

The analysis of standardized precipitation index (SPI) in cotton growing Yavatmal district, Maharashtra

Abstract

The extremes of long term distribution of rainfall in drought hit hot semiarid agro ecoregion of Yavatmal district, Maharashtra have significant implications on rainfed cotton productivity and socioeconomic activity of farming community. In the present approach, the occurrence of week wise dry spells during crop calendar were examined with the computation of standardized precipitation Index (SPI) covering the period of 1971 to 2005. The standard week wise rainfall analysis further showed that 27th to 35th week have mean of 43±35.9 to 65±93.2 mm with coefficient of variation of 83.6 to 141.4 per cent. The week wise SPI values for 35 years were categorized into 6 classes such as near normal dry periods occurring 63 % followed by 19.73% of normal wet periods, 5.71% of severely wet periods, 4.72% of moderately wet periods, 4.28% of extremely wet periods and 2.41% of moderately dry weeks. The occurrence of prolonged dry spells with mean of 38 to 41.36 % in 36th to 44th week during critical cotton growth stages (branching and flowering stages) often coincides with reduction in lint yield. The study demonstrated that SPI considered as valuable tool to construct historical events of dry spells and its impact on soil water content in shrink-swell soils in drought hit areas.

Keywords: rainfall variability, dry spells, semi arid, Yavatmal, cotton growing

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Introduction

Drought indices such as Palmer Drought Severity Index (PDSI) and Standardized Precipitation Index (SPI) are important tools to monitor and to assess drought. The SPI has an advantage over others because of rainfall data alone and its variable time scale to describe drought conditions.¹ and calculated for 3, 6, 12, 24, and 48th month scales to reflect the temporal behaviour of the impact. SPI was applied to monitor the intensity and spatial extension of droughts at different time scales in South Africa.² and in Thessaly region of Greece.^{3,4} carried out a study on temporal and spatial analyses of meteorological drought using SPI and hydrological drought based on theory of runs. Similarly the severity and spatial pattern of drought in Purulia district, West Bengal was studied using SPI by Moumita Palchoudhuri and Sujata Biswas.⁵ Many studies have been done on the impact of changing precipitation pattern in India under climate variability and its regional pattern.⁶⁻⁹ Dry spell in Indian summer monsoon season causes to decrease in food production. Precipitation hardly follows a typical normal distribution for the whole duration of the year, therefore standardized precipitation index (SPI) has been computed to overcome this limitation for analyzing the wet and dry spell of precipitation (Shahid, 2009). There is scanty of long term rainfall analysis of rainfed cotton belt of Yavatmal district and in working out the wet and dry spells during crop growing season using SPI. Hence, an attempt has been made using to analyze spatial pattern of meteorological drought using SPI and analysed the seasonal changes of soil water dynamics in cotton growing shrink-swell soils of Yavatmal district, Maharashtra.

Materials and methods

Study area

Yavatmal district in the eastern vidharbha region of Maharashtra state (19°26' to 20°42'N latitude and 77°18' to 79°08'E longitude) consists of masses of Deccan trap basaltic plateaus with very steep sides and ridges or into flat-topped or pointed hills broken by broad

valleys and partially surrounded by plains in north west and southern half with east-west ranges of hills. This district comes under Deccan Plateau, Hot Semi-Arid Eco-Region (6) of Western Maharashtra plateau and hot moist semi-arid eco - subregion (Figure 1) Mandal et al.¹⁰ The mean annual rainfall ranges from 1,125mm of rain in eastern parts of Wani to 889 mm in western parts of Darwah and 1099.5 mm in central portion of Yavatmal showing an increasing trend as one proceeds from West to East. Yavatmal district has per capita ecologically productive land (ha) of about 0.16 ha with an ecological deficit of 0.84ha (534%). The water balance diagram of Yavatmal, Figure 1 shows that the black soils in the region are saturated with water and kept close to field capacity from June to August. It was observed in field surveys of this region and also 35 years of climatic data that soil water recovers from short dry spells with the receipt of intermittent rains and restore excess water in the top soil. Delayed sowing after 15th July resulted in drastic reduction in productivity (up to 40–50 and needs to be irrigated at 50–70% depletion of available soil moisture. In black cotton soils 'protective irrigation' must be provided for every 20 days, if rains fail, especially during the boll development stage.

