Journal of Engineering and Applied Sciences 11 (3): 339-345, 2016
ISSN: 1816-949X

Evaluation of the Meteorological Drought Phenomenon by Using Four Indices of Drought (Case Study: Qaenat City in South Khorasan Province)

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Abstract: Meteorological drought as a creeping phenomenon is considered as one of the most destructive natural disasters in various regions of Iran. The first step for management of drought phenomenon to reduce its harmful effects is to monitor and evaluate drought based on the indices by which one can quantify the mentioned phenomenon in terms of the its intensity and continuity in one region. The aim of this study is to examine the drought situation of Qaenat City located in South Khorasan Province as one of the strategic regions of East of the country which has been affected by the phenomenon in recent years. In this regard, after examining the quantity and quality of the rainfall statistics of the synoptic station of Qaen as the representative of the region under study during the period of water years 1989-1990 and 2013-2014, the drought situation was studied using the indices of percent normal precipitation index, standardization precipitation index, deciles ofprecipitation index and rainfall anomaly index. Based on the results, the mentioned indices described drought of the region with nearly identical features and since water year 1999-2000 drought has become a dominant phenomenon in the climate of the region and unfortunately due to lack of management of water resources consumption especially in the agriculture section, the condition of the water resources of the region has changed to the forbidden state. Presence of successive mild droughts after aperiod of intense drought in the region is possibly indicative of substitution of mild drought by wet periods.

Key words: Meteorological drought, intensity and continuity, drought indices, Qaenat City, region

INTRODUCTION

Water is the basic element for continuous development and the source of human life. Thus, its shortage (drought) through its impact on the food and water sources and energy resources directly affects the societies (Karimi *et al*., 2001). According to a definition by Palmer (1995), drought is continuous and unnatural shortage of wet compared to its average amount. The phenomenon of drought is open to examination from the four meteorological, hydrologic, agricultural and economic-social perspectives (Alizadeh, 2006). Therefore, precipitation is considered as one of the most important variables in evaluating the phenomenon of drought.

Because of being located on the dry line, Iran has experienced massive losses on its hydrologic and economic-social system.

Different indices have been provided for monitoring the drought phenomenon by different researchers including Percent of Normal precipitation index (PN), Standardization Precipitation Index (SPI), Deciles of precipitation Index (DI) and Rainfall Anomaly Index (RAI) (Alizadeh, 2006). Ghatreh Samani investigated the drought phenomenon based on rainfall data of 11 stations in Chaharmahal and Bakhtiari Province using the DI index. Farajzadeh by examining the different indices of drought, introducedthe PN index because of simplicity, comprehensiveness and high flexibility as an appropriate index for examining the drought phenomenon (Gibbs and Maher, 1967).

Borna *et al*. (2010) investigated the drought in KhuzestanProvince by using the data from the stations of Abadan and Dezful and with the help of SIAP, PN and RAI indices.

Erfanian examined the drought phenomenon in Khorasan Razavi Province by using the indices of the PN and SPI indices.

Mosaedi *et al*. (2008) investigated the drought phenomenon by using the SIP index and concluded that in this province important drought and wet periods occurred with the return period of 11 years.

In this study, by using the indices of PN, SPI, DI and RAI, the meteorological phenomenon in Qaenat city located in the province of Southern Khorasan has been

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estimated and it has been assumed that the meteorological droughts of the region are under the effect of the patterns of time and space fluctuations and major changes in these patterns affect the indices of the case study.

MATERIALS AND METHODS

Geographical situation of the region: The region under study is Qaenat City located in South Khorasan Province with the capital city of Qaen and with >40, 226 residents based on the census of 2011. Qaenat City has an area of 18783 km^2 and the longitude of 58° and 38 min to 60° and 56 min and the latitude of 33° and 15 min to 34° and 12 min. This city is located on the drainage area of the Kalshour River and with the average altitude of 1420 m above the sea level. It has average amount of 163.8 mm of precipitation and a dry and cold climate according to the Emberger's Climagram. Figure 1 shows the geographical situation of Qaenat City.

The data: One of the main important problems in the study of hydrology and related issues in South Khorasan province is the significant lack and deficiency of the statistical hydrological and meteorological data banks of the region. In the area, rain-gage, evaporative, climatology and the synoptic stations have been active, however, lack of proper placement of the stations, change of the status of surrounding stations and its effect on the measured data and lack of expertise and commitment in the field of collecting statistics have greatly affected the quality of available statistics. In this study, after collecting and analyzing the data and verifying its accuracy and uniformity using the homogeneity test and run test and also visiting the site of the existing stations, the statistics of the synoptic station of Qaen as a representative of the case study and the statistics from other stations due to the mentioned problems were ignored. The duration of the statistical case of the study at synoptic station of Qaen was from water year 1989-1990 to 2013-2014 (24 years).

Fig. 1: The geographical situation of Qaenat City

Test of normality of data: After verifying the accuracy and the quality of the statistics of synoptic station of Qaen, the quality of the data was evaluated by Minitab 16 Software. Based on the mentioned results, monthly precipitation data did not follow a normal distribution and only the annual series of the cited station followed a normal distribution.

The studied indices: In evaluating the meteorological drought of Qaenat, four indices were used based on the rainfall data. The drought indices are often based on measurement of deviation of precipitation mean over a period of time. The indices examined in this study are as follows.

Percent of Normal Precipitation Index (PN): This index is one of the simplest and at the same time one of the most effective indices in determining drought or wet year of a location in a season or certain place. The mentioned index is obtained by dividing the actual precipitation by the amount of normal precipitation (the long-term mean precipitation):

$$PN = \frac{P_i}{\bar{P}}$$

Where:

P_i = The precipitation of the ith month or year

$\bar{P}$ = The long-term mean precipitation of the same month or period

According to the obtained results, the above method of drought classification is provided in Table 1.

Deciles of Precipitation Index (DI): This index has been provided for the first time by two researchers named Gibbs and Maher to avoid some of the shortcomings of the PN index method. In this method, the precipitations are organized increasingly as monthly, seasonal and annual time scales. If the data follow a normal distribution, they would be divided as tenths of the mentioned

Table 1:Classification of drought based on the PN index (1)

Drought condition (drought)	Amount of PN (%)
Partial	70-80
Moderate	55-70
Severe	40-55
Very severe	<40

Table 2: Drought classification based on the DI index (8)

DI rank	Deciles (%)	Deciles classification	Drought condition
1	<10	Very much less than normal	Very severe drought
2	Between 10-20	Much less than normal	Severe drought
3	Between 20-30	less than normal	Drought
4	Between 30-40	A little less than normal	Almost normal
5	Between 40-50	Normal	Normal
6	Between 50-60	Normal	Normal
7	Between 60-70	A little more than normal	A little wet
8	Between 70-80	More than normal	Wet
9	Between 80-90	Much more than normal	Very wet
10	Between 90-100	Very much more than normal	Super wet

distribution and each of them is called a decile the first of which is the amount of precipitation that does not exceed 10% of the smallest amounts of precipitation. The second to the tenth decile is defined similarly. Based on above classification, drought is defined as follows (Gibbs and Maher, 1967) (Table 2).

Standardization Precipitation Index (SPI): The standardized precipitation index has been provided by Mckee from the university by Colorado (1993) to define and monitor the drought. This index is able to analyze the phenomena of drought and wet year at a certain time scale for any desired location. This index is calculated for short-term (Alizadeh, 2006; Borna *et al*., 2010) months and long-term (Mosaedi *et al*., 2008) months. To achieve this purpose, a probability distribution function (generally gamma probability density function) is fitted on the long-term rainfall data in the desired time period and then converted to a normal distribution. Thus, the mean of SPI index is zero and the standard deviation is 1. The mentioned index is calculated by this equation:

$$SPI = \frac{P_i - \bar{P}}{SD}$$

Where:

SPI = The standardization precipitation index
P_i = Amount of precipitation during the desired year
$\bar{P}$ = The long-term annual precipitation average
SD = The standard deviation from the data (Alizadeh, 2006)

The calculations of the SPI index have been estimated by SPI-SL-6 Software. Numerical values of the SPI index for monitoring drought are shown in Table 3.

Rainfall Anomaly Index (RAI): The rainfall anomaly index was provided by Rooy. This index is based on the standard deviation of the precipitation amounts from the normal precipitation and is applicable in two annual and monthly time scales. The calculation stages for this index are as follows:

Table 3: The numerical values of the SPI index for monitoring drought (1)

Row	SPI index	Drought condition
1	Greater than 2	Ultra wet
2	1.5-1.99	Very wet
3	1-1.49	A little wet
4	0-0.99	Almost normal (wet)
5	-0.99-0	Almost normal (dry)
6	-1 to -1.49	A little dry
7	-1.5 to -1.99	Very dry
8	Smaller than -2	Ultra dry

Table 4: Different classifications of the drought index based on the RAI (2)

