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Relationship of ENSO and Standardized Precipitation Index (SPI) to Characterize Drought at Different Locations of Punjab, India

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Drought is generally considered as a deficiency in precipitation over an extended period usually a season or more. It is a natural hazard that differs from other hazards since it has a slow onset, evolves over months or even years and its severity is often difficult to determine. Standardized Precipitation Index (SPI) is a widely used index to characterize drought on a range of timescales. In this study SPI was calculated annually and season (*Kharif* and *Rabi*) wise to correlate drought with ENSO events at different locations of Punjab viz. Amritsar, Ballowal Saunkhri, Bathinda, Ludhiana and Patiala. The historical data of rainfall for different locations of Punjab viz. Amritsar (1971-2017), Ballowal Saunkhri (1984-2018), Bathinda (1971-2018), Ludhiana (1971-2018) and Patiala (1971-2018) were collected from the Department of Climate Change and Agricultural Meteorology, PAU, Ludhiana and Met Centre, India Meteorological Department, Chandigarh. It was found that at all the

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locations very strong *El Nino* of 1997-98 resulted in above normal rainfall. Drought like conditions was observed during *El Nino* years as value of SPI was negative but with few exceptions. The SPI values were positive during *La Nina* and neutral years. Droughts during *kharif* season were found to be more related to *El Nino* years compared to *La Nina* years.

Keywords: Standardized precipitation index; monsoon; El Nino; La Nina; drought.

1. INTRODUCTION

Drought is the consequence of a natural reduction in the amount of precipitation over an extended period of time, usually a season or more in length, often associated with other climatic factors (viz. high temperature, high winds and low relative humidity) that can aggravate the severity of the drought event. According to IMD, it was categorized in to mild, moderate and severe. Agriculture is highly vulnerable to drought and even its occurrence in shortest possible duration can have a visible negative impact. The monsoon season (June, July, August and September) rainfall is very critical for agriculture. The June and July rainfall is very crucial for sowing of *kharif* crops and August rainfall is vital for the vegetative and reproductive growth of different crops. Rainfall pattern in these four months plays a greater role in the occurrence of agricultural drought.

A drought index is a prime variable for assessing the effect of drought and defining different drought parameters, which include intensity, duration, severity and spatial extent. Every index has its own problems and constraints and thereby it is difficult to devise a single index for monitoring drought over large geographic area which has their own distinct climate and topographic identities from region to region. Among different drought indices of the recent times, standardized precipitation index is found to serve better in monitoring drought in effective way. It provides a better spatial standardization with respect to extreme drought events [1,2]. Positive rainfall deviations (when actual rainfall is more than normal) are associated with positive SPI values indicating wetness and negative rainfall deviations (when actual rainfall is less than normal) are associated with negative SPI values indicating mild to severe drought. The more negative deviations from normal rainfall more is severity of drought. McKee *et al.* [3] also defined the criteria for a drought event for any of the time scales. A drought event occurs any time; the SPI is continuously negative and reaches intensity where the SPI is -1.0 or less. The event ends when the SPI becomes positive. Thereby using SPI duration and intensity of drought can precisely be defined. Most of the drought conditions of the Indian summer monsoon rainfall (ISMR) are associated with *El Nino* (13 of the 18 years) indicating that about 72 per cent of drought years were associated with Pacific region. Among the 13 drought years, 7 of them were associated with strong *El Nino*. The entire north India and most of the regions of central India were under below normal conditions Varikoden *et al.* [4]. Zang *et al.* [5] demonstrated that vegetation condition index (VCI) at anthesis stage was a good indicator for final yield loss in wheat due to drought. The study attempted to identify the spatio-temporal extent of agricultural drought over Mewar region of Rajasthan. SPI was used as a drought indicator which was found effective in analyzing the short term droughts, causing significant impact on agriculture. Analysis indicated that region experienced short term droughts frequently during study period, in which mild droughts occurred more frequently and extreme droughts were least [6]. Keeping all this in view a study was planned to characterize drought at micro level on the basis of global weather phenomenon i.e *El Nino* and *La Nina*. The rainfall data was analyzed to compute SPI for different locations of Punjab viz. Amritsar, Ballowal Saunkhri, Bathinda, Ludhiana and Patiala. It will be helpful in developing mitigation strategies for a particular location for future challenges that may arise due to drought like conditions.

2. METHODOLOGY

2.1 Study Area

Punjab state represents 1.5 per cent geographical area of India with its latitudinal extent from 29° 33' to 33°34' N and longitudinal extent from 73°53' to 76°56'E. The state is divided into six agro-climatic zones on the basis of physiography, amount of rainfall, moisture index and underground water quality and quantity (Fig. 1). The five different locations viz. Amritsar, Ballowal Saunkhri, Bathinda, Ludhiana and Patiala were selected for this study. The location taken from zone two was Ballowal Saunkhri which is located in undulating plain region of Punjab. Amritsar, Ludhiana and Patiala are the locations taken from zone three i.e. central plain region which covers almost 36 per cent area of state. Bathinda is situated in the agro-climatic zone four of Punjab. This zone comprises of western plain region covering almost 19 per cent area of the Punjab.

Long term daily rainfall data of Ballowal Saunkhri (1984-2018), Bathinda (1971-2018) and Ludhiana (1971-2018) were collected from the Department of Climate Change and Agricultural Meteorology, PAU, Ludhiana. The rainfall data of Amritsar (1971-2017) and Patiala (1971-2018) were collected from Met centre, India Meteorological Department, Chandigarh. The *El Nino/ La Nina* events data were retrieved from Golden Gate Weather Services (2019).

