Monitoring drought by Reconnaissance Drought Index (RDI) and Standardized Precipitation Index (SPI) using DrinC software

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Abstract: Drought is a significant phenomenon affecting several economic, agricultural, social and environmental sectors. Therefore, monitoring drought in different areas is too important especially those with arid climates. In this study drought was monitored in Shiraz which is located in southwest of Iran, between the years 1982 and 2017. Aimed to this purpose, RDI and SPI indices were assessed. For surveying drought, SPI and RDI indices were compared. The SPI and RDI annual results showed extreme dry conditions for the years 1983-1984 and 2008-2009, but with difference in the values. For the year 1999-2000, the SPI showed near normal condition, while the RDI categorized this year in moderately dry condition. The other notable difference is in 1995-1996; the SPI categorized this year in very wet condition, but the RDI set it to moderately wet condition. According the above, it is clear that the RDI shows better and more accurate results. This research proposes as climactic index the Reconnaissance Drought Index, for drought monitoring particularly in arid and semi-arid area which precipitation amounts are low, so evapotranspiration acts as a key factor for monitoring drought, because of using both precipitation and evapotranspiration. It is expected that these documents will be useful for future decisions and drought monitoring in other areas.

Key words: Drought monitoring; RDI; SPI; Iran; Shiraz; DrinC software

1. INTRODUCTION

Drought is precipitation shortage in long periods which leads to low humidity in the soil and reduction of surface water. Drought is a periodic natural phenomenon which is associated in deficiency of the available water resources in a vast geographical area in a significant time period (Rossi, 2000). It could affect the economy, the environment, the agriculture and the community members (Asadi Zarch et al., 2011; Tsakiris, 2010; Tsakiris and Vangelis, 2005). Based on this definition, drought is a regional phenomenon, characterized by three dimensions: intensity, duration and extent, the most important of which is intensity. Though, the drought intensity could be estimated based on the damage occurred to different economic, environmental and social sectors under influence, but using drought indices has more supporters due to their higher accuracy. Droughts are usual variations that cover many arid and semi-arid areas of the world with high intensities once per several years. There is a close relation between occurrence of droughts and change in the climate. Global warming has led to increased evaporation and water vapor density and, as a result, the extent and pattern of precipitations (rain and snow) will change (Jaefari, 2007). It is considered as the most complex, but the least understandable phenomenon of all the natural hazards affecting more people than any other hazard (Mishra and Desai 2005).

Drought has been sorted into four types (Wilhite and Glantz 1985): meteorological, agricultural, hydrological and socio-economic (Asadi Zarch et al., 2011; Tigkas et al., 2016). Meteorological drought is defined as the lack of precipitation over a region in a specific time period, lasting sufficiently to cause hydrological and agricultural hazards. It is determined in the form of deviation from normal precipitation. According to the meteorologists, a significant decrease in stream flow, water level of lakes or a change in the ground water levels, are signals of an upcoming drought event. While according to hydrologists, drought prevails with the lack of soil moisture to sustain the
crop growth. Agricultural scientists determine the drought as a famine condition, while economists monitor it in the form of short supply of tap water to the cities (Dracup et al., 1980; Asadi Zarch et al., 2011).

Droughts are common throughout the globe with a devastating damage potential on agriculture, economy, and society in many parts of the world. At the same time, due to the multi-discipline character of this natural hazard, a single, unique definition of drought does not exist, but is subject to the domain of interest of the research (e.g. Niemeyer, 2008; Wilhite and Glantz, 1985; Maracchi, 2000; Tate and Gustard, 2000). The drought indices are used extensively in the world because of easiness, so both scientists and specialists in water management suggest them (Tsakiris et al., 2005). The phenomenon of climate change is affected by change in the extent of energy exchange. Therefore, it has an intensive influence on the hydrological cycle.

One half of Iran’s area is desert and two thirds of it are arid and semi-arid areas regarding to precipitation. Iran’s weather is influenced by several systems, including: high-pressure system, Mediterranean rain system which enters from the west and low pressure system which in the Southern and Southwestern Iran leads to rain. The rate of precipitation in Iran is too variable. In the North it is more than 2113 mm, in desert areas it is about 15 mm, in Northwestern areas it is about 500 mm and in other areas it is about 200 mm per year. Drought is one of the most important natural hazards in Iran and frequently affects a large number of people, causing tremendous economic losses, environmental damages and social hardships. Especially, it has a strong impact on water resources. This situation has made more considerations toward the study and management of drought. Also, in many years, the occurrence of drought is not recognized for some time. Therefore, detection of drought is a valuable finding for management of water resources in some regions such as Iran which the major part of its constituted by arid and semi-arid areas (Hashemi and Shahmizadi, 2011).

The Standardized Precipitation Index (SPI) is a widely used index to characterize meteorological drought on a range of timescales. On short timescales, the SPI is closely related to soil moisture, while at longer timescales, the SPI can be related to groundwater and reservoir storage. The SPI can be compared across regions with markedly different climates. It quantifies observed precipitation as a standardized departure from a selected probability distribution function that models the raw precipitation data.

Several studies have been conducted in different parts of Iran for determination of drought, its intensity, endurance and extent. For instance, Asadi Zarch et al. (2011) used the RDI (Reconnaissance Drought Index) and SPI (Standardized Precipitation Index) to compare drought based on the two variables of evaporation and precipitation. Findings of their study showed that since SPI uses precipitation as the unique factor for estimation of drought, it could not be a good criterion since the water deficiency could be estimated solely based on the input (precipitation) and the output (water consumption). Based on that argument, the newer index (RDI) was proposed since it uses the data of both factors affecting drought such as P and PET. Studies showed that RDI plays an important role in lowering the water resources of the watersheds. For that reason, it is regarded as an important index for drought research in Iran (Asadi Zarch et al., 2011).

2. STUDY AREA

Fars Province is located in Southwest of Iran. Its climate in different points could be divided into three categories: mountainous, moderate and warm. At the center of Fars Province is Shiraz city. The elevation is between 1480 m and 1670 m above the sea level in the mountainous region of Zagros, which has a moderate weather. The extent of Shiraz is about 1268 km² which sets in the form of an east-west rectangle and located at 29°, 36’ North and 52°, 33’ East. Its average annual precipitation and temperature are about 337 mm and 18 ºC (I.R. of Iran Meteorological Organization).
3. METHODS

The Reconnaissance Drought Index (RDI) proposed by Tsakiris et al. (2007). It is one of the most recent developments in the field of meteorological drought indices. Essentially, it relates precipitation to potential evapotranspiration at a location, and can be considered as an extension of the SPI. However, Tsakiris et al. (2007) state that especially the characterization of drought severity could be improved in test areas of the Mediterranean region as compared to SPI (Niemeyer, 2008).

Reconnaissance Drought Index (RDI) was characterized as a general meteorological index for drought assessment. The RDI is expressed in three forms: the initial value \( (a_k) \) normalized and standardized \( RDI_n \). The initial value \( (a_k) \) is presented in an aggregated form using a monthly time scale and may be calculated on a monthly, seasonal or annual basis.

The initial value \( (a_k) \) of RDI is calculated for the \( i \)-th year in time basis of \( k \) (months) as follows (Tigkas et al., 2016; Tsakiris et al., 2007):

\[
\alpha_k^{(i)} = \frac{\sum_{j=1}^{k} P_{ij}}{\sum_{j=1}^{k} PET_{ij}}, \quad i=1(1) N \text{ and } j=1(1) k
\]

where \( P_{ij} \) and \( PET_{ij} \) are the precipitation and potential evapotranspiration of the \( j \)-th month of the \( i \)-th year and \( N \) is the total number of years. The normalized form \( (RDI_n) \) is computed using the following equation:

\[
RDI_n^{(i)} = \frac{\alpha_k^{(i)}}{\overline{\alpha_k}^{(i)}} - 1
\]

in which \( \overline{\alpha_k}^{(i)} \) is the arithmetic mean of \( \alpha_k^{(i)} \).

The values of \( \alpha_k \) follow satisfactorily both the lognormal and the gamma distributions in a wide range of locations and different time scales, in which they were tested (Tigkas, 2008; Tsakiris et al., 2008). By assuming that the lognormal distribution is applied, the following equation can be used for the calculation of \( RDI_{st} \) (Tigkas et al., 2016; Tsakiris and Vangelis, 2005):

\[
RDI_{st}^{(i)} = \frac{y^{(i)} - \overline{y}}{\sigma_y}
\]

in which \( y_i \) is the \( \ln (\alpha_k^{(i)}) \), \( \overline{y} \) is its arithmetic mean and \( \sigma_y \) is its standard deviation. In case the gamma distribution is applied, the RDI can be calculated by fitting the gamma probability density function (pdf) to the given frequency distribution of \( (\alpha_k^{(i)}) \) (Tigkas et al., 2013).

DrinC (Drought Indices Calculator) aims at providing a user-friendly tool for the calculation of several drought indices, with emphasis on two recently developed ones: the Reconnaissance Drought Index (RDI) and the Stream flow Drought Index (SDI). Also, the widely used Standardized Precipitation Index (SPI) and the Rainfall Declines can be calculated. The common characteristic of the selected indices is that they require relatively small number of data for their calculation and the results can be easily interpreted and used in strategic planning and operational applications. DrinC has full graphical user interface functionality (GUI) and runs on MS Windows operating systems (Tigkas et al., 2015; Tsakiris et al., 2007). In this study, computation and analysis of drought was made using DrinC software.

After calculating the drought indices, we can use the drought classification to estimate areas condition drought. Table 1 shows drought classification.
4. RESULTS

Meteorological data (precipitation, minimum and maximum temperature and evapotranspiration) of Fars Meteorological Bureau for 35 years are used.

