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Comparison of Spi, Spei and Sri Drought Indices for Seyhan Basin

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Abstract - Today, mitigation of the adverse impacts of drought has gained considerable importance in the context of the management of water resources, which is adversely affected by climate change. In this context, to be able to achieve drought risk analyses, meteorological and hydrological data should be sufficient; if they are not, they should be completed. Seyhan Basin spread across the Seyhan River to an area of 2.203.544 ha, extending from Sivas to the Eastern Mediterranean. With 22.035 km^2, the basin area constitutes 2.07% of Turkey's surface area. In this study, by using the meteorological and hydrological data of Seyhan basin between 1970 and 2016, drought risk analyses of the basin with the most widely used around the world SPI, SRI and SPEI drought indices were discussed. In first step of this study, incomplete data was completed with regional analyses. According to these indices, drought severity and magnitude were found. Analyses were performed according to 1, 3, 6, 9, 12, 18, 24, 48-month repeat intervals. Classification of droughts and threshold values were determined. The indices were compared, the correlation between them was examined, and drought risk analyses and drought maps were made separately for each index.

Keywords: Basin, water resources, drought index, SPI, SRI, SPEI

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1. Introduction

Today, mitigation of the expected impacts of drought is vitally important in the context of the planning, development and management of the water resources, which is adversely affected by climate change. Management of increasing drought risk and adaptation to it can only be achieved through the development of sustainable and effective water management strategies that adopt holistic approaches [1]. Management of water resources is also important in terms of meeting the energy needs [2]. Drought risk management is an important part of water resources management policies and strategies. Drought management is also a part of the disaster management [3]. Drought risk management is the process of prevention and mitigation concept and effort against the negative consequences of drought hazard and the potential disaster effects through activities and measures for prevention, mitigation of damage and preparedness [4]. National drought policies play a major role in managing the drought risk [5]. Research on how the negative impact of climate change on the environment, especially on water resources will be shed light on the measures that should have been taken in the future [6]. In order to reduce the impacts caused by drought, drought management plans need to be prepared based on country legislation and by taking into account the specific drought characteristics and impacts of the basin [7, 8]. In order to create integrity, it is very important that these plans are prepared as part of the basin management plan. The objective here is to provide information at an early time before or during the onset of drought, within a drought risk management plan, in order to reduce potential impacts [9]. Because drought is a slow-starting and progressing hydrological phenomenon, monitoring and analysis of the drought are of great importance. In this study, the comparison of SPI, SPEI and SRI drought indices and their compatibility for Seyhan Basin were analyzed. For this purpose, meteorological, hydrological and hydrogeological data between 1970 and 2016 were based on.

2. Material and Method

Seyhan Basin spread across the Seyhan River to an area of 2.203.544 ha, extending from Sivas to the Eastern Mediterranean. With 22.035 km^2, the basin area constitutes 2.07% of Turkey's surface area.

Standardized Precipitation Index (SPI): SPI, which is the most common used meteorological drought index, is an index based on precipitation for different time periods and ignoring other effects [10].

While negative values show lack of precipitation, positive values show excess precipitation. The severity of drought can be classified according to the size of negative SPI values. SPI drought classes are obtained from the normally distributed precipitation series. By dividing the difference between the precipitation on a specific time scale and the average precipitation by the standard deviation of the series, SPI is calculated as equation 1.

$$SPI = \frac{x_i - x_j}{\sigma} \tag{1}$$

where x_i is existing precipitation in the examined period, x_j is the average precipitation of the series and σ is the standard deviation of the series. With SPI, it is possible to express the lack of precipitation in more than one time scale. The lack of precipitation in different time scales can be effective on different water sources. For example, while the moisture of the ground may be affected by lack of precipitation in a shorter period of time, the storage may be affected in a longer period of time. Therefore, SPI can be calculated on 3, 6, 9, 12, 18, 24 and 48-month time scales. SPI-3 can be used to understand short and medium term humidity conditions, SPI-6 can be used to understand medium term precipitation trends, SPI-9 can be used for medium term precipitation patterns and SPI-12 can be used to understand long term precipitation patterns [11, 12]. The fact that SPI can be calculated for different time intervals has allowed this index to be applied in different areas. Therefore, SPI can provide detection of different types of drought. Based on long-term precipitation observations, SPI is calculated for a specific location and the desired duration. The following steps were followed when calculating SPI;

1. Conversion of probability distribution function of raw precipitation data to gamma probability distribution function,
2. Calculation of standardized precipitation sequences (that is, SPI values) for the precipitation probability obtained from the gamma probability distribution function, by using the reverse-standard normal distribution function [13].

