ARID ECOSYSTEMS, 2023, Vol. 29, No 1 (94), P. 36-45.

SYSTEMATIC STUDY OF ARID TERRITORIES

UDC 551.5:005.8

METEOROLOGICAL DROUGHT MEASUREMENT WITH DEFICIT IN RAINFALL OCCURRENCE ACCORDING TO SPI INDICES: A CASE STUDY OF PESHAWAR, PAKISTAN

© 2023 г. ShahlaNazneen*,TehreemAyaz, YamnaDurrani*, Neelum Ali*, Ming Lei**, SaeedaYousa***

***Department of Environmental Sciences, University of Peshawar, Peshawar, 25120, Pakistan.*
****College of Resources and Environment, Hunan Agricultural University, Changsha 410128, P. R. China.*
Postal Address: College of Resources and Environment, Hunan Agricultural University, Changsha, 410128, P.R. China.E-mail: tehreemayaz17301@yahoo.com

Received April 1, 2023.RevisedJune 30, 2023.Accepted July 1, 2023.

The study aimed to analyze the probability of occurrence/severity situation of meteorological drought in Peshawar, Pakistan and its impacts on agriculture. Therefore, the past 30-years (1986-2016) meteorological data was collected from Peshawar Meteorological Department and analyzed through Standardized Precipitation Index (SPI) drought software for mild, moderate, severe and extreme droughts on monthly, seasonally and annually basis. Results for the monthly and seasonal analysis found that severe and extreme droughts occurred mostly in May and June in summer, and March and April in spring seasons. The annually basis analysis found severe drought for the years 1989, 2000, 2001 and 2006, in which the most extreme drought year was 2001. Furthermore, the probability of occurrence/percentage of mild drought (12-month) in past 30 years was calculated 34%, moderate 9%, severe 8% and extreme drought 1.6%, These results also provide an insight of drought probability of occurrence and severity in next hundred years. The study concluded that most immediate consequence of drought can be seen in a fall in crop production. No work has been conducted before on measurement of meteorological drought of Peshawar through SPI. Therefore, it is a novel study and will contribute towards preparing for the drought which may affect the crops of Peshawar.

Keywords: Drought; Meteorological Drought; SPI; Probability of recurrence; Precipitation Deficit and Shortfall.

DOI: 10.24412/1993-3916-2023-1-36-45
EDN: HINEPB

Drought is below normal or deficient protracted period of precipitation which results in loss of yield, extensive damage to crops and is a recurring extreme climate event over a period of months to years. It can be considered as purely a meteorological phenomenon (Palmer, 1965) and a temporary aberration from normal climatic conditions, varying significantly from one region to another (Fuchs, 2019). Increase in the emissions of greenhouse gases not only cause environmental changes but also probability of drought thereby, influences the stability of ecosystems worldwide (Parry et al., 2007; Albert et al., 2011; Pei et al., 2013). Drought differs from one another in arsenical characteristics such as intensity, duration and spatial coverage (Wilhite, 2019), as well as spatial extent and timing (Orville, 1990).

There are four types of drought, which includes agricultural, socioeconomic, meteorological and hydrological drought (Wilhite, 2000) expressed in four classes according to Standardized Precipitation Index (SPI): mild, moderate, severe, and extreme (Wang et al., 2016). Meteorological, hydrological and agricultural droughts are measured as a physical phenomenon, while socioeconomic drought deals with supply, demand and the tracking of the effects of water shortfall (Wilhite, 2000; Nebraska-Lincoln, 2017). Meteorological drought also called climatological drought is «the magnitude of a precipitation shortfall and the duration of this shortfall»(Orville, 1990). It can begin and end rapidly (NOAA, 2019), taking place when dry weather patterns are dominant over an area. Conceptual models are used to study the relationship between drought, intensity, duration and frequency (Ojos Negros Research Group, 2019). The impacts of drought are monitored by remote sensing technology in the fields of agriculture, water and related sectors (Chaudhry et al., 2001). There are very few extreme events and natural hazards, which are as economically,

ecologically and environmentally disruptive as drought, affecting millions of people in large areas of the world each year (Dai, 2013; Asrari and Masoudi, 2014). The crop yield and food production gets affected due to drought and climatic change and are globally well documented (Mishra and Cherkauer, 2010). It has been observed that not only the numbers of droughts but also their intensity over the last few decades has increased (Tigkas et al., 2012), attributing to the change of climatic conditions, which puts additional pressure on hydrological systems and water resources. Severe drought conditions can not only impact agriculture but ecosystems, tourism, basic human welfare and most importantly water resources (Dai, 2013), as well as desertification, increased crop losses, social alarm, urban water supply shortages, degradation and forest fires (Flannigan and Harrington, 1988; Pausas, 2004; Asrari and Masoudi, 2014). There has been an increase in the average global temperature of earth by 0.7% in the last century (Parry et al., 2007); leading to the increase in the number of droughts recorded per year in general.

Drought has affected many parts of the world in terms of crop losses, water supply shortage etc. including North America (Cook et al., 2007; Herweijer et al., 2007), Mexico (Seager et al., 2009; Méndez and Magaña, 2010), Asia (Zhai et al., 2010), Africa (Shanahan et al., 2009) and Australia (Kiem and Franks, 2004; Dai, 2013). Pakistan has experienced several drought years (e.g., 1899, 1920, 1935), also affecting Khyber Pakhtunkhwa (KP) region in 1902 and 1951, similarly, Sindh region experienced its worst drought in the years of 1871, 1881 and 1931 (Chaudhry et al., 2001). It is expected that climate change may increases the frequency, duration and severity of extreme events of drought, thus threatening millions of people around the world in terms of food security and reduced water availability (Lasage et al., 2008).