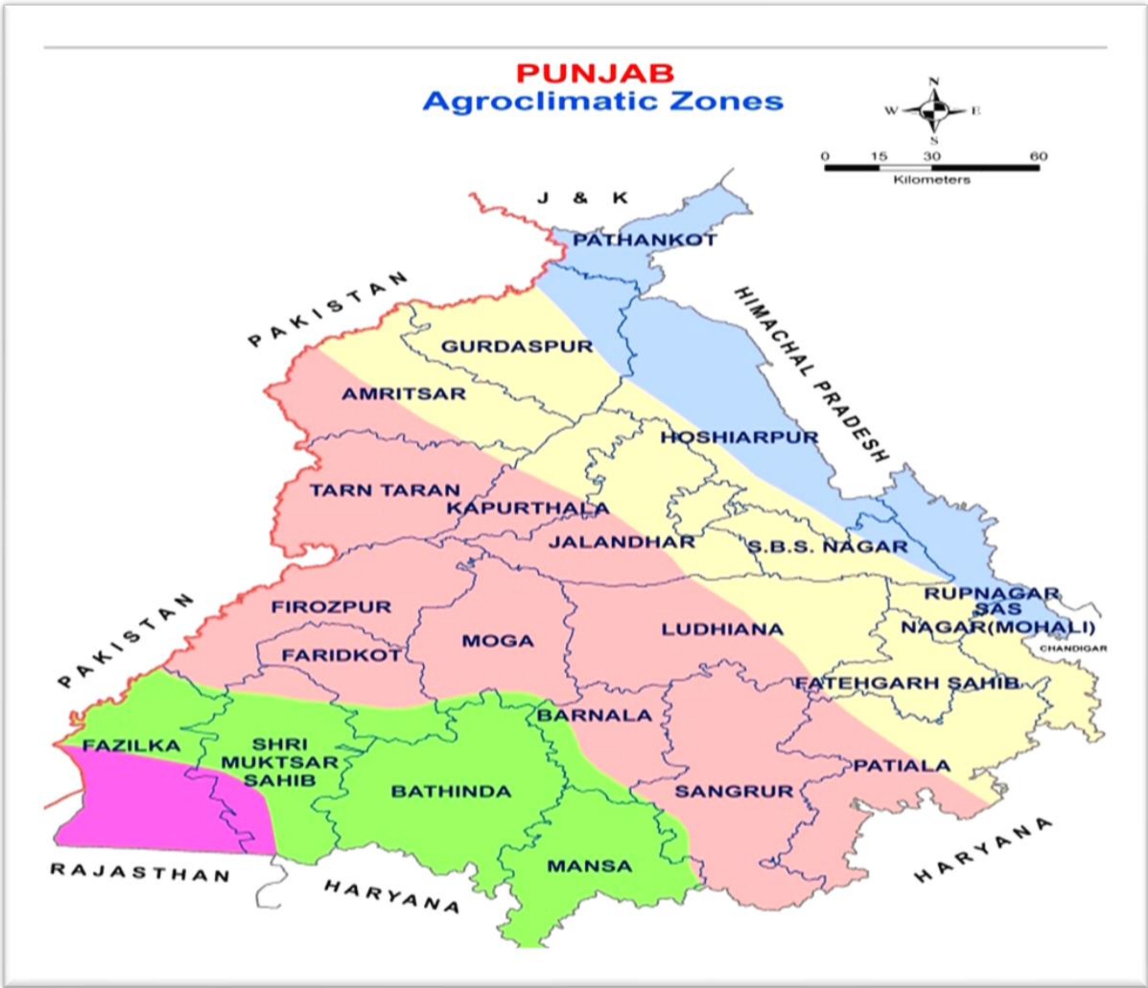


Fig. 1. Map of different locations of study area

Table 1. Period of study, latitude, longitude, height (amsl) of various locations of Punjab

Location	Period of study	Latitude	Longitude	Height above mean sea level (m)
Amritsar	1971-2017	31°63’N	74°87’	234
Ballowal Saunkhri	1984-2018	31°09’N	76°38’	355
Bathinda	1971-2018	30°21’N	74°94’	207
Ludhiana	1971-2018	30°54’N	75°48’	247
Patiala	1971-2018	30°33’N	76°38’	258

2.2 Evaluation of Drought Using SPI

Standardized precipitation index is defined as the difference of the precipitation from the mean for a particular time scale, then dividing it by standard deviation. There are various advantages of using SPI compared to other drought indices. It is simple to calculate, easy to understand; spatially invariant and it can be calculated for any period of interest. SPI should be used to characterize meteorological droughts by all National Meteorological and Hydrological services around the world as suggested by WMO Hayes *et al.* [7]. Pai *et al.* [8] reported that SPI is better index than per cent normal for monitoring district wise drought in India. Positive rainfall deviations (when actual rainfall is more than normal) are associated with positive SPI values indicating wetness and negative rainfall deviations (when actual rainfall is less than normal) are associated with negative SPI values indicating mild to severe drought. The more negative deviation from normal rainfall more is the severity of drought. The following formula was used to calculate SPI [3]. They classified SPI values to define drought intensities (Table 2).

Table 2. Drought categories for SPI values

SPI Values	Drought Categories
2.0+	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-.99 to .99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 and less	Extremely dry

$$SPI = \frac{a - A}{SD}$$

Where,

a - Current precipitation for a given period
A - Long term normal of precipitation for the same period
SD - Standard deviation of precipitation for the given period

3. RESULTS AND DISCUSSION

3.1 Standardized Precipitation Index

SPI monitors precipitation deficit, the primary cause for drought development but takes no account of the impact. Despite of negative SPI, a region could be free from water-stress and might maintain normal vegetation. Thus, negative SPI anomalies not always correspond to drought. On the contrary, drought may appear in hydrologic and vegetative spheres in spite of positive SPI [9]. The SPI for different locations of Punjab viz. Amritsar, Ballowal Saunkhri, Bathinda, Ludhiana and Patiala were calculated as under:

3.2 Amritsar

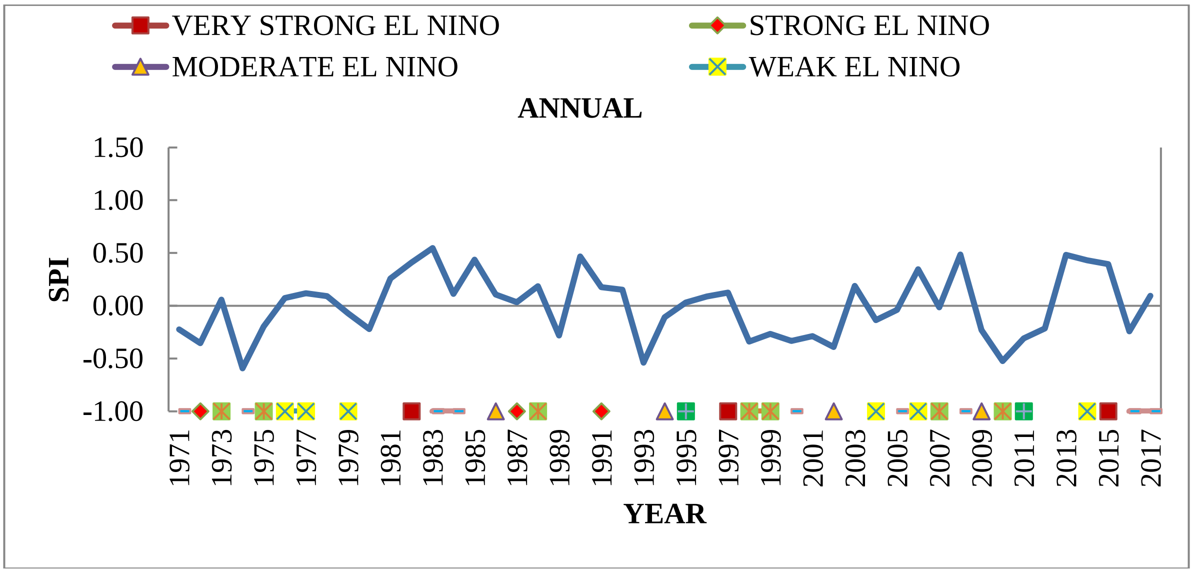
The SPI was calculated at Amritsar and presented in Fig. 2. During three very strong *El Nino* years there were no drought conditions as SPI values were found to be positive. Drought conditions prevailed continuously from 1998-2003 which included two strong *La* Nina and one moderate *El Nino* year. Drought persisted for long time from 2009-13. It included two moderate *El Nino* years, one strong and one weak *La Nina* year. During normal years (1980-81, 1989-90 and 1993-94) also dry conditions occurred at Amritsar. During *kharif* season drought conditions occurred mostly in *El Nino* years (1972-73 and 2009-10). There were two periods of continuous drought i.e 1998-2006 which included *La Nina* and neutral years along with *El Nino* years and 2009-12 including one *El Nino* years, two *La Nina* years and two neutral years. It can be inferred that during *kharif*, drought years were not always related to *El Nino* event. During *rabi* season in earlier decades drought like conditions occurred in *La Nina* and neutral years but 2001 onwards *El Nino* has played a significant role in causing drought (2009-2013 and 2015-2017). Droughts during *kharif* season were found to be more related to *El Nino* years compared to *La Nina* years. Chattopadhyay and Bhatla [10] re-examined the ENSO/ anti-ENSO events and their relationship with Indian summer monsoon and concluded that the 70 per cent drought events were ENSO related.

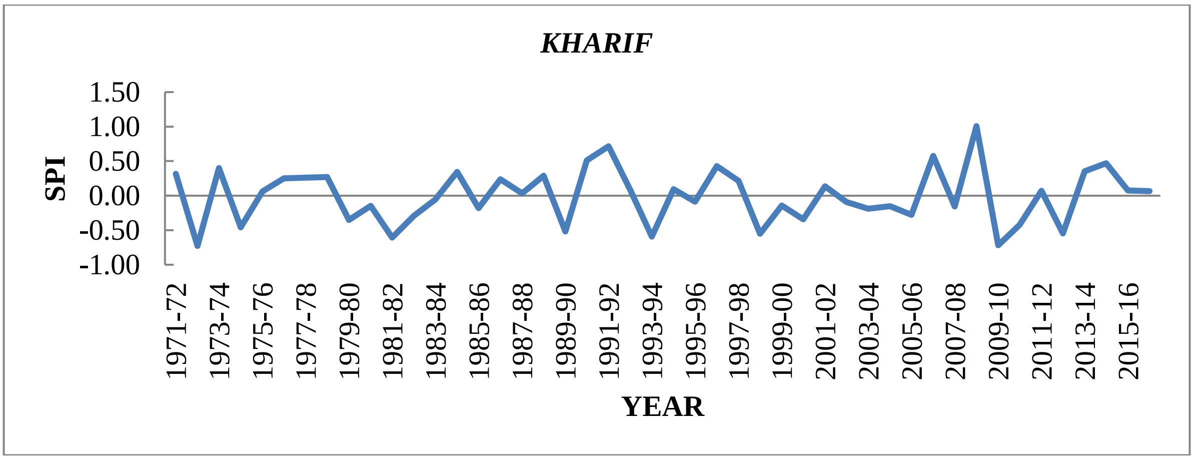
3.3 Ballowal Saunkhri

The SPI for Ballowal Saunkhri was calculated from 1984-2018 and presented in Fig. 3. The annual SPI showed drought like conditions in 2002-03 and 2009-10 which were moderate *El Nino* years whereas 1997-98 which was very strong *El Nino* year resulted in the highest positive value of SPI which means conditions were wet. Most of the *La Nina* years resulted in surplus rainfall. During *kharif* almost similar trends were observed. *El Nino* years i.e. 2002-03, 2006-07, 2009-10 and 2014-16 resulted in drought at Ballowal Saunkhri. The highest positive value was observed during strong *La Nina* year 1988-89. During *rabi* season excess rainfall occurred during *El Nino* years (1997-98, 2004-05, 2006-07 and 2014-15) as the value of SPI was positive during these years. The *La Nina* and neutral years caused drought conditions at Ballowal Saunkhri with exception of 2014-15 which was a weak *El Nino* year. Kane [11] reported that periodicities and ENSO relationships of the seasonal rainfall over six major divisions of India for the period (1848-1995) found an overwhelming association between warm events with drought and cold events with floods.

3.4 Bathinda

The SPI was calculated from 1971-2018 for Bathinda (Fig. 4). The annual SPI values showed that *El Nino* year (1994-95, 2002-03 and 2009-10) were found to be drought years whereas *La Nina* year also caused drought like conditions. During *kharif* season very strong *El Nino* years 1997-98 and 2015-16 resulted in excess rainfall at Bathinda. The strong, moderate and weak *El Nino* years caused drought like conditions as the value of SPI was negative during these years (1972-73, 1979-80, 1991-93 and 1994-95). During *rabi* season, very strong *El Nino* years i.e. 1982-1983 and 1997-1998 resulted in excess rainfall. The *La Nina* events caused drought like conditions in 1974-75, 1984-85 and 2016-17 whereas *El Nino* year of 2009-10 and neutral years also caused drought. The variation in frequency of temperature extremes in the East Asia–west Pacific region was found to be strongly related with *El Nino* – Southern Oscillation. The number of hot days and warm nights increased substantially in the year after the onset of *El Nino* events. The number of cool days and cold nights tend to decrease, although the relationship with *El Nino* was weaker for these variables [12].





