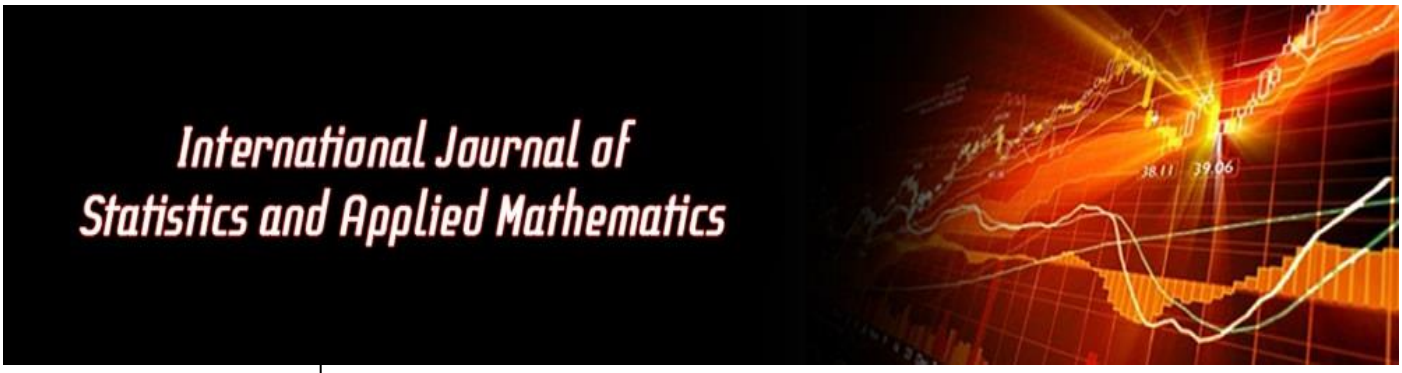

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Drought characterization based on multi-scaler SPEI at Barnala district of Punjab, India

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Abstract
Drought varies in terms of its occurrence, duration, intensity, and extent on a spatiotemporal scale and is carried on by the relative absence of rainfall. The Standardized Precipitation Evapotranspiration Index (SPEI) is based on precipitation and temperature data from 1985 to 2020 at Barnala meteorological station for southwestern Punjab, India. The SPEI can monitor and assess drought characteristics on different time scales. The findings of analysis showed that the drought duration, severity, and intensity were 3 months, -6.24 to -3.52 and -2.08 to -1.77 for SPEI-1; 6 months, -9.13 to -9.01 and -1.52 to -1.50 for SPEI-3; 7 months, -14.52 to -8.63 and -2.07 to -1.23 for SPEI-6; 11 months, -21.96 and -2.00 for SPEI- 9; 11 months, -23.02 to -13.19, -2.09 to -1.20 for SPEI-12; 18 months -26.14 and -1.45 for SPEI-24 respectively. Similarly, for the wet duration, severity and intensity were 4 months, 5.87 and 1.47 for SPEI-1, 7 months, 13.64 and 1.95 for SPEI-3, 10 months 14.86 and 1.49 for SPEI-6, 12 months, 16.37 and 1.36 for SPEI-9, 12 months, 23.77 to 17.21 and 1.43 and 1.98 for SPEI-12, 24 months, 33.31and 1.39 for SPEI-24 respectively. Overall results revealed moderate drought conditions during shorter and longer time scales.

