DROUGHT ANALYSIS OF THE CEYHAN BASIN IN TURKIYE USING DIFFERENT INDICES BASED ON PRECIPITATION

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Abstract - Drought is one of the most important natural disasters threatening life, and its impact is becoming more evident daily. Therefore, it is important to analyse the drought regionally, which is expected to substantially impact the Mediterranean region, and develop adaptation strategies against it. In this study, drought analyses were carried out in the Ceyhan Basin for 12-month time periods with various indices using precipitation and temperature data between 1989-2019. Standardized Precipitation Index (SPI), Reconnaissance Drought Index (RDI), and Deciles Index (DI) methods were used to analyse the dry periods in the region. According to the results of these methods, the periods, including extremely dry and wet years, were analysed and compared. As a result, the driest year was found to be 2014, and the wettest year was found to be 2010.

Keywords: Drought, Standardized Precipitation Index, Deciles Index, Reconnaissance Drought Index, Ceyhan Basin

1. INTRODUCTION

Drought is a climatic phenomenon and is generally considered a natural event. The term meteorological drought is used to describe situations where precipitation amounts are below long-term average values. Over time, the effects of meteorological drought can lead to agricultural drought, hydrological drought, and socioeconomic consequences. In this case, depending on the type of problem at hand, it is necessary to correctly identify the relevant drought category and plan to mitigate its impacts. Moreover, the occurrence of drought events can have economic impacts far beyond the affected area (Mishra et al. 2007). Scientific and technological research worldwide has revealed that one of the areas most affected by climate change will be the Mediterranean Basin, including Turkiye. The Intergovernmental Panel on Climate Change (IPCC) report states that global climate change's effects on the Mediterranean Basin will manifest themselves in the form of significant temperature increases with a decrease in precipitation (IPCC 2014). Drought as a physical phenomenon is only natural, but it can have devastating impacts as societies are heavily dependent on water resources. Studies using data from past years to identify drought-risk areas are critical to minimize the damage caused by these devastating impacts.

Drought indicators usually describe drought events as variables that describe the characteristics of drought, namely its magnitude, duration, severity, and spatial extent. However, various indices have been proposed to detect and monitor drought over the years. The drought index is the preferred method for characterizing and monitoring droughts as it simplifies complex climate processes and allows climate anomalies to be quantified in terms of severity, duration, and frequency. Gibbs and Maher (1967) developed the Deciles Index (DI) to monitor and quantify drought using precipitation data. The Standardized Precipitation Index (SPI), one of the precipitation-based meteorological drought indices, was developed by McKee et al. (1993). An alternative precipitation-based meteorological drought index, the Reconnaissance Drought Index (RDI), was developed by Tsakiris and Vangelis (2005) using precipitation rates over reference crop evapotranspiration (ET) for different time scales to represent the region of interest.

Sener et al. (2021) used the SPI, the Rainfall Anomaly Index (RAI), and the Percent of Normal Precipitation (PNP) to conduct a meteorological drought analysis for Isparta province. Kayam et al. (2017) studied SPI, DI, PNP, RDI, and Keetch-Byram drought indices in the Izmir-Menemen region. Irvem et al. (2019) conducted drought analysis with SPI for Mugla Province; Dinc et al. (2016) conducted drought analysis with SPI for Antalya province; Karaer et al. (2018) conducted drought analysis with SPI for Bilecik province. Anli (2014) studied Reconnaissance Drought Index and reference evapotranspiration (ET_0) in the Southeastern Anatolia Region.

In this study, using the meteorological data of the Ceyhan Basin between 1989-2019, drought analysis was carried out using the Standardized Precipitation Index, Reconnaissance Drought Index, and Deciles Index methods for 12 months. The drought analysis results of these indices were compared.

2. MATERIAL AND METHODS

2.1. STUDY AREA AND DATA

Ceyhan Basin is located in the Eastern Mediterranean region of Turkiye between 36°55′ to 38°72′ north latitude and 35°45′ to 37°81′ east longitude. The basin lies in Kahramanmaras, Osmaniye, and Adana provinces, with an area of 21,391 km^2, corresponding to approximately 2.73% of Turkiye. The Ceyhan Basin, which stretches from the Iskenderun Gulf to the Southeastern Taurus Mountains, is made up of steep mountainous terrain and extensive alluvial lands (Republic of Turkiye Ministry of Agriculture and Forestry General Directorate of Water Management Department of Flood and Drought Management 2019). The Ceyhan Basin has a transitional climate between the Mediterranean and continental climates, with rainy and mild winters and hot and dry summers (Yuce and Esit 2020). In the southern part of the Ceyhan Basin lies the Cukurova Delta, one of Turkiye's most important agricultural production areas (Gumus and Algin 2017). Ceyhan Basin is adjacent to the Euphrates Basin to the east and northeast, Seyhan Basin to the west and northwest, and Asi Basin to the south.

Drought analysis of the Ceyhan Basin was carried out using meteorological data obtained from the General Directorate of Meteorology between 1989-2019 in various indices. The data were taken from 17355 Osmaniye, 17866 Goksun, 17868 Afsin, 17870 Elbistan, 17908 Kozan, 17960 Ceyhan, and 17979 Yumurtalik meteorological stations with numbers defined by the General Directorate of Meteorology of Republic of Turkiye.