Row	RAI index	Drought condition
1	>3	Very severe wet
2	2.1-3	Severe wet
3	1.2-2.1	Average wet
4	0.3-1.2	Mild wet
5	-0.3-0.3	Normal
6	-1.2 to -0.3	Mild drought
7	-2.1 to -1.2	Average drought
8	-3 to -2.1	Severe drought
9	<-3	Very severe drought

- Calculating the long-term mean value of precipitation
- Duration in the desired stations $\bar{P}$
- Extracting the mean values of 10 cases of the greatest values of precipitation happening during the study period (m)
- Extracting the mean values of 10 smallest cases of the precipitation values occurringduring the studying period (x)
- Comparison of the precipitation data (P) with the mean value of long-term precipitation ($\bar{P}$) in case $(P > \bar{P})$ or anomaly is positive, the anomaly precipitation index is calculated by:

$$RAI = 3\left[\left(P-\bar{P}\right)/\left(m-\bar{P}\right)\right]A$$

- If $(P > \bar{P})$ or the anomaly is negative the precipitation anomaly index is as follows:

$$RAI = -3\left[\left(P-\bar{P}\right)/\left(x-\bar{P}\right)\right]$$

- Attributing of thresholds of +3 and -3 to ten average cases of the most severe positive and negative anomalies, respectively
- Finally, by scaling the values obtained from the index of rainfall anomalies, ninecategories of anomaly within the range from the conditions of very severe wetto very severe drought are determined by Bazrafshan, (2002). Table 4 shows the different classifications of the drought index based on the RAI

RESULTS AND DISCUSSION

In this study, the phenomenon of drought was examined in the city of Qaenat based on four indices of

Table 5: Classification of drought in the area under study based on the PN

Drought intensity	Years
Average	1993-94
Mild	1996-97
Severe	99-2000
Average	2000-2001
Average	2003-2004
Average	2005-2006
Severe	2007-2008
Mild	2012-2013
Mild	2013-2014

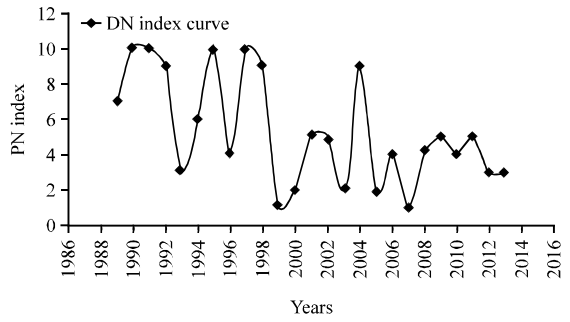

Fig. 2: The curve of the index of PN during the statistical period of the study

the PN, SPI, DI and RAI during the period of water years 1979-1980 to 2013-2014. The details are presented as follows:

Percent of Normal Precipitation index (PN): Based on the index of the PN, drought classification for the studied years is shown in Table 5. As it can be observed in Fig. 2:

- The amount of precipitation since the period 1998-1999 in the region as a whole has decreased and the number and severity of drought has increased compare to its previous period
- Before 1998, the passage of drought with the wet period has had favorable rainfall while since 1998 untilnow; the passage through drought has just ended with entering into the normal condition
- Reduction of precipitation since the end of the 90s until now has had a significant impact on reducing the vegetation density and dropping of the underground water level

Deciles of Precipitation Index (DI): In order to study the drought area by deciles of precipitation index, the ability to fit a normal distribution of precipitation data monthly, seasonal and yearly of Qaen synoptic stations were analyzed and it was found that only annual precipitation data follow a normal distribution. Therefore, based on mentioned index, the classification of drought for the years studied years is shown in Table 6.

Table 6: Classification of drought based on the DI

Drought condition	Years
Drought	1993-94
Almost normal	1996-97
Very severe drought	99-2000
Severe drought	2000-2001
Severe drought	2003-2004
Severe drought	2005-2006
Almost normal	2006-2007
Very severe drought	2007-2008
Almost normal	2008-2009
Almost normal	2010-2011
Drought	2012-2013
Drought	2013-2014

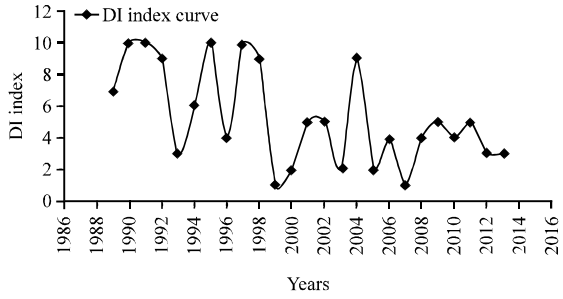

Fig. 3: Drought classification based on the DI for the statistical period of the area under study