Computation of SPI (Standardized precipitation index)

The SPI is the number of standard deviations that the observed value would deviate from the long-term mean, for a normally distributed random variable. The SPI calculation for any location is based on the long-term precipitation record that 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. The mathematical equation used to compute SPI as given under:-

$$\Pi = (X_i^c - \bar{X}) / \sigma$$

Where, Π stands for SPI, X for rainfall, and σ for standard deviation of X with subscript i signifying the location and superscript c the time scales (monthly or seasonal). Over bar on X indicates

mean climatology. Negative values of SPI indicate dry atmospheric condition or less rainfall while SPI less than -1 indicates drought. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and intensity for each month that the event continues. The positive sum of the SPI for all the months within a drought event can be termed the drought's "magnitude" as 2.0+extremely wet, 1.5-1.99 -very wet, 1.0-1.49 -moderately wet, -0.99 to +0.99 near normal, -1.0 - -1.49 moderately dry, -1.5 - -1.99 severely dry and >-2.0 extremely dry Drought is indicated by SPI values of -1 or below.¹¹

Results and discussion

Rainfall analysis

The thirty five years of rainfall data during the period of 1971 to 2005 was used to calculate monthly mean and standard deviations of rainfall. The data shows that August and July receives peak rainfall (250 to 320mm) with maximum deviation from mean. The rainfall begins in June and retreats in second week of October. The mean rainfall during September and October is 50 to 200 mm with maximum variations from the mean. Tehsil wise average rainy days and average rainfall (mm) is recored as mean rainfall of 1180 mm with 62 average rainy days in Yavatmal (Northern side) to minimum of 587 mm of rainfall in Ner with 47 rainy days (Table 1). The major crops are cotton (52% of total area) followed by Jowar (22%) and Redgram (6.6%). The monthly mean rainfall (mm) data shows that June, July and August are peak rainy months and recedes after September onwards. Standard week wise rainfall and rainy days shows that 27th to 34th week have mean amount of rainfall of 43.03 mm to 54.25 mm with CV of 35.98 to 53.9%. The mean rainy days for these weeks are four for 27th week to 3.8 for 34th week with CV of 50 to 52%. The gradual decrease in mean amount of rainfall from 36th to 45th week with CV of 137.5 to 280.47 %. Similar trends are noticed for rainy days with mean less than 1 from 43 to 45th week and CV of 180 to 237% (Table 2).

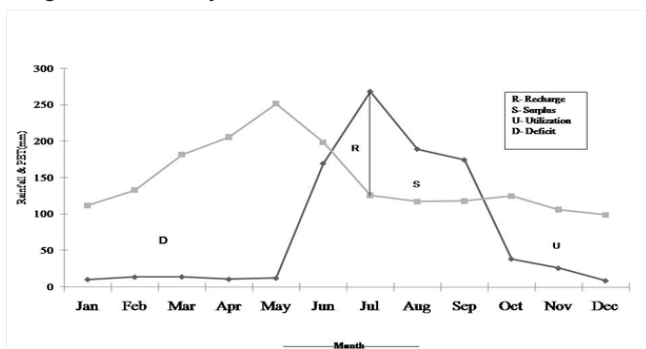


Fig.1. Water balance of Yavatmal district

Figure 1 Water balance of Yavatmal district.