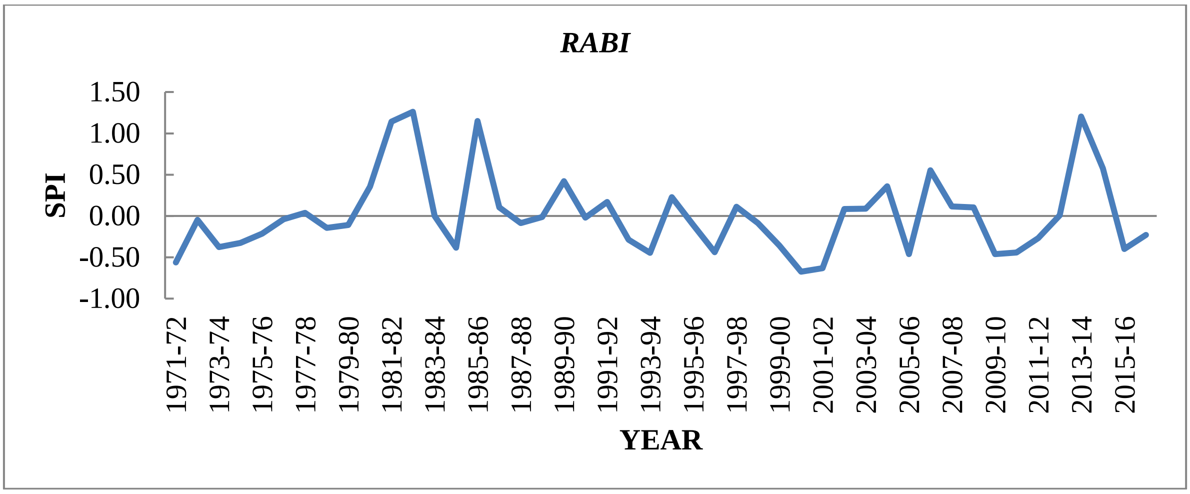
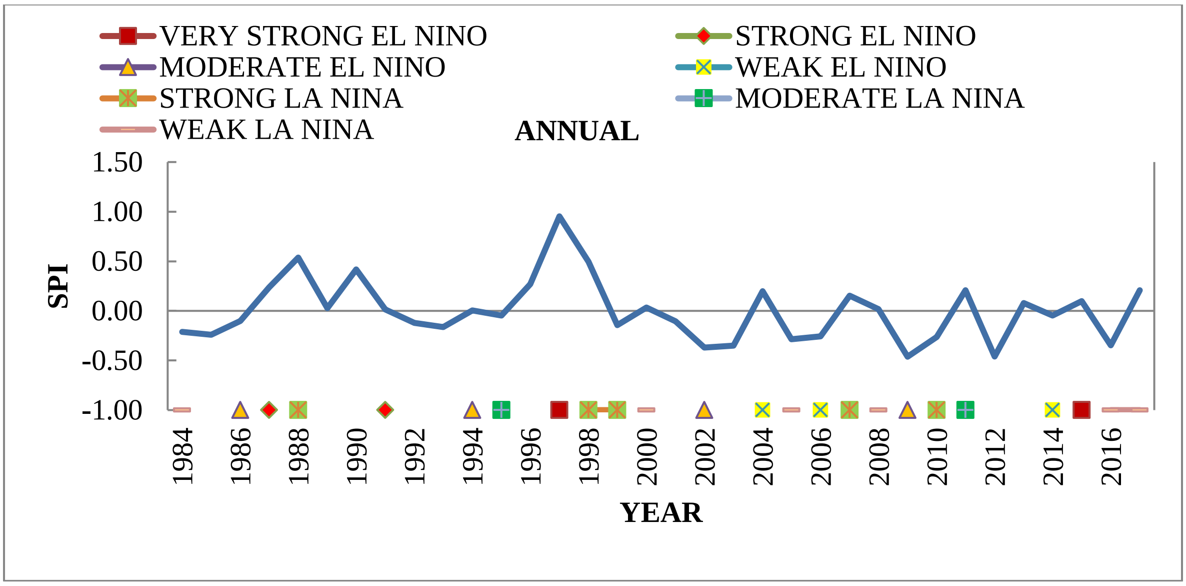
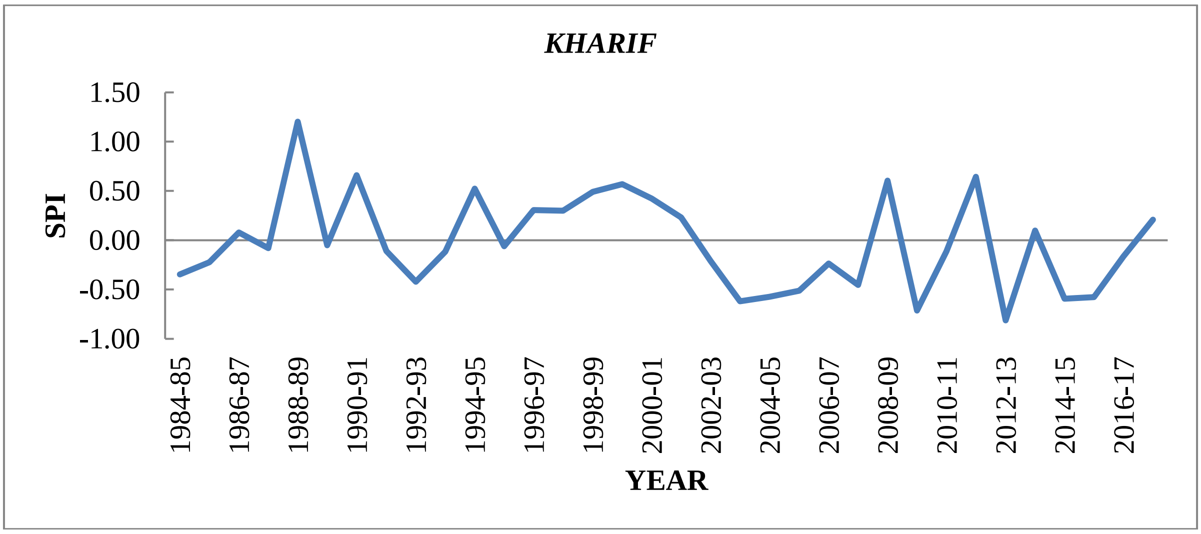


Fig. 2. Standardized precipitation index at Amritsar (Annual, *Kharif* and *Rabi*)





