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Trend of standardized precipitation index during Indian summer monsoon season in agroclimatic zones of India

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Abstract

Standardized precipitation index (SPI) was computed with CRU TS3.0 gridded $0.5 \times 0.5^{\circ}$ monthly precipitation dataset for each of the 14 mainland agroclimatic zones (ACZs) of India for individual months (June, July, August and September) and season (JJAS) of summer monsoon for 56 yr (1951–2006). Mann Kendall Trend Test with the representative SPI of the ACZs shows that only six out of 14 mainland ACZs have a significant trend during summer monsoon. Trans-Gangetic plain significantly gains wetness during the month of June. West coast plain and hill has a typical feature of significant increasing trend of wetness during June and increasing dryness during July. In general Upper Gangetic plain, Middle Gangetic plain, Central plateau and hill and Eastern plateau and hill have a significantly increasing drying trend during the whole duration of summer monsoon season.

1 Introduction

Rise and fall of human civilization are dependent on the prevalence of moderate climate in a region. Regions characterized by monsoonal circulation under changing climate pattern have undergone the destruction of many flourishing civilizations since prehistoric time (Gupta et al., 2006; Stone, 2009; Lawler, 2010). Asian summer monsoon has been conspicuous in continuing its changing trend in climatic extremes especially the drought proneness since long time. It also has a long reach impact on human lives spatially as far away of Mexico (Lawler, 2010). Indian subcontinent is going to become the most populous region and is supply source of grain basket of two most important food crops namely rice and wheat. Thus it requires a keen focus towards analyzing the impact of changing trend of climate especially drought proneness on Indian summer monsoon in relation to agro-climatic perspective. Uncertainties in onset and intra-seasonal oscillation of the Indian summer monsoon directly affect the food production with causing huge loss in grain yield during the drought spell. Many

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studies have been done on the impact of changing precipitation pattern in India under climate variability and its regional pattern (Ashok and Saji, 2009; Ghosh et al., 2009; Goswami et al., 2006; Pal and Al-Tabbaa, 2009). But delineation of homogeneous regions under climate variabilitywith reference to agriculture has been a debatable matter due to unwise delineation of the homogeneous regions based on single climatic variable, mostly the isohyets. Ghosh et al. (2009) has shown that usual way of delineating homogeneous region based only on rainfall is catastrophically a wrong assumption. Assumption of homogeneous Central Indian region in the study by Goswami et al. (2006) has been found to be contradicted by the study of Ghosh et al. (2009). Intra-region variability of the extreme of seasonal precipitation of summer monsoon is reported to be high for India and even many of meteorological subdivisions of India are found to be similar to their neighboring subdivisions (Pal and Al-Tabbaa, 2009). Homogeneous region delineation based on homogeneity of multiple climatic variables and other ecosystem related variables gives near natural homogeneous regions of study for the zone. Agroclimatic zones (ACZs) of India represent the homogeneous regions with respect to holistic natural resource endowment. It is delineated as par the studies and recommendations of scientific review based on homogeneity of multiple agroclimatic variables (viz. mean annual rainfall, mean seasonal rainfall, mean temperature, soil types, topography and cropping pattern) within each region and which are heterogeneous across various ACZs (Gupta, 2002; Sharma, 2009; Kashyap and Mathur, 1999; Matthews et al., 1995). Besides, delineation of regions of 15 agroclimatic zones of India which is based primarily on natural resource inventory offers a holistic and sustainable approach to typology for drought management. Agroclimatic regional planning (ACRP) approach was found to be the best technologically sound agricultural policy as well as sustainable system to raise natural resource capabilities (Kashyap and Mathur, 1999). Dry spell in Indian summer monsoon season causes to decrease in food production. Few studies have been done to address the changing aspects of food availability in global climate change (Aggarwal et al., 2004; Frolking et al., 2006; Gupta and Seth, 2007; Matthews et al., 1995; Narang and Virmani, 2001; Palmer-Jones, 2003).

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Agro-climatic zones (ACZs) signify the most effective homogeneous regions to study the impact of climate change on agro-ecosystem of regions. Various ACZs of India are shown in Fig. 2a and the detail description of various homogeneous characteristics of these zones is provided in Appendix A. In India erratic monsoonal rainfall often leads to increase the frequency and magnitude of dry spell at various spatio-temporal scale which causes meteorological drought, hydrological drought, agricultural drought and finally famine or socio-economic drought. Complex interplay of climatic variability of El Nino & Southern Oscillation (ENSO) activity and Indian Ocean dipole (IOD) aggravates the situation (Ashok and Saji, 2009).