Therefore, keeping in mind the deleterious effects of drought as apparent from the literature, this study was conducted to analyze the rainfall data of the last 30-years (1986-2016) through SPI for the measurement of meteorological drought expressed as: mild, moderate, severe and extreme drought, and on monthly, seasonally and yearly basis. Findings of this research can also be useful to the policy makers and experts of water resources involved in drought planning and mitigation. This research also forms a basis for further investigation, by climatologist, meteorologists and economist for future research.

Study Area

The study area demarcated for the measurements of the meteorological drought was Peshawar, the capital city of the province Khyber Pakhtunkhwa (KP), Pakistan. Peshawar lies between 33°44′ and 34°15′ north latitude and 71°22′ and 71°42′ east longitude. The total area of Peshawar is 1.257 square km^2(Government of Pakistan, 2011), and situated at an altitude of 347 m (138 ft.) above sea level. The average population was about 193.2 million in 2016. The dates for the onset and termination of average annual rainy days are from February to April in the winter seasons and from July to August in the summer season. The average annual rainfall is 5908 mm (20 inches). The driest months in terms of rainfall are from October to December, the annual monthly sunshine hours are recorded in the months of May to July, respectively. Winter season starts from mid-November to the end of March. The mean maximum temperature in summer is over 40ºC (104ºF) and the mean minimum temperature is 25ºC (77ºF). The mean minimum temperature in winter is 4ºC (39ºF) and its maximum is 17.8ºC (64.04ºF). The wind speed varies from 5 knots (5.8 mph; 9.3 km/h) in December to 24 knots (28 mph; 44 km/h) in June. There is a variation in the relative humidity from 46% in June to 76% in August (Regional Meteorological Centre Peshawar, 2011).

Peshawar is known for fertile and highly cultivated soil and its food and cash crops. Subsistence agricultureformsthe base and primary crops are wheat, barley, corn, peppers, millet, cotton and sugarcane. The two major planting and harvesting periods are winter for wheat and barley, and summer for corn. Planting and harvesting of sugarcane overlap both the periods. In nay villages of pepper, cotton, wheat and especially sugarcane and tobacco are grown for the local consumption and for the market as well. In Peshawar there are peach, apricot, pear and grape vineyards (Government of Khyber Pakhtunkhwa, 2018). It is pertinent to mention that total irrigated area of Peshawar is 75758 ha with 99.6% crop intensity (Fig. 1). Maize is cultivated on 16777 ha with production of 29477 tons in 2013, rice 340 ha and production 711 tons, pigeon pea 33 ha and production 22 tons, chilies 12 ha and production 11 tons, sugarcane 11164 ha and production 576880 tons, wheat 36228 ha and production 80061 tons, Barley 51 ha and production 62 tons, rape and mustered 25 ha and production 20 tons, garlic 214 ha and production 2696 tons, coriander 16 ha and production 8 tons, onion 27 ha and production 251 tons, potato (summer + autumn) 58 ha and production 975 tons, Potato (Spring) 32 ha and production 228 tons (Government of Khyber Pakhtunkhwa, 2013).

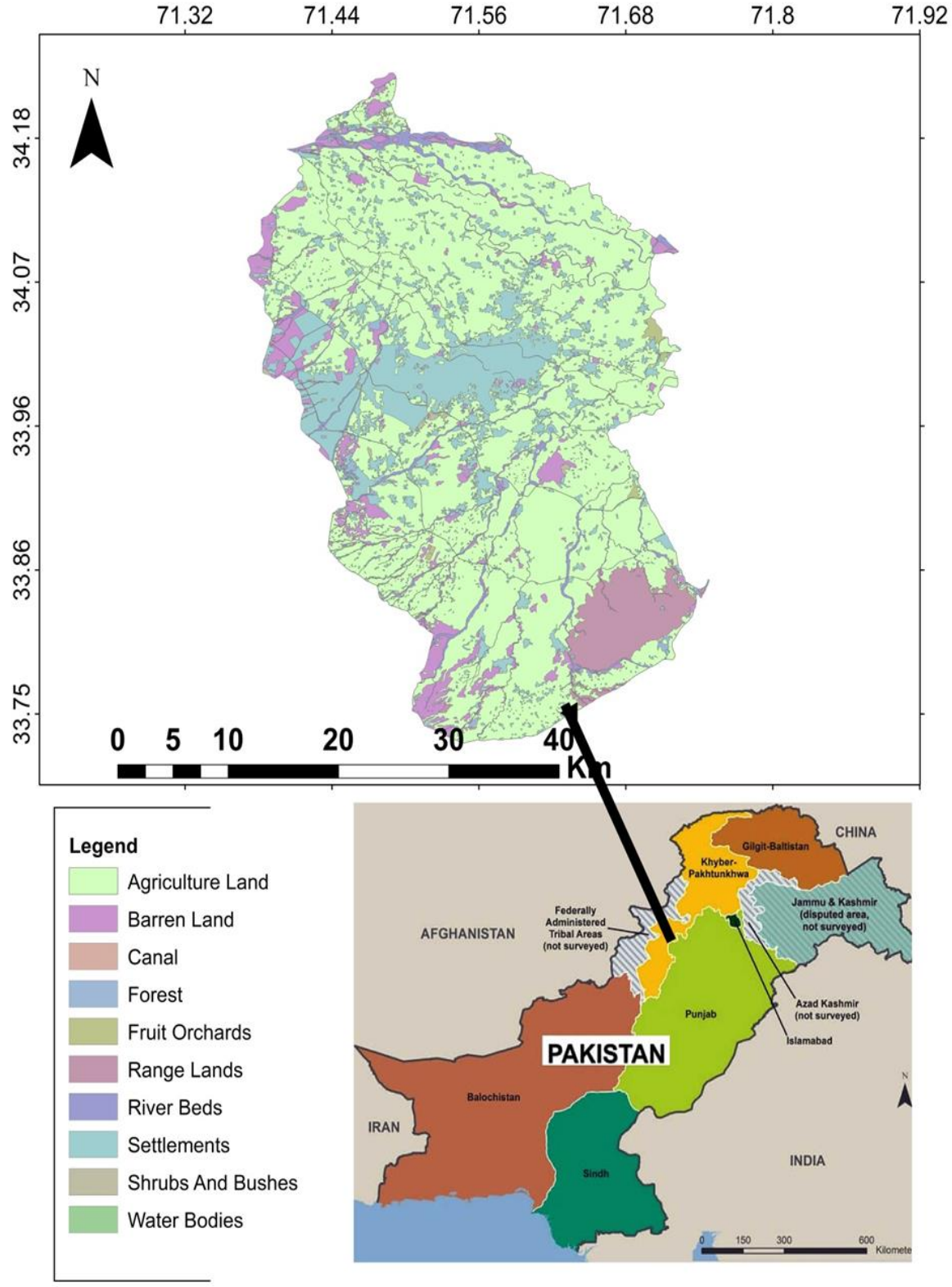


Fig. 1. Land use map of Peshawar district.

Methods and materials

Data set on rainfall for the period of 30-years (1986-2016) was obtained from Regional Meteorological Center (RMC), Peshawar. This was a real time data manually recorded at 0300Z, Greenwich Mean Time (GMT). The recorded length of 30-years provides a good basis for evaluating measurements of

meteorological drought of Peshawar region and to assess rainfall and climate. In this study, the deficits in normal rainfall were analyzed, assessed, interpreted, and calculated. The SPI drought software was used for the data analysis and SPI drought classification types were used which include mild, moderate, severe and extreme drought on monthly, seasonal and yearly scale. The classification of meteorological drought according to Pakistan Meteorological Department, 2008 is given in Table 1.

Table 1.SPI drought classification and Types of droughts.

SPI drought classification		
2.0+	Extremely wet	No drought
1.55 to 1.99	Very wet	No drought
1.0 to 1.49	Moderately wet	No drought
-0.99 to 0.99	Nearnormal	Milddrought
-1.0 to -1.49	Moderatelydry	Moderatedrought
-1.5 to -1.99	Severelydry	Severedrought
-2.0 andless	Extremelydry	Extremedrought

For this study, standard deviation from normal rainfall was calculated by the SPI values of 1, 3, 6, 9 and 12 months through which the deficiency or shortfall in rainfall was calculated. SPI 1-3 months reading can be used to identify meteorological drought, 3 to 6 months readings, agriculture drought and 6-12 months readings, hydrological drought. The same methodology has also been adopted previously by many authors (Palmer, 1965; Dai, 2013; Asrari and Masoudi, 2014; Szarzynski et al., 2014; Fahim et al., 2016). SPI has been used widely in numerous parts of the world because of its reliability, accuracy, efficiency and ability to report drought at various time scales for a variety of different climatic regions (Mishra and Cherkauer, 2010; Zhai et al., 2010; Jain et al., 2015) and most suitable for Asian region (Jain et al., 2015). It measures water deficit, observed precipitation and associated variation in moisture (McKee et al., 1993) used in identifying meteorological drought (Mishra and Cherkauer, 2010).

Classification of meteorological droughtbased on the SPI indices

Meteorological drought classified into four types based on the SPI indices are described as (a) mild drought, (b) moderate drought, (c) severe drought, and (d) extreme drought.

(a) Mild drought is further classified into «going into drought»; A situation in which a short-term dryness is observed and in which slow plant growth or pastures is observed and «coming out of drought»; A situation in which crop or pastures are not fully recovered, and some lingering water deficits are eminent. (b) Moderate drought is a situation in which some damages to pastures, crops, reservoirs, streams, or wells are observed, or when some prominent water shortages and voluntary water-use restrictions are requested. (c) Severe drought is a situation in which there is eminent crop or pasture losses, water shortages, and water restrictions are imposed. (d) Extreme drought is a situation in which major crops/pasture losses are widespread, while water shortages or restrictions are present.

Further, in this study number of times drought occurred in thirty years, probability of reoccurrence, and severity of the drought events of each category of the drought in the next hundred years have also been predicted.

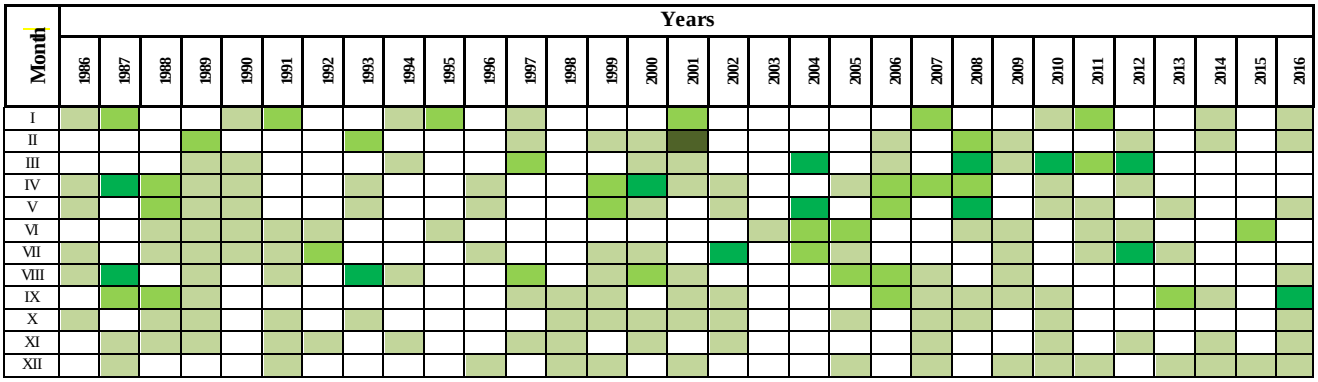
Results and discussion

Occurrence of mild, moderate, extreme and severe drought in Peshawar district from 1985-2016 was determined through 1, 3, 6, 9 and 12-month SPI readings and are depicted in Table 2 (A-E). Yearly drought was determined through 12-month SPI reading, while seasonal drought was determined by 6 and 9-month SPI reading. In the year 1989, 2000, 2001 and 2006 drought has been recorded all year round and therefore classified as major drought years. From the above-mentioned years, only 2001 is categorized as extreme drought year while rest are classified as severe drought years according to WMO (World Meteorological Organization, 2012) classification system. The report produced by the Global Facility for Disaster Risk Reduction, shows that the drought of 2000 in Pakistan was severe that it destroyed the livelihoods of people. It was due to the extremely less rainfall reported i.e., 30% below of which is normally expected (Qureshi and Akhtar, 2004; Larsen et al., 2014; Ullah and Takaaki, 2016). According to Economic Survey of Pakistan, the drought in Pakistan was due to the monsoon season failing