According to the results of the drought analysis based on the deciles of precipitation index during the interal under study (Fig. 3):

- From water year 1999-2000 up to the persent time, except for 3 years, the region has experienced sever droughts
- The amount of precipitation since the 90s untile now has decreased and the distance of the droughts, espicially in the 2000s has shortened and their severity has increased. The above conditions and also the lack of drought management by the relevant organs have significantly decreased the reservoirs of underground water in the region
- The intervals between the successive drought periods is covered along with an interval of mild drought and wet years which indicates the high level alert about decline in the underground reserves water and the change climate of the region

Standardization Precipitation Index (SPI): In order to examine the phenomenon of drought in the city of Qaenat and its impact on the water resources of the region, the index of SPI of 9, 12 and 24 months have been used.

The index of SPI has more fluctuations in short-term time scale compared to the long-term time scale which is indicative of the sensitivity of the short-term SPI index compared to wet conditions. Moreover, with the increase of the time scale, the number of droughts decreased and their continuity is increased.

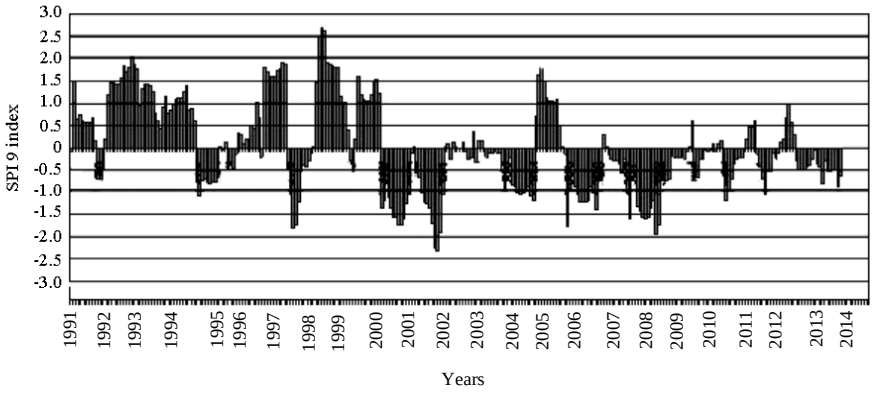

Fig. 4: Drought categorization based on the index of SPI in the 9 months scale during the statistical period of the studied region

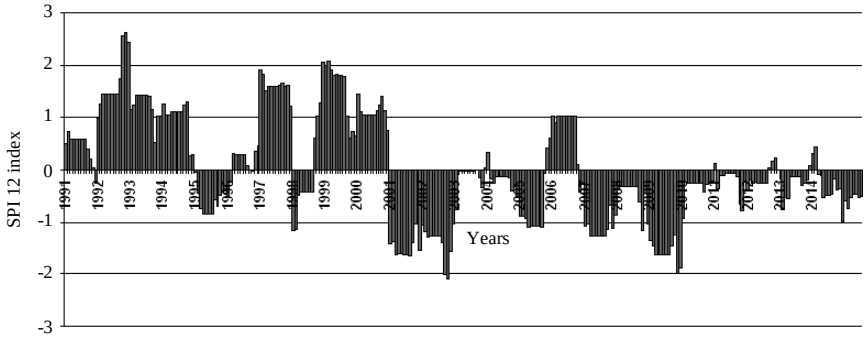

Fig. 5: Drought categorization based on the index of SPI in the 12 months scale during the statistical period of the studied region

The best time scale of the SPI index in order to analyze drought of the region is in two scales of 9 and 12 months because in scales of shorter periods, the little changes of precipitation have been regarded as drought and in the longer time period scales, short and mild wet periods does not show.

Based on the mentioned index from the water year of 1999-2000 drought has been prevalent in the region up to the present time and the 2000s has witnessed the most severe of droughts. Moreover, a decrease has been observed in the rainfalls since the end of the 90s until the present time.

Based on the SPI index of 24 months it can be concluded that from the water year of 1999-2000 the region under study has not excluded its drought condition. Nowadays the excluding condition of the regional aquifers is a proof to this claim. The graph of time scale index of 9, 12 and 24 months are displayed in Fig. 4-7.

The index of Rainfall Anomaly (RAI): By examining the phenomenon of meteorological drought of the region by index of RAI the following results are obtained:

- Since, the middle of the water year of 1998-1999 until the present time, except some months of the water years of 2003-2005, droughts have been prevalent in the region with strength and weakness
- The occurrence of mild drought period after a period of severe drought can be indicative of the potential climatic fluctuations of the region with this concept: it can be stated as the replacement of the wet periods by the mild drought periods and reentering into the drought period again

Based on the results, the phenomenon of drought in the region based on the studied indices is shown in Table 7.

