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Pearl Millet Yield and Drought Assessment using Standardized Precipitation Index

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Abstract: Using Standardized Precipitation Index (SPI), an analysis on incidence and severity of droughts occurred in arid Rajasthan during the period 1960-2009 showed that the drought frequency varied from 32 years at Barmer to 24 years at Hanumangarh. The decades 1960-1969, 1980-89 and 2000-2009 experienced highest number of moderate and severe droughts. Year-wise and monthly SPI was also calculated for Barmer, Churu and Jodhpur, to know drought severity during the cropping period of July, August and September. To validate the SPI as a drought indicator, a multiple-linear regression analysis between SPI of July, August and September as independent variables and pearl millet grain yield as dependent variable was made. The regression model using SPI predicted pearl millet yield up to 83% of Barmer district, 47% of Churu district and 62% of Jodhpur district, thus the SPI is found useful as an indicator for monitoring drought conditions in arid Rajasthan

Key words: Standardized Precipitation Index, drought, pearl millet, arid Rajasthan.

Drought resulting due to failure of monsoon rainfall, is a common phenomena in arid Rajasthan, when rainfall falls below a critical level causing failure of crops and scarcity of drinking water resulting in setback to livelihood of people in the region. For quantification of drought, there are several indices viz., Aridity Index (Thornthwaite and Mather, 1955), Moisture Adequacy Index (Ramana Rao *et al*., 1981; 1983), Palmer Drought Severity Index (Palmer, 1965; 1968), Standardized Precipitation Index (McKee *et al*., 1995; Komuscu, 1999), etc. Earlier study on drought classification for 12 arid districts of Rajasthan based on moisture adequacy index taken at different crop phases (Ramana Rao *et al*., 1981) showed that the frequency of agricultural drought in the region was high and it varied from once in three years to alternate years as they identified 52 to 63 years as drought years over a period of 109 years (1901-2009).

Globally, the Standardized Precipitation Index (SPI) has gained wider acceptance for quantification of drought severity over a region. The main advantage of the SPI, in comparison with other indices, is that the SPI enables determination of both drought conditions at different time scales, as well as the monitoring of different drought types. This index captures the accumulated deficit (SPI<0) or surplus (SPI>0) of precipitation over a specified period, and provides a normalized measure (i.e. spatially invariant Z score) of relative precipitation anomalies at multiple time scales (McKee *et al*., 1995). In this paper, the SPI was used for quantification of drought in relation to pearl millet crop productivity in the arid region of Rajasthan.

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Materials and Methods

Analysis of temporal and spatial extent of drought occurred in arid Rajasthan during 50 years period (1960-2009) was carried out using the SPI of McKee *et al*. (1995), an index based on the probability of precipitation for any time scale. The SPI defined by Komuscu (1999) and McKee *et al*. (1995) with the following classes was used in the drought analysis:

$$SPI = \frac{X-\overline{X}}{\sigma}$$

where, X= Precipitation for the station; $\overline{X}$= Mean precipitation; σ= Standardized deviation.

SPI	Drought class
<-2.00	Extreme drought
-1.50 to -1.99	Severe drought
-1.00 to -1.49	Moderate drought
-0.99 to 0.00	Mild drought