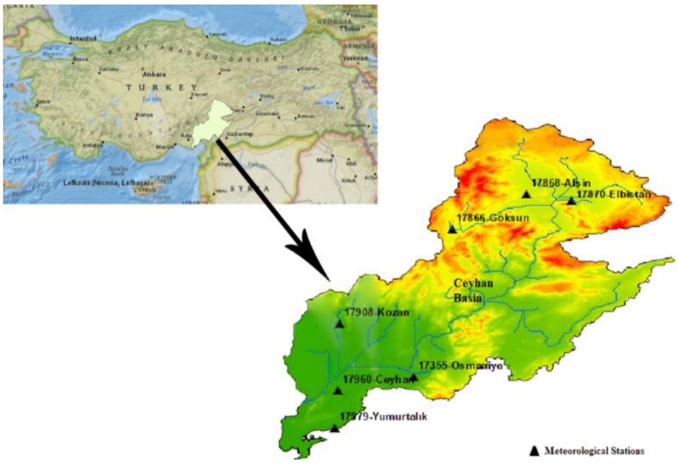

Fig -1: Geographical location of Ceyhan Basin and its meteorological stations

2.2. THE STANDARDIZED PRECIPITATION INDEX (SPI)

The Standardized Precipitation Index (SPI) is an important index that uses specific time-precipitation data as input parameters developed by McKee et al. (1993) to determine periodic meteorological droughts. The Standardized Precipitation Index (SPI) is calculated by dividing the difference between the mean and the standard deviation of precipitation data within specified periods (McKee et al. 1993, 1995).

$$\mathrm{SPI} = \frac{x_i - x_j}{\sigma} \qquad (1)$$

where x_i is current precipitation, x_j is average precipitation and σ is the standard deviation.

In the results obtained, SPI values show a linearly decreasing or increasing trend with the lack of precipitation. By obtaining the SPI results, the dry and wet periods within the selected period are represented to the same extent. A period with consistently negative SPI values is an dry period. The first month the index decreases to a negative value are considered the beginning of the drought, and the month in which the index increases to a positive value is considered the end of the drought (Sırdas 2002). Drought-moisture classification can be made by considering the values given in Table 1 of the obtained SPI values (McKee et al. 1993).

Table -1: Drought classification according to SPI values

Classification	SPI Value
Extremely Wet	2.00 <
Severely Wet	1.50 – 1.99
Moderately Wet	1.00 – 1.49
Near Normal	-0.99 – 0.99
Moderately Dry	-1.00 – -1.49
Severely Dry	-1.50 – -1.99
Extremely Dry	> -2.00

2.3. THE RECONNAISSANCE DROUGHT INDEX (RDI)

Reconnaissance Drought Index (RDI) is a drought index developed by Tsakiris et al. (Tsakiris and Vangelis 2005; Tsakiris et al. 2007). It is an index based on the ratio between two total quantities, Precipitation (P) and Potential Evapotranspiration (PET), to determine periodic meteorological droughts. The initial value of the index for a given period, denoted by a month (*k*) for a given year (*i*) during a year, is calculated as:

$$a_k = \frac{\sum_{j=1}^{j=k} \mathrm{P}_j}{\sum_{j=1}^{j=k} \mathrm{PET}_j} \qquad (2)$$

where P_j and PET_j are the precipitation and potential evapotranspiration for the *j*-th month of the hydrological year, respectively.

The calculated values were found to satisfactorily follow both lognormal and gamma distributions at different time scales and over a wide range of locations (Tsakiris and Vangelis, 2005; Tsakiris et al., 2007). Normalised $\mathrm{RDI_n}$ is calculated for each year using the following:

$$\mathrm{RDI_n}(k) = \frac{a_k}{\bar{a}_k} - 1 \qquad (3)$$

where, the parameter $\bar{a}_k$ is the arithmetic mean of a_k values calculated for N years of data.

Furthermore, if a_k values follow a lognormal distribution, the following equation can be used to calculate the RDI:

$$\mathrm{RDI_{st}}(k) = \frac{y_k - \bar{y}_k}{\hat{\sigma}_k} \qquad (4)$$

where the value of y_k in the equation is $\ln(a_k)$, where $\bar{y}_k$ is its arithmetic mean and $\hat{\sigma}_k$ is its standard deviation.

When the gamma distribution is applied, the index can be calculated by approximating the initial value of the probability density function of the gamma distribution to the frequency distribution (Tsakiris et al. 2007).

It was stated by Tsakiris et al. (2007) that the Standardized RDI (RDI_{st}) behaves similarly to the Standardized Precipitation Index (SPI), and the interpretation of the results is also similar. Therefore, the RDIst can be compared with the SPI using the same thresholds. The choice of the lognormal distribution is not limiting. However, it helps to develop a single procedure instead of different procedures depending on the probability distribution function that can be best adapted to the data. The drought classes of the RDI index are given in Table 2 (Tsakiris et al. 2007; Kayam et al. 2017).

Table -2: Drought classification according to RDI values

Classification	RDI Value
Extremely Wet	2.00 <
Severely Wet	1.50 – 1.99
Moderately Wet	1.00 – 1.49
Near Normal	-0.99 – 0.99
Moderately Dry	-1.00 – -1.49
Severely Dry	-1.50 – -1.99
Extremely Dry	> -2.00

2.4. The Deciles Index (DI)

The Deciles Index method was developed by Gibbs and Maher (1967). It is a simple method since it requires only precipitation parameters. The precipitation series of each hydrological year of the region for which the Deciles Index values are to be calculated are sorted according to the frequency and distribution of precipitation. The precipitation series is divided into ten parts. The first decimal is determined from the precipitation amounts that do not exceed the precipitation amount of the lowest 1/10th part.

Table -3: Drought classification according to DI values

Deciles	Description
1 - 2	Much below normal
3 - 4	Below normal
5 - 6	Near normal
7 - 8	Above normal
9 - 10	Much above normal

3. RESULTS AND DISCUSSION

This study used SPI, RDI and DI indices for annual drought analysis with meteorological data (12 months) from 1989 to 2019 for the Ceyhan Basin. Although precipitