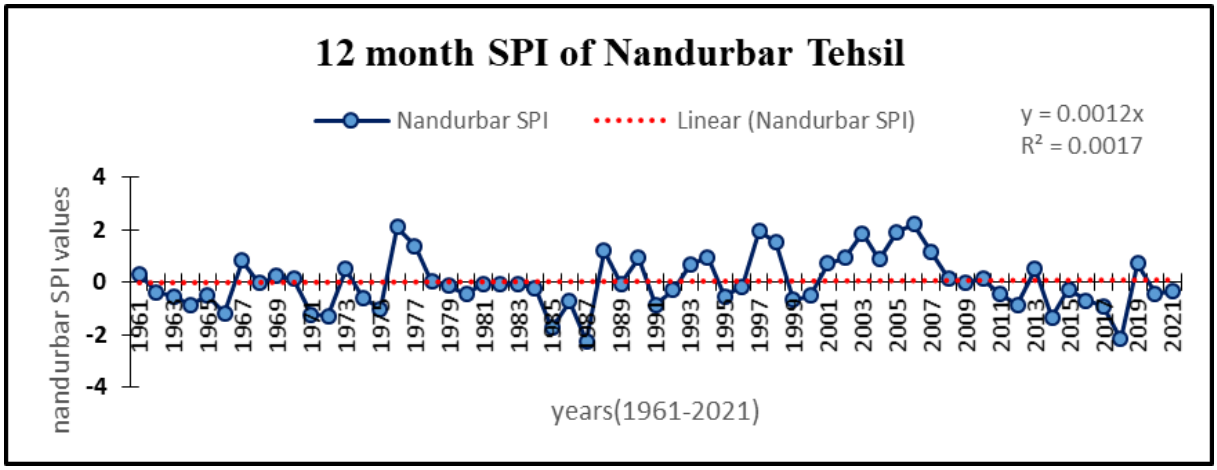
The probability of recurrence of mild drought is 26 percent, which means once every 4 years, the probability of recurrence of moderate drought is 5 percent, which means once every 20 years, the probability of recurrence of severe drought is 4 percent, which means once every 25 years, and the probability of recurrence of extreme drought is 1 percent, which means once every 100 years over Shahada tehsil (table 4). However, in 1990 and 2005, and from 2009 to 2021, the frequency and intensity of drought years increased quickly, negatively impacting the cropping system.

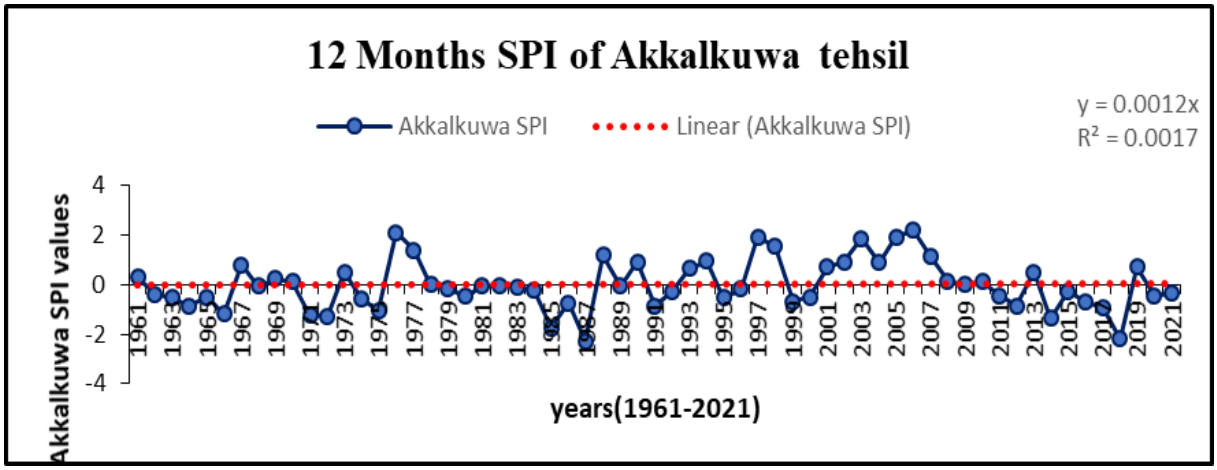
3.2. SPI of Taloda Tehsil

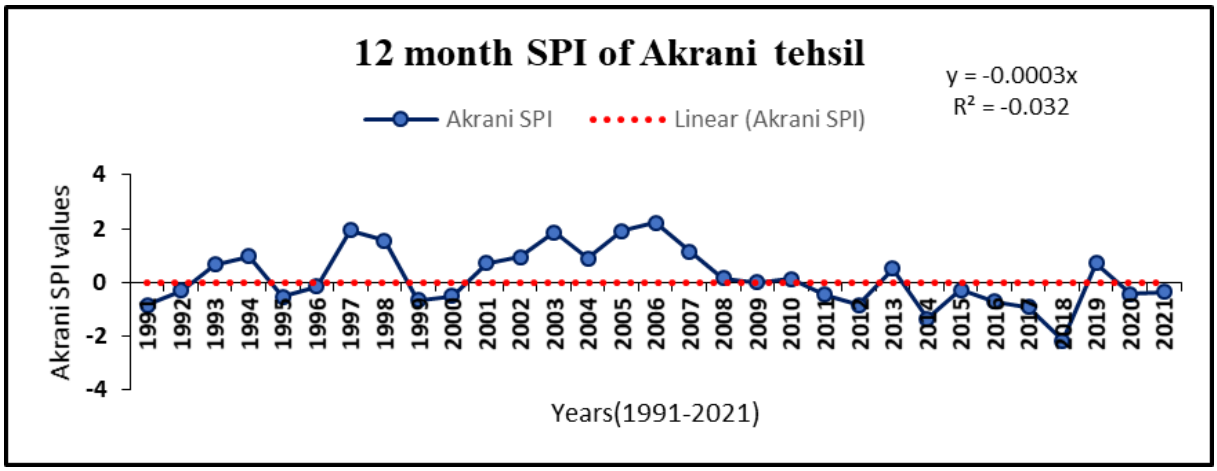
Indices were calculated for the Taloda Tehsil using long-term historical rainfall data spanning 61 years (1961–2021), tehsil has 9 wet years, 40 near average years, while the remaining 12 years display dry or high drought conditions. The probability of recurrence of mild drought is 19 percent, which means once every 5 years, the probability of recurrence of moderate drought is 7 percent, which means once every 14 years, the probability of recurrence of severe drought is 4 percent, which means once every 25 years, and the probability of recurrence of extreme drought condition is not observed in 100 years over Taloda tehsil (table 4). However, between 1999 and 2004, and again from 2009 to 2021, the frequency and intensity of drought years increased quickly, negatively impacting agriculture.

