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Comparison of the Impact of Drought on Surface and Sub-Surface Water in the Kaka-Reza Basin

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Abstract
Awareness of drought interrelationships and hydrological response of watersheds is a prerequisite for optimal management of surface and groundwater resources. The aim of the present study was to compare the impact of drought on surface and subsurface waters in the Kaka-Reza basin. In this study, after controlling the data, a common period (1982-2017) for hydrometric and rainfall stations was considered. Then the standardized precipitation index (SPI) and the standardized discharge index (SDI) were calculated for the 1-, 3-, 6-, 9-, 18-, 12- and 24-month time steps. The base flow and the corresponding index were calculated by B-Flow Lyne and Hollick recursive digital filter. Then, the standardized base flow index (SBFI) was calculated by adapting the SPI method for the corresponding time steps. Finally, the relationships between SPI, SDI and SBFI were investigated and analyzed using correlation method. The results showed that the greatest effect of drought on groundwater for the 9- and 12-month time step with coefficient of determination 0.87, While the effect of drought on surface water for the corresponding time step has a coefficient of determination of about 0.4.

Keywords: Standardized precipitation; Standardized discharge index, Standardized base flow index.

1. Introduction

Drought is one of the climatic phenomena, which causes a lot of damage every year. This phenomenon is in fact one of the main and recurring features of different climates and its effects are not limited to arid and semi-arid areas, but drought occurs in both arid and wet areas and causes water shortages. But the characteristics of drought such as frequency, severity and duration of drought vary from place to place. According to Wilhite and Glantz (1985), droughts are classified into four categories: meteorological, agricultural, hydrological, and socio-economic droughts (Wilhite and Glantz, 1985). Various researchers have presented several features to evaluate and monitor drought, each of which is designed based on the use of meteorological variables and different computational methods. The standardized precipitation index (SPI) was introduced by McKee et al. (1993). This index is designed to quantify the amount of rainfall shortage for various time steps. The researchers calculated the SPI index for 3-, 6-, 12-, 24- and 48-month time steps. This index is also used to study and monitor hydrological droughts. In Iran, Parsamehr and Khosravani (2017) used this method to analyze the severity, duration and return period of drought in Fars province and concluded that the SPI index as the best index has been able to have a good interpretation of drought calculations in Fars province. Researchers in various fields have studied this phenomenon from their point of view, which has ultimately led to the classification of this phenomenon. Numerous studies have been conducted to investigate the interaction of drought phenomenon and flow components in rivers of different regions of Iran and the world. The results of this research show evidence of drought in the river (Eghtedari et al, 2016). The results of Agawala et al. (2001) showed that in Iran and Southeast Asian countries from 1999 to 2001, there was a severe drought for three years (Agawala et al, 2001) and caused a decrease of 45% in Iran's water storages. The results of the study of the relationships between SPI and SDI indices by Mofidipoor et al. (2012) in Atrak watershed showed the time relationship between the occurrence of meteorological and hydrological droughts for the 3-month time step with the highest correlation and at the level of 99%. The time interval between meteorological and hydrological drought in Zayandeh Rud watershed has been reported by Babaei et al. (2011) as three to eleven months. The results of research in the watershed of Karaj Dam, by Azareh et al. (2014) showed that the occurrence of drought affects surface water without delay. The temporal relationship between meteorological and hydrological drought in Karkheh watershed was investigated using two SPI and SDI indices in different time bases by Koushki et al. (2017); He concluded that the correlation between the two indices in all time bases is significant at the level of 99%, but this correlation has the highest correlation without delay (Koushki et al, 2017; Verdi Pourazad et al, 2014). The results of analysis and monitoring of hydrological drought in Lorestan province, using two SPI and SDI indices by Jahangir and Yarahmadi (2020) for different time steps showed that all hydrometric stations have experienced at least one severe drought (Jahangir and Yarahmadi, 2020). Base flow as defined by Smakhtin (2001) is the part of river flow that originates from delayed groundwater and subsurface water sources such as riverside reservoirs, lakes, wetlands, and snow and ice melting (Smakhtin, 2001). Relationships and how the impact of drought on the base flow was examined by Bazrkar, and Chu (2020) using a standardized index and reported the extent and how the delay effect of drought on subsurface flows (Bazrkar and Chu, 2020). Summary of literature review shows that in the last two decades, several studies have been conducted to identify the interaction of drought indices with the hydrological response of the watershed, in order to estimate and predict future surface and groundwater conditions. However, little research has been done to know the differences between the impact of drought on surface water and groundwater in karst watersheds. Therefore, the purpose of this study is to identify the differences in drought index behavior on surface and subsurface waters in a karst watershed.