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 (McKee et al., 1993; Shahid, 2009). Objective of this paper is to study the trend of SPI for the Indian summer monsoon season for the last 56 yr (1951–2006) in 14 mainland ACZs of India and to categorize the ACZs with significant increasing or decreasing SPI trend or ACZs with no trends in SPI. Besides, significantly drought vulnerable agroclimatic zones are found out which necessitate immediate attention by the global community of scientists, planners and administrators for its mitigation towards drought proneness and food insecurity.

2 Methodology

CRU TS 3.0 gridded monthly $0.5 \times 0.5^{\circ}$ resolution observed precipitation dataset made by Climate Research Unit of University of East Anglia (accessed in http://badc.nerc.ac.uk/data/cru/) for the period 1951–2006 has been used in this study. Standardized precipitation index (SPI) is computed to analyze the precipitation pattern over spatio-temporal dimension in India. SPI (McKee et al., 1993) is simply the difference of standardized precipitation from its mean for a specified time period divided by the standard

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deviation. SPI is computed as follows;

$$\Pi_i^c = \{(X_i^c - \overline{X}_i^c)/\sigma_i^c\}$$

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. As precipitation is typically not normally distributed for accumulation periods of 12 months or less, SPI overcomes this disadvantage by fitting an incomplete gamma distribution and then transforming it to normal distribution. Negative values of SPI indicate dry atmospheric condition or less rainfall while SPI less than −1 indicates drought. SPI values and corresponding moisture category are shown in Table 1. Numerous studies have shown that SPI is a well recognized index for meteorological drought monitoring purpose and it rightly indicates the probability of occurrence of normal, deficit or excess rainfall in a region (Khan et al., 2008; Loukas et al., 2008; Manatsa et al., 2008; Patel et al., 2007; Shahid, 2009). Well tested DOS executable program for computation of SPI was taken from the website of University of Nebraska-Lincoln (accessed in http://www.drought.unl.edu) and an IDL program was encoded to run this SPI computing executable in batch mode at remote sensing and image processing software IDL-ENVI™ version 4.5 interfaces. Thus, SPI was computed grid-wise for the Indian summer monsoon rainfall (ISMR) period for each individual month (viz. June, July, August and September) and the whole duration of the four months of summer monsoon season (viz. June-July-August-September i.e. JJAS) for the period from 1951 to 2006 over the domain of Indian subcontinent.

Frequency of occurrence of drought and the magnitude of its dryness in India have a high spatial and temporal variability. Drought is indicated by SPI values of −1 or below (Edward and McKee, 1996), therefore frequency of drought occurrence is computed by the total number of counting a grid-point has passed through SPI value less than or equal to −1 for each month and the whole summer monsoon season for 56 yr. Magnitude of drought has been computed by cumulatively adding up the SPI values less than or equal to −1 in each grid for each month and the whole summer monsoon season for

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56 yr. Thus high positive values in frequency give the highly drought frequented grids and the high negative values in magnitude give the maximum (in dryness) drought hit grids. Frequency and magnitude of drought computation have been done grid point wise ($0.5 \times 0.5^{\circ}$) instead of zonal average to show the spatial and temporal high variability of drought in India during monthly and the whole summer monsoon season period.

Agroclimatic zones of planning commission of Government of India have been taken as the homogeneous zones in Indian subcontinent for the present study. In consonance with the objective of this study of impact of changing climate on food insecurity the agroclimatic zones represent the homogeneous regions with respect to holistic natural resource endowment (Gupta, 2002; Sharma, 2009; Kashyap and Mathur, 1999; Matthews et al., 1995). Various agroclimatic zones (ACZs) are shown in Fig. 2a. In this study 14 mainland Agroclimatic Zones (ACZs) of India out of the total 15 ACZs were selected for SPI trend analysis leaving the island delineating ACZ (i.e. ACZ15) due to very small number of grids accounting for collecting observed precipitation by CRU TS 3.0 dataset over the narrow zone.

ArcGIS has been used to make a digitized map of ACZs of India. CRU gridded precipitation has been averaged over 14 ACZs for month (June, July, August and September) and season (June-July-August-September) for 56 yr with IDL-ENVI$^{\text{TM}}$ version 4.5. Monthly and Seasonal (JJAS) SPI have been computed for 56 yr (1951–2006) for 14 ACZs of India.