Drought severity is the absolute value of the sum of the SPI values of each month in which the drought event occurs. Table 1 shows the levels of drought and threshold values proposed and widely used in the literature [9] for SPI.

Table 1. Standard Precipitation Index (SPI) drought classification and threshold values

Threshold values	Drought severity
2 and above	Excessive humidity
1,5 — 1,99	Very humid
1 — 1,49	Moderate humidity
-0,99 — 0,99	**Normal**
-1 — -1,49	Moderate dry
-1,5 — -1,99	Severe dry
< -2	Excessive dry

Standardized Precipitation Evapotranspiration Index (SPEI): Comparing the other indices, the Standardized Precipitation Evapotranspiration Index (SPEI) is a newer drought index. SPI is based on two main assumptions;

1- The importance of precipitation is much higher than other variables that may affect the severity of drought.

2- Drought is controlled only by the temporal variability emerging in precipitation.

In the calculation of SPEI, although it is based on the principles of SPI, the effect of temperature on drought is also taken into consideration as different from SPI and superior to it. Therefore, SPEI is an ideal index in the examination of climate change with climate model projections.

SPEI is an index based on the values of precipitation, potential transpiration and evaporation. Thus, SPEI can take into account the changes in evaporation values depending on the temperature change. SPEI calculation requires both precipitation data and complete time series data for potential evapotranspiration. Because of this, it is not possible to calculate SPEI where there is insufficient data. The longer the data, the stronger the calculation results [8]. SPEI considers the cumulative climatic water budget anomalies (precipitation - potential transpiration and evaporation). The SPEI calculation also covers the determination of the appropriate probability distribution of long-term observations (such as SPI) and the conversion of them to normal distribution [14]. In this study, the method [15] was used to calculate the required potential transpiration and evaporation values in SPEI calculations because this method requires only monthly average temperature data. In the second phase, in the context of the equation given below; the potential transpiration and evaporation value (PET_i) calculated by using the method is subtracted from the precipitation value (P_i) for the investigated month, and then, a simple criterion (D_i) is obtained for the excess water or shortage of it in that month:

$$D_i = P_i - PET_i \quad (2)$$

In the third phase, the values of D_i are converted to the log-logistic probability distribution function. In the fourth and final phase, D_i series (that is SPEI values), which has been standardized, as in SPI, by using the inverse-standard normal distribution function for the probabilities of access or shortage of water (D_i) obtained from the log-logistic probability distribution function, is obtained. SPEI can be calculated monthly for time intervals ranging from 1 month to 48 months or more. For the SPEI, the drought severities and threshold values commonly used in the literature are given in Table 2.

Table 2. Standardized Precipitation Evapotranspiration Index (SPEI) Drought classification and threshold values

Threshold values	Drought severity
2 and above	Excessive humidity
1,5 — 1,99	Very humid
1 — 1,49	Moderate humidity
0,5 – 0,99	Close to normal humidity
-0,499 — 0,499	**Normal**
-0,5 — -0,99	Close to normal dry
-1 — -1,49	Moderate dry
-1,5 — -1,99	Severe dry
< -2	Excessive dry

Standardized Runoff Index (SRI): SRI is a drought index developed in 2008 as an expression of hydrological drought and based on SPI methodology. As distinct from SPI, runoff data (river discharge data) is used in SRI calculation. Dividing the difference between the runoff values for a specific time scale and the average runoff value by standard deviation of the series, SRI is calculated as equation 3.

$$SRI = \frac{x_i - x_j}{\sigma} \quad (3)$$

where x_i is existing runoff in the examined period, x_j is the average runoff of the series and σ is the standard deviation of the series. Sri is an index that is easy to calculate as SPI because it only requires the use of runoff data. SRI, such as SPI, can be calculated daily or monthly by using both observed and predicted runoff data. Thus, information about high and low runoff periods related to flood and drought can be obtained. Thanks to SRI, hydrological conditions can be monitored in multiple time scales for a place [8]. SRI results can be evaluated in comparison with SPI analysis of the same region. A strong relationship between SPI and SRI was observed in the studies conducted to see the relationship between precipitation and runoff [16]. When calculating the SRI, it is important that the stations represent the basin and that the runoff series are natural. While examining the hydrological drought in drought analyses, 9-12-month SRI results are preferred because they reflect a complete hydrological precipitation period. Table 3 shows drought severity and threshold values used commonly in the literature for SRI. Because the calculation method of SRI was same with the calculation method of SPI and SPEI, similar threshold values were used.

Table 3. Standardized Runoff Index (SRI) drought classification and threshold values

Threshold values	**Drought severity**
2 and above	Excessive humidity
1,5 — 1,99	Very humid
1 — 1,49	Moderate humidity
-1 — 1	**Normal**
-1 — -1,49	Moderate dry
-1,5 — -1,99	Severe dry
< -2	Excessive dry

Drought Classification and Threshold Values Used for Drought Analysis of Seyhan Basin: In the scope of Seyhan Basin drought analysis studies, four main drought severity classes were used to allow consistent comparison of all indices instead of the drought severity and threshold values preferred in the literature to use for the indices whose methods were described in this section: These were determined as severe drought, moderate severe drought, mild drought, no drought-normal/humid. Table 4 shows the drought classification and threshold values of the indices used in the context of the drought analysis study in Seyhan Basin.

Table 4. Drought classification and threshold values used for drought analysis of Seyhan Basin

SPI, SPEI, SRI	Drought Classes
> -0,99	(no drought-normal/humid)
-1,49 — -1	(mild drought)
-1,99 — -	(moderate severe drought)
< -2	(severe drought)

1, 3, 6, 9, 12, 18, 24 and 48-month values belonging to Standardized Precipitation Index (SPI) were calculated for stations in the basin. Then, weighted averages of these values were obtained to cover the entire Seyhan Basin, and they were regionalized. SPI drought severity time series of Seyhan Basin is shown on Figure 1. In the series, the blue periods represent normal and above (humid) periods and red periods represent dry periods.