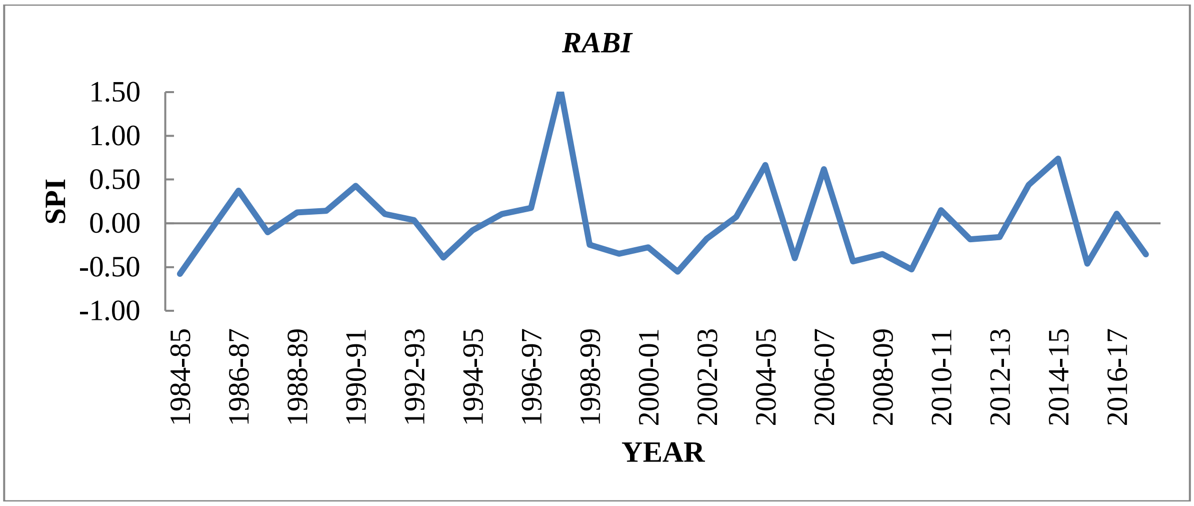
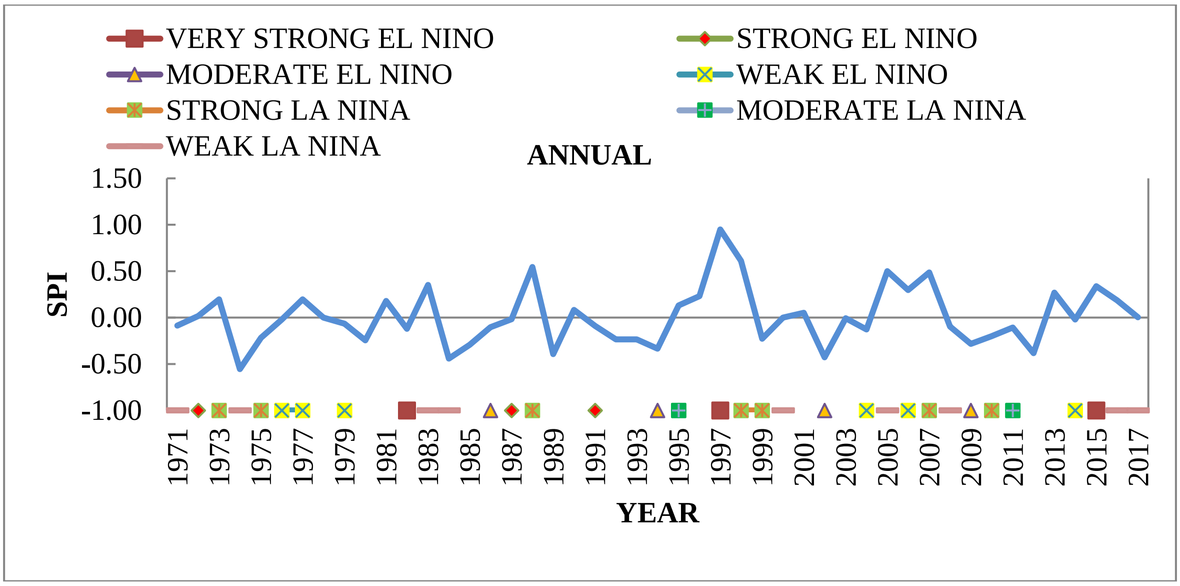
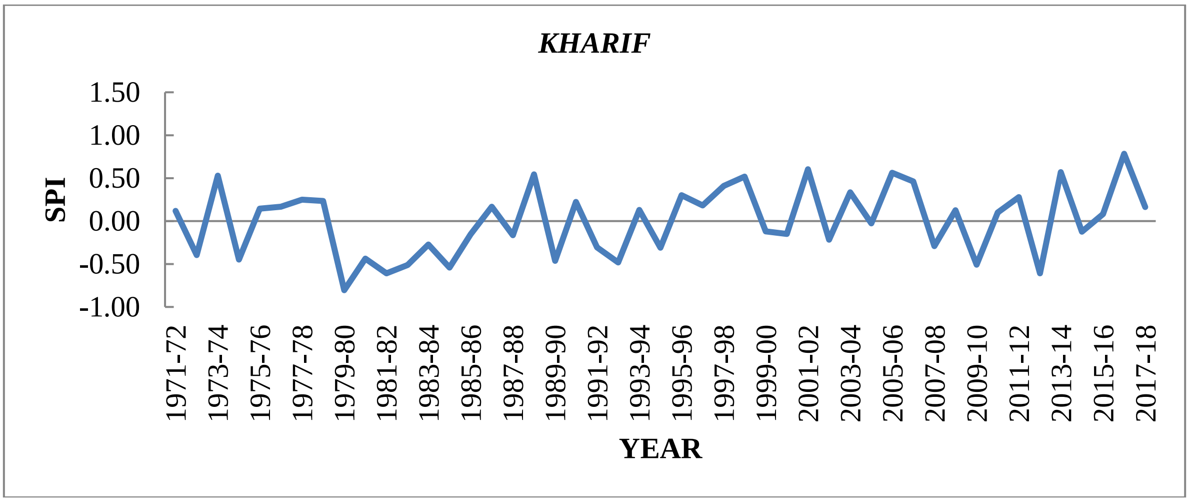


Fig. 3. Standardized precipitation index at Ballowal Saunkhri (Annual, *Kharif* and *Rabi*)