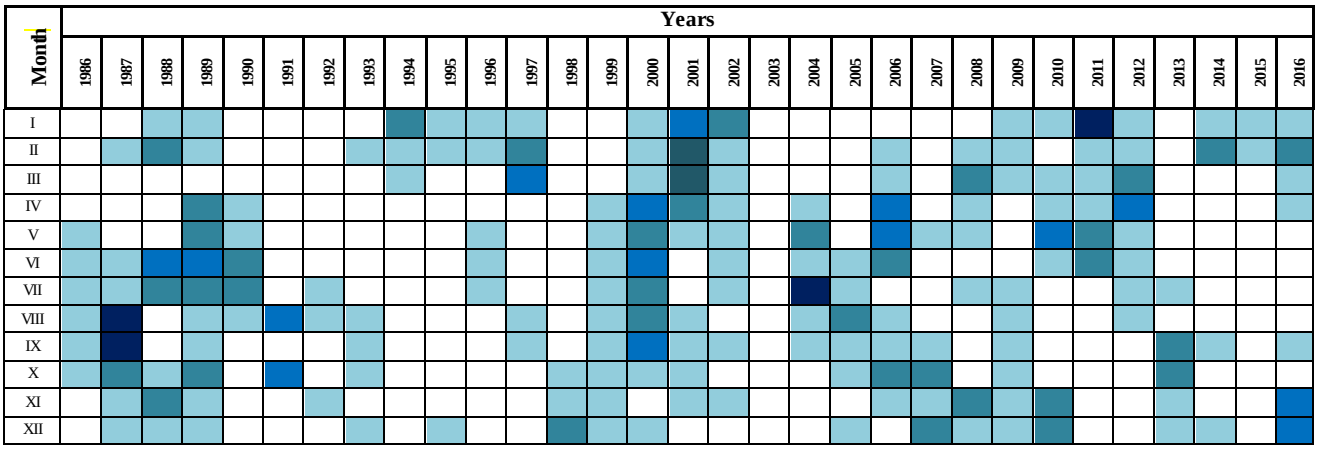
to deliver rain (PWP, 2011). One of the major reasons of the drought was the presence of El-Nino, and the lack of winter rains, this causing 30% below normal monsoon rainfall in the region, and also increased the chances of moderate to extreme drought (National Disaster Management Authority of Pakistan, 2012).The Intergovernmental Panel on Climate Change (IPPC) indicated an increase in the drought conditions in different parts of the world as well as South Asia (Parry et al., 2007).

Table 2. Occurrence of mild, moderate, extreme and severe drought in Peshawar district from 1985-2016 {1-month SPI reading (A), 3-month SPI reading (B), 6-month SPI reading (C), 9-month SPI reading (D) and 12-month SPI reading (E)}.

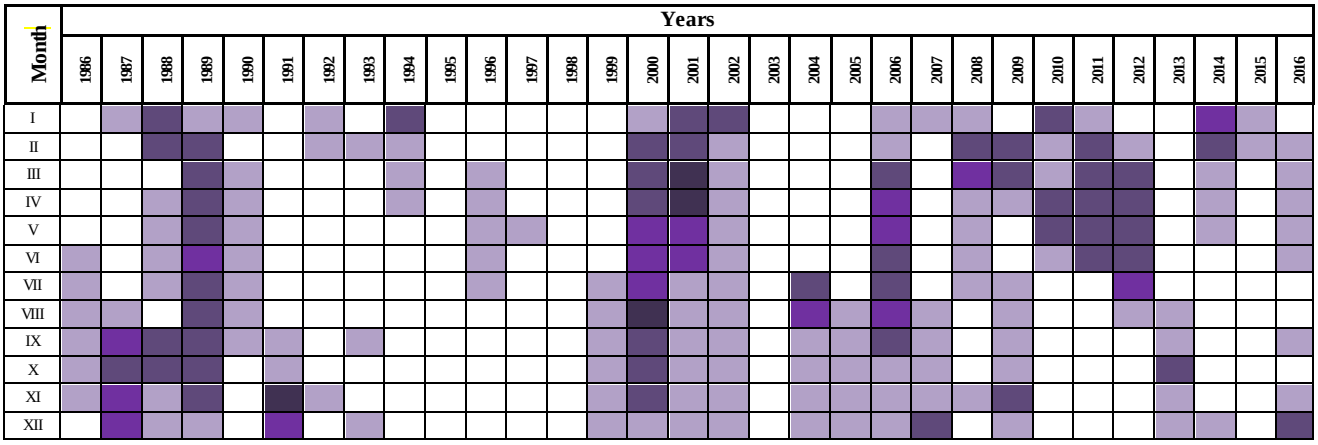
1-month SPI reading (A)



3-month SPI reading (B)