2. Materials and Methods

2.1. Study Area

Kaka-Reza watershed is a karst watershed with a wide range of carbonate formations. In terms of distribution of geological formations, about 50% of the watershed surface is limestone, dolomitic limestone and marl limestone and about 19% of alluvial formations and the rest are impermeable formations. The area of the basin is equal to 1148 km^2 at the outlet of the hydrometric station with the code 21-169 is one of the sub-basins of Kashkan in Aleshtar region of Lorestan province. The length of the main river is 83 km and the mean slope of the river is 34.0% and the total length of the stream network is 521 km with drainage density of 0.45. The average height of the watershed, 2027 m which is in the coordinates of longitude 33 °-43’ and latitude 48 °-16’ (Kazemi and Ghermezcheshmeh, 2021). Figure (1) shows the geographical location of the research area in Lorestan province.

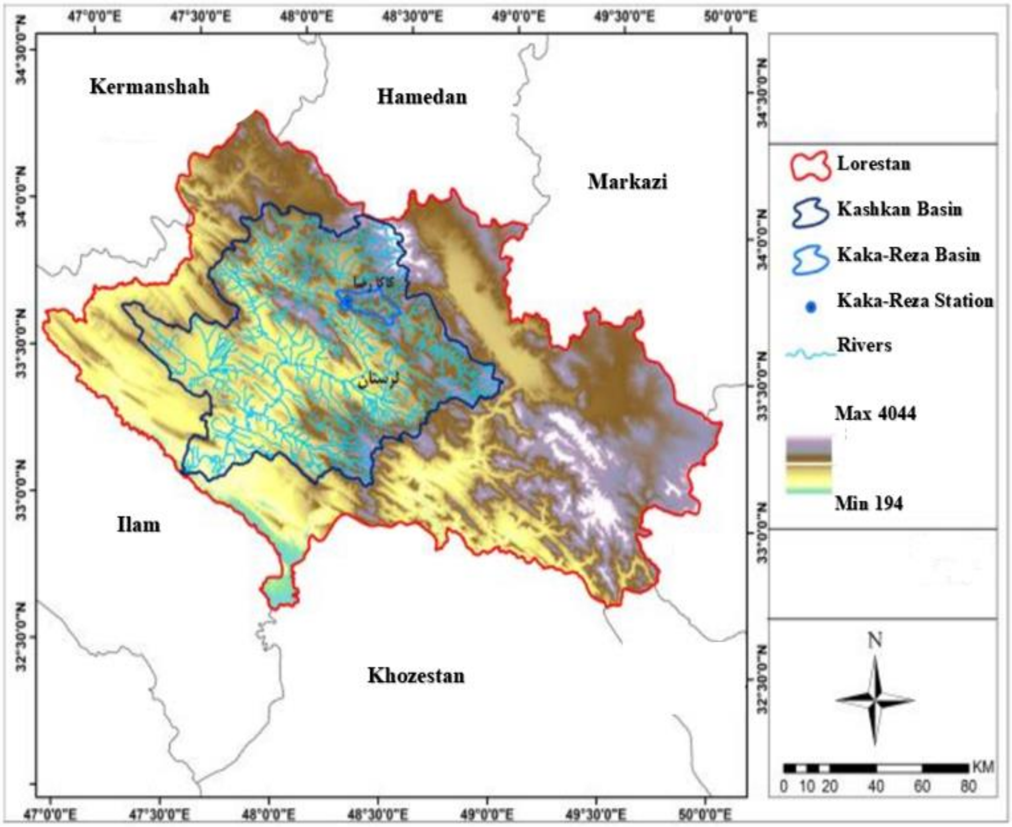

Fig. 1. Location of the research area in Lorestan province

2.2. Methodology

First, after checking the data, the same period (1982-2012) was considered for the corresponding hydrometric and rain gauge stations. Then, the standardized precipitation index (SPI) and Standardized discharge index (SDI) were calculated for the 1-, 3-, 6-, 9-, 12-, 18- and 24- month time steps. The base flow and the corresponding index were calculated by B-Flow Lyne and Hollick recursive digital filter. Standardized base flow index (SBFI) was calculated by adapting the standardized precipitation index to the corresponding time steps. Then, the relationships between drought index and standardized flow index and standardized base flow index were investigated and analyzed using correlation method.

2.2.1. Base flow extraction:

Extraction of the base flow can be done during the flow hydrograph separation process by identifying the starting and ending point of direct runoff. The starting point is the point at which the flow ascends, and the end point is when the logarithm of the descending branch turns straight into time. In this study, flow hydrograph separation and calculation of base flow index using B-Flow Lyne and Hollick recursive digital filter, by Hydro Office software (2015) and after preparing daily flow data was done as recommended by Kazemi and Porhemmat (2020). According to this method, using the graphical display capability of the software and using different parameter values and its calibration with observed river flow rates of the dry season, the optimal parameter value of the algorithm was determined, and the amount of base flow and relevant index were extracted.

2.2.2. B-Flow Lyne and Hollick recursive digital filter:

The algorithm introduced by Lyne and Hollick (1979) with equation (1) and has the ability to pass the flow data three times and passing the flow data several times reduces the base flow and gives the user the flexibility in more accurate separation of the base flow (Lyne and Hollick, 1979).

$$q_{f(i)} = \alpha q_{f(i-1)} + (q_i - q_{(i-1)})\frac{1+\alpha}{2} \qquad (1)$$
$$q_{f(i)} \geq 0$$

where $q_{f(i)}$ is direct runoff filtered for time step i, $q_{f(i-1)}$ is indirect runoff filtered for time step i-1, α is filter parameter related to basin, q_i is total flow for time step I, and $q_{(i-1)}$ is flow for time step i-1.

2.2.3. Standardized precipitation index (SPI):

If the monthly rainfall time series of the stations in the region are introduced as P_i, in which the index i indicates the water year and the index j indicates the month corresponding to the water year (i = 1 for October and j = 12 for September). Rainfall time series with different periods can be obtained using the following equation:

$$R_{ik} = \sum_{j=1} P_{ij} \quad i = 1, 2, 3, ... \qquad (2)$$
$$j = 1, 2, .., 12 \qquad k = 1, 2, ..., 6$$

Standard precipitation index (SPI) is obtained based on the height of cumulative precipitation (R_k) for the base period K related to (i) of the water year as relation (3):

$$SPI_{ik} = \frac{R_k - \bar{R}_k}{S_k} \quad i = 1, 2, 3, ... \qquad (3)$$
$$j = 1, 2, .., 12 \qquad k = 1, 2, ..., 6$$

Where S_k and $\bar{R}_k$ are the mean cumulative rainfall height and the standard deviation of the cumulative rainfall height for the base period k, respectively. Table (1) shows the classification of different drought conditions by SPI method (Amini et al. 2019). Standardized base flow index (SBFI): This index has been used and introduced by (Bazrkar and Chu, 2020). After separating the B-Flow Lyne and Hollick recursive digital filter method and preparing the time series of the base flow data, it is calculated by adapting the SPI (formula) method, with the difference that instead of rainfall data, the base flow data is placed (Bazrkar and Chu, 2020).

Table 1. Meteorological drought classification based on SPI index

Range	Drought Condition
[2.0, +∞]	Extremely wet
[1.5 , 2.0)	Very wet
[1.0 , 1.5)	Moderately wet
(-1.0 , 1.0)	Normal
(-1.5 , -1.0]	Moderately dry
(-2., -1.5]	Severely dry
[-∞, -2.0]	Extremely dry

3. Results and discussion

The results of SPI and SBFI correlation relationships for the 1- to 24-month time steps calculated in Figure 2. Given that, by definition, the basal flow is representative of the participation of groundwater in subsurface water. Therefore, the correlation relationships between these two indices were used to interpret and analyze the impact of drought on groundwater. As can be seen from the Figure 2; the minimum correlation between the standardized precipitation index and the standardized baseline flow occurred for the 1-, 18- and 24-month time steps. With increasing time step from 1- to 12-month, the correlation between drought index and base flow showed an increasing trend; The greatest impact of drought phenomenon on river subsurface flows occurred for the 9- and 12-month time steps and the correlation with the coefficients of determination of 0.86 and 0.87 confirms the highest level of subsurface water flow in the river, with a delay of 9- to 12-month. The analysis of this rate of delay in the impact of droughts can be interpreted according to the characteristics of Karst water resources. Coverage of more than 50% of the study basin by carbonates, and the possibility of karst reservoirs, has caused the gradual impact of meteorological drought on groundwater with a delay of several months.

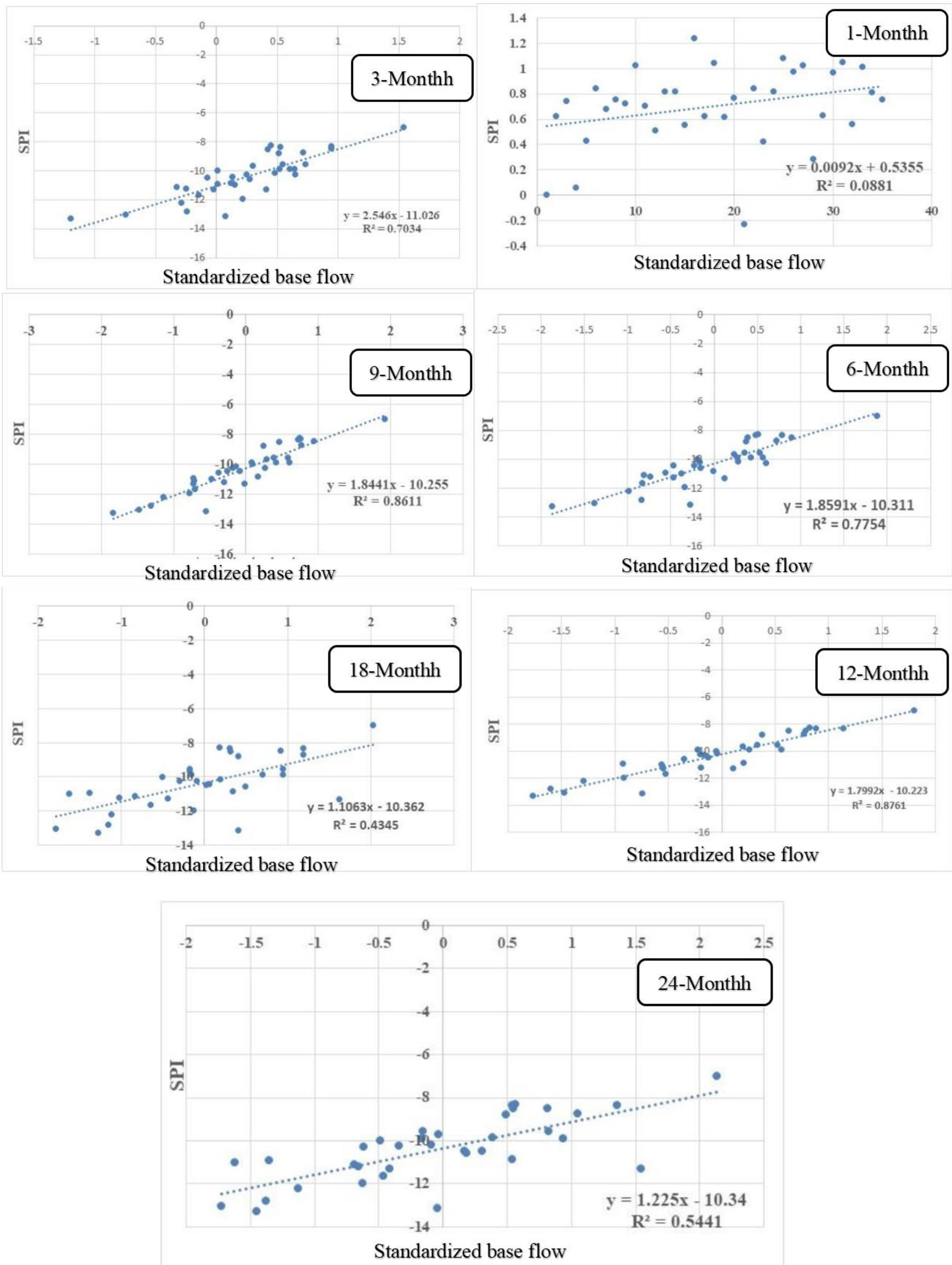

Fig. 2. Correlation of standardized base flow with SPI for the 1- to 24-month time steps in Kaka-Reza basin