Keywords: Barnala districts, SPEI, drought and wet, Punjab state

Introduction
All climate zone in the world experiences drought at some point, but the tropics and neighbouring regions are most affected by this invasive phenomenon. Large-scale drought affects the Indian subcontinent in one form or another nearly every year. It is crucial to conduct drought studies because Punjab is an arid and semi-arid region. The major cause of water stress in any region is the rapid increase in population along with an expansion of agricultural, energy and industrial sectors which is a growing concern (IPCC, 2012). Measurement of drought is done under four categories (Wilhite and Glantz, 1985; American Meteorological Society, 2004) [13, 2]: meteorological drought (precipitation deficit), hydrological drought (scarcity of surface and subsurface water is resources) and agricultural drought (shortage of water during growing and mature periods for crops). Meteorological drought is defined as a situation when a precipitation deficit (i.e.,> 25%) from the average amount occurs over an area for some time. The Indian Meteorological Department (IMD) sub-classified the meteorological drought as (i) moderate drought when the rainfall deficit is 26 to 50%, and (ii) severe drought when the rainfall deficit is 50 to 75% from the long-term mean precipitation. Due to the dynamic nature of drought, a region may experience wet and dry spells simultaneously on various timescales. Different drought characteristics are defined to create a drought index that is used to evaluate the impact of drought (intensity, duration, severity and areal extent). Several indicators, for example, Palmer Drought Severity Index (PDSI) (Palmer, 1965) [9], China-Z index (CZI) (Wu *et al*., 2001) [14], Aggregated Drought Index (ADI) (Keyantash and Dracup, 2002 and 2004) [5-6], Standardized Precipitation Index (SPI) (McKee *et al*., 1993) [8], Percent of Normal Precipitation (PNP) (Willeke *et al*., 1994) [12] etc., have been established in the past to assess the characteristics of meteorological drought. The SPEI method is designed to take into account both precipitation and potential evapotranspiration (PET) in determining drought. Because it employs a more thorough assessment of water availability and climatic water balance.

Agriculture is a major source of livelihood for Punjab's rural and urban population. The purpose of the current study was to evaluate the severity, duration, and intensity of the meteorological drought and wet conditions at Barnala stations in Punjab, India, applying SPEI values at different time scales.

Materials and Methods

Study area and data collection: The analysis was conducted in the south-western region comprising the Barnala districts of Punjab State, India (Fig. 1). The total geographical area of the Barnala district is 1481.47 km^2 with altitudes 229 m above mean sea level. The Barnala district is located between 30^o 22' 55.2" N (latitude) and 75^o 32' 49.2" E (longitude) in the state of Punjab of India. The climate of Barnala is humid subtropical with dry winters. The district's average annual temperature is 29.49 °C, which is 3.52% warmer than the country's average. In Barnala, there are generally 63.47 wet days per year and 36.31 mm of precipitation. The daily metrological data for 36 years (1985-2020) were arranged into monthly sets for analysis of meteorological drought and wet.