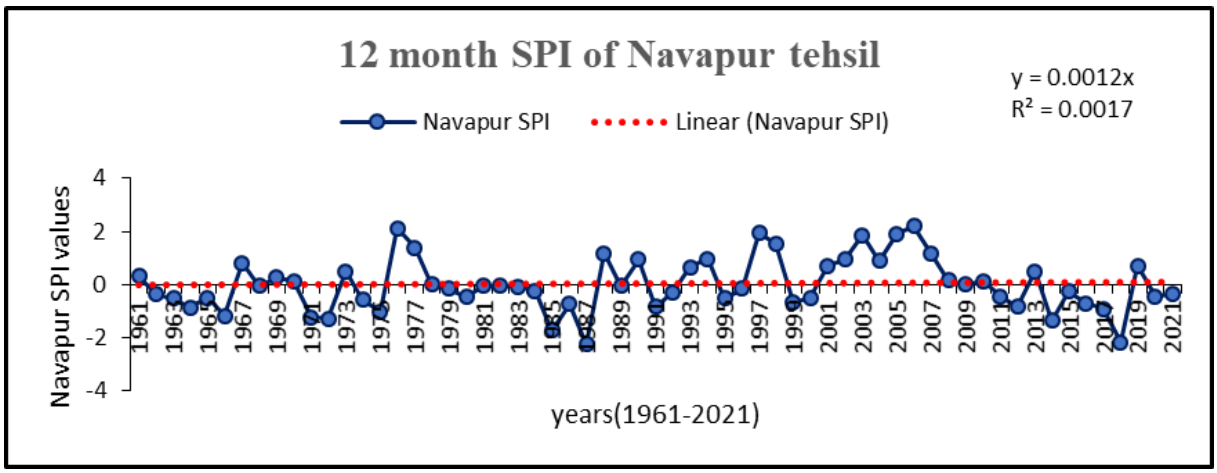
Table 4: Annual SPI values (12 months basis) of different tehsils of Nandurbar district

Annual SPI Probability of tehsils						
Years	**Nandurbar**	**Akkalkuwa**	**Akrani**	**Navapur**	**Shahada**	**Taloda**
1961	0.31	0.64	NA	-1.36	0.66	0.38
1962	-0.38	0.25	NA	-0.92	-1.12	-0.42
1963	-0.53	-0.65	NA	0.81	0.32	0.16
1964	-0.86	-0.73	NA	0.58	-0.13	-0.33
1965	-0.5	-1.04	NA	0.64	-0.56	-0.31
1966	-1.17	-1.52	NA	-0.19	-0.24	-0.55
1967	0.82	-2.06	NA	0.25	0.33	-1.75
1968	-0.04	-2.2	NA	0.71	-0.24	-0.17
1969	0.25	2.01	NA	2.06	0.4	0.91
1970	0.13	1.54	NA	1.85	0.49	1.28
1971	-1.23	-0.72	NA	0.32	-0.23	-1.03
1972	-1.28	-0.84	NA	-0.43	-1.61	-1.5
1973	0.5	0.91	NA	-0.67	1.02	0.05
1974	-0.58	-0.36	NA	-1.15	0.04	-0.85
1975	-1.03	0.29	NA	0.38	0.28	-0.2
1976	2.11	2.18	NA	2.56	0.8	1.68
1977	1.39	1.21	NA	1.61	0.56	0.7
1978	0.01	0.4	NA	-1.19	0.05	0
1979	-0.15	0.52	NA	0	0.31	0.22
1980	-0.47	-0.47	NA	-1.14	-0.24	-0.37
1981	-0.05	0.89	NA	-0.42	4.15	-1.47
1982	-0.06	-0.74	NA	-0.45	-0.07	-1.01
1983	-0.08	0.68	NA	0.6	1.66	0.63
1984	-0.23	-0.19	NA	-0.62	-0.01	-0.23
1985	-1.73	-1.02	NA	-0.84	-1.56	-1.45
1986	-0.73	-1.35	NA	-0.92	-1.24	-1.85
1987	-2.26	-1.8	NA	-1.16	-0.36	-1.45
1988	1.19	0.35	NA	0.15	1.05	1.36