Nonparametric trend tests are extensively used for trend analysis for climatic variables and Mann Kendall test is such a nonparametric test for skewed-distributed atmospheric variable like rainfall (Mann, 1945; Helsel et al., 2006; Hamed, 2008; Wilks, 1995; Onoz and Bayazit, 2003). Onoz and Bayazit (2003) has shown that power of nonparametric Mann Kendall test is higher than the power of parametric t-test. Non-parametric Mann Kendall trend test was performed with the 56-yr time series SPI data for each ACZ to analyze the trend of SPI across ACZs for June, July, August, September and the whole summer monsoon period (JJAS), separately. Mann

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Kendall trend test reveals the significant spatio-temporal SPI trend for different ACZs for each month and the whole duration of the summer monsoon period. Well-tested DOS executable program for Mann Kendall Trend Test and Regional Kendall Trend Test were taken from the United States Geological Survey website (accessed in http://pubs.usgs.gov/sir/2005/5275/downloads/) for the present analysis. Finally, the significance test of output of the trend analysis was judged with two categories; highly significant with $p \leq 0.01$ and significant with $0.01 < p \leq 0.05$.

3 Results and discussion

Drought in India is characterized with a high spatio-temporal variability in frequency of occurrence and magnitude of dryness. Figure 1 shows the frequency and magnitude of drought (i.e. SPI < = −1) for the last 56 yr (1951–2006) for each of the summer monsoon month (June, July, August and September) and the whole duration of the summer season (JJAS) for India in a $0.5 \times 0.5^{\circ}$ grids. Variable frequency and the magnitude of dry spell results in complex interaction among multiple agroclimatic variables. Results (Fig. 1) show presence of high spatial and temporal variability of drought in India both in frequency and magnitude during the summer monsoon period of the last 56 yr (1951–2006). Maximum frequency of drought occurrence is found in a zone spanning from latitude 20.0–28.5° N and longitudes 77–88° E delineating Indo-Gangetic plain and eastern India during June. A spectacular zonal belt running from east to west nearly at the middle region of India between latitudinal ranges of 20 to 29° N is found with significantly less frequency of drought during July. Maximum drought frequency during August is found to be distributed in bipolar pattern with eastern (21–25.5° N, 83–86.5° E) and western (27–29° N, 72–78° E) regions of India. Drought frequency of September has shown a significant spiral zone of very high frequency of drought in west of 80° E meridian. Approximately 80° E meridian is found to be dividing India into two halves with the western part with very high drought frequency and the eastern half with less drought frequency during the September. Pattern of distribution of seasonal magnitude

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of drought is found conspicuously similar to the distribution of drought frequency of the respective month. High Seasonal frequency of drought is found to be distributed in irregular patches along central India, western India, peninsular India and the upper Gangetic plain. Seasonal magnitude of drought is found to have three nuclei of maxima along a zone (20–28° N, 76.5–81° E) covering upper Gangetic plain and central India. Thus, the frequency and magnitude of drought pattern in India during summer monsoon period reveals a high spatial and temporal variation requiring multivariate homogeneous regions for climate data analysis.

Mann Kendall trend analysis for the month of June shows that SPI trend for most of the ACZs of India is positive i.e. June precipitation has increased for the last 56 yr (Table 2). It also reveals that the positive SPI trend is significant for ACZ6 and ACZ12; positive SPI trend in ACZ6 is highly significant (at 1 % level) whereas ACZ12 is significant (at 5 % level). Pai et al. (2010) also reported that district wise long-term linear trend in SPI has an increasing trend sparsely distributed in India including parts of western ghats and northwest part of India. Dash et al. (2011) reported that all India, West and Central India and Northwest India homogenous zones have significantly increasing heavy rainfall events during June and the whole summer monsoon season. In the present study Mann Kendall trend analysis for the peak monsoon month July reveals a reverse trend than that of the June month. July SPI trend is negative for most of the ACZs of India with ACZ4, ACZ5 and ACZ12 having a high significant negative SPI trend (at 1 % level) (Table 3). SPI trend for the month of August has shown a similar trend like that of July with most of ACZs has a negative SPI trend. SPI trend for this month is significant for ACZ4 (5 % level), ACZ5 (1 % level) and ACZ8 (1 % level) (Table 4). SPI trend for the month of September has shown that most of the ACZs has a negative SPI trend with ACZ7 have a highly significant (at 1 % level) negative SPI trend (Table 5). Mann Kendall Trend analysis for the whole monsoon season (JJAS) shows that most of the ACZs of India (11 ACZs out of total 14 ACZs as shown in Table 6) has a negative SPI over the last 56 yr (1951–2006). Negative seasonal SPI is significant for four ACZs of India; ACZ4 and ACZ5 are highly significant (at 1 % level) whereas ACZ7

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& ACZ8 are significant at (5 % level) (Table 6). Intercept for the Mann Kendall median line is higher for ACZ4 (intercept 42.708) and ACZ5 (intercept 39.075) than the ACZ7 (intercept 25.387) and ACZ8 (intercept 27.3) (Table 6). Agro-climatic zones with significant trends (positive or negative) for various month of summer monsoon are shown in Fig. 2. There was no significant trend of SPI (neither positive or negative) in other agro-climatic zones except six agro-climatic zones viz. ACZ6, ACZ12, ACZ4, ACZ5, ACZ8, ACZ7. Two agro-climatic zones viz. ACZ6 (Trans-Gangetic Zone) and ACZ12 (western coast) have increasing precipitation during the onset month of Indian summer monsoon i.e. in June. Western coast has a typical trend that it has a significant (at 5 % level) increasing trend of precipitation during June followed by a highly significant (at 1 % level) decreasing trend of precipitation in July. In India most of the agro-climatic zones (numbering 10) have no significant trend of SPI during the whole summer monsoon season for the last 56 years except the four ACZs. Pai et al. (2010) reported a significant decreasing trend of SPI in Middle Gangetic plain and Eastern Plateau and Hill regions of India which is in agreement with the findings of this present study. Pal and Al-Tabbaa (2009) reported that magnitude of extreme monsoon rainfall deficiency has an increasing trend in India except northwest and peninsular India. Short spell rain events with heavy intensity have an increasing trend over India whereas long spell rain with moderate and low intensities has a decreasing trend (Dash et al., 2011). Short spell heavy and moderate intensity rain events are contributing increasingly to the total seasonal and the June rainfall of India (Dash et al., 2011). Present study also agrees with increasing SPI trend in Trans-Gangetic plain and Western Ghat during the month of June.

4 Conclusions

Present study shows that spatial distribution of frequency of occurrence and magnitude of dryness of droughts in India varies temporally during the months of Indian summer monsoon. Six agroclimatic zones (viz. Trans-Gangetic plain, Upper Gagetic plain,

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Middle Gangetic plain, Central plateau and hill, Eastern plateau and hill and West coast plains and hill regions) out of the 14 mainland ACZs of India have significant trend of SPI during any month of summer monsoon in India. Rest agroclimatic zones do not have any significant trend of precipitation pattern. Trans-Gangetic plain has a significant increasing trend of wetness with time during the June, but it does not have any trend during any other month of summer monsoon. West coast plain and hill region has a typical significantly increasing trend of wetness during the June alongwith a highly significant increasing trend of dryness during the July. This typical trend may have a tremendous impact on the agroclimatic condition of the west coast, especially the biodiversity hotspot zone of Western Ghat where fragile ecology prevails. Upper Gangetic plain, Middle Gangeticplain, Central plateau and hill zone and Eastern plateau and hill zones are the four agroclimatic zones which are affected significantly with increasing dryness during the whole summer monsoon period (JJAS). These four agroclimatic zones are thus very important with respect to drought management because these regions have a significantly high crop and population exposure to drought.

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Table 1. Standard Precipitation Index and corresponding moisture category (after Edward and McKee, 1996).

SPI Range	Definition
Greater than or equal to 2.0	Extremely wet
1.5 to 1.9	Very wet
1 to 1.49	Moderately wet
−0.99 to 0.99	Near normal
−1 to −1.49	Moderately dry
−1.5 to −1.9	Severely dry
Less than or equal to −2.0	Extremely dry

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Table 2. Mann Kendall Trend analysis of SPI for the month of June for the period 1951–2006 for ACZs of India (* shows the significant trend).