Table 1 Tehsil wise rainy days and rainfall (mm)

Tehsil	Average		2004		Average /year (%)		Area under crops (ha)				Total cultivated area (ha)
	Rainy days	Rainfall (mm)	Rainy days	Rainfall (mm)	Cotton	Jowar	Red gram	Gram			
1.Ner	47	587	45	329	56	29870	8836	3539	80	50918	
2.Arni	47	594	34	282	48	29177	12215	4052	250	58337	
3.Kelapur	56	1052	46	830	79	26947	13954	4891	58	51483	
4.Babulgaon	55	909	43	462	51	26139	8960	5229	74	45211	
5.Ralegaon	57	1742	47	524	30	31956	12009	5884	822	58505	
6.Maregaon	55	882	40	327	37	23970	8748	4942	147	42417	
7.Jhari Jamni	50	653	48	324	50	24449	6227	1685	70	40812	
8. Kalamb	58	1275	43	388	30	28811	11726	4647	158	50418	
9.Darhwa	51	962	43	424	44	33925	19121	2865	156	63930	
10.Mahagaon	58	1309	46	451	34	31063	14226	2738	46	59158	
11.Ghatanji	53	1149	40	438	38	37968	13888	1167	73	56630	
12.Yavatmal	62	1180	58	662	56	30214	12133	3432	230	57639	
13..Digras	50	964	43	462	48	18923	8977	2685	167	37955	
14.Pusad	53	1066	39	477	45	28839	21280	3445	83	72326	
15.Umarkhed	55	669	39	357	53	24602	11324	2330	3123	78825	
16.Wani	62	1400	50	592	42	34428	9310	4725	565	59308	
Total area (ha)						461281	192934	58250	6102	883872	
Total area(%)						52.2	21.8	6.6	0.7		

Ha, hectare; mm, millimetre; %, per cent

Table 2 Standard week-wise descriptive statistics for amount of rainfall and rainy days

Standard week	Amount of rainfall				Rainy days			
	Sum (mm)	Mean (mm)	Standard deviation	Coefficient of variation (%)	Sum (mm)	Mean (mm)	Standard deviation	Coefficient of variation (%)
20	227.4	5.92	15.07	254.28	20	0.57	0.81	142.58
21	195.8	4.99	12.28	245.96	19	0.54	0.7	129.05
22	302	8	18.07	225.91	32	0.91	1.22	133.61
23	714.4	19.75	33.81	171.18	68	1.94	1.79	92.53
24	1846	52.04	76.53	147.06	107	3.05	1.75	57.17
25	2189	61.84	52.41	84.76	133	3.8	1.89	49.76
26	2421	68.44	82.72	120.9	140	4	2.03	50.72
27	1533	43.03	35.98	83.6	136	3.88	1.95	50.23
28	2517	71.12	66.32	93.26	161	4.6	1.83	39.87
29	2582	72.93	68.85	94.39	159	4.54	1.8	39.71
30	1971	55.47	57.69	104	144	4.11	1.99	48.52
31	2769	78.24	75.76	96.83	154	4.4	1.95	44.84
32	2584	72.92	63.78	87.46	163	4.65	1.71	41.96
33	1891	53.09	44.4	83.64	146	4.17	1.71	40.9
34	1933	54.25	53.9	99.35	134	3.82	1.99	52.04
35	2341	65.89	93.15	141.4	123	3.51	2.09	59.51
36	1388	38.62	53.09	137.5	109	3.11	2.08	66.89
37	821.6	22.42	26.4	117.7	87	2.48	2.12	85.27
38	1185	32.77	57.52	175.5	72	2.06	1.99	97.18
39	980.5	26.9	33.34	123.9	88	2.51	2.09	83.19
40	966.1	26.46	37.48	141.6	63	1.8	1.84	102.43
41	545	14.4	23.24	161.4	37	1.06	1.21	114.58
42	473.9	12.34	24.42	197.89	35	1	1.37	137.19
43	313.2	7.72	17.21	222.95	27	0.77	1.39	180.84
44	91.6	1.36	2.9	213.33	14	0.4	0.69	173.62
45	213.7	4.82	13.51	280.47	9	0.26	0.61	237.54

Precipitation index

The semiarid Yavatmal district, precipitation is quite variable and shows fluctuations in its distribution and quantity that have significant implications on agricultural productivity, food security, land use as well as ecological impacts. The week-wise SPI values were calculated during crop calendar for 35 years (1971 to 2005) and categorized into 6 classes (Table 3). The near normal dry periods are 63 % followed by 19.73% of normal wet periods, 5.71% of severely wet periods, 4.72% of moderately wet periods, 4.28% of extremely wet periods and 2.41

% of moderately dry weeks. The occurrence of the normal dry weeks exceeding more than 18 out of 26 weeks in 11 years and nine years with 8 wet weeks during 25th to 35th standard week of cotton growing period in the region with severe water stress for 40th to 45th standard week. The decadal rainfall data shows that there is gradual increase of number of occurrence of dry weeks from 1971 to 2005. It is observed from the data that there is increase of dry weeks more than 15 in 5 years from 1970 to 1980 but increased to 7 years from 1981 to 1990 and 9 years from 1991 to 2000. The dry weeks from 2001 to 2005 is almost normal drought like situations in the district.

Table 3 Year wise classification and characterization of standardized precipitation index in defining wet and dry weeks

Year	SPI Classification (Weeks)					
	Normal dry	Moderately dry	Normal wet	Moderately wet	Severely wet	Extremely wet
1971	18	1	4	1	1	1
1972	19	1	5	0	1	1
1973	14	1	8	1	2	1
1974	14	3	7	0	2	3
1975	14	0	7	3	2	0
1976	14	0	7	3	2	0
1977	16	1	7	0	1	1
1978	19	0	5	0	0	0
1979	15	1	6	2	2	1
1980	18	0	3	2	3	0
1981	15	0	7	2	2	0
1982	16	1	7	1	0	1
1983	11	1	7	0	1	6
1984	17	2	4	1	0	2
1985	19	1	3	1	1	1
1986	15	0	7	3	0	1
1987	20	0	3	3	0	1
1988	12	1	8	1	3	1
1989	17	0	5	2	0	2
1990	11	4	7	2	2	0
1991	21	0	3	1	1	0
1992	18	1	4	1	1	1
1993	17	0	5	3	0	1
1994	17	0	6	2	1	0
1995	16	1	2	2	2	3
1996	18	0	5	0	2	1
1997	16	2	5	0	1	2
1998	20	0	5	0	1	0
1999	15	2	3	1	2	3
2000	18	0	2	1	4	1
2001	15	1	6	0	3	1
2002	18	0	2	0	4	2
2003	15	0	6	1	3	1
2004	19	0	6	1	0	0
2005	18	1	3	2	2	0
number of weeks	575	22	180	43	52	39
Per cent of total	63.2	2.41	19.75	4.72	5.71	4.28

SPI, standardized precipitation index

Seasonal factors influencing soil water dynamics

The climate in Yavatmal district is hot Semi-arid eco-region with four seasons such as: hot season (March and extends up to the first week of June), south west monsoon season (June 2nd week to till the 1st week of September), post monsoon season (2nd week of September to 1st week of December) and cold season (2nd week of December to till February) with the mean daily minimum temperature at about 13°C. The cold waves over northern India sometimes affect the district and the minimum temperature may drop to about 5°C. It is reported that the monsoon sowing, 24th to 25th meteorological week (15 June to 5 July) is optimum for cotton sowing in the region with minimum of 30 to 40 % of rainfall. The shallow, medium deep and deep shrink-swell soils account for 35, 50 and 15% of total area with an average water content (AWC) ranging from 100–500 mm/m, a slope of 0.5–3%, well to moderately drained, with a soil depth ranging from 0.6 to 0.9 m and a pH of between 7.0–8.2 . The water retention curve of shrink-swell soils were similar with respect to depth of layers showing decreasing

soil water content with the increase of water suction applied. The water content decreased at 800kPa as the curves of cambic and slickensided horizons intersect with each other with soil water values of 25 to 50% from 1 to 800 kPa. At field capacity the water suction for top A horizon is 20 kPa but of 30 kPa for cambic and slicken sided zones (Figure 2). Depending upon the irregularities in soil water movement under hot semiarid climate, the shrink-swell soils experiences the period of wet stage and alternate wet - dry stages during cotton growing season. These soils have 12.7% of mean plant available water content with standard deviation of 2.95 % and negative relation with CaCO₃ content ($r = -0.41^*$, significant at 1% level). The clay and fine clay has a significant positive relation with water held at-33 kPa and -1500 kPa.¹² The plant available water can be approximated with multiple regression equation with R² value of 0.29, and F value of 2.25.