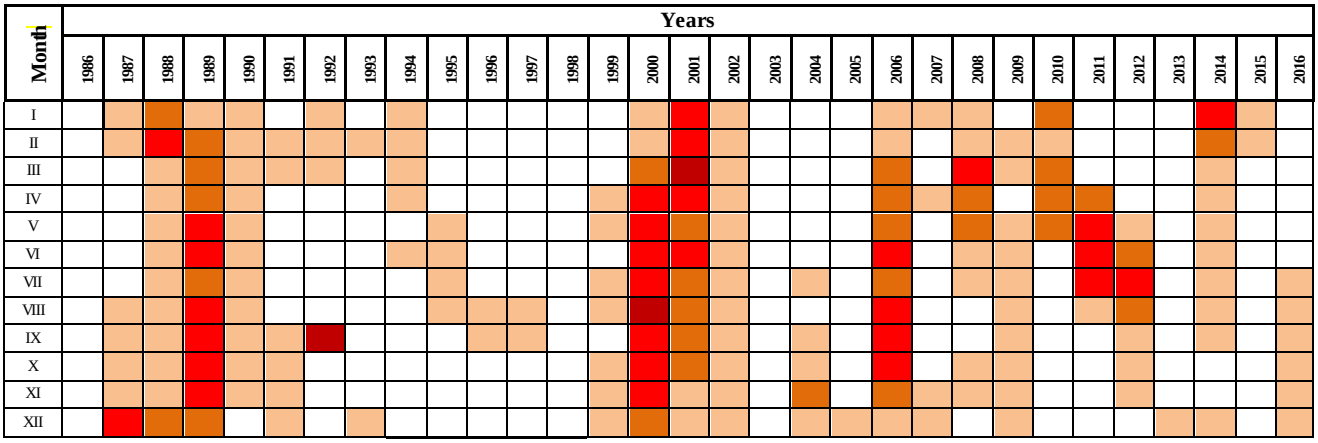


6-month SPI reading (C)

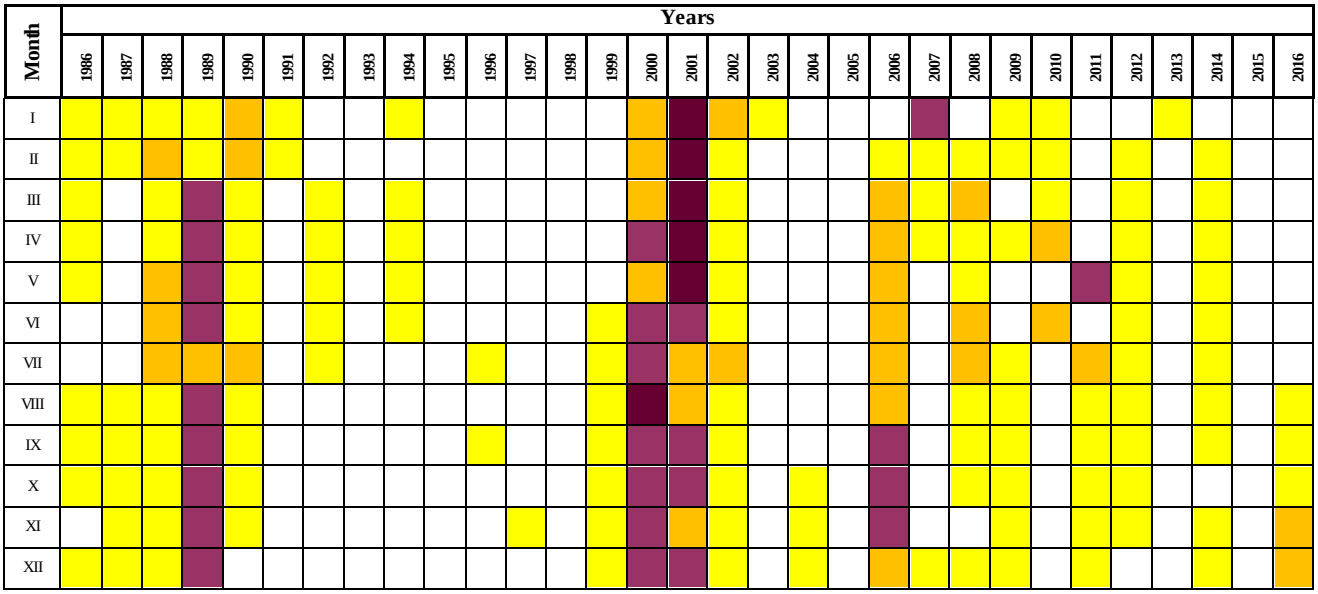


Continuation of the table2. Occurrence of mild, moderate, extreme and severe drought in Peshawar district from 1985-2016 {1-month SPI reading (A), 3-month SPI reading (B), 6-month SPI reading (C), 9-month SPI reading (D) and 12-month SPI reading (E)}.

9-month SPI reading (D)



12-month SPI reading (E)



DroughtType	(A)	(B)	(C)	(D)	(E)
Nodrought					
Mild					
Moderatedrought					
Severedrought					
Extremedrought					

Seasonal drought determined from the 6-month SPI readings were recorded for the years 1987-1989, 2000-2001 and 2006. Whereas, in the 9-month SPI readings seasonal drought has been recorded for the years 1988, 1989, 2000, 2001 and 2006 (Fig. 2 A-E).

It is pertinent from the 1-month SPI reading that mild drought occurred almost every year from 1986-2016 with the highest percentage of 36%. The percentage of time for mild drought for 3, 6, 9, and 12-months SPI readings are almost same, followed by moderate drought. Similarly, probability of occurrence of moderate and severe drought for 9 and 12-month SPI readings are almost same i.e., 8% (Table 3).

Fig. 2 clearly shows that extreme droughts also occurred in the past 30 years. Previous studies showed that because of the climatic change in Peshawar, a change in the monsoon periods is also observed (Bukhari and Bajwa, 2012), which is also one of the factors leading to drought. Maize, wheat, sugarcane, tobacco and different kinds of vegetables are the main agricultural products and rainfall is the main water source for agricultural activities in the province (Fahim et al., 2016). Heat and drought are the major abiotic stresses that restrain crop production (Iqbal et al., 2017).Due to the variation in the temperature or precipitation patterns of Peshawar, from the normal climatic conditions which are generally expected, sensitivity may be shown by the yield of maize as it is highly vulnerable to water stress, whereas the yield of wheat and rice is sensitive to heat stress. Heat stress upsets various biochemical and physiological processes in wheat thereby affecting its growth. Heat stress does not affect the protein content of the plant but a strong correlation has been shown by the grain protein and leaf nitrogen content (Iqbal et al., 2017).

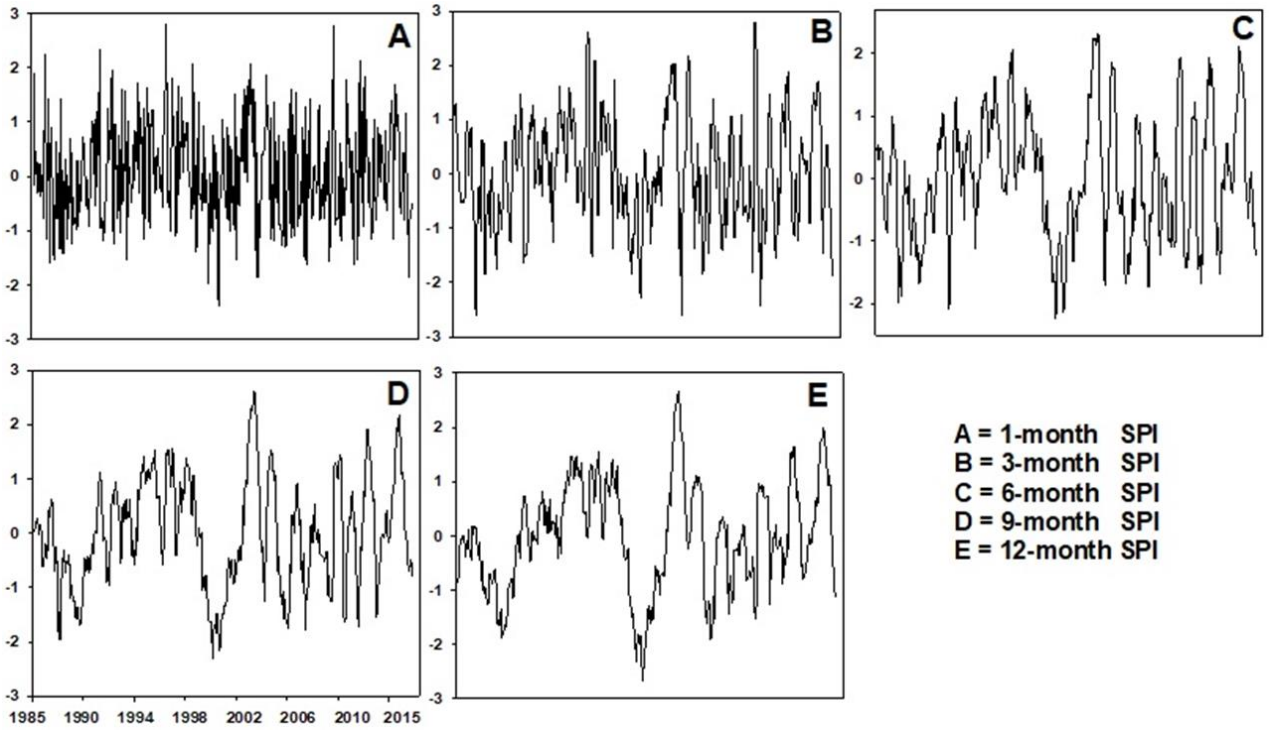


Fig. 2.1, 3, 6, 9 and 12 months SPI of drought for Peshawar district from 1985-2016.

Table 3. Probability of occurrence of drought in Peshawar in last 30 years (1986-2016) and next 100 years.

Category	Probabilityofoccurrence, %					No. of times in next 100 years	Severityofevents
	1-month	3-month	6-month	9-month	12-month		
Milddrought	36.0	36	33	36.0	34.0	34	1 in 3 years
Moderate drought	9.0	9	14	8.0	9.0	9	1 in 11 years
Severe drought	3.6	4	5	8.3	8.0	8	1 in 12.5 years
Extremedrought	0.2	2	1	1.0	1.6	6	1 in 16 years

As the severity of events clearly indicates that severe drought can occur once in 12.5 months and extreme drought can occur once in sixteen years, it may have antagonistic impacts on agriculture such as low crop yields, low average productivity (Ali et al., 2017), and loss of biodiversity (Metz et al., 2001) as well as adverse influences on human and animal health. As agriculture and crops fully rely on a particular season,

changes are also expected in the sowing and harvesting period, as well as yield and productivity. Being totally dependent on the climate and weather of a region, agriculture sector is the most susceptible sector to drought and even every small change can have far reaching effects on agriculture (Mendelsohn, 2001). Due to change in the precipitation and increase in the temperature of the area, in case of annual crop productivity, the duration between sowing and harvesting will shorten and senescence will occur sooner thus having an adverse effect on productivity (Haldar, 2010). Wheat and tobacco being the main cash crops of the Peshawar are cultivated in winter. In the winter season (December-February), wheat crops may be badly damaged due to insufficient or ill-timed rainfall. As Peshawar experienced an extreme drought twice in the month of January in the winter season according to the SPI indices, in the past 30 years, therefore, there are high chances that winter crops may get affected if the same temporal trend is followed. Vast majorities of the population in Peshawar depend directly or indirectly, in one form or the other on agriculture. Sugar cane is a high-water demand crop, due to higher temperatures and insufficient water availability, the rate of evaporation will increase, resulting in the crop not giving proper produce and yield. In Peshawar, the spring season is very essential for many types of crops especially cereals like wheat (Government of Khyber Pakhtunkhwa, 2013). The maturation of wheat crop seeds occurs in the spring season, so if it does not get adequate and enough spring period and rainfall, or if the temperature has changed then there is a risk of lower yield. According to the SPI values, it can be predicted that severe and extreme drought can occur mostly in the summer season in the months of May and June and spring season in the months of March and April. As the spring season March and April according to the SPI indices also have severe and extreme drought occurrence, crops may get affected. Thus, effects of climate change phenomenon like drought, is causing a considerable impairment to crops (Nelson et al., 2009), and can also be observed in Peshawar, as the production of the crops got affected due to not only changes in seasonal precipitation but its pattern of variability. This could be due to the change and shifting of seasons and temperature (Olesen and Bindi, 2002). These both factors are of major importance for agricultural system, which can be changed due to the drought conditions of the area. Crop yield being both hazard and context dependent is affected by the Prevailing temperatures and moisture conditions (Iqbal et al., 2009).