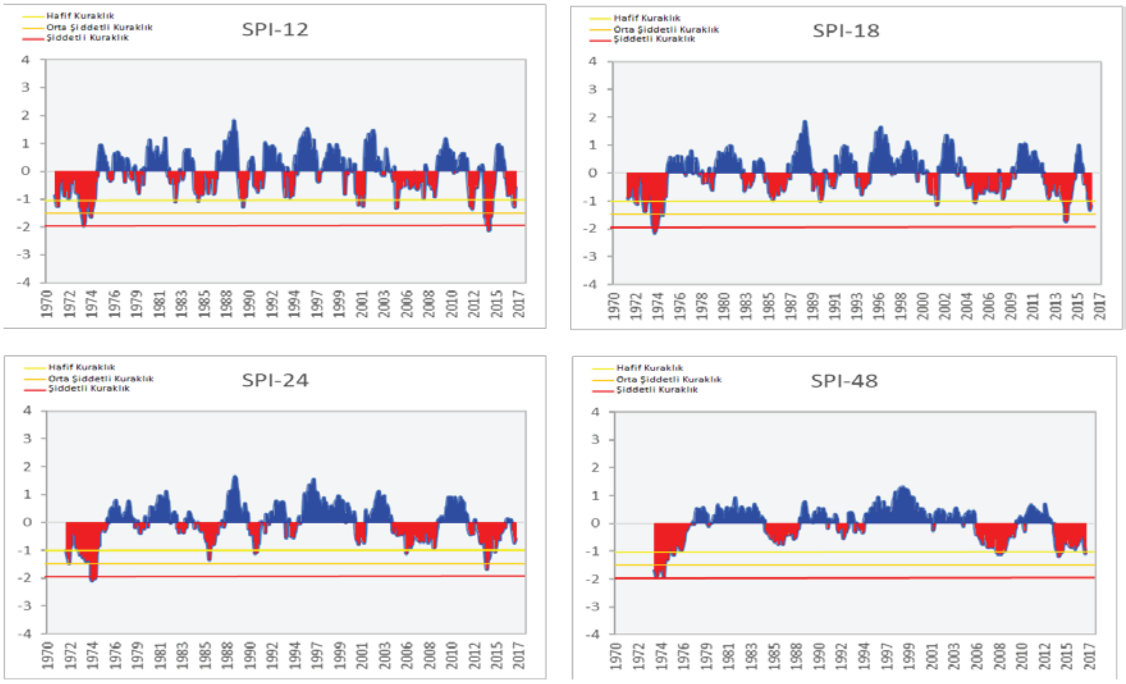

Figure 1. Seyhan Basin SPI drought severity time series

The Standardized Precipitation Evapotranspiration Index (SPEI) and Standardized Runoff Index (SRI) were calculated in different periods (1, 3, 6, 9, 12, 18, 24 and 48-month), and the time series of the SPEI values calculated for the basin were found. Values for the basin were obtained by taking weighted averages of SPEI and SRI values, which were calculated based on stations in the basin, to cover the entire Seyhan Basin and they were regionalized.

3. Results and Discussion

The aim of this study was to present drought risk analysis created by using calculated meteorological and hydrological indices. The meteorological, hydrological and agricultural drought was analyzed by the values of the Standardized Precipitation Index (SPI – 1, 3, 6, 9, 12, 18, 24 and 48-month), the Standardized Precipitation Evapotranspiration Index (SPEI – 1, 3, 6, 9, 12, 18, 24 and 48-month) and the Standardized Runoff Index (SRI – 1, 3, 6, 9, 12, 18, 24 and 48-month). Risk analysis of 12-month index values was carried out in order to represent the past drought periods consistently. In Seyhan Basin, the calculated drought indices for the determination of the dry periods of the past were examined in detail and with this study it was aimed to determine the common periods between the indices . The method used is described below:

1- 24 drought indices selected for the comparison for the purpose of determining the dry periods were listed monthly by bringing them to the same time period for the time frame (1970 – 2016) examined within the scope of this report.

2- It was calculated whether the basin-wide was dry above normal by taking the area weighted average of each index for the basin and using its own parametric drought classification. At this level, it was only determined whether drought occurred or not; the severity of drought itself was not investigated. The color scale used in the charts is based on the common classification determined for drought indices; white color is normal and above (humid), yellow color is mild drought, orange color is moderate severe drought, red color is severe drought indicator.

3- It was aimed to determine the period of common drought in the chart by comparison between indices and examine within the scope of this study. In this context, dry periods in various lengths in 1973-1974, 1989, 2001, 2007-2008, 2014 and 2016 were determined for Seyhan Basin.

In the scope of the study, agricultural, hydrological and meteorological drought analyses were carried out with the help of indices by using the data available for 47 years of time period between 1970 and 2016. This study was carried by using a total of 24 indices: The Standardized Precipitation Index (SPI1, SPI3, SPI6, SPI9, SPI12, SPI18, SPI24, SPI48), the Standardized Precipitation Evapotranspiration Index (SPEI1, SPEI3, SPEI6, SPEI9, SPEI12, SPEI18, SPEI24, SPEI48) and the Standardized Runoff Index (SRI1, SRI3, SRI6, SRI9, SRI12, SRI18, SRI24, SRI48). The threshold values corresponding to the normal and above condition, mild drought, moderate-severe drought and severe drought classes of each index were determined and all analyses were performed taking into account these values. For all indices, risk analysis was performed by determining the percentages of incidence corresponding to drought classes. Risk analysis was conducted for both stations and the basin.

Results were determined by maps and graphs. It was observed that the indices calculated within the scope of the study had high relations with each other. It was determined that the indices calculated for the same periods shows a higher correlation than those calculated for the different periods. The comparison of the indices with each other is presented in Figure 2.