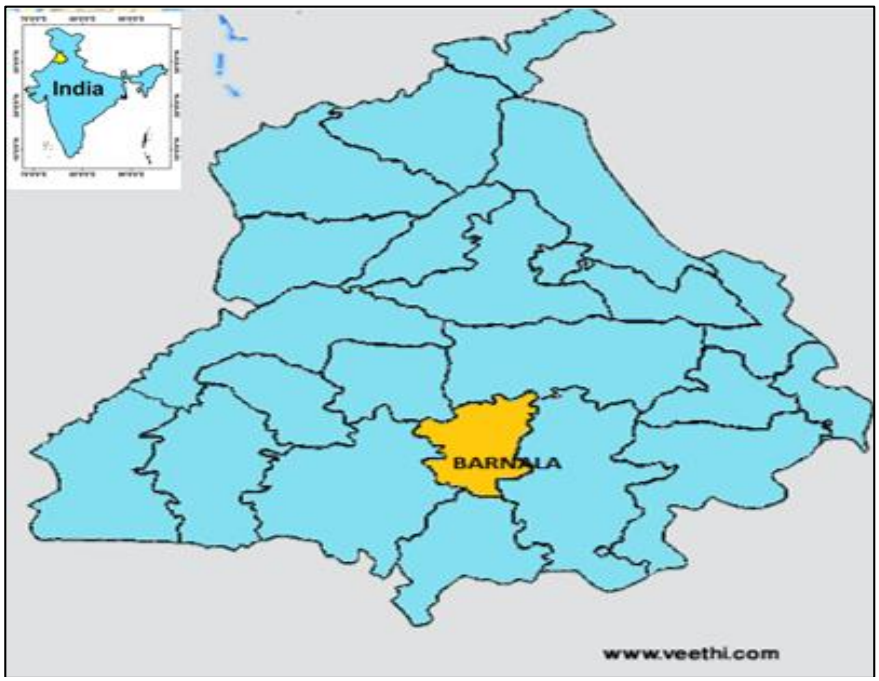


Fig 1: Location map of the study region

Standardized Precipitation Evapotranspiration Index (SPEI): To calculate the SPEI, this reflects an easily understood climatic water balance. SPEI were calculated at intervals of 1, 3, 6, 9, and 12 months. As a result, the multi-scaler SPEI captures the primary effect of rising temperatures on water demand, in contrast to the SPI. Vicente-Serrano *et al*. (2010) [10] used the difference between precipitation (Pi) and potential evapotranspiration (PET) to develop the multi-scaler SPEI. The Hargreaves method was used to determine PET in the current study (Hargreaves and Samani 1985) [3] in R studio software. In the next step, a simple monthly water balance was calculated as the difference between precipitation (Pi) and evapotranspiration (PET) according to the:

$$Di = Pi - PET \quad (2)$$

SPEI employs the log-logistic distribution.

$$f(x) = \frac{\beta}{\alpha}\left(\frac{x-\gamma}{\alpha}\right)^{\beta-1}\left[1+\left(\frac{x-\gamma}{\alpha}\right)^{\beta}\right]^{-2} \quad \ldots. (3)$$

Where α, β, and γ are scale, shape, and origin parameters respectively, for D values in the range ($\gamma > D > \infty$) (Vicente-Serrano *et al*. 2010; Alam *et al*. 2017) [10,]. The log-logistic distribution's formulation of the probability distribution function of the D series is as follows:

$$F(x) = \left[1+\left(\frac{\alpha}{x-\gamma}\right)^{\beta}\right]^{-1} \quad (4)$$

As the standardised values of F(x), the SPEI is easily obtainable. By conventional approximation Abramowitz and Stegun (1965) [1].

$$SPEI = W - \frac{C_0+C_1W+C_2W^2}{1+d_1W+d_2W^2+d_3W^3} \quad (5)$$

Where, $W = \sqrt{-2\ln(P)}$ for $P \leq 0.5$ and P is the probability of exceeding a determined D value, P = 1 – F(x). If $p > 0.5$, then P is replaced by 1 − P and the sign of the resultant SPEI is reversed. The constants are C_0 = 2.515517, C_1 = 0.8022853, C_2 = 0.010328, d_1 = 1.432788, d_2 = 0.189269, and d_3 = 0.001308. The drought and wet conditions present at a location could be determined and described based on the computed value of SPEI (Table 1).

Table 1: Classification for drought & wet conditions according to SPEI (Wang, *et al*. 2020) [11]

SPEI threshold	Category	Symbol (class)
SPEI ≥ 2.0	Extremely wet	EW (C)
1.5 ≤ SPEI< 2.0	Severe wet	SW (B)
1.0 ≤ SPEI< 1.5	Moderate wet	MW (A)
-1.0 < SPEI<1.0	Normal condition	NC (N)
-1.5 < SPEI≤ -1.0	Moderate drought	MD (1)
-2.0 < SPEI ≤ -1.5	Severe drought	SD (2)
SPEI≤ 2.0	Extremely drought	ED (3)

Drought characterization is defined as severity (S), duration (D), and intensity (I), which were estimated using the run theory (Mishra & Singh 2010) [7]. One of the most effective techniques for obtaining drought characteristics is the run theory method. The copulas approach is another such technique. In their comparison of the two approaches (run theory and copulas), Wang, *et al*. (2020) [11] found that both approaches performed similarly. The run theory approach was chosen in this investigation due to its simplicity.