The Third Assessment Report of the IPCC has stated that the frequency and intensity of droughts will most probably increase during the 21st Century (Orville, 1990). The most immediate consequence of drought can be seen due to the inadequate and poor distribution of rainfall, which is a fall in crop production. The SPI indices and reoccurrence of drought clearly indicate that drought may cause damage to the crop yield as observed all over Peshawar thus leading to a period of drought-induced food deficit and affecting the wellbeing of farmers.

Conclusion

This study concludes that significant meteorological drought occurred for four years, and in those years severe and extreme drought was recorded all year round. According to the SPI values severe and extreme drought occur mostly in the summer season in the months of May, June, and spring season in the months of March and April thus affecting the important cash crops of Peshawar. It is worth mentioning that extreme drought can occur once in sixteen years, therefore it is important to draft a strategy to cope with any emergency situation.

This study helps in quantifying the drought situation in the region on monthly, seasonal as well as on annual basis**.** In the future, more work can be done by hydrologists and agriculturalists, which will help in streamlining mitigation activities in the case of drought reoccurrence.

Statements and declarations

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work. This manuscript is not under review elsewhere and its publication in the *Arid Ecosystems* is approved by all authors.

Competing interests

The authors have no conflict of interest.

Funding

The research work is not funded by any organization.

Availability of data and material

All data generated or analyzed during this study are included in this published article.

The datasets generated and/or analyzed during the current study are available in the repository of Regional Meteorological Department, Peshawar, Pakistan.

Code availability

Not applicable.

Authors' contributions

ShahlaNazneen: Conceptualization, Roles/Writing-Original Draft preparation,Software, Visualization, Methodology. **TehreemAyaz:**SPI Analysis, Visualization, Editing and Reviewing. **YamnaDurrani**:Roles/Writing-Original Draft preparation, SPI Analysis, Visualization. **Neelum Ali**:Software and Editing. **Ming Lei:** Reviewing and Editing.**SaeedaYousaf**:Reviewing and Editing.

Acknowledgment

We are highly thankful to Meteorological Department-Peshawar for providing data and technical support.

Ethics approval

Not applicable.

Consent to participate

Not applicable.

Consent forpublication

Not applicable.

REFERENCES

Albert K., Mikkelsen T., Michelsen A., Ro-Poulsen H. and van der Linden L. 2011. Interactive effects of drought, elevated CO_2 and warming on photosynthetic capacity and photosystem performance in temperate heath plants. Journal of Plant Physiology, 168(13), p. 1550-1561.

Ali S., Liu Y., Ishaq M., Shah T., Ilyas A., Din IU. 2017. Climate change and its impact on the yield of major food crops: Evidence from Pakistan, Foods, 6(6), p.39.

Asrari E., Masoudi M. 2014. A New Methodology for Drought Vulnerability Assessment Using SPI (Standardized Precipitation Index). Int J Sci Res Knowl 2(9), p.425.

*Bukhari S., Bajwa G.*2012. Development of national response strategy to combat impacts of climate change on forest of Pakistan. Pakistan Forest Inistitute Peshawar.

Chaudhry Q., Sheikh M., Bari A., Hayat A. 2001. History's worst drought conditions prevailed over Pakistan. Cook ER, *Seager R, Cane MA, Stahle DW*. 2007. North American drought: Reconstructions, causes, and consequences. Earth Sci Rev 81(1-2), p. 93-134.

Dai A. 2013. Increasing drought under global warming in observations and models. Nat Clim Chang 3(1), p.52.

Fahim AM., Shen R., Ali SM., Zhang J. 2016. Characteristics of drought variation in winter using drought indices during the period 1971-2010: a case study of khyber pakhtunkhwa (pakistan). Mausam 67(3), p. 697-708.

Flannigan M., Harrington JB. 1988. A study of the relation of meteorological variables to monthly provincial area burned by wildfire in Canada (1953-80). J Appl Meteorol 27(4), p.441-452.

Fuchs B. 2019. National Drought Mitigation Center. US Drought Monitor.

Government of Khyber Pakhtunkhwa. 2013. Crop Statistics, Khyber Pakhtunkhwa. In: L.C.D. Agriculture (Editor).

Government of Khyber Pakhtunkhwa. 2018. Peshawar.

Government of Pakistan. 2011. Crops Area and Production (By Districts) (1981-82 TO 2008-09).

Haldar I. 2010. Global warming: the causes and consequences. Mind Melodies. ASBN:13, p. 200.

Herweijer C., Seager R., Cook ER., Emile-Geay J. 2007. North American droughts of the last millennium from a gridded network of tree-ring data. J Clim 20(7), p.1353-1376.

Iqbal MM., Goheer MA., Noor S., Sultana H., Salik K and Khan A. 2009. Climate Change and Agriculture in Pakistan: Adaptation Strategies to Cope with Negative Impacts, Research Report GCISC-RR-16, Global Change Impact Studies Centre, Islamabad.

