Characteristics of drought variation in winter using drought Indices during the period 1971-2010 : A case study of Khyber Pakhtunkhwa (Pakistan)

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सार – सामान्यतः लम्बे समय तक वर्षा में कमी के कारण सूखा पड़ता है। विश्व के किसी भी भाग में सूखा पड़ सकता है और मानव जीवन व पर्यावरण तंत्र पर हानिकारक प्रभाव डाल सकता है। सूखा पड़ने के कई सूचकांक है जिन्हें विश्लेषण करने के लिए प्राप्त किया जा सकता है और सूखा पड़ने की मात्रा का निर्धारण किया जाता है। इस अध्ययन में मानक वर्षा वाष्पन वाष्पोत्सर्जन सूचकांक (एस पी ई आई) का उपयोग कर सूखा पड़ने की स्थिति का विश्लेषण करने के लिए मासिक वर्षा और तापमान के आंकड़ों का उपयोग किया गया है। शीत ऋतु (दिसंबर, जनवरी और फरवरी) के लिए पाकिस्तान के खैबर पखतुंखवा (के पी के) प्रांत में 1971-2010 की अवधि के लिए मानक वर्षा सूचकांक) (एस पी आई) और जेड - इंडेक्स (चीन जेड - इंडेक्स के नाम से भी ज्ञात) किए गए। एस पी ई आई और एस पी आई के लिए 3, 6 और 12 महीनों के समयमान पर विश्लेषण किए गए। जेड-इंडेक्स का उपयोग शीत ऋतु में सूखा / आर्द्रता (बाढ़) की स्थिति का परिकलन करने के लिए किया गया है। इन सभी सूचकांकों के आधार पर शुष्कता और आर्द्रता की तीव्रता समयमान और स्थान के साथ अलग-अलग रहती है। वर्ष 1971, 1988, 2001 और 2002 के दौरान तीन समयमानों के आधार पर अध्ययन किए गए अधिकतम स्टेशनों में सूखे की स्थिति (विभिन्न तीव्रताओं के साथ) पाई गई है। एस पी ई आई और एस पी आई में कभी कभी विषम परिणाम प्राप्त होते है क्योंकि एस पी आई में तापमान के प्रभाव को नही लिया जाता है। एस पी ई आई के आधार पर सूखा पड़ने की आवृत्ति उत्तर से दक्षिण की ओर बढ़ती है। डेरा इस्माइल खान (डी आई खान) और कोहाट में बहुत अधिक वर्षों तक सूखा पड़ा जबकि बालाकोट में बहुत कम सूखा पड़ा। इस डी आई खान के विपरीत एस पी आई आधारित सूखा पड़ने के वर्ष बहुत कम रहे।

ABSTRACT. Generally drought is the outcome of reduction in precipitation for a long period of time. It can happen anywhere in the world and cause harmful effect to human life and eco system. There are different drought indices, derived for analysis and quantification of drought. In this study monthly precipitation and temperature data was used to analyze drought situation using Standardized Precipitation Evapotranspiration Index (SPEI), Standardized Precipitations Index (SPI) and Z-index (also known as China Z-index) for the period 1971-2010 over Khyber Pakhtunkhwa (KPK) province of Pakistan for winter season (December, January & February). Analyses were performed on 3, 6 and 12 month timescale for SPEI and SPI. Z-index is used to calculate drought/wet (flood) situation in winter season. Based on all these indices, dryness and wetness intensity varies with timescale and location. On basis of three time scale, during the years 1971, 1988, 2001 and 2002, majority of the stations of study area were under the drought conditions (of different intensities). SPEI and SPI sometime portray contrasting results, because the later does not take into account the effect of temperature. Based on SPEI, drought frequency increases from north to south. Dera Ismail Khan (D.I. Khan) & Kohat suffered drought conditions for highest number of year, while Balakot the least. Contrary to this D. I. Khan has the least number of drought years based on SPI.

Key words – Drought, SPEI, Temperature, SPI, Khyber Pakhtunkhwa, Evapotranspiration.

1. Introduction

Drought is a natural disaster associated with lack of precipitation for a considerable long period of time. There is no single definition of drought (Wilhite and Glantz, 1985) that's why it is defined separately in the perspective of meteorology, agriculture and hydrology. Drought is characterized by lack of water availability in a region (Beran and Rodier, 1985). It is different from other natural disaster because its onset, extent and end are difficult to determine. It is a regional phenomenon and generally extends for long period and has large areal extent. On scientific basis, droughts are classified into four types namely meteorological, hydrological, agricultural and socio economic (Wilhite and Glantz, 1985). Different indices are used to analyze different types of droughts. Intergovernmental Panel on Climate Change (IPCC) indicated increase in drought conditions in different parts

TABLE 1

Metadata of stations located in study area

Stations	Latitude (°N)	Longitude (°E)	Altitude (m)	Precipitation (mm)	Temperature (°C)
Kohat	33.57	71.43	513	29.3	12.8
Balakot	34.38	73.35	981	105.8	9.8
Chitral	35.85	71.83	1500	46.6	5.3
DIKhan	31.82	70.92	174	11.7	13.7
Drosh	35.57	71.78	1465	53.6	5.9
Parachinar	33.87	70.08	1729	50.9	5.0
Peshawar	34.02	71.58	360	31.6	12.4
Risalpur	34.07	71.98	315	40.4	11.2
Saidu Sharif	34.73	72.35	962	79.7	9.1
Dir	35.2	71.85	1370	123.2	5.7
Cherat	33.82	71.88	1302	43.2	7.6
Kakul	34.18	73.25	1309	78.7	7.7

of the world including South Asia (IPCC AR4, 2007). Droughts have been remained a major concern for both policy makers and individuals. Among all the natural disasters droughts are proven to be the most devastating for US economy (Cook *et al*., 2007). Increase in the demand of water which is already limited, has made the situation worse during the last thirty years (Mishra and Singh, 2010). Over the past thirty years drought frequency in China has increased (Meixiu *et al*., 2013). A severe drought prevailed over South and South West Asia during 1999 and 2003, which affected many countries including Pakistan (Waple and Lawrimore, 2003; Levinson and Waple, 2004).

There is a decrease in rainfall in Pakistan particularly during last decade of the 20th century (Salma *et al*., 2012). In the mountainous areas of Pakistan, rise in temperature has been recorded (Hussain *et al*., 2005). This simultaneous rise in temperature with decrease in rainfall will aggravate the scarcity of water, for agricultural, drinking and industrial usage, because rise in temperature will stimulate the evapotranspiration process. In order to fulfill crop water requirements, additional water will be required for supplementary irrigation.