Results and Discussion

The drought and wet conditions i.e., total drought/wet months, number of drought/wet months, number of drought/wet incidents (single or successive), drought/wet percentage (%), average duration (month) of drought/wet, longest duration (month) of the drought/wet, drought/wet severity, the average intensity of drought/wet, drought/wet category for 1, 3, 6-, 9-, 12- and 24-months time scales at Barnala polygon are given in Tables 2(a) and 2(b). From Table 2(a) it was noted that the drought's longest duration/severity (intensity) was 3 months/-3.52 to -6.24 (-1.17 to -2.08) for SPEI-1; 6 months/-9.01 to -9.13 (-1.50 to -1.52) for SPEI-3; 7 months/-8.63 to -14.52 (-1.23 to -2.07) for SPEI-6; 11 months/-21.96 (-2.00) for SPEI-9; 11 months/-13.19 to -23.02 (-1.20 to -2.09) for SPEI-12; and 18 months/-26.14 (-1.45) for SPEI-24, respectively. Likewise, the drought category varies between moderate to extreme for SPEI-1, moderate to severe for SPEI-3, moderate to extreme for SPEI-6, and SPEI-12, extreme for SPEI-9, and moderate for SPEI-24.

Similarly, Table 2(b) summaries the results of wet events at the Barnala polygon, which indicates that wet's longest duration/severity (intensity) was 4 months/5.87 (1.47) for SPEI-1; 7 months/13.64 (1.95) for SPEI-3; 10 months/14.86 (1.49) for SPEI-6; 12 months/16.37 (1.36) for SPEI-9; 12 months/17.21 to 23.77 (1.43 to 1.98) for SPEI-12; and 24 months/33.31 (1.39) for SPEI-24, respectively. Also, the wet category fluctuates from moderate for SPEI-1, SPEI-6, SPEI-9, and SPEI-24, severe for SPEI-3, and moderate to severe for SPEI-12. The temporal distribution of drought and wet conditions for multi-scalar SPEI from 1985 to 2020 at the Barnala polygon are plotted in Fig. 2(a-f).

The probability percentage of drought and wet incidents (i.e., extreme, severe, and moderate) for multi-scalar SPEI at Barnala polygon are given in Table 2(c), which clearly shows that the probability of moderate drought/wet incidences was higher (0.66/0.65, 0.63/0.58, 0.65/0.61, 0.56/0.54, 0.70/0.50, 0.82/0.77) than severe and extreme drought/wet incidents for SPEI-1, SPEI-3, SPEI-6, SPEI-9, SPEI-12, and SPEI-24, respectively. Figure 3(a-b) illustrates the probability percentage of drought and wet incidents for SPEI-1, SPEI-3, SPEI-6, SPEI-9, SPEI-12, and SPEI-24 at Barnala polygon. Also, the average probability of moderate drought/wet (0.67/0.61) events was higher than the severe (0.25/0.29) and extreme (0.08/0.11) drought/wet events.

Table 2(a): Classification of drought pattern based on multi-scalar SPEI values at Barnala polygon

SPEI Category	Total months	No. of drought months	No. of drought incidents	Drought Percentage (%)	Average duration (month)	Longest drought pattern				
						Longest duration (month)	Period of the longest drought	Drought severity	Average intensity	Drought category
SPEI-1	432	67	54	15.51	1.24	3	Jan to Mar, 1985 Jul to Sep, 1987 Nov, 1987 to Jan, 1988 Oct to Dec, 1993 Jun to Aug, 2002 Mar to May, 2010 Jun to Aug, 2014	-4.02 -4.52 -6.24 -4.00 -3.52 -5.76 -4.02	-1.34 -1.51 -2.08 -1.33 -1.17 -1.92 -1.34	1 2 3 1 1 2 1
SPEI-3	430	68	54	15.81	1.2	6	Sep, 2001 to Feb, 2002 Mar to Aug, 2011	-9.13 -9.01	-1.52 -1.50	2 1
SPEI-6	427	69	54	16.16	1.28	7	Aug, 1987 to Feb, 1988 Jul, 1999 to Jan, 2000	-14.52 -8.63	-2.07 -1.23	3 1
SPEI-9	424	61	50	14.39	1.22	11	Aug, 1987 to Jun, 1988	-21.96	-2.00	3
SPEI-12	421	69	58	16.39	1.19	11	Sep, 1987 to Jul, 1988 Sep, 2009 to Jul, 2010	-23.02 -13.19	-2.09 -1.20	3 1
SPEI-24	409	71	61	17.36	1.16	18	Aug, 2001 to Jan, 2003	-26.14	-1.45	1