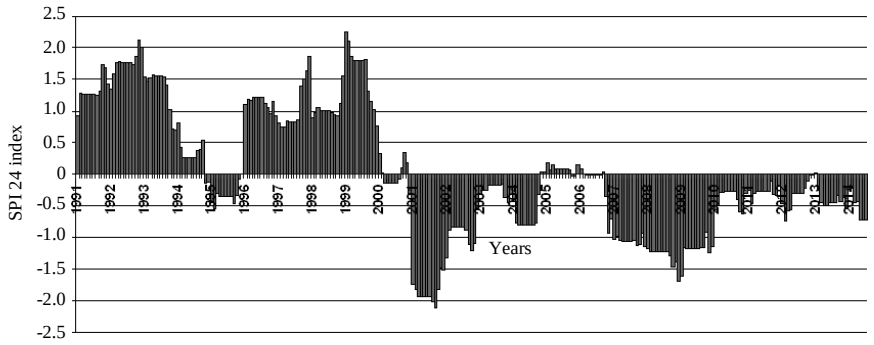

Fig. 6: Drought categorization based on the index of SPI in the 24 months scale during the statistical period of the studied region

Table 7: The comparison of the drought phenomenon during the statistical period of the region on the study based on the different indices

Water year	PN	DI	RAI	SPI
1989-1990	Normal	A little wet	Average wet	Normal
1990-1991	-	-	-	-
1991-1992	-	-	-	-
1992-1993	-	-	-	-
1993-1994	Mild drought	Drought	Severe drought	Mild drought
1994-1995	Normal	Normal	Mild wet	Normal
1995-1996	-	-	-	-
1996-1997	Mild drought	Almost normal	Average drought	Mild drought
1997-1998	-	-	-	-
1998-1999	-	-	-	-
1999-2000	Severe drought	Very severe drought	Very severe drought	Severe drought
2000-2001	Average drought	Severe drought	Very severe drought	Average drought
2001-2002	Normal	Normal	Mild drought	Mild drought
2002-2003	Normal	Normal	Mild drought	Mild drought
2003-2004	Average drought	Severe drought	Very Severe drought	Average drought
2004-2005	-	-	-	-
2005-2006	Average drought	Severe drought	Very severe drought	Average drought
2006-2007	Normal	Almost normal	Average drought	Mild drought
2007-2008	Severe drought	Very severe drought	Very Severe drought	Severe drought
2008-2008	Normal	Almost normal	Mild drought	Mild drought
2008-2010	Normal	Normal	Mild drought	Mild drought
2010-2011	Normal	Almost normal	Mild drought	Mild drought
2011-2012	Normal	Normal	Mild drought	Mild drought
2012-2013	Mild drought	Drought	Average drought	Mild drought
2013-2014	Mild drought	Drought	Average drought	Mild drought

CONCLUSION

Drought is one of the destructive natural phenomena until the present time that has been studied by various indices. In this study, by examining the meteorological phenomenon of drought in the region of Qaenat by means of four indices of PI, DI, SPI and RAI the following results obtained.

The four indices defined drought with almost the same characteristics, among which the two indices of PI and SPI are more similar. Thus, due to the simple analysis of the drought phenomenon by PI index, one can use it to determine the drought years and use SPI index for result contorol and to accurately determine its months.

Since, the end of the 90s until the present time, the drought has been present in the region as a dominant phenomenon. According to dry and cold climate of the region and presence of appropriate plants, lack of surface water resources and using the underground water resources for agriculture, drought at the beginning of its emergence in the region did not have short-term remarkable effects but along with the rise in the duration and severity of drought and unfortunately mismanagement of water resources, especially in agriculture in order to compensate for the reduction in precipitation rather than changing the crop farming patterns resulted in the creation of the forbidden condition in the underground water resources of the city.

The presence of successive mild droughts after the occurrence of one period of severe drought can be indicative of this bitter reality meaning that the intervals between the severe and long drought periods in the region replace wet years by the periods of mild drought.

By examining the phenomenon of meteorological drought in the city of Qaenat as one of the strategic cities of the East of the country, this study attempted to cast light on the evident but bitter fact based on the apprehensive future of the climatological conditionand the water resources of the region in order to provide an appropriate solution for the managers and the officials towards a meticulous plan for the stable development.

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