1.1. *Drought indices*

Throughout the world, different indices are used for the analysis and quantification of drought. Among these, Standardized Precipitation index (SPI) by (McKee *et al*., 1993) is famous. SPI only needs precipitation as input variable. Because of its simplicity SPI is used widely. SPI does not take into account the effect of temperature. So the areas where daily bright

sunshine hours are greater, this can lead to erroneous results. Because temperature has a vital contribution in the process of evapotranspiration. Increase in evapotranspiration will results in increase of water loss from the land surface. This water loss is not handled in SPI. Standardized Precipitation Evapotranspiration Index (SPEI) developed by (Vicente-Serrano *et al*., 2010) is a drought index similar in calculation to SPI. The main difference between these two is that SPEI takes into account the temperature, while SPI solely depends upon precipitation. In the perspective of climate change and global warming, main focus is on the rise in temperature. Rising trend in the temperature extreme will continue in the next century (Tebaldi *et al*., 2006). So drought indices which incorporate temperature as well will be more beneficial for drought analysis. These will be helpful in projecting the future scenarios. PDSI is also temperature sensitive, but it lacks the multi-scalar character. Keeping in view this advantage of SPEI, in this study we incorporated it.

2. Data and methodology

2.1. *Study area*

Khyber Pakhtunkhwa (KPK) province is located in North West of Pakistan, with a variety of landscape. It has total area of 74521 km^2. The province can be divided into two zones on geographical bases. Northern zone, from the foothills of Hindu Kush up to the boundary of Peshawar. The southern zone is extended from Peshawar to the D. I. Khan and adjacent areas. Sothern zone consist of mainly dry land, rocky areas and some fertile plains. North is abundant with forest, lush green mountains and fertile
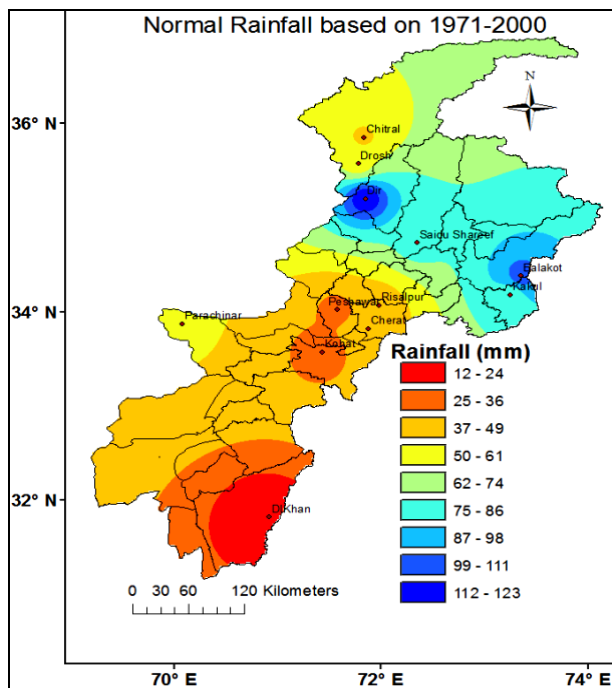
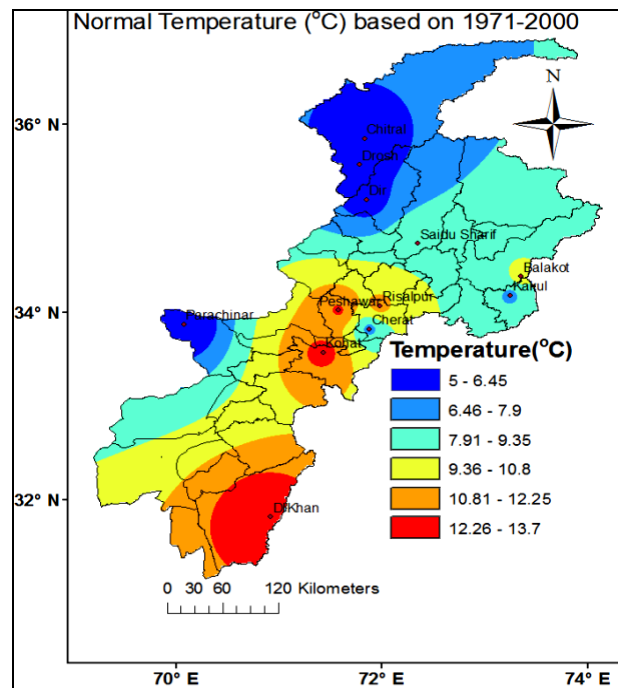**Fig. 1.** Normal rainfall (mm) based on 1971-2000

Fig. 2. Normal temperature (°C) based on 1971-2000

land. Geographical coordinates, mean winter precipitation and temperature are shown in Table 1. Majority of the population live in rural areas and depends directly or indirectly on agriculture. Maize, wheat, sugarcane, tobacco and different kinds of vegetables are the main agricultural products. Rainfall is the main water source for agricultural activities in the province, although in some parts of the province, supplementary system for irrigation is available. Normal precipitation and temperature of the study area are show in Fig. 1 & Fig. 2 respectively.

Most parts of KPK receive precipitation from western disturbances in winter season (Hussain and Lee, 2009). Wheat and tobacco are the major cash crops of the province, are cultivated in winter. Tobacco is grown mostly in irrigated land, while wheat in both irrigated and arid land. In winter (December-February) Due to insufficient or ill-timed rainfall damage wheat crop badly.

To conduct this study, monthly precipitation and air temperature data of 12 stations of KPK for the period 1970-2010 were used. Data was acquired from Pakistan Meteorological Department (PMD). Fig. 3 shows location of selected stations on the map of KPK. SPEI and SPI were calculated for the study period for timescale of 3, 6 and 12 months and then averaged over the winter season (December to February).

2.2. *Standardized precipitation evapotranspiration index*

Potential evapotranspiration (PET) is required in order to calculate SPEI. PET can be calculated in different ways simple or complex, but the resultant drought index will be similar (Mavromatis, 2007). In this study evapotranspiration is calculated using the technique formulated by (Thornthwaite, 1948).

$$PET = 16K\left(\frac{10T}{I}\right)^m \tag{1}$$

where, T is the mean monthly temperature, I is the heat index and is sum of monthly heat index i. computed from the monthly index i.

K is the correction factor coupled as a function of latitude and months.

$$K = \left(\frac{N}{12}\right)\left(\frac{n}{30}\right) \tag{2}$$

where, n is the number of days in the month and N is the number of maximum sunshine hours. Difference between precipitation and PET for a month i calculated as:

$$D_i = P_i - PET_i \qquad (3)$$

Water deficit D_i is aggregated at different time scale. Let $D_{i,j}^k$ is the difference in a specific month j in the year i depends on the time scale k. The accumulated difference for one month in a specific year with 12 month timescale is calculated using:

$$X_{i,j}^k = \sum_{l=13-k+j}^{12} D_{i-1,l} + \sum_{l=1}^{j} D_{i,l} \quad \text{if } j < k \qquad (4)$$

$$X_{i,j}^k = \sum_{l=j-k+1}^{j} D_{i,l} \quad \text{if } j \geq k \qquad (5)$$

where, $D_{i,l}$ is the water balance (surplus or deficit) in the first month of year i. This water balance is normalized into log-logistic probability distribution in order to obtain SPEI index series. The probability density function of log logistic distributed variable is expressed as:

$$f(x) = \frac{\beta}{\alpha} \left(\frac{x-\gamma}{\alpha} \right) \left[1 + \left(\frac{x-\gamma}{\alpha} \right) \right]^{-2} \qquad (6)$$

where, α, β and γ are scale, shape and origin parameters respectively for D values in the range (γ> D < ∞). The probability density function (pdf) of D is given by:

$$F(x) = \left[1 + \left(\frac{\alpha}{x-\gamma} \right)^{\beta} \right]^{-1} \qquad (7)$$

With $F(x)$ the SPEI can be easily obtained as the standardized values of $F(x)$. Following the classical approximation of (Abramowitz and Stegun, 1965).

$$SPEI = W - \frac{C_0 + C_1 W + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3} \qquad (8)$$

where, $W = \sqrt{-2\ln(p)}$ for P ≤ 0.5 and P is the probability of exceeding a determination D value, $P = 1 - F(x)$. If P > 0.5, then P is replaced by 1-P and the sign of resultant SPEI is reversed. The constants are C_0 = 2.515517, C_1 = 0.802853, C_2 = 0.010328, d_1 = 1.432788, d_2 = 0.189269 and d_3 = 0.001308. In SPEI dry/wet conditions are divided into seven categories and are shown in Table 2. The detailed procedure to calculate SPEI is thoroughly described in (Vicente-Serrano *et al.*, 2010).

TABLE 2

Drought categories based on SPEI/SPI

SPEI/SPI	Drought category	Probability
≥ 2.00	Extreme wet	0.02
1.50 - 1.99	Severe wet	0.06
1.49 - 1.00	Moderate wet	0.10
0.99 - (-0.99)	Normal	0.65
(-1.00) - (-1.49)	Moderate drought	0.10
(-1.50) - (-1.99)	Severe drought	0.05
≤ (-2.00)	Extreme drought	0.02

2.3. *Standardized precipitation index (SPI)*

Standardized Precipitation Index developed by McKee *et al.* (1993). It is based on the probability of accumulated precipitation. Gamma distribution function is used for fitting the data. Other distribution functions, such as Pearson type-III and Normal distribution function can also be used. Numerous studies conducted reveal that resultant SPI values differs using different distribution functions (Guttman, 1999; Lana & Burgueno, 2000; Vicente-Serrano, 2006).

If *x* is the precipitation amount in a particular period, in order to remove skewness, Gamma distribution function is applied as:

$$g(x) = \frac{1}{\beta^{\alpha} \Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \qquad (9)$$

where, α > 0 is a shape parameter, β > 0 is a scale parameter, *x* > 0 is the precipitation amount, $\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y} dy$ is the gamma function. For each of the stations and desired timescale (in this study timescale of 3, 6 and 12 months) are determined. α and β are determined on the basis of maximum likelihood using:

$$\hat{\alpha} = \frac{1}{4A} \left(1 + \sqrt{1 + \frac{4A}{3}} \right), \hat{\beta} = \frac{\bar{x}}{\hat{\alpha}}$$

and $A = \ln(\bar{x})^{\wedge} - \frac{\sum \ln(x_i)}{n}$

Here, x_i is the precipitation, $\bar{x}$ is the long time average precipitation and n is the length of precipitation time series. Cumulative probability distribution for a

given length of time is then calculated using these estimated parameters, for a specific precipitation event:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\hat{\beta}^{\hat{\alpha}}\Gamma(\hat{\alpha})} \int_0^x x^{\hat{\alpha}''-1} e^{-x/\hat{\beta}} dx \qquad (10)$$

As for a shorter time steps there may be events with no precipitation and Gamma function is not defined at $x = 0$, so in order to include these events cumulative distribution is modified as:

$$H(x) = q + (1-q)G(x) \qquad (11)$$

where, q is the probability of precipitation = 0. Let m be the number of events with precipitation = 0 in the time series, then $q = m/n$ (where, n is the length of time-series in calculation).

Cumulative probability distribution (x) is then transformed into standardized normal distribution Z having 0 average and 1 as standard deviation. SPI is number of standard deviation left (drought) or right (wet) from 0.

For $0 < H(x) \le 0.5$

$$SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right) \qquad (12)$$

where, $t = \sqrt{\ln\left\{ \frac{1}{\left[H(x) \right]^2} \right\}}$

Similarly, for $0.5 < H(x) < 1$

$$SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right) \qquad (13)$$

where, $t = \sqrt{\ln\left\{ \frac{1}{\left[1.0 - H(x) \right]^2} \right\}}$

$C_0 = 2.515517$, $C_1 = 0.802853$, $C_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$ and $d_3 = 0.001308$ are constants. Dry/wet categories for SPI is exactly same as that for SPEI and are represented in Table 2.