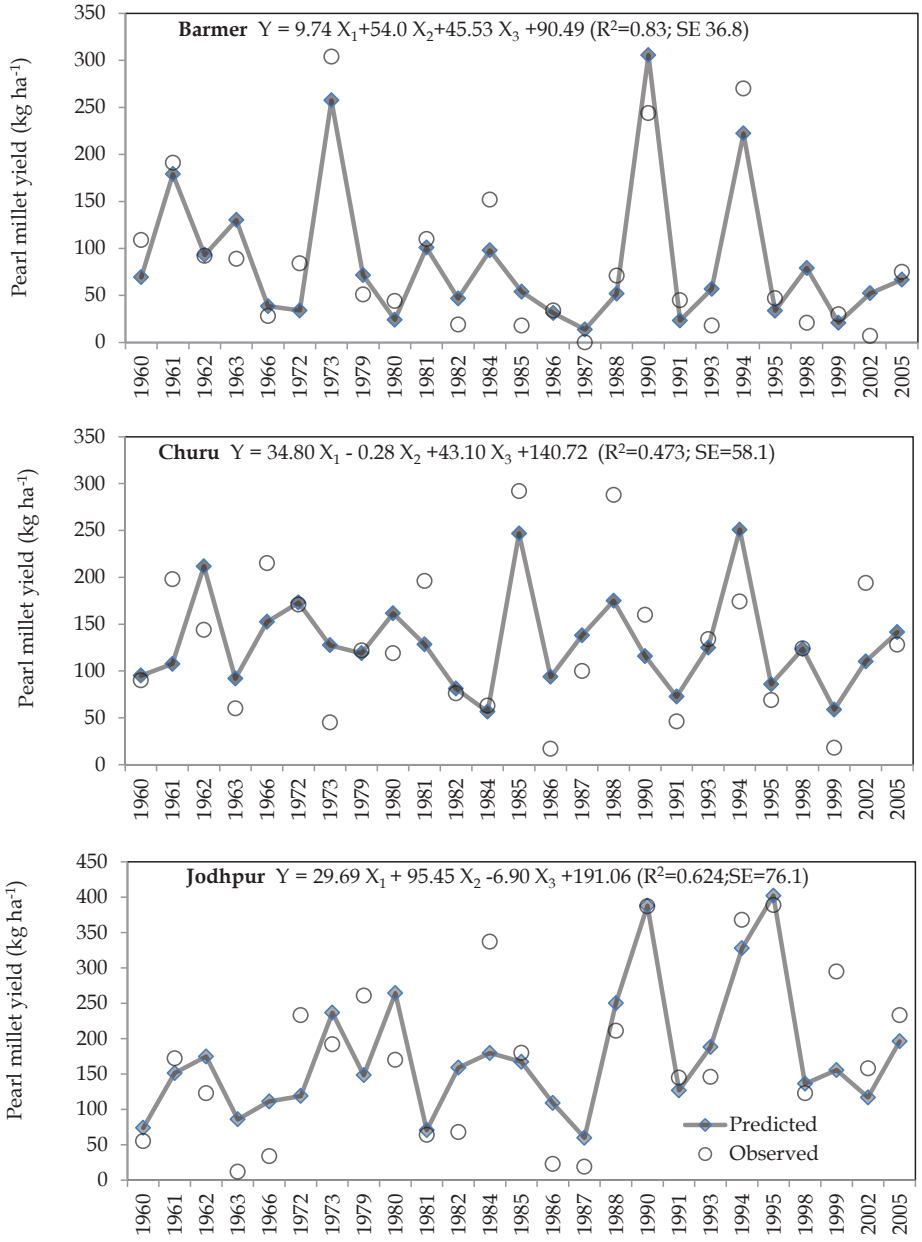

Fig. 1. Observed and predicted pearl millet yield using SPI.

The monthly and seasonal (June to September) rainfall data of 12 arid districts of western Rajasthan for the period 1960 to 2009 were used for calculation of SPI. The year-wise pearl millet yield data for the selected districts Barmer, Churu and Jodhpur for the period 1960-2009 was collected from the Directorate of Economics and Statistics, Jaipur, and related with SPI. A multiple-linear regression analysis between SPI of July, August and September as independent variables and pearl millet grain yield as dependent variable was made for three selected districts. The average seasonal (June to September) rainfall of these districts was 243 mm at Barmer, 314 mm at Churu and 331 mm at Jodhpur with an average pearl millet yield of 86 kg ha^{-1}, 130 kg ha^{-1} and 176 kg ha^{-1}, respectively.