$$\text{Plant available water (\%)} = -6.39 + 0.156 (\text{sand}) + 0.283 (\text{silt \%}) + 0.189 (\text{clay \%}) - 0.433 (\text{organic carbon g/kg}) - 0.022 (\text{calcium carbonate, g/kg})$$

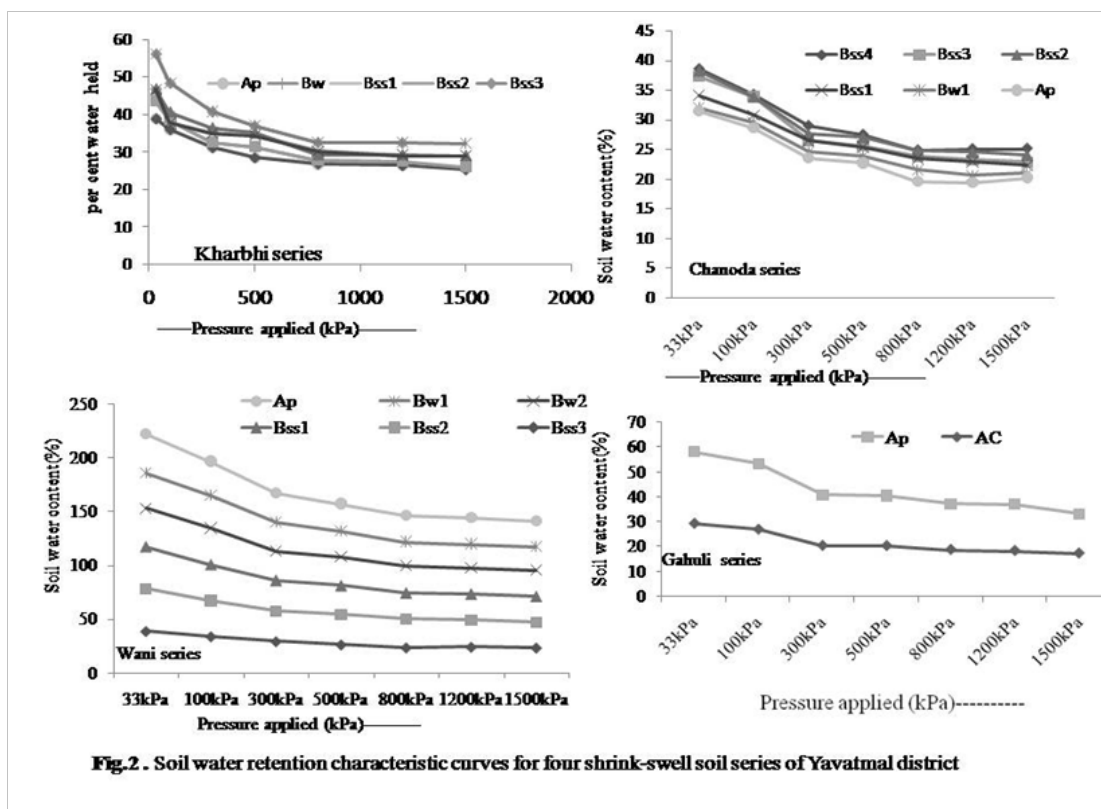


Figure 2 Soil water retention characteristic curves for four shrink- swell soil series of Yavatmal district.