2.4. *Z-index*

China *Z*-index is a drought index used by China Meteorological Administration (CMA) to monitor drought
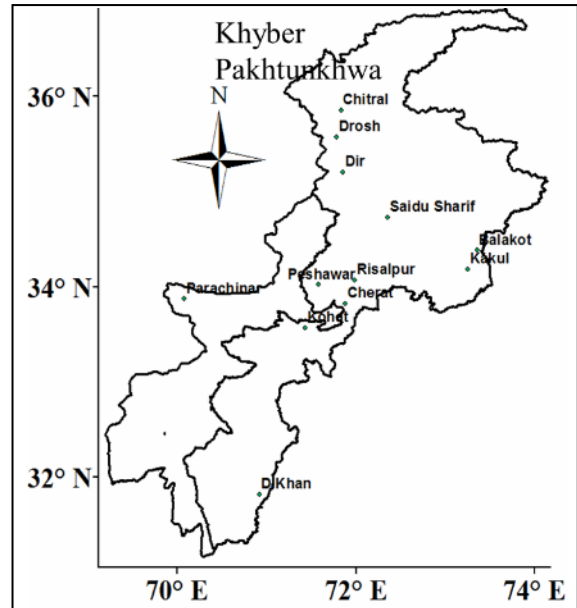

Fig. 3. Location of station on the map of Khyber Pakhtunkhwa

and flood. *Z*-index adopted by (Tan *et al.*, 2003) is used for grading dry/wet (flood) spells as well as their intensity. *Z*-index has been effectively used by (Sun *et al.*, 2000 and Wu *et al.*, 2001) for monitoring drought flood conditions over different regions of China. Assuming that rainfall data follows Pearson type three distribution, formula for grading dry/wet situation at each station is as under:

$$\text{where, } Z_i = \frac{6}{C_s}\left(\frac{C_s}{2}\varphi_i + 1 \right)^{1/3} - \frac{6}{C_s} + \frac{C_s}{6} \qquad (13)$$

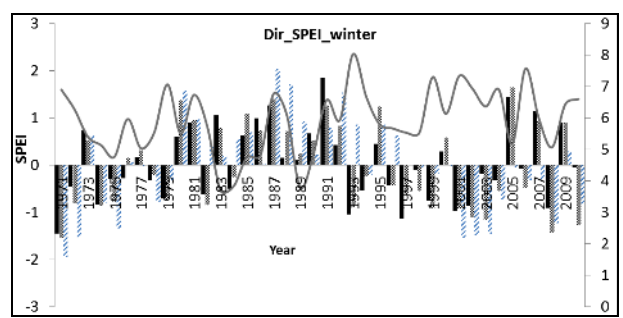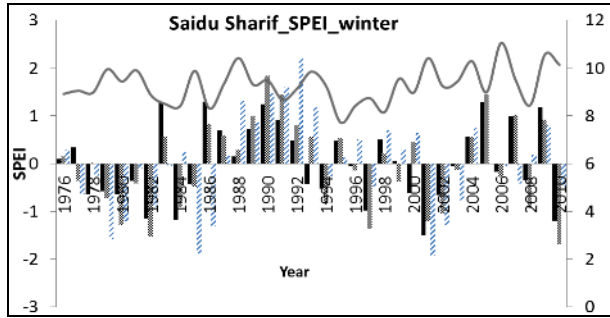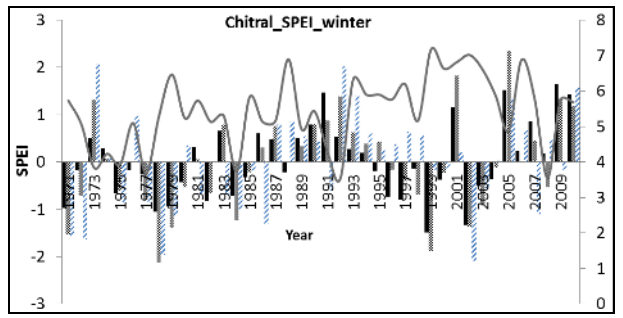where, C_s and φ_i are skewness coefficient and normalized variables defined as:
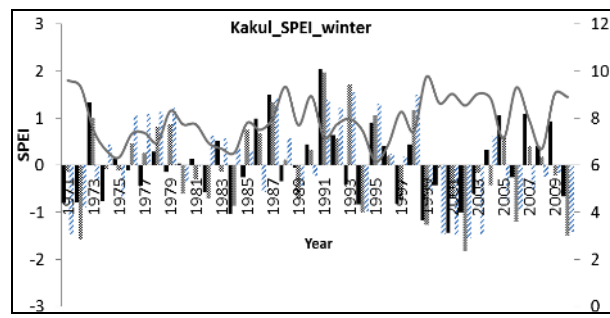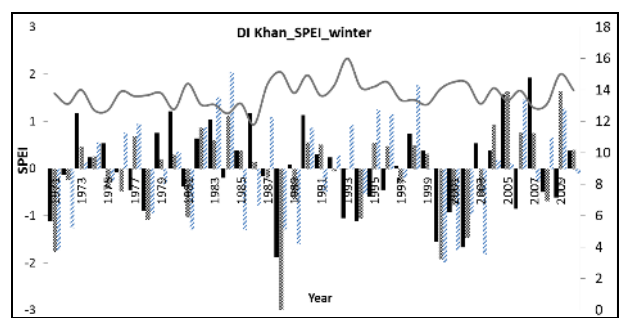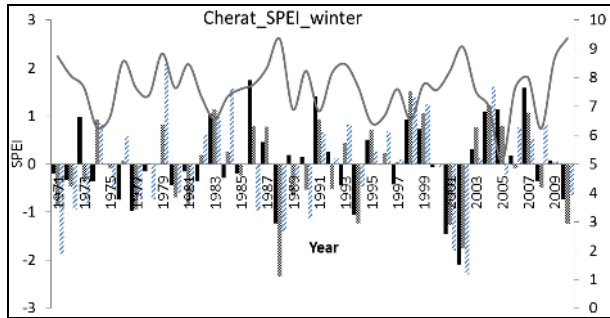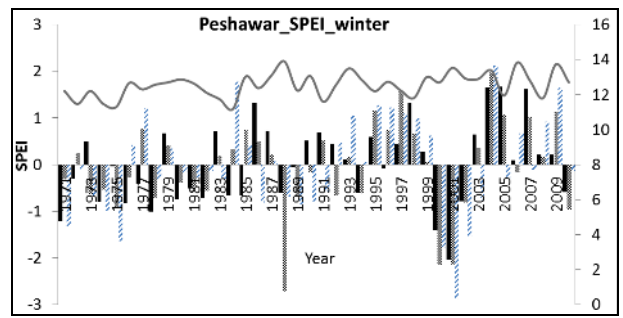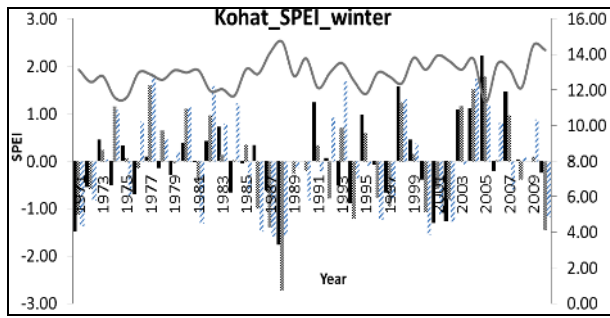
$$C_s = \frac{\sum_{i=1}^n (x_i - x)}{n\sigma^3}, \varphi_i = \frac{x_i - \bar{x}}{\sigma}$$