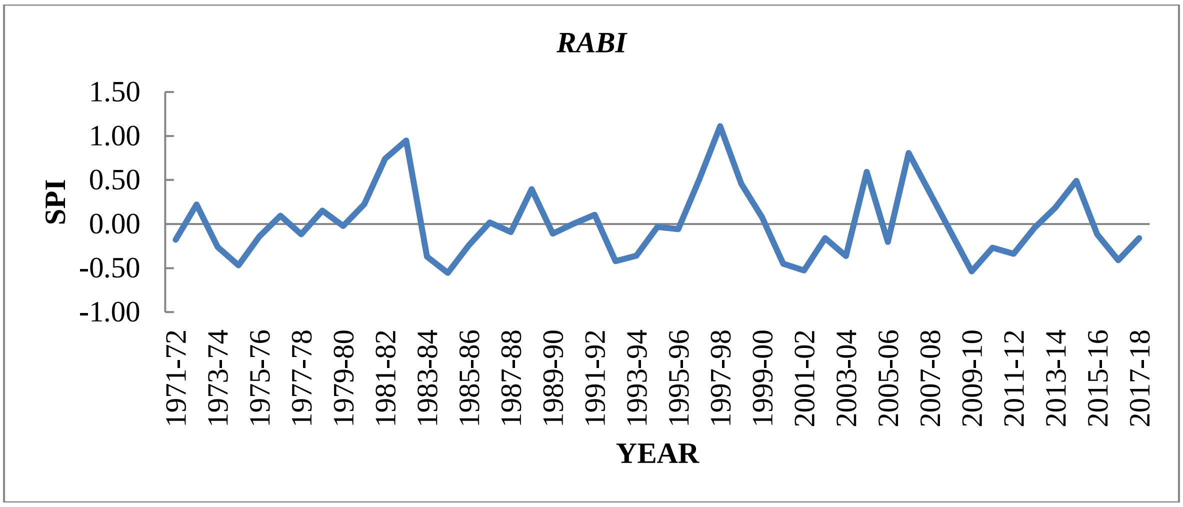
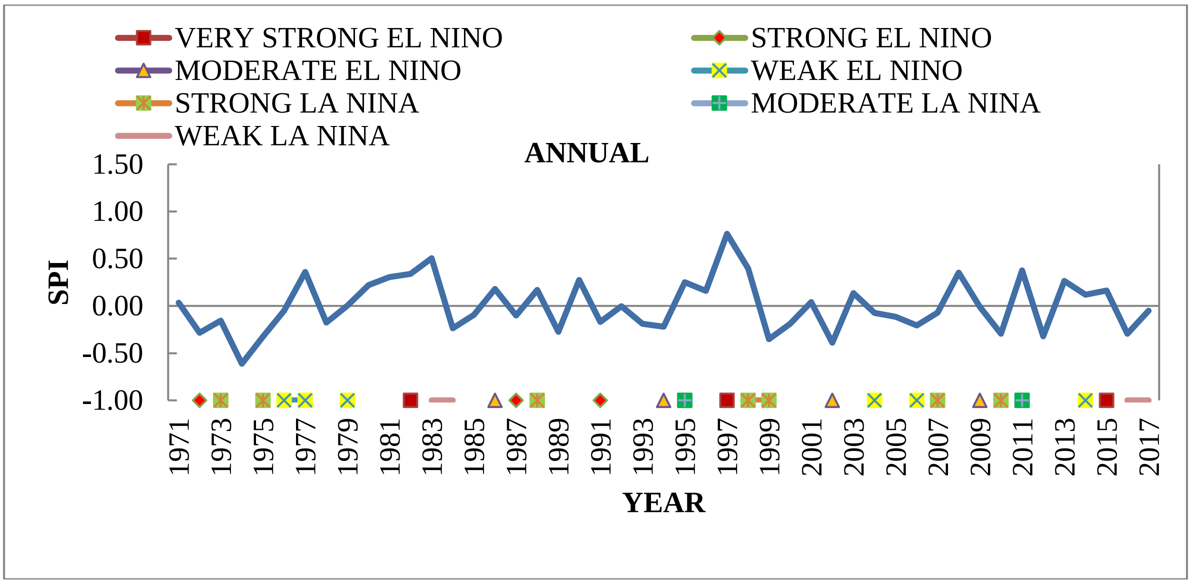
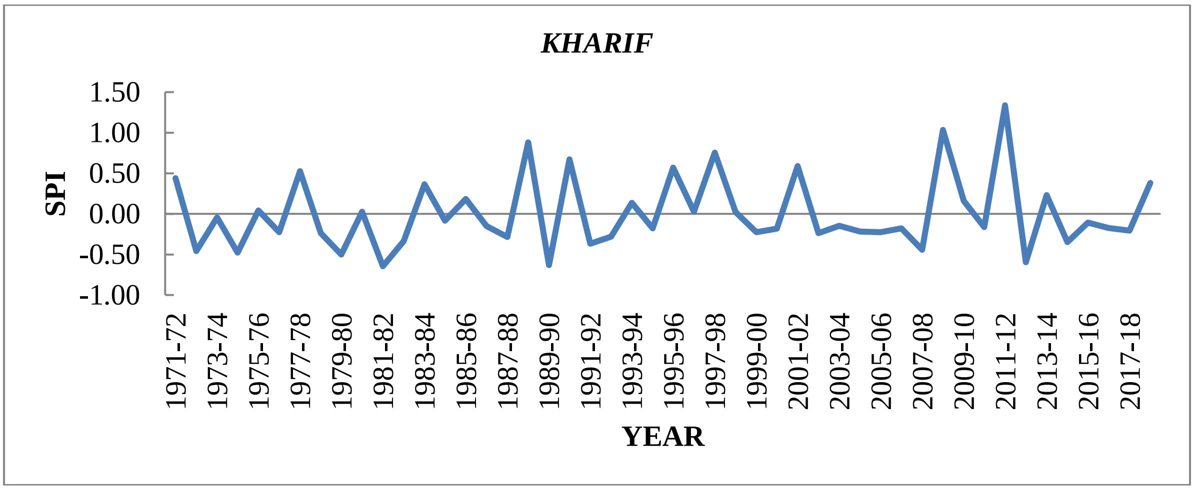


Fig. 4. Standardized precipitation index at Bathinda (Annual, *Kharif* and *Rabi*)