The dry stage is often with at least 15 days of dry spells after September 15th and have rainfall of less than 20 % of total precipitation which often coincide with flowering and boll development stages of cotton. During this period, the top A horizon has low soil water content and reaches to wilting point. The stored water in subsoils is used by crop in times delay in rains and often experiences drought like situations with prolonged dry spells. The water stress occurs when cotton attains early bloom stage and is highly sensitive to water stress. The water content of shrink-swell soils in the region varies from the zone of 0-40cm at the rate of 14 to 32 % to 24 to 32% from the zone of 40-110cm and 28 to 32% from the zone of, 110-260cm.¹³ The change in soil water at 0-20cm in the cotton growing season (from June to February) is main supplying water source to support seedling

emergence to primordial branching stage and sensitive to water stress that ultimately influence lint yield. Late sowing because of the late arrival of the monsoon leads to a significant yield loss due to terminal moisture stress as well as low temperature effect in the months of December and January.¹⁴

Conclusion

In the present approach, the occurrence of week wise dry spells during cotton crop calendar were examined with the computation of standardized precipitation Index(SPI) for the period of 1971 to 2005. The weekwise rainfall analysis revealed that 63 % of crop season experiences near normal dry periods with prolonged dry spells in 36th to 44th week during critical growth stages (branching and flowering

stages). The study demonstrated that SPI considered as valuable tool to construct historical events of dry spells in drought hit areas and had strong influence on change in soil water at 0-20cm. It was observed that there is increase of dry weeks more than 15 in 5 years from 1970 to 1980 but increased to 7 years from 1981 to 1990, 9 years from 1991 to 2000 and normal drought like situation from 2001 to 2005.

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Conflicts of interest

I hereby declare that there is no financial interest and any other conflict of interests exist in this project work done by me at NBSS&LUP, Nagpur under the Institute approve project.

References

- McKee TB, Doesken NJ, Kleist J. The relationship of drought frequency and duration of time scales. *Eighth Conference on Applied Climatology, American Meteorological Society*. 1993;179–186.
- Rouault M, Richard Y. Intensity and Spatial Extension of Drought in South Africa at Different time Scale. *Water SA*. 2003;29(4).
- Loukas A, Vasiliades L. Probabilistic analysis of Drought spatiotemporal characteristics in Thessaly region, Greece. *Natural Hazards and Earth System Sciences*. 2004; 4(5/6):719–731.
- Edossa DC, Babel MS Gupta AD. Drought Analysis in the Awash River Basin, Ethiopia. *Water Resource Management*. 2010;24(7):1441–1460.
- Moumita P, Sujata B. Analysis of Meteorological Drought Using Standardized Precipitation Index – A Case Study of Puruliya District, West Bengal, India. *International Journal of Environmental, Ecological, Geological and Mining Engineering*. 2013;7(3):119–126.
- Ashok K, Saji NH. On the impact of ENSO and Indian Ocean dipole events on subregional Indian summer monsoon rainfall. *Nat Hazards*. 2009;42(2):273–285.
- Ghosh S, Luniya V, Gupta A. Trend analysis of Indian summer monsoon rainfall at different spatial scales. *Atmos Sci Lett*. 2009;10(4):285–290.
- Goswami BN, Venugopal V, Sengupta D, et al. Increasing trend of extreme rain events over India in a warming environment. *Science*. 2006; 314(5804):1442–1445.
- Pal I, Al-Tabbaa A. Regional changes in extreme monsoon rainfall deficit and excess in India. *Dynam Atmos Ocean*. 2009;49:206–214.
- Mandal C, Mandal DK, Srinivas CV, et al. Soil climatic database for crop planning in India. *National Bureau of Soil Survey & Land Use Planning (ICAR)*. 1999; 994p.
- Edwards DC, McKee TB. Characteristics of 20th Century drought in the United States at multiple time scales. *Climatology Report Number 97-2, Department of Atmospheric Science, Colorado State University, Fort Collins*. 1997;429–449.
- Bhaskar BP, Dipak Sarkar, Bobade SV, et al. Land resource evaluation for optimal land use plans in cotton growing yavatmal district, Maharashtra. *The Ecoscan*. 2011;1:251–259.
- Meng K, Zhang X, Sui Y, et al. Analysis of water characteristics of black soils over long term experimental researches in North East China. *Bulg J Plant Physiol*. 2004;30(3-4):111–120.
- Hebbar KB, Venugopalan MV, Rao MRK, et al. Effect of sowing dates and fertilizer levels on phenology, growth and yield of cotton. *Indian J Plant Physiol*. 2003;7(4):380–383.