Climatic mean x and variance is calculated as:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^n x_i, \quad \sigma = \sqrt{\frac{1}{n}\sum_{i=1}^n \left(x_i - \bar{x} \right)^2}$$

Z-index also asses the drought/flood severity of the region as follows:

$$I_F = \frac{\left(\sum_{i=1}^3 n_i / p_i + n_4^+ / p_4 \right)}{n}, I_D = \frac{\left(\sum_{i=5}^7 n_i / p_i + n_4^- / p_4 \right)}{n}$$
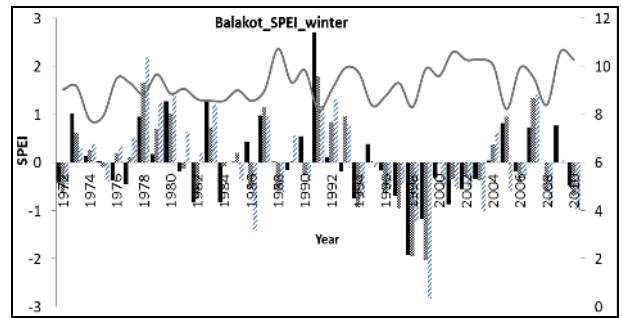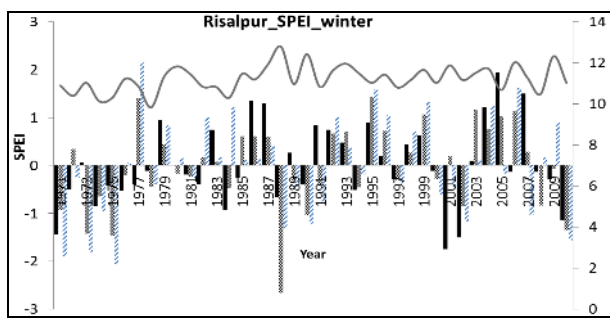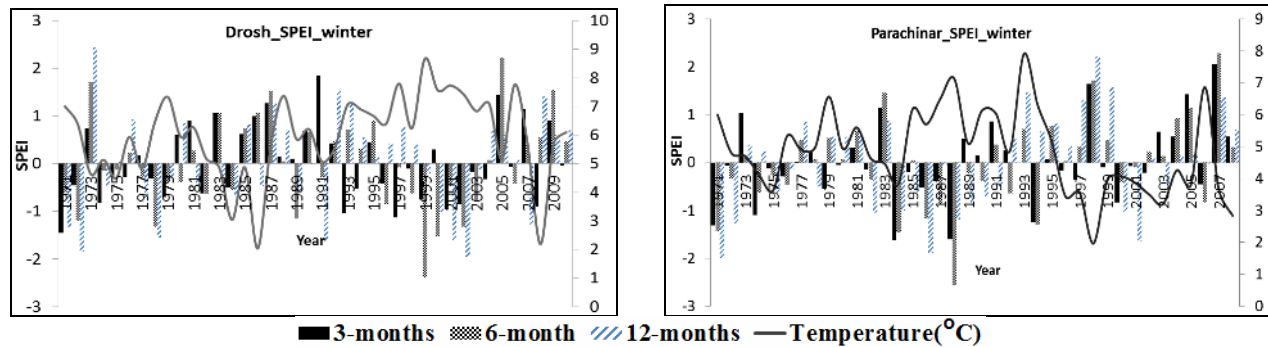
Fig. 4. SPEI based on 3, 6 and 12 months timescale and temperature for winter season during 1971-2010

where, I_F is for wet index and I_D is for dry index. p_i denotes probability of grade i, *e.g.*, p_4 is the probability of grade 4. n_i is the number of stations with grade i, positive or negative sign in the superscript represent the anomaly.

In order to calculate Z-index, monthly precipitation was averaged over winter season. This seasonal mean rainfall data is used to calculate Z-index for winter season.

3. Results and discussion

In the following section results of SPEI and SPI for different timescale and Z-index for KPK is discussed separately.

3.1. *SPEI for different time scale*

SPEI calculated on 3, 6 and 12 - month's timescale and temperature for 12 stations of KPK are shown in Fig. 4.

All the stations behave differently, depending on timescale, during the study period. Dry and wet conditions changes from station to station. There is no solid coherence among all the stations, but still during some year most of the stations experiencing the same situation. Here two year are mentioned during which majority of the stations were under drought conditions of different intensities. In early 1970s most of the stations show drought trends of different intensities. In 1971, on the basis of 3-months timescale, 7 stations (Kohat, Peshawar, D. I. Khan, Risalpur, Dir, Drosh and Parachinar) out of 12 stations experienced moderate drought. In the year 1988, severe drought was observed in 3 stations (D. I. Khan, Kohat & Parachinar) and 1 (Cherat) station was experiencing moderate drought. In 2001, extreme (Peshawar), severe (Risalpur) and moderate (Kohat, Cherat & Kakul) droughts prevailed. In 2002, five stations (Cherat, D. I. Khan, Risalpur, Chitral and Kohat) were

under drought conditions. On the basis of 6-months timescale, during 1971, five stations experienced drought out of which three (D. I. Khan, Chitral & Dir) were under severe drought, while in two stations (Kohat & Parachinar), moderate conditions prevailed. In the year 1988 six stations (Kohat, Peshawar, Cherat, D.I. Khan, Risalpur and Parachinar) were suffering from extreme drought conditions. In 2000, four stations, Peshawar (extreme), D. I. Khan (severe), Drosh (severe) and Kohat (moderate) were under drought situations. In 2001, Peshawar (extreme), Cherat (moderate) and Saidusharif (moderate) were experiencing drought. During 1971, six stations (Cherat, D. I. Khan, Risalpur, Chitral, Dir and Parachinar) were facing severe drought conditions. While four stations (Kohat, Peshawar, Kakul and Drosh) were under moderate drought on 12 month based analysis. In 2001, Peshawar was under extreme drought, while six stations (Cherat, D. I. Khan, Saidu Sharif, Dir, Drosh and Parachinar) were facing severe drought conditions. During 2002, Cherat and Chitral experienced extreme drought, while severe drought prevailed over three stations (Peshawar, Kakul and Drosh), four stations (Kohat, Risalpur, Saidusharif and Dir) were suffering from moderate drought during that particular year.