In order to analyze the impact of drought on surface water, the results of correlation between SDI and SPI indices are presented in Figure 3. Examining the correlation relationships between the two precipitation and discharge standardized indices for different time steps, indicates that precipitation for the 1- and 3-month time steps does not have a good relationship with discharge for the corresponding time step. The effect of drought on surface water for the 3- to 12-month time steps has a similar effect and a correlation of 0.4 between standardized rainfall and standardized discharge indicates showed this subject. Poor correlation between standardized precipitation index and standardized discharge index for the 18-month time step and also the appropriate relationship between these two indices for the 24-month time step, can be scientifically related to the capacity and volume of karst reservoir and unpredictable nature of karst reservoirs. Arguing that the larger the volume of the karst aquifer reservoir; the time step of precipitation and discharge matching can be larger. Comparing the results of the impact of drought on SDI and SBFI shows that the time delay of the impact of drought on the base flow for the time step is 9- to 12-month with a coefficient of determination of 0.87 while the relationship between drought index and standardized discharge index for the corresponding time step base on coefficient of determination is 0.43 to 0.44. Indicates that in this karst basin, drought for the 9- to 12-month time steps is more likely to affect groundwater; but in terms of impact on surface water, this relationship is weaker.

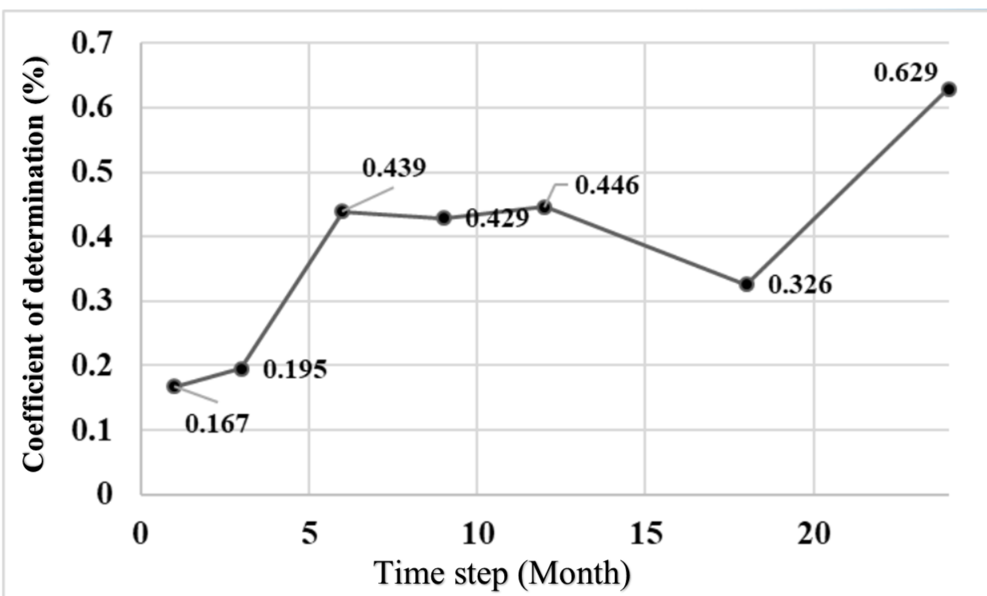

Fig. 3. Correlation between SDI and SPI for the 1- to 24-month time steps in Kaka-Reza basin

Also, the comparison of the results showed that the maximum correlation is between drought indices and surface water and groundwater indices is for the 3- to 12-month time steps. This result is not consistent with the results of the Mofidipoor et al. (2011) on the maximum correlation between the occurrence of meteorological and hydrological drought for a 3-month time step. But This result is consistent with the results of the Babaei et al. (2011); Verdi Pourazad et al. (2014); and Azareh et al. (2014) base on the simultaneous occurrence of two types of meteorological and hydrological droughts.

4. Conclusion

Summarizing the results showed that the relationship between drought and surface water and groundwater in karst basins is different from non-karst basins. Depending on the type of basin and the size of karst reservoirs, the delay steps of the impact of drought on surface water and groundwater will be different and should be analyzed separately. The results of this study can be considered for the development of surface water and subsurface water management methodologies in karst areas.

5. Conflicts of Interest

No potential conflict of interest was reported by the authors

6. Acknowledgment

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