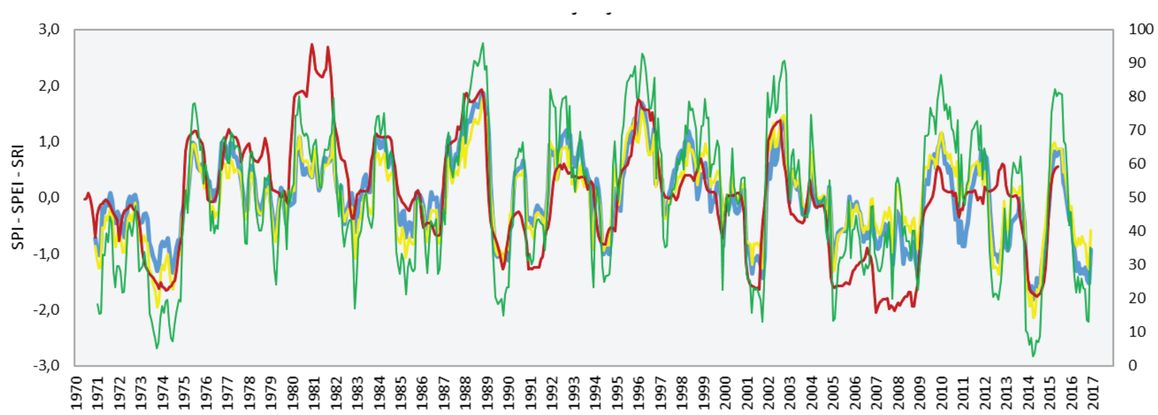

Figure 2. The comparison of SPEI12, SPI12 and SRI12 of Seyhan Basin (12-month)

4. CONCLUSION

As a result of the examination of all indices together, the periods in which the indices indicated the drought for Seyhan Basin in common were determined as 1973-1974, 1989, 2001, 2007-2008, 2014 and 2016. It was observed that the indices based on precipitation, runoff and evaporation values are compatible with each other. It was also proved in Seyhan Basin case that the indices in the same period gave very close results. At the end of the study, it is seen that all indices used are compatible with each other and calculate approximately the same values, but the most compatible index with meteorological data is SRI index for this region.

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References

[1] Yuksel, I. (2018). The South-Eastern Anatolia project factor on water management and energy demand in Turkey. Fresenius Environmental Bulletin. 27(1), 246-253.

[2] Gulbaz, S., et al. (2017). A calibrated hydrological model for Alibeyköy watershed in İstanbul, Turkey incorporating lid implementation. FEB-Fresenius Environmental Bulletin, 6112.

[3] Wilhite, D. (2000), *Drought: A global assessment Hazards and disasters: A series of definitive major works*. Routledge, New York.

[4] UNDP (2016). Drought Risk Management.

[5] Wilhite, D.A., Sivakumar, M.V., and Pulwarty, R. (2014). Managing drought risk in a changing climate: The role of national drought policy. Weather and Climate Extremes. 3, 4-13.

[6] Al-Safi, H.I.J. and Sarukkalige, P.R. (2017). Assessment of future climate change impacts on hydrological behavior of Richmond River Catchment. Water Science and Engineering. 10(3), 197-208.

[7] EC (2007), *Drought management plan report: including agricultural, drought indicators and climate change aspects European Commission Directorate of Environment*.

[8] Svoboda, M. and Fuchs, B. (2016). Handbook of Drought Indicators and Indices.

[9] McKee, T.B., Doesken, N.J., and Kleist, J. (1993). *The relationship of drought frequency and duration to time scales*. in *Proceedings of the 8th Conference on Applied Climatology*. American Meteorological Society Boston, MA.

[10] WMO (2012). Statement on the Status of the Global Climate in 2012. Geneva, Switzerland: World Meteorological Organization.

[11] Zargar, A., et al. (2011). A review of drought indices. Environmental Reviews. 19(NA), 333-349.

[12] Lloyd-Hughes, B. and Saunders, M.A. (2002). A drought climatology for Europe. International journal of climatology. 22(13), 1571-1592.

[13] Vicente-Serrano, S.M., Beguería, S., and López-Moreno, J.I. (2010). A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index. Journal of climate. 23(7), 1696-1718.

[14] Van Loon, A.F. (2015). Hydrological drought explained. Wiley Interdisciplinary Reviews: Water. 2(4), 359-392.

[15] Thornthwaite, C.W. (1948). An approach toward a rational classification of climate. Geographical review. 38(1), 55-94.

[16] Sheffield, J. and Wood, E.F. (2008). Projected changes in drought occurrence under future global warming from multi-model, multi-scenario, IPCC AR4 simulations. Climate dynamics. 31(1), 79-105.