Fig. 5 represents the frequency distribution map. It can be seen easily the southern part of KPK experienced more drought events on basis of SPEI. Drought frequency decreases towards the north. Maximum number of drought events occurred in D. I. Khan, while the least in Balakot.

3.2. *SPI for different timescale*

SPI for the timescales of 3, 6 and 12 months were also calculated. Results are shown in Fig. 6. Drought intensity intensifies with the increase in timescale. On 3-months scale, 2002 and 2005 were identified as extreme drought, in Cherat & Peshawar respectively. In the year 1971, five stations were under drought conditions, two

TABLE 3

Standard for categorizing wet and dry on single Z-index and regional index

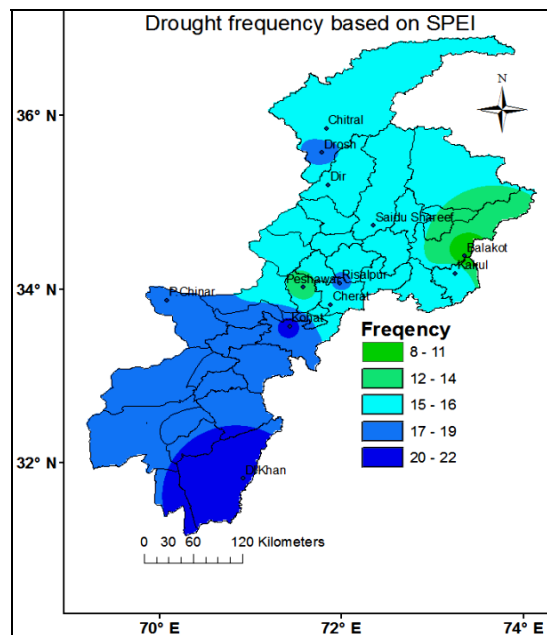| S. No.	Category	Single Z-index	Theoretical Probability	Regional index
1.	Extreme Wet	Z≥1.645	5%	$I_{F\_}I_{p \geq 1/p2}$
2.	Sever Wet	1.0367≤Z≤1.645	10%	$1/p3 \leq I_{F\_}I_p < 1/p2$
3.	Mild Wet	0.5244<Z<1.0367	15%	$1/p4 < I_{F\_}I_p < 1/p3$
4.	Normal	-0.5244≤Z≤0.5244	40%	$-1/p4 \leq I_{F\_}I_p < 1/p4$
5.	Mild Drought	-1.-367<<-0.5244	15%	$-1/p5 \leq I_{F\_}I_p < 1/p4$
6.	Severe Drought	-1.645<Z<-1.0367	10%	$-1/p6 \leq I_{F\_}I_p < 1/p5$
7.	Extreme Drought	Z≤-1.645	5%	$I_{F\_}I_{p \leq 1/p6}$

Fig. 5. Frequency of drought events based on SPEI

stations (Cherat & D. I. Khan) faced moderate drought conditions, while three stations (Peshawar, Risalpur & Dir) were under moderate drought. In 1984, four stations (Risalpur, Balakot, Saidusharif and Parachinar) experienced moderate drought.

During 2001, four stations (Peshawar, Cherat, Risalpur and Saidusharif) were under severe drought conditions, while Balakot and Kakul were facing moderate drought. On 6-months scale six stations experienced extreme drought in different years. During 1988, three stations (Cherat, D. I. Khan & Risalpur) were under extreme drought conditions, while Parachinar experienced severe drought. In year 1999, drought

situation prevailed in different stations, Balakot (extreme), Drosh (severe), Kohat (moderate) and Chitral (moderate). During 1999, Balakot (extreme), Drosh (severe), Kohat (severe) and Chitral (severe) were under drought conditions. In 2001, three stations, Peshawar (extreme), Cherat (severe) and Saidusharif (moderate) experienced drought. In 2010, in Kakul (extreme), Dir (severe) and Saidusharif (moderate) drought prevailed. On the basis of 12-month timescale, nine stations experienced extreme drought conditions in different years. During 2001 and 2002 seven stations were under drought condition of different intensities.

Number of drought events based on SPI, over the province is shown in Fig. 7. Results are quite different from that based on SPEI. Southern part of the province (D. I. Kahn) experienced the least number of drought events. While Saidu Sharif has been identified as station with highest number of drought events. Normal rainfall at D. I. Khan is the least among all other stations while Normal Temperature is the highest (based on 1971-2000 Normal from PMD). D. I. Khan is categorized as arid during Rabi (winter) season (Choudhry and Rasul, 2004). In order to categorize drought or wet, SPI does not take into account the effect of temperature. So this is the reason that frequency distribution of drought is different based on the two indices. SPI also fails to capture the 1998-2002 drought spell in some stations, particularly in Risalpur and D. I. Khan whereas SPEI was able to indicate that dry period.