1989	-0.06	0.51	NA	-0.09	1.21	-0.08
1990	0.93	0.59	NA	0.05	0.71	1.06
1991	-0.85	-0.28	-0.05	-0.89	-1.28	-0.24
1992	-0.29	-0.29	-0.09	0.17	-0.22	0.55
1993	0.66	0.29	0.08	0.72	0	0.72
1994	0.96	1.04	0.74	0.91	0.96	1.34
1995	-0.53	-0.26	0.25	-0.53	-1.04	-0.52
1996	-0.16	-0.61	0.54	0.36	-0.16	0.17
1997	1.94	0.35	1.19	0.67	-0.47	0.68
1998	1.55	0.63	0.46	1.09	0.48	0.93
1999	-0.67	-1.5	-0.37	0	-1.75	-1.82
2000	-0.51	-1.45	-1.36	-1.43	-2.01	-1.52
2001	0.71	-0.22	0.32	-0.9	-0.53	-0.01
2002	0.94	-0.89	0.46	-0.99	-1.23	-0.99
2003	1.87	0.18	0.82	0.48	0.9	0.94
2004	0.89	0.18	1.2	1.56	-0.21	0.3
2005	1.92	0.51	0.42	2.31	-0.36	1.05
2006	2.21	1.71	2.12	0.97	1.95	2.58
2007	1.15	1.59	0.82	1.14	0.77	1.41
2008	0.15	1.24	0.42	0.52	0.29	0.54
2009	0	-0.16	-0.32	-0.77	-0.11	-0.07
2010	0.13	-0.14	-0.07	-0.09	-0.13	0.38
2011	-0.45	0.41	0.14	-0.66	-0.36	0.11
2012	-0.85	-0.31	-0.05	-0.66	-0.2	-0.01
2013	0.51	2.28	1.36	1.14	1.4	2.4
2014	-1.35	-0.15	-0.21	-1.4	-0.66	-1.21
2015	-0.27	-0.08	0.18	-1.12	-0.45	0.26
2016	-0.71	-0.13	-1.08	-0.66	-0.93	-0.28
2017	-0.92	0.61	-1.87	-0.17	-0.3	0.13
2018	-2.17	-0.19	-2.4	-1.46	-1.65	-1.45
2019	0.71	0.33	-0.04	0.77	1.06	0.94
2020	-0.44	-1.12	-2.01	-0.63	-0.08	-0.56
2021	-0.36	-0.86	-1.46	-1.55	-0.29	-0.13