*Iqbal M., Raja N., Yasmeen F., Hussain M., Ejaz M., Shah M. 2*017. Impacts of heat stress on wheat: a critical review. Adv. Crop Sci Technol 5, p.1-9.

Jain VK, Pandey RP, Jain MK, Byun HR. 2015. Comparison of drought indices for appraisal of drought characteristics in the Ken River Basin. Weather Clim Extrem 8, p.1-11.

Kiem AS., Franks SW. 2004. Multi-decadal variability of drought risk, eastern Australia. HydrolProcess 18(11), p.2039-2050.

Larsen O., Oliver J., Casiles Lanuza E. 2014. Developing a disaster risk insurance framework for vulnerable communities in Pakistan: Pakistan disaster risk profile. Report No. 16. Bonn: United Nations University Institute for Environment and Human Security (UNU-EHS).

Lasage R., Aerts J., Mutiso G., De Vries A. 2008. Potential for community based adaptation to droughts: Sand dams in Kitui, Kenya. Phys Chem Earth, Parts A/B/C 33(1-2), p.67-73.

McKee TB, Doesken NJ, Kleist J, 1993. The relationship of drought frequency and duration to time scales, Proceedings of the 8th Conference on Applied Climatology. American Meteorological Society Boston, MA, pp. 179-183.

Mendelsohn R. 2001. Global Warming and the American Economy. Edward Elgar Publishing. Méndez M., Magaña V., 2010. Regional aspects of prolonged meteorological droughts over Mexico and Central America. J Clim 23(5), p. 1175-1188.

Metz B., Davidson O., Swart R., Pan J. 2001. Climate change 2001: mitigation: contribution of Working Group III to the third assessment report of the Intergovernmental Panel on Climate Change, 3. Cambridge University Press.

Mishra V., Cherkauer KA. 2010. Retrospective droughts in the crop growing season: Implications to corn and soybean yield in the Midwestern United States. Agric and For Meteorol 150(7-8), p.1030-1045.

National Disaster Management Authority of Pakistan, 2012. National Disaster Management Plan. Islamabad.

Nebraska-Lincoln N, 2017. Types of droughts. In: N.D.M. Centre (Editor). University of Nebraska-Lincoln.

Nelson GC, Rosegrant MW, Koo J., Robertson R., Sulser T., Zhu T., Ringler C., Msangi S., Palazzo A., Batka M. 2009. Climate change: Impact on agriculture and costs of adaptation, 21. Intl Food Policy Res Inst.

NOAA. 2019. National Oceanic and Atmospheric Administration's. Definition of Drought.

Ojos Negros Research Group. 2019. Drought Facts.

Olesen JE., Bindi M. 2002. Consequences of climate change for European agricultural productivity, land use and policy. Eur j Agron 16(4), p.239-262.

Orville HD. 1990. AMS statement on meteorological drought. Bulletin of the American Meteorological Society 71(7), p.1021-1025.

*Palmer WC.*1965. Meteorological drought (Vol. 30). US Department of Commerce, Weather Bureau.

Parry M., Parry ML., Canziani O., Palutikof J., Van der Linden P., Hanson C. 2007. Climate change 2007-impacts, adaptation and vulnerability: Working group II contribution to the fourth assessment report of the IPCC, 4. Cambridge University Press.

Pausas JG. 2004. Changes in fire and climate in the eastern Iberian Peninsula (Mediterranean basin). Clim change 63(3), p.337-350.

Pei F., Li X., Liu X., Lao C. 2013. Assessing the impacts of droughts on net primary productivity in China. J Environ Manage,114, p.362-371.

PWP. 2011. History of drought in Pakistan – In detail. Pakistan Weather Portal.

*Qureshi AS, Akhtar M.*2004. Analysis of drought-coping strategies in Baluchistan and Sindh provinces of Pakistan, 86. IWMI.

Regional Meteorological Centre Peshawar. 2011. Drought Basics RMC Peshawar, Monthly Climate Normal's of Pakistan.

Seager R., Ting M., Davis M., Cane M., Naik N., Nakamura J., Li C., Cook E., Stahle D. 2009. Mexican drought: an observational modeling and tree ring study of variability and climate change. Atmósfera, 22(1), p.1-31.

Shanahan TM, Overpeck JT, Anchukaitis K., Beck JW, Cole JE, Dettman DL, Peck JA, Scholz CA, King JW. 2009. Atlantic forcing of persistent drought in West Africa. Science, 324(5925), p.377-380.

Szarzynski J., Zhang W., Tatem B. 2014. Climate Change and Drought in California. https://digitalcommons.pepperdine.edu/sturesearch

Tigkas D., Vangelis H., Tsakiris G. 2012. Drought and climatic change impact on streamflow in small watersheds. Sci Total Environ 440, p.33-41.

Ullah W., Takaaki N. 2016. Climate Change Vulnerability of Pakistan Towards Natural Disasters: A Review. Int J Enviro Prot Policy 4(5), p. 1-7.

Wang L., Chen W., Zhou W., Huang G. 2016. Understanding and detecting super-extreme droughts in Southwest China through an integrated approach and index. Quarterly Journal of the Royal Meteorological Society 142(694), p. 529-535.

Wilhite DA. 2000. Drought as a natural hazard: concepts and definitions. Published in Drought: A Global Assessment Vol. I. (1), p. 3-18.

Wilhite DA. 2019. Drought Management, Water Encyclopedia. retrieved from http://www.waterencyclopedia.com/Da-En/Drought-Management.html

World Meteorological Organization, 2012. Standardized Precipitation Index User Guide, (WMO-No. 1090), World Meteorological Organization, Geneva, Switzerland.

Zhai J., Su B., Krysanova V., Vetter T., Gao C., Jiang T. 2010. Spatial variation and trends in PDSI and SPI indices and their relation to streamflow in 10 large regions of China. JClim 23(3), p.649-663.