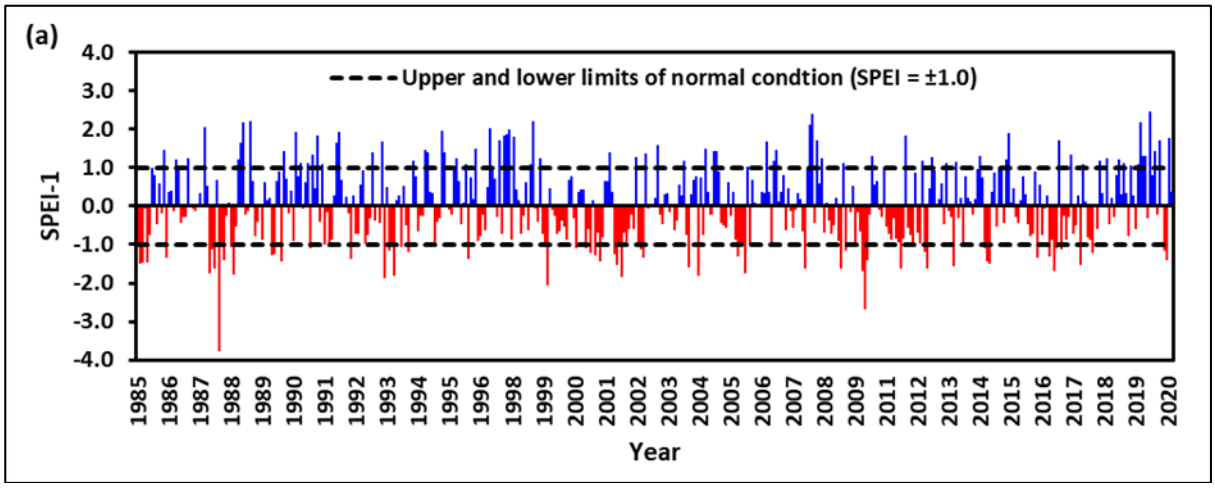
Table 2(b): Classification of wet pattern based on multi-scalar SPEI values at Barnala polygon

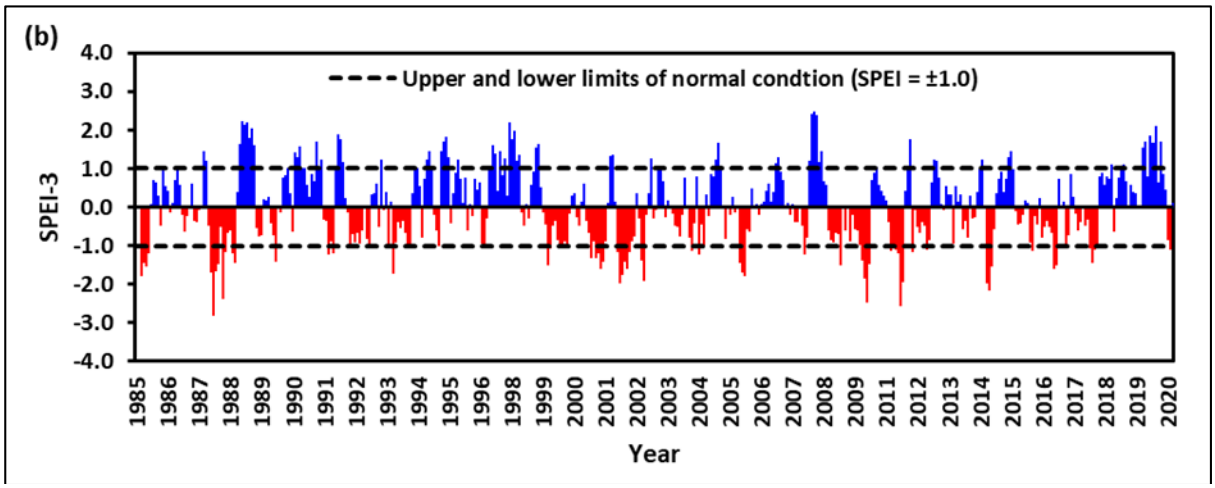
SPEI Category	Total months	No. of wet months	No. of wet incidents	Wet Percentage (%)	Average duration (month)	Longest wet pattern				
						Longest duration (month)	Period of the longest wet	Wet severity	Average intensity	Wet category
SPEI-1	432	82	69	18.98	1.19	4	Oct, 2019 to Jan, 2020	5.87	1.47	A
SPEI-3	430	72	54	16.74	1.33	7	Aug, 1988 to Feb, 1989	13.64	1.95	B
SPEI-6	427	71	59	16.63	1.20	10	Aug, 1997 to May, 1998	14.86	1.49	A
SPEI-9	424	69	61	16.27	1.13	12	July, 1990 to Jun, 1991	16.37	1.36	A