Agroclimatic Zones	Tau corr. Coeff.	S value	Z value	P value	Intercept	Slope
ACZ1	0.018	28	0.191	0.849	−2.457	0.0012
ACZ2	−0.118	−182	−1.279	0.201	17.188	−0.0087
ACZ3	−0.006	−10	−0.064	0.949	1.236	−0.0007
ACZ4	−0.168	−258	−1.816	0.069	23.814	−0.0121
ACZ5	0.034	52	0.360	0.719	−6.437	0.0033
ACZ6*	0.275	423	2.983	0.003	−38.436	0.0194
ACZ7	−0.006	−10	−0.064	0.949	0.417	−0.0002
ACZ8	0.152	234	1.647	0.100	−23.363	0.0118
ACZ9	0.103	158	1.110	0.267	−12.045	0.0061
ACZ10	0.121	186	1.307	0.191	−11.968	0.0061
ACZ11	0.017	26	0.177	0.860	−1.256	0.0006
ACZ12*	0.204	314	2.212	0.027	−22.179	0.0113
ACZ13	0.103	158	1.110	0.267	−16.567	0.0085
ACZ14	0.105	162	1.138	0.255	−13.324	0.0068

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Table 3. Mann Kendall Trend analysis of SPI for the month of July for the period 1951–2006 for ACZs of India (* shows the significant trend).

Agroclimatic Zones	Tau corr. Coeff.	S value	Z value	P value	Intercept	Slope
ACZ1	0.132	204	1.435	0.151	−18.276	0.0093
ACZ2	−0.042	−64	−0.445	0.656	5.149	−0.0026
ACZ3	−0.060	−92	−0.643	0.520	7.521	−0.0038
ACZ4*	−0.266	−410	−2.891	0.004	35.456	−0.0180
ACZ5*	−0.248	−382	−2.693	0.007	38.774	−0.0195
ACZ6	0.034	52	0.360	0.719	−4.074	0.0022
ACZ7	−0.125	−192	−1.350	0.177	15.340	−0.0077
ACZ8	−0.129	−198	−1.392	0.164	14.171	−0.0071
ACZ9	−0.094	−144	−1.011	0.312	11.749	−0.0059
ACZ10	−0.122	−188	−1.322	0.186	16.901	−0.0086
ACZ11	−0.075	−115	−0.806	0.420	8.541	−0.0044
ACZ12*	−0.269	−415	−2.926	0.003	32.910	−0.0166
ACZ13	−0.014	−22	−0.148	0.882	1.785	−0.0009
ACZ14	0.031	48	0.332	0.740	−5.586	0.0029

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Table 4. Mann Kendall Trend analysis of SPI for the month of August for the period 1951–2006 for ACZs of India (* shows the significant trend).

Agroclimatic Zones	Tau corr. Coeff.	S value	Z value	P value	Intercept	Slope
ACZ1	0.003	4	0.021	0.983	−0.499	0.0002
ACZ2	−0.084	−129	−0.905	0.366	11.610	−0.0059
ACZ3	0.086	132	0.926	0.355	−10.224	0.0052
ACZ4*	−0.206	−318	−2.240	0.025	27.696	−0.0140
ACZ5*	−0.296	−456	−3.216	0.001	46.432	−0.0235
ACZ6	−0.092	−142	−0.997	0.319	13.243	−0.0067
ACZ7	−0.077	−118	−0.827	0.408	9.818	−0.0049
ACZ8*	−0.244	−376	−2.650	0.008	30.653	−0.0155
ACZ9	−0.005	−8	−0.049	0.961	0.274	−0.0002
ACZ10	0.095	146	1.025	0.306	−8.017	0.0041
ACZ11	0.014	22	0.148	0.882	−1.556	0.0008
ACZ12	−0.035	−54	−0.375	0.708	4.641	−0.0023
ACZ13	0.003	4	0.021	0.983	−0.508	0.0002
ACZ14	−0.160	−246	−1.732	0.083	25.209	−0.0126

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Table 5. Mann Kendall Trend analysis of SPI for the month of September for the period 1951–2006 for ACZs of India (* shows the significant trend).