Number and categories of drought/wet events, for individual stations, along with percentage probability are shown in Table 4 these categories are based on the threshold values shown in Table 3. Although theoretical and calculated probabilities are not same, but difference in these two are not too much. Advantage of Z-index is that
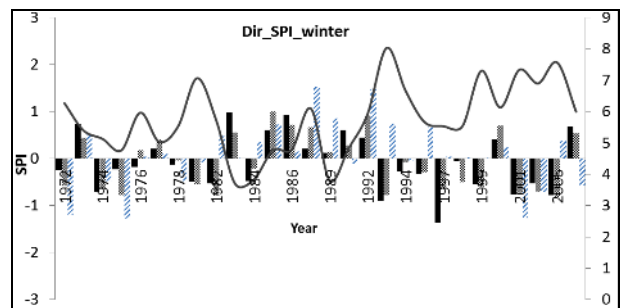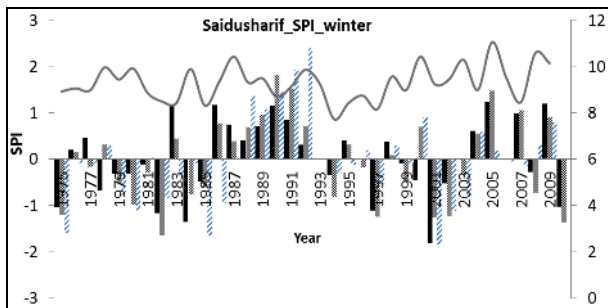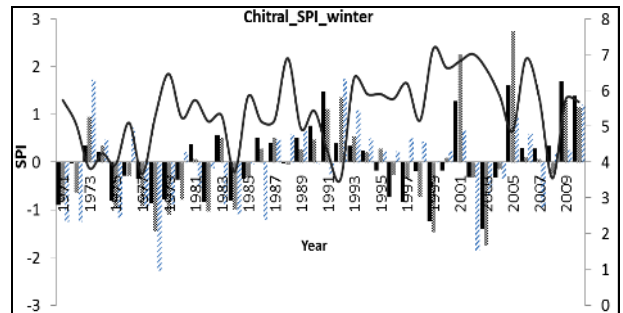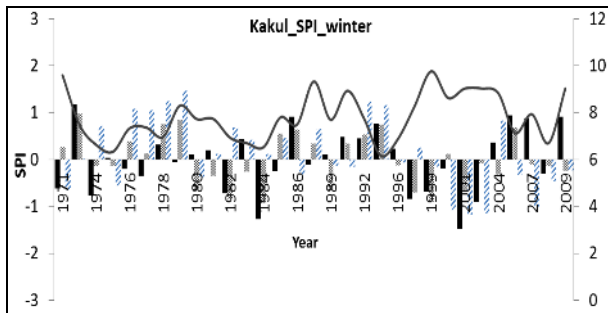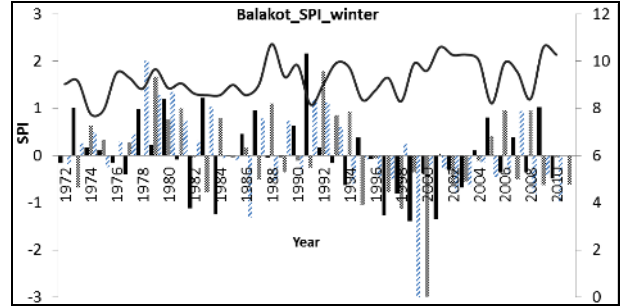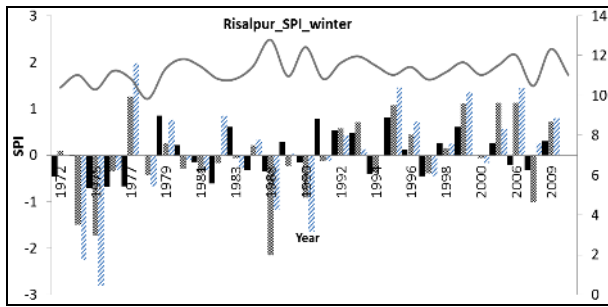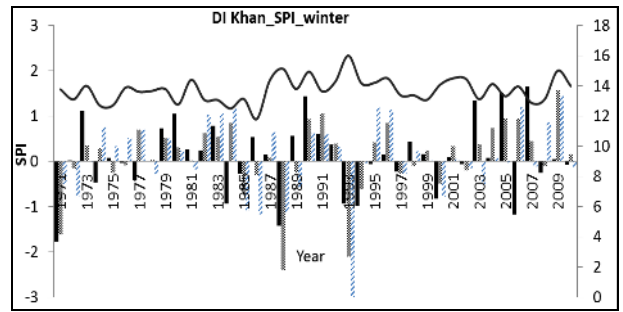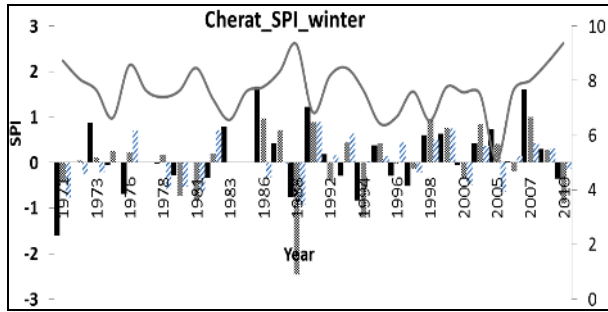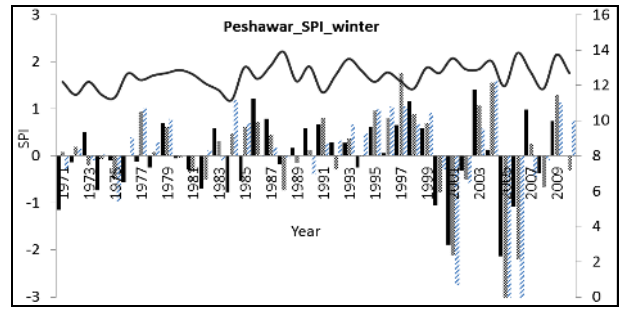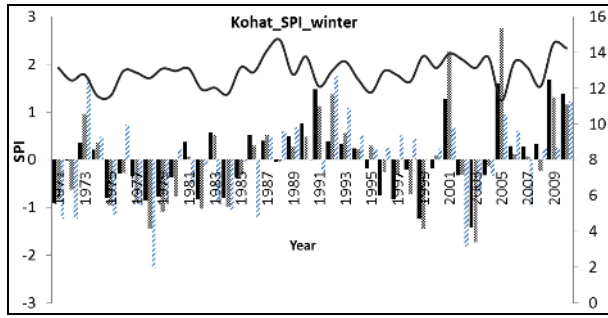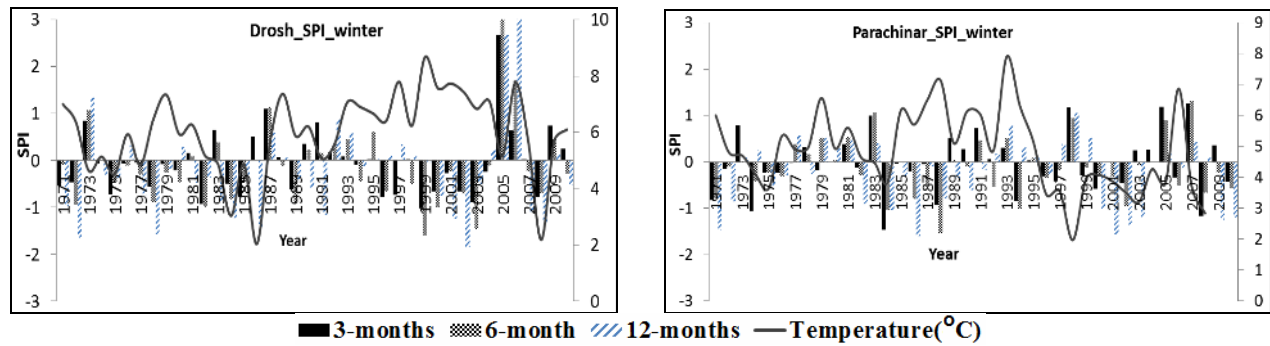
Fig. 6. SPI based on 3, 6 and 12 month timescale and temperature for winter season during 1971-2010