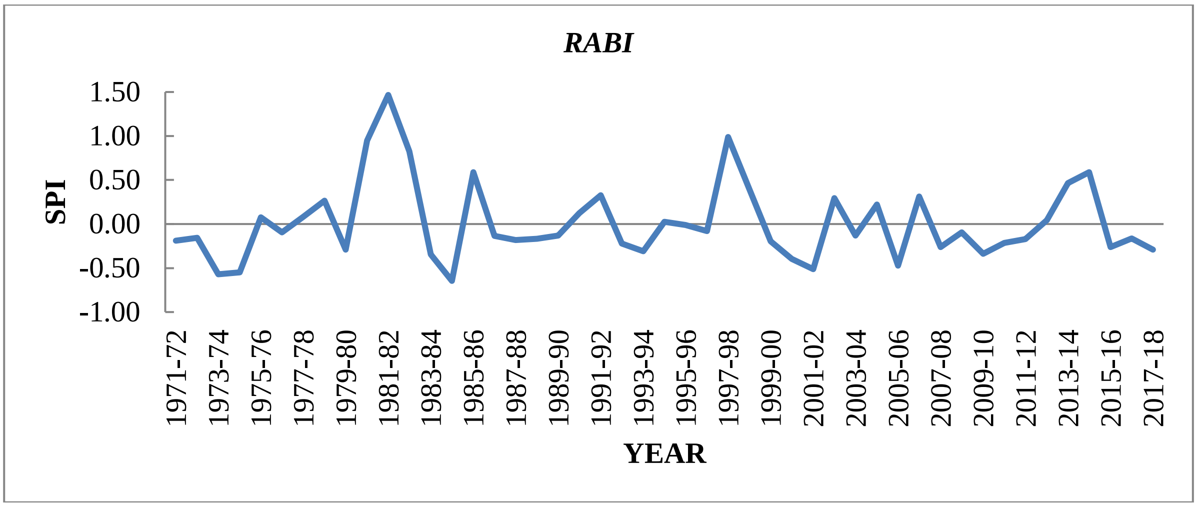
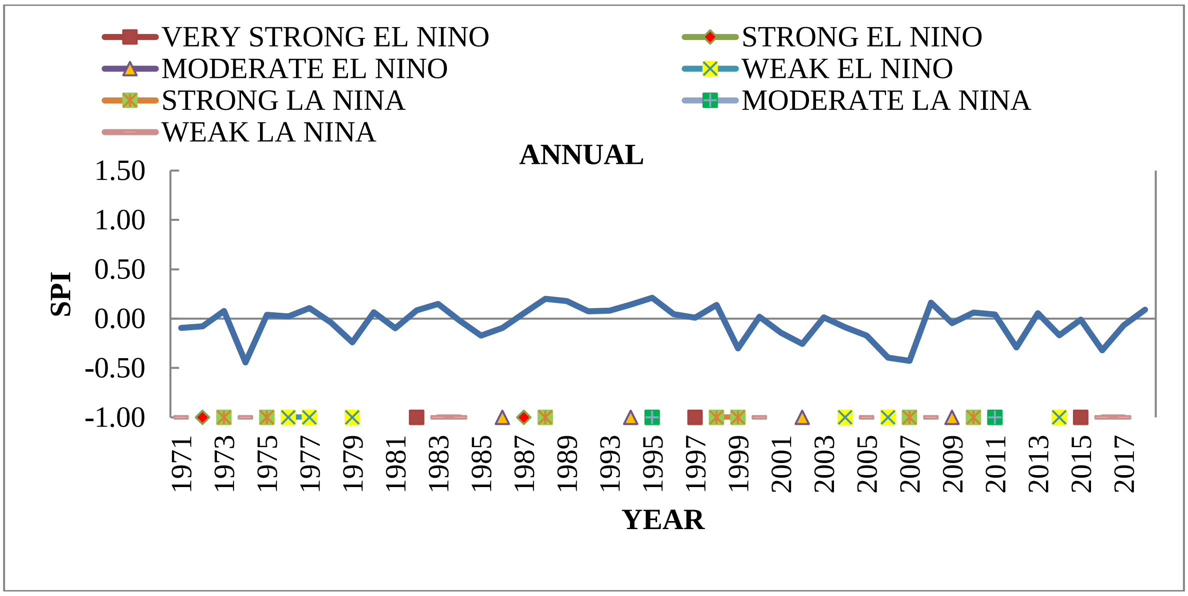
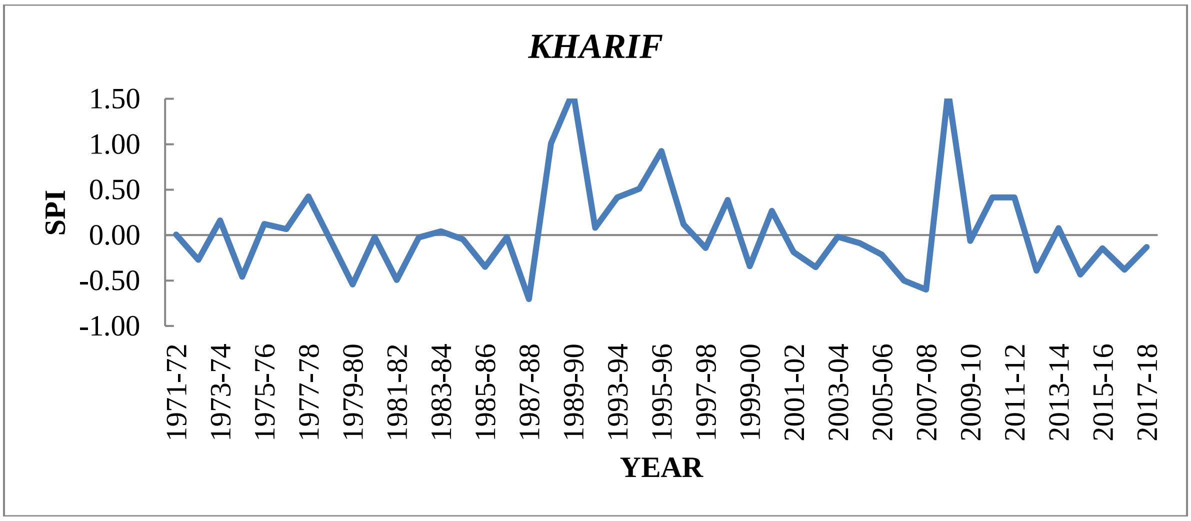


Fig. 5. Standardized precipitation index at Ludhiana (Annual, *Kharif* and *Rabi*)





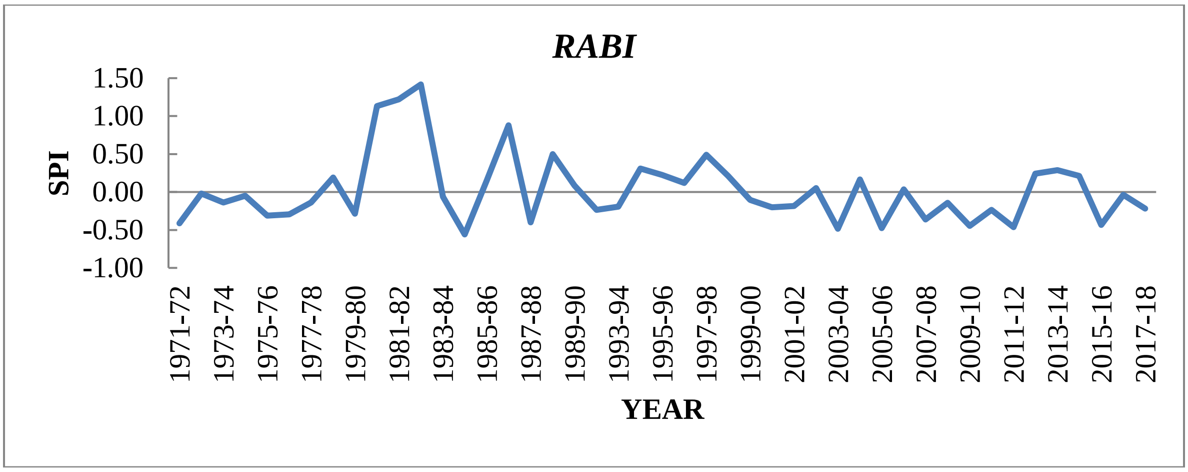


Fig. 6. Standardized precipitation index at Patiala (Annual, *Kharif* and *Rabi*)