Agroclimatic Zones	Tau corr. Coeff.	S value	Z value	P value	Intercept	Slope
ACZ1	0.072	111	0.777	0.437	−10.179	0.0051
ACZ2	0.023	36	0.247	0.805	−3.974	0.0020
ACZ3	0.092	141	0.989	0.322	−11.487	0.0058
ACZ4	0.014	22	0.148	0.882	−2.644	0.0013
ACZ5	−0.047	−72	−0.502	0.616	5.867	−0.0029
ACZ6	−0.084	−130	−0.912	0.362	14.334	−0.0072
ACZ7*	−0.269	−414	−2.919	0.004	32.952	−0.0167
ACZ8	−0.099	−152	−1.067	0.286	11.586	−0.0058
ACZ9	−0.108	−166	−1.166	0.244	17.060	−0.0086
ACZ10	−0.029	−44	−0.304	0.761	4.882	−0.0025
ACZ11	−0.012	−18	−0.120	0.904	1.070	−0.0005
ACZ12	0.012	18	0.120	0.904	−2.662	0.0013
ACZ13	−0.090	−138	−0.968	0.333	18.226	−0.0092
ACZ14	−0.026	−40	−0.276	0.783	4.057	−0.0021

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Table 6. Mann Kendall Trend analysis of SPI for the season of summer monsoon (JJAS) for the period 1951–2006 for ACZs of India (* shows the significant trend).

Agroclimatic Zones	Tau corr. Coeff.	S value	Z value	P value	Intercept	Slope
ACZ1	0.048	74	0.516	0.606	−9.052	0.0046
ACZ2	−0.112	−172	−1.209	0.227	12.933	−0.0066
ACZ3	0.038	58	0.403	0.687	−6.596	0.0033
ACZ4*	−0.367	−565	−3.986	0.000	42.708	−0.0216
ACZ5*	−0.264	−406	−2.862	0.004	39.075	−0.0197
ACZ6	0.014	22	0.148	0.882	−1.696	0.0008
ACZ7*	−0.188	−290	−2.043	0.041	25.387	−0.0129
ACZ8*	−0.226	−348	−2.452	0.014	27.300	−0.0138
ACZ9	−0.070	−108	−0.756	0.450	12.115	−0.0061
ACZ10	−0.065	−100	−0.700	0.484	8.800	−0.0045
ACZ11	−0.022	−34	−0.233	0.816	2.135	−0.0011
ACZ12	−0.068	−104	−0.728	0.467	9.346	−0.0048
ACZ13	−0.056	−86	−0.601	0.548	9.576	−0.0048
ACZ14	−0.097	−150	−1.053	0.292	14.420	−0.0073

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Table A1. Description of Homogeneous characteristics of ACZs of India is given below.

No.	Agro-climatic Zones (ACZ) of India	Annual rainfall (mm)	Climate	Average Temperature (°C)		Representative soil
				Maximum	Minimum	
1.	Western Himalayas (ACZ1)	165–2000	Cold arid to humid	22.6	2.6	Brown hill, Alluvial meadow, Skeletal
2.	Eastern Himalayas (ACZ2)	1840–3528	Perhumid to humid	26.2	8.8	Alluvial, Red, loamy, Red sandy, Brown hill
3.	Lower Gangetic plain (ACZ3)	1302–1607	Moist subhumid to dry subhumid	35.5	11.0	Red and yellow deltaic alluvium, red loamy
4.	Middle Gangetic plains (ACZ4)	1211–1470	Moist subhumid to dry subhumid	30.5	16.8	Alluvial, loamy alluvial
5.	Upper Gangetic plains (ACZ5)	721–979	Dry subhumid to semi arid	35.8	12.8	Alluvial
6.	Trans-Gangetic plains (ACZ6)	360–890	Extreme arid to semi-arid	33.5	14.0	Alluvial
7.	Eastern Plateau and hills (ACZ7)	1271–1436	Moist subhumid to dry subhumid	32	19.7	Red sandy, red, yellow
8.	Central Plateau and hills (ACZ8)	490–1570	Semi-arid to dry sub humid	34.8	16.3	Mixed red and black. Red and Yellow, Medium black and alluvium
9.	Western plateau and hills (ACZ9)	602–1040	Semi-arid	36.8	16.6	Medium black, Deep Black
10.	Southern plateau and hills (ACZ10)	677–1001	Semi-arid	34.7	21.3	Medium black, Deep Black, Red sandy and Red loamy
11.	East coast plains and hills (ACZ11)	780–1287	Semi-arid to dry sub humid	30.0	21.0	Deltaic alluvium, Red loamy, Coastal, alluvium
12.	West coast plains and hills (ACZ12)	2226–3640	Dry subhumid to Perhumid	14.0	12.0	Laterite, Red loamy coastal alluvium
13.	Gujarat Plains and hills (ACZ13)	340–1793	Arid to dry subhumid	40.0	11.3	Deep black, coastal alluvium, Medium black
14.	Western dry (ACZ14)	395	Arid to Extreme Arid	45.0	2.0	Desert, gray, brown
15.	Islands (ACZ15)	1500–3086	Humid	29.9	22.5	Gray, Brown