12 month SPI of Nandurbar Tehsil
Nandurbar SPI
Linear (Nandurbar SPI)
y = 0.0012x
R² = 0.0017
nandurbar SPI values
years(1961-2021)


12 Months SPI of Akkalkuwa tehsil
Akkalkuwa SPI
Linear (Akkalkuwa SPI)
y = 0.0012x
R² = 0.0017
Akkalkuwa SPI values
years(1961-2021)


12 month SPI of Akrani tehsil
Akrani SPI
Linear (Akrani SPI)
y = -0.0003x
R² = -0.032
Akrani SPI values
Years(1991-2021)


12 month SPI of Navapur tehsil
Navapur SPI
Linear (Navapur SPI)
y = 0.0012x
R² = 0.0017
Navapur SPI values
years(1961-2021)

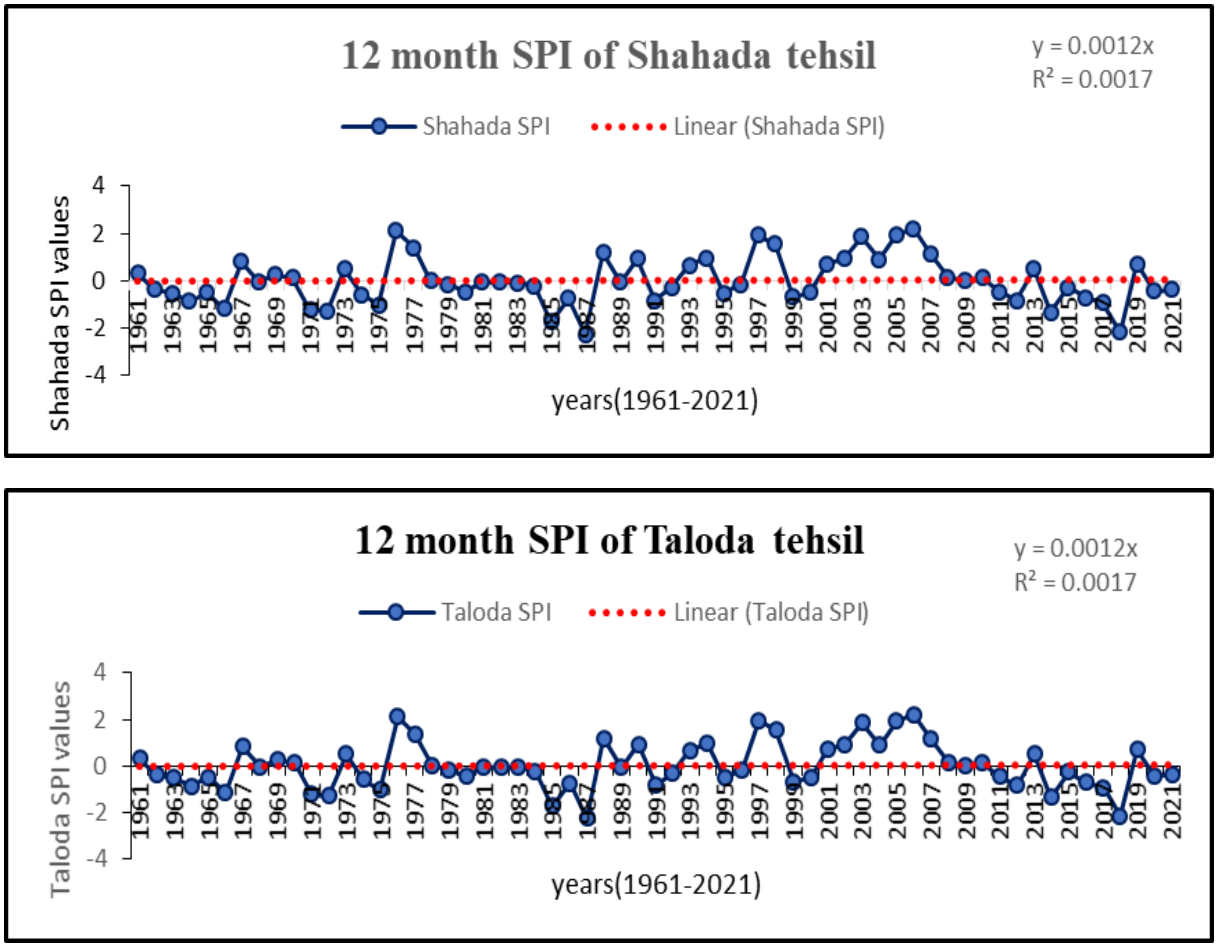


Fig 2: SPI for the period of 1961-2021 of different stations of Nandurbar district

4. Conclusions

Meteorological drought is being examined for various tehsils in the Nandurbar and Dhule districts during a12-month period (SPI 12). A negative SPI value suggested a drought (dry) situation, whereas a positive value indicated a wet condition.

For Nandurbar tehsil out of 61 years 9, 44 and 8 years observed at wet, near normal and dry or extreme drought condition respectively. Similarly, For Akkalkuwa tehsil out of 61 years 9, 42 and 8 years observed at wet, near normal and dry or extreme drought condition respectively. For Akrani tehsil out of 31 years 4, 21 and 6 years observed at wet, near normal and dry or extreme drought condition respectively. For Navapur tehsil out of 61 years 9, 12 and 10 years observed at wet, near normal and dry or extreme drought condition respectively. For Shahada tehsil out of 61 years 8, 43 and 10 years observed at wet, near normal and dry or extreme drought condition respectively. For Taloda tehsil out of 61 years 9, 40 and 12 years observed at wet, near normal and dry or extreme drought condition respectively.

It was concluded that in all stations during the last two decade (2001-2010, 2011-2019) the frequency of drought increased. In 2020 and 2021 the normal year significant condition is seen all over the tehsils except Akrani tehsil.

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