Results and Discussion

Temporal and spatial variability of drought

The decadal drought frequency at 10 locations in arid Rajasthan during 1960-2009 as per the classification based on SPI is given in Table 1. Bikaner, Churu and Jalore

Table 1. Decadal-wise drought frequency (1960-2009) in arid Rajasthan

District	Drought frequency (Number of years)							
	Mild	Moderate	Severe	Total	Mild	Moderate	Severe	Total
		Barmer				Bikaner		
1960-1969	1	2	3	6	2	2	2	6
1970-1979	1	3	2	6	3	1	0	4
1980-1989	4	2	3	9	2	2	2	6
1990-1999	1	2	1	4	2	2	0	4
2000-2009	4	1	2	7	2	5	2	9
Total	11	10	11	32	11	12	6	29
		Churu				Ganganagar		
1960-1969	4	3	0	7	2	0	4	6
1970-1979	3	1	1	5	4	1	2	7
1980-1989	3	2	1	6	3	2	0	5
1990-1999	1	1	0	2	2	0	0	2
2000-2009	1	4	1	6	0	3	3	6
Total	12	11	3	26	11	6	9	26
		Hanumangarh				Jalore		
1960-1969	3	3	1	7	2	4	2	8
1970-1979	1	1	2	4	2	0	1	3
1980-1989	0	2	3	5	4	3	2	9
1990-1999	2	1	2	5	3	0	1	4
2000-2009	0	1	2	3	2	3	1	6
Total	6	8	10	24	13	10	7	30
		Jaisalmer				Jodhpur		
1960-1969	1	4	3	8	3	1	3	7
1970-1979	0	2	2	4	0	3	0	3
1980-1989	2	2	3	7	3	3	2	8
1990-1999	1	2	0	3	2	1	0	3
2000-2009	2	3	2	7	1	4	3	8
Total	6	13	10	29	9	12	8	29
		Jhunjhunu				Nagaur		
1960-1969		1	1	4	3	3	2	8
1970-1979	1	3	0	4	3	0	0	3
1980-1989	3	4	1	8	2	5	0	7
1990-1999	5	0	1	6	2	2	0	4
2000-2009	1	4	1	6	1	2	2	5
Total	12	12	4	28	11	12	4	27

experienced least number of droughts i.e., 25 years, whereas Barmer experienced highest number of droughts i.e., 32 years over the 50 years of study period. The analysis on drought also showed that the decades 1960-1969, 1980-1989 and 2000-2009 experienced highest number of moderate and severe droughts. This is the period that the arid Rajasthan was rated decreasing rainfall trend and higher air temperatures (Rao, 2010) during these three decades as compared to temperature and rainfall conditions over rest of the decades in this region. The district-wise meteorological drought classification showed that the eastern parts have a lower frequency of drought occurrence (25-29 out of 50 years) compared to the western parts of arid Rajasthan (28-32 out of 50 years; Table 1).

SPI and pearl millet production

To validate the SPI as a drought indicator, a multiple-linear regression analysis between SPI of July (X1), August (X2) and September (X3) as independent variables and pearl millet grain yield (Y, kg ha^{-1}) as dependent variable was made and the equations are given below:

Barmer Y = 9.741 X1 + 54.027 X2 + 45.533 X3 + 90.496 (R2=0.832; SE 36.8)

Churu Y = 34.807 X1 - 0.283 X2 + 43.103 X3 + 140.724 (R2=0.473; SE=58.1)

Jodhpur Y = 29.695 X1 + 95.456 X2 - 6.906 X3 + 191.063 (R2=0.624; SE=76.1)

Figure 1 shows the observed and estimated pearl millet yield for different years. It can be seen from figure that the scatter was high during the severe drought years viz., 1979, 1982, 1986, 1987, 1993 and 2002 thus indicating the regression equations using SPI can be used for pearl millet yield estimation, except during severe drought years. The regression model for prediction of pearl millet yield with SPI of July, August and September explained 83% of millet grain yield of Barmer district, 47% of Churu district and 62% of Jodhpur district indicating the SPI's usefulness as an indicator for monitoring drought in the arid Rajasthan.

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