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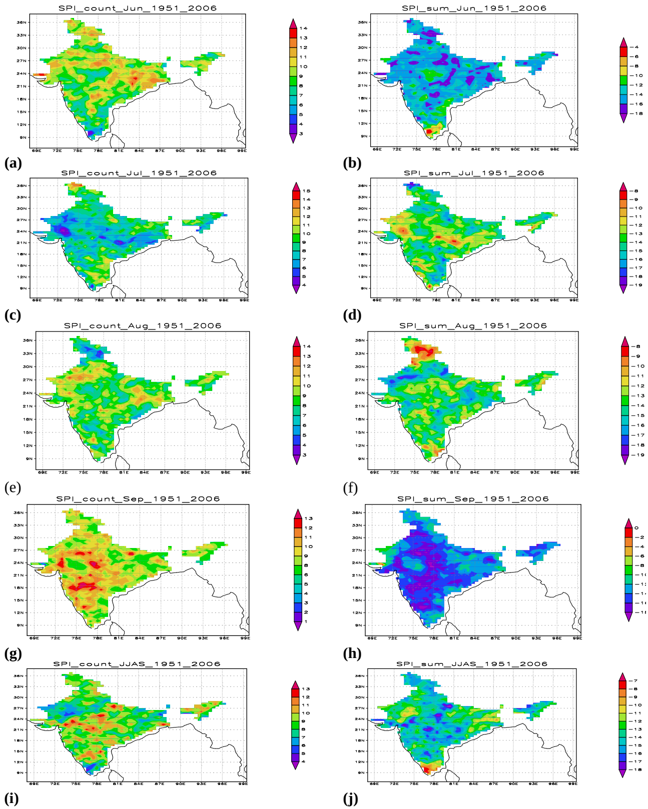

Fig. 1. SPI frequency (count) and magnitude (sum) for June, July, August, September and JJAS for the period 1951–2006. **(a)**, **(c)**, **(e)**, **(g)** and **(i)** represent the frequency of SPI < -1 for June, July, August, September and JJAS, respectively; **(b)**, **(d)**, **(f)**, **(h)** and **(j)** represent the magnitude of SPI for June, July, August, September and JJAS, respectively.

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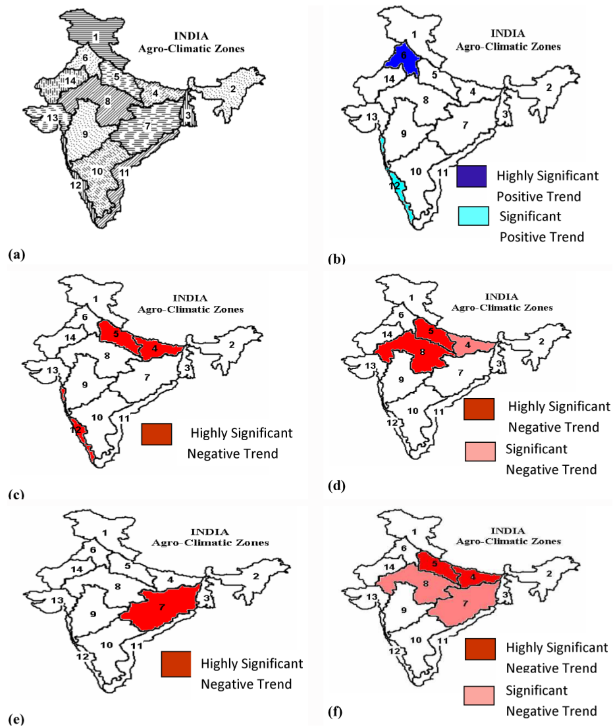

Fig. 2. Agroclimatic zones (ACZs) of India which show highly significant ($p \le 0.01$) and significant ($0.01 < p \le 0.05$) positive and negative SPI trend in Mann Kendall Trend test during various months of summer monsoon for the period 1951–2006; **(a)** 14 ACZs of India; **(b)** ACZs of Significant SPI trend for June month; **(c)** ACZs of Significant SPI trend for July month; **(d)** ACZs of Significant SPI trend for August month; **(e)** ACZs of Significant SPI trend for September month; **(f)** ACZs of Significant SPI trend for the whole summer monsoon period (JJAS).

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