SPEI-12	421	76	68	18.05	1.12	12	Sep, 1988 to Aug, 1989 Aug.1995 to Jul, 1996 Aug.1997 to Jul, 1998 Jun, 2008 to May, 2009	23.77 18.58 17.21 20.49	1.98 1.55 1.43 1.71	B B A B
SPEI-24	409	108	99	26.41	1.09	24	Sep, 1995 to Aug, 1997	33.31	1.39	A

Table 2(c): Probability of occurrence of drought and wet incidents on multi-scalar SPEI at Barnala polygon

SPEI time scale	Drought incidents			Wet incidents		
	Moderate (1)	Severe (2)	Extreme (3)	Moderate (A)	Severe (B)	Extreme (C)
SPEI-1						
Incident months	44	20	3	53	20	9
Total month	67	67	67	82	82	82
Probability	0.66	0.30	0.04	0.65	0.24	0.11
SPEI-3						
Incident months	43	20	5	42	21	9
Total month	68	68	68	72	72	72
Probability	0.63	0.29	0.07	0.58	0.29	0.13
SPEI-6						
Incident months	45	14	10	43	14	14
Total month	69	69	69	71	71	71
Probability	0.65	0.20	0.14	0.61	0.20	0.20
SPEI-9						
Incident months	34	21	6	37	23	9
Total month	61	61	61	69	69	69
Probability	0.56	0.34	0.10	0.54	0.33	0.13
SPEI-12						
Incident months	48	13	8	38	32	6
Total month	69	69	69	76	76	76
Probability	0.70	0.19	0.12	0.50	0.42	0.08
SPEI-24						
Incident months	58	12	1	83	25	0
Total month	71	71	71	108	108	108
Probability	0.82	0.17	0.01	0.77	0.23	0.00