TABLE 4

Number of years and the corresponding probability for grading flood/drought

Stations	Extreme wet	Severe wet	Mild wet	Normal	Mild drought	Severe drought	Extreme drought
D. I. Khan	2	2	6	22	2	3	3
Balakot	2	1	12	12	9	1	3
Cherat	2	4	4	20	5	2	3
Chitral	3	2	6	17	7	4	1
Dir	1	5	6	16	9	1	2
Drosh	3	3	6	16	6	4	2
Kakul	1	4	7	17	6	2	3
Kohat	4	1	7	17	6	3	2
P. Chinar	2	4	5	20	3	3	3
Peshawar	2	4	5	18	4	5	2
Risalpur	2	4	5	18	6	4	1
Total	24	34	69	193	63	32	25
Probability	5.45%	7.73%	15.68%	43.86%	14.32%	7.27%	5.68%

TABLE 5

Classification of years into dry/wet during the period 1970-2000

S. No.	Category	Years	Total	Probability
1.	Ext-Wet	1991, 2005, 2007	3	7.5
2.	Severe Wet	1990, 1992, 2003, 2009	4	10
3.	Mild Wet	1972, 1973, 1976, 1980, 1986, 1998, 1999	7	17.5
4.	Normal	1974, 1975, 1979, 1981, 1983, 1987, 1989, 1995, 1996, 2004, 2008, 2010	12	30
5.	Mild Drought	1971, 1977, 1978, 1982, 1988, 1993, 1994, 2002, 2006	9	22.5
6.	Severe Drought	1984, 1985, 2000	3	7.5
7.	Ext Drought	1997, 2001	2	5

Fig. 7. Frequency of drought events based on SPI

Fig. 8. Year wise intensity of drought/flood from 1971-2010 over the region

it categorizes years into drought/flood over the entire region. Fig. 8 shows time series graph of the index. Interannual variability can be seen also some high ridges and troughs are visible indicating flood and drought conditions.

To check the regional situation during the period 1970-2000 all the years are classified into seven categories and are shown in Table 5. Numbers of drought years (all categories) are equal to wet years (all categories). Highest numbers of years fall in normal categories. Years 1991, 2005 and 2007 were classified as extreme wet (flood), while 1997 and 2001 were extreme drought.

4. Conclusions

Keeping in view the above results derived from SPEI and SPI analysis for different timescale and *Z*-index, it can be seen that difference exists between these two indices. During 1971, on 12-months timescale, based on SPEI considers drought situation in 10 stations (Cherat, D. I. Khan, Risalpur, Chitral, Dir, Parachinar, Kohat, Peshawar, Kakul and Drosh). Severe drought in the first six, while moderate drought in the later four stations. Based on SPI only five stations (Risalpur, Dir, Kohat, Chitral and Parachinar) were suffering from drought. Sever in first two and moderate in last three stations. *Z*-index classified 1971 as mild drought over the region. In 1984, based on
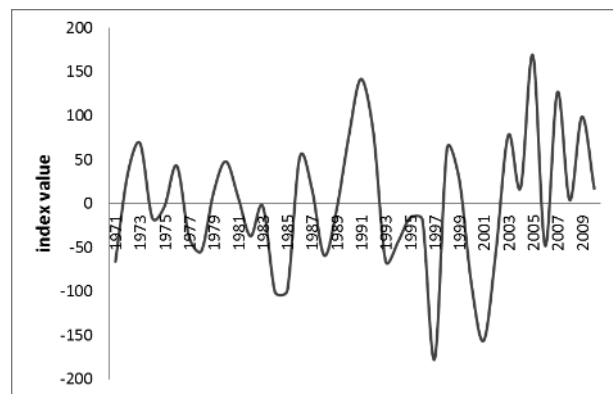
SPI 4 stations (Risalpur, Balakot, Kakul and Saidusharif) were facing moderate drought, while SPEI indicates only two (Kakul and Parachinar). *Z*-index reveals severe drought conditions during 1984. Average winter temperatures, during 1984 were below mean winter temperature, for all the mentioned four stations, which can reduce water lose through evapotranspiration and may cause reduce water stress. In 1988, on basis of 6-months timescale SPEI indicated extreme drought in Peshawar and Kohat, while SPI could not and considered it as normal. Temperatures at these two stations were above normal during that year. 2010 was indicated as moderate dry by SPEI and moderate wet by SPI in Kohat. That year the temperature was higher than normal about 1.4 °C. On the basis of 1999-2002 drought episodes, SPI fails to capture that particular event in some stations for example D. I. Khan, Risalpur and Cherat, while SPEI was able to highlight it. D. I. Khan lies in the south of the province with low elevation; it is a drought prone area, with least amount of rainfall and high temperatures as compared to other stations. Number of drought events based SPI analysis is less than the other stations, while SPEI based analysis shows that D. I. Khan suffered most drought events than any other station. More over in the context of global warming, rise in temperature is a hot issue, SPI neglect the effect of temperature, but SPEI takes into account of this important meteorological parameter (for calculating evapotranspiration). So SPEI can be a better choice as compared to SPI. Same contrasting result is visible in 2005, at Peshawar stations, SPEI considered it as moderate wet, while in SPI it is declared as extreme dry, temperature was below normal in 2005. *Z*-index categorizes 2005 as extreme wet. Ability of SPEI to take into account the effect of temperature makes it a better index in the context of global warming. *Z*-index has advantage that it gives regional picture of drought/flood along with the individual stations.

This study will help to quantify drought situation in the region on monthly as well as seasonal basis. In future hydrological and agricultural datasets, such as soil moisture, runoff and stream flow (observed or satellite derived) can be incorporated in order to develop a real time drought monitoring system. This will help to streamline the mitigation activities in case of drought occurrence.

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