In Figures 1 and 2, the values of the normalized and standardized RDI and SPI are presented for three periods. The first one is annual period (October - September) which represents the entire hydrological year, the second period is October- June, the first nine months of the hydrological year and the third is six months that corresponds to the first and the second half of the hydrological year.

The RDIst values in different periods of hydrological years 1982-2017, which indicated above, was assessed.

According to the RDI annual values for the wet situation, there was moderately wet condition in the years 1995-1996 and 1997-1998. Very wet condition, indicated by green color, refers to the years 1992-1993 and 2004-2005.

For dry situation, moderately dry condition was happened in the years 1988-1989, 1993-1994, 1996-1997 and 1999-2000. In Figure 1(a), extreme dry condition is showed by red color which refers to the years 1993-1994 and 2008-2009. This situation showed near normal and moderately wet conditions for the other years. RDI-9 (October-June) showed the same results with RDI annual values, but in Figure 1(c) extreme dry condition happened in the 1996-1997 for RDI first 6 months. Also, Figure 1(d) showed extreme dry condition in the year 2008-2009 for the RDI second 6 months.

The SPI index which surveys drought by precipitation, calculated for the years 1982-2017 and presented in Figure 2.

The SPI annual results showed extreme dry condition for the years 1983-1984 and 2008-2009, same as the annual RDI, but with a difference in the values. The SPI value in 1983-1984 is -2.41, while in RDI this value is -2.03. The other difference is for the year 1999-2000: according to the SPI value -0.94, near normal condition occurred, while the RDI value was -1.33, so this year categorized in moderately dry condition. For the wet situation there are also some differences. For example, in spite of the fact that the years 1992-1993, 2004-2005 categorized in very wet condition, the values have notable differences. In 1995-1996, the SPI categorized this year in very wet condition, but the RDI set it to moderately wet condition.

Drought observation in 3 or 6 months after October, gives the opportunity to adjust management plans for the late spring and summer, during which demand is normally very high and no significant precipitation depths are expected to contribute towards the water balance of available quantities (Tsakiris and Vangelis, 2005).

5. CONCLUSION AND DISCUSSION

According to research studies aimed at determining the intensity and extent of drought, general indices developed, each of which has its own inputs and conditions. A review of the studies conducted on drought in Iran reveals the fact that due to changes in the physiographic and climatic characteristics in different areas of the country, the phenomenon of drought in Iran shows differences in positional extension, decrease in degree and intensities. Inconsistency of drought in

Table 1. Drought classification

<table>
<thead>
<tr>
<th>No.</th>
<th>RDI or SPI value</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.0 and above</td>
<td>Extreme wet condition</td>
</tr>
<tr>
<td>2</td>
<td>1.5 to 1.99</td>
<td>Very wet condition</td>
</tr>
<tr>
<td>3</td>
<td>1.0 to 1.49</td>
<td>Moderately wet condition</td>
</tr>
<tr>
<td>4</td>
<td>-0.99 to 0.99</td>
<td>Near normal condition</td>
</tr>
<tr>
<td>5</td>
<td>-1.0 to -1.49</td>
<td>Moderately dry condition</td>
</tr>
<tr>
<td>6</td>
<td>-1.5 to -1.99</td>
<td>Severely dry condition</td>
</tr>
<tr>
<td>7</td>
<td>-2.0 and less</td>
<td>Extreme dry condition</td>
</tr>
</tbody>
</table>
different parts of the country is an important subject that effective factors must be identified. According to the existing theory and relevant studies, probably the elevation from the sea level is one of those factors. Usually, drought is related to high temperatures, resulting in higher evapotranspiration rates. Potential evapotranspiration (PET) represents the environmental demand for evapotranspiration. It represents the evapotranspiration rate of a short green crop, completely shading the ground, with uniform height and adequate water status in the soil profile.

Figure 1. Values of the RDI: (a) RDI -12 (October- September), (b) RDI -9 (October- June), (c) RDI -6 (October- March) and (d) RDI -6 (March-September)
This study exhibits monitoring of drought during the hydrological years of 1982 to 2017, for surveying drought, SPI and RDI indices were used. We compare the results of RDI and SPI, according them it is clear that the RDI shows better and more accurate results. This index can used for every purpose in surveying drought especially agriculture sector. This research proposes as climatic index the Reconnaissance Drought Index, for drought monitoring particularly in arid and semi-arid area which precipitation amounts are low, evapotranspiration acts as a key factor for

Figure 2. Values of the SPI: (a) SPI-12 (October-September), (b) SPI-9 (October-June), (c) SPI-6 (October-March) and (d) SPI-6 (March-September)
monitoring drought, because of using both precipitation and evapotranspiration. It is expected that these documents will be useful for future decisions and drought monitoring in other areas.

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