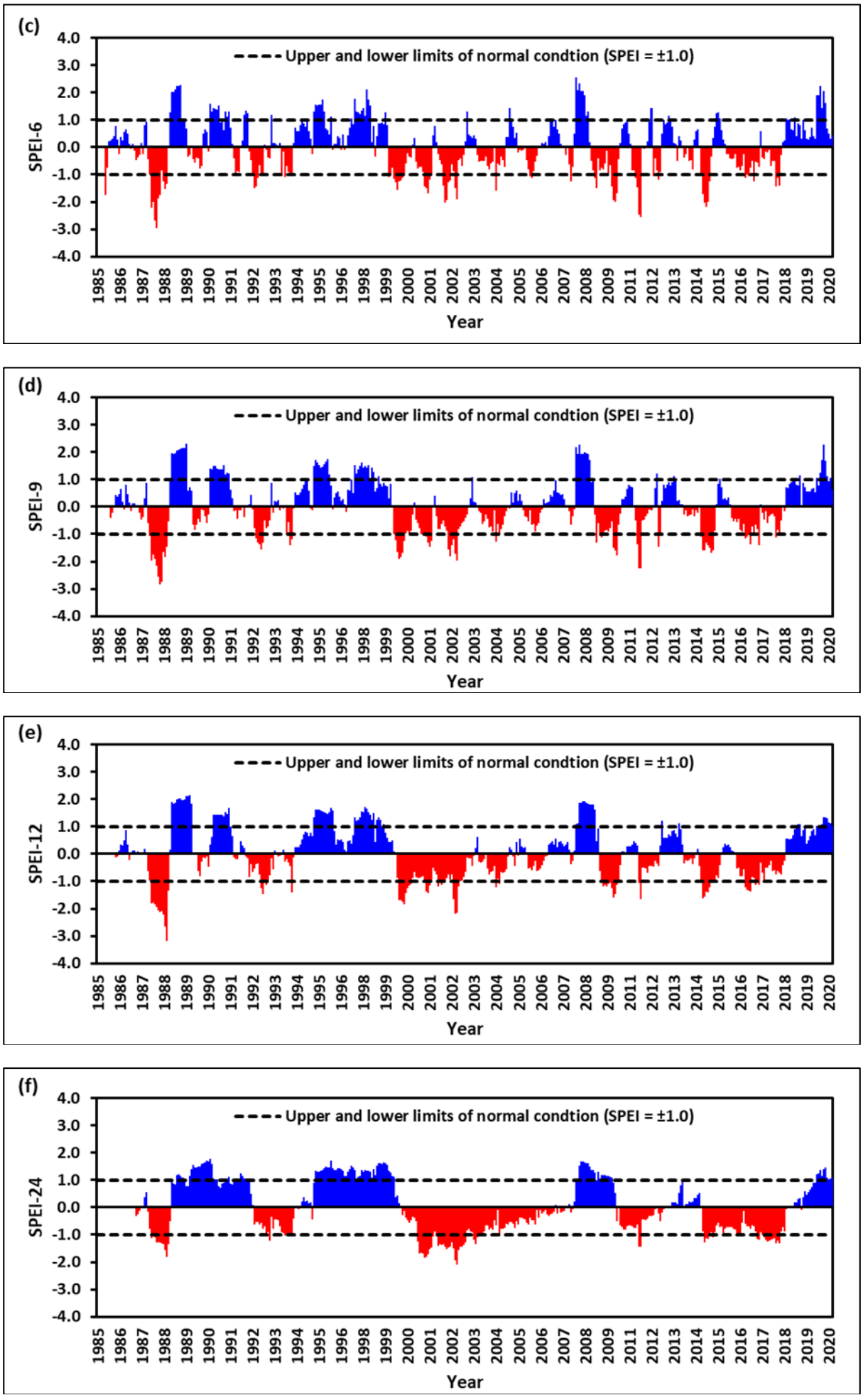


Fig 2(a-f): Temporal distribution of drought and wet events for multi-scalar SPEI at Barnala polygon