3.5 Ludhiana

At Ludhiana, annual SPI showed no particular relation of ENSO event with drought (Fig. 5). As both *La Nina* years (1974-75, 1984-85 and 2011-12) and *El Nino* year (2002-03) caused drought like conditions. Very strong *El Nino* years of 1983-84, 1997-98 and 2015-16 showed the highest positive values of SPI at Ludhiana. According to SPI values during *kharif* season drought period was continuous from 2002-08 and 2014-17 which included four *El Nino* years (2002-2003, 2004-2005, 2006-2007 and 2014-2015). Also 2012-13 which was a neutral year caused drought at Ludhiana. Excess rainfall occurred during *La Nina* years except during 1997-98 which was very strong *El Nino* year. During *rabi* season drought like conditions occurred during *La Nina* years i.e. 1973-74, 1984-85, 2005-06 and 2008-09 whereas 2001-02 which was neutral year also caused deficit rain. The highest SPI value was found during two very strong *El Nino* event years of 1997-98 and 2015-16. Kothawale *et al.* [13] studied the relationship between *El Nino* Southern Oscillation (ENSO) and monsoon rainfall over India and reported a strong association between *El Nino* events and deficient monsoon rainfall. In India major droughts nearly 60 per cent have occurred in association with *El Nino* events.

3.6 Patiala

At Patiala SPI was computed for annual, *kharif* and *rabi* season from 1971-2018 (Fig. 6). The SPI values showed that the rainfall deficit years were 1974-75 (weak *La Nina*), 2006-07 (weak *El Nino*), 2012-13 (neutral) and 2016-17 (weak *La Nina*). Excess rainfall occurred during *La Nina* and neutral year. During *kharif* season the highest positive SPI value was found in 2008-09 which was weak *La Nina* year and 1989-90 which was neutral year. Drought like conditions occurred during 1974-75 (weak *La Nina*), 1987-88 (strong *El Nino*) and 2007-08 (strong *La Nina*) years. During *rabi* season 1984-85, 1991-92, 2003-04, 2005-06 and 2011-12 were drought years which were *La Nina* years except for 2004-05 which was neutral year. SPI value was the highest during 1982-83, 1986-87 and 1997-98 which were very strong *El Nino*, moderate *El Nino* and very strong *El Nino* year respectively. Pai *et al.* [8] found significant positive trends in the SPI series which were observed over several districts from west Uttar Pradesh, west Madhya Pradesh, South & north Interior Karnataka, Konkan and Goa, Madhya Maharashtra, Tamil Nadu, East Uttar Pradesh, Punjab, Gujarat etc. Trenberth *et al* [14] reported that from 1950–1998, ENSO linearly accounted for 0.06°C increase in global surface temperature [15].

4. CONCLUSION

It can be concluded that very strong *El Nino* of 1997-98 resulted in above normal rainfall at all the locations. Drought like conditions was observed during *El Nino* years as value of SPI was negative but with few exceptions. The SPI values were positive during *La Nina* and neutral years. Droughts during *kharif* season were found to be more related to *El Nino* years compared to *La Nina* years. During *rabi* season, very strong *El Nino* years resulted in excess rainfall at Bathinda whereas annual SPI showed no particular relation of ENSO event with drought at Ludhiana. At Patiala excess rainfall occurred during *La Nina* and neutral years.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Sims AP, Niyogi DS, Raman S. Adopting drought indices for estimating soil moisture: A North Carolina case study. Geophys Res Lett. 2002;29:1-4.
2. Hayes MJ, Savoboda M, Wilhite DA, Vanyarkho OV. Monitoring the 1996 drought using the standardized precipitation index. Bull Amer Meteorl Soc. 1999;80:429-38.
3. McKee TB, Doesken NJ, Kleist J.) The relationship of drought frequency and duration to time scales. In proceedings 8th Conference on Applied Climatology. 17-22 January, Anaheim, CA. 1993;179-84.
4. Varikoden H, Revadekar J V, Choudhary Y and Preethi B. Droughts of Indian summer monsoon associated with El Nino and Non-El Nino years. Int J Climatol. 2015;35: 1916–25.
5. Zhang X, Obringer R, Wei C, Chen N and Niyogi D. Droughts in India from 1981 to 2013 and implications to wheat production. Sci Rep. 2017;7:1-12.
6. Basamma KA, Purohit RC, Bhakar SR, Kothari M, Joshi RR, Sharma D, Singh PK, Mittal HK. Analysis of short-term droughts in the Mewar region of Rajasthan by standard precipitation index. Int J Curr Microbiol App Sci. 2017;6:182-92.
7. Hayes M, Savoboda M, Wall M, Widhalm M. The Lincoln declaration on drought indices: Universal meteorological drought index recommended. Bull Amer Meteor Soc. 2011;92:485-88.
8. Pai DS, Sridhar L, Guhathakurta P, Hatwar HR. District-wise drought climatology of the southwest monsoon season over India based on standardized precipitation index (SPI). Nat Haz. 2011;59:1797–813.
9. Bhuiyan C, Singh RP, Kogan FN. Monitoring drought dynamics in the Aravalli region (India) using different indices based on ground and remote sensing data. Int J App Earth Observ Geoinfor. 2006;8:289–302.
10. Chattopadhyay J, Bhatla R. A re-examination of ENSO/anti-ENSO events and simultaneous performance of the Indian summer monsoon. Mausam. 1996; 47:59-66.
11. Kane RP. Periodicities and ENSO relationships of the seasonal precipitation over six major sub-divisions of India. Mausam. 1999;50:43-54.
12. Nicholls N, Baek HJ, Gosai A, Chambers L E, Choi Y, Collins D, Manton MJ, Nakamigawa H, Ouprasitwong N, Solofa D, Tahani L, Thuy DT, Tibig L, Trewin B, Vediapan K, Zhai P. The El Nino–Southern Oscillation and daily temperature extremes in east Asia and the west Pacific. Geophy Res Lett. 2005;32:L16714:(1-4).
13. Kothawale DR, Munot AA, Kumar K. Surface air temperature variability over India during 1901–2007, and its association with ENSO. Clim Res. 2010; 42:89–104.
14. Trenberth KE, Caron JM, Stepaniak DP, Worley S. Evolution of El Nino–Southern Oscillation and global atmospheric surface temperatures. J Geophy Res. 2002;107: 1-14.
15. Barring L, Hulme M. Filters and approximate confidence intervals for interpreting rainfall anomaly indices. J Clim. 1991;4:837-47.

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