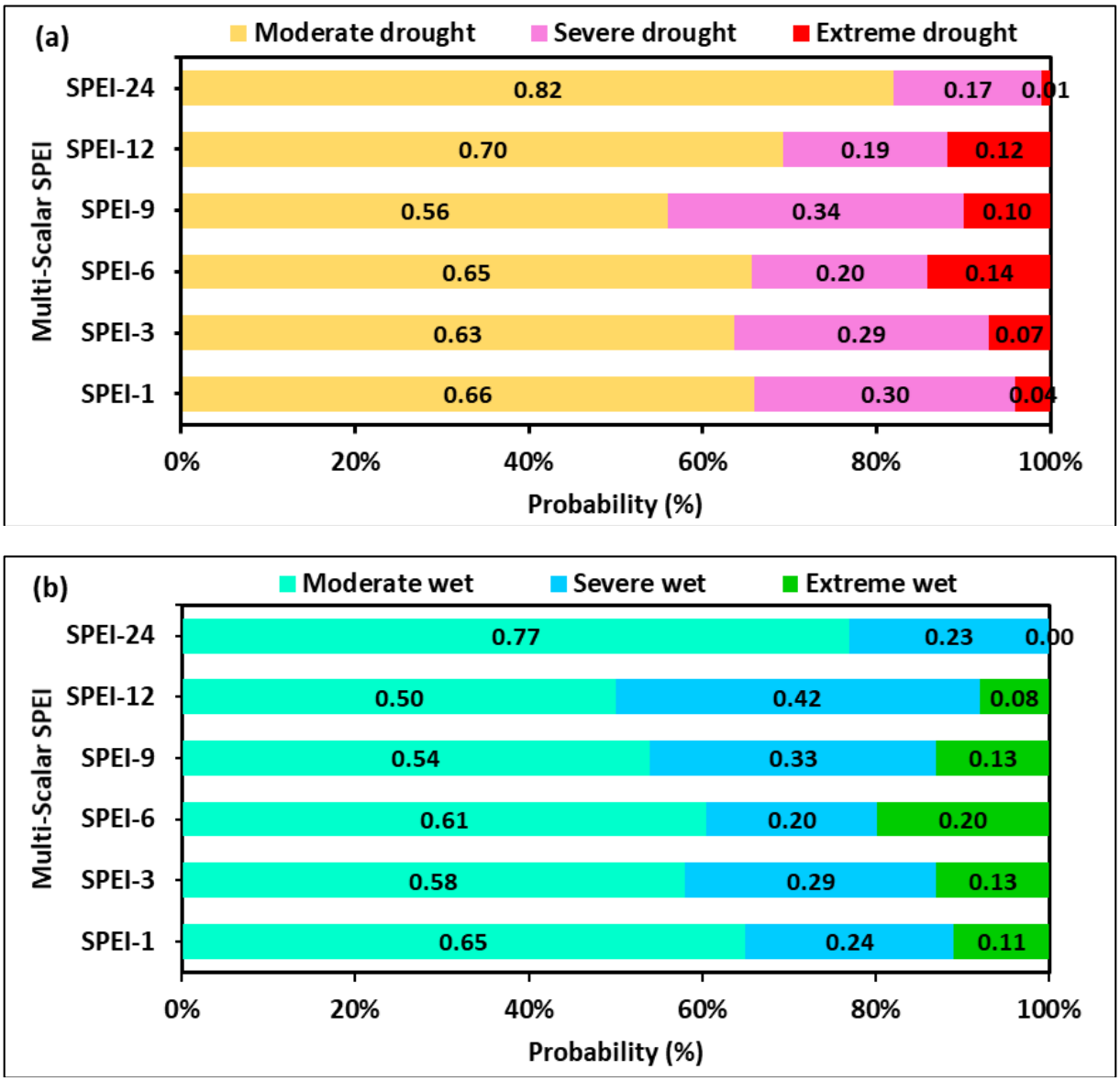


Fig 3(a-b): Probability percentage of drought and wet incidents for multi-scalar SPEI at Barnala polygon

Summary and Conclusion

Drought and wet conditions in any location are caused by the random and uneven distribution of temperature, precipitation, and other various weather factors. With the explicit aim of assessing meteorological drought based on SPEI over various time scales, for 36 years (1985-2020) at Barnala district. The longest duration of drought severity, according to the study, became continuously from 3 months based on SPEI-1 to 18 months with SPEI-24; however, its average intensity varied from -1.17 to -2.08, falling into the severe to extreme drought conditions. With an average intensity ranging from 1.36 to 1.98, the longest wet severity, which correlates to moderate to severe wet conditions, became continuous from 4 months with SPEI-1 to 24 months with SPEI-24. In addition, there was a higher probability of moderate drought/wet incidences than severe and extreme events for SPEI-1, SPEI-3, SPEI-6, SPEI-9, SPEI-12, and SPEI-24, respectively. These outcomes will help to formulate better plans for sustainable management of the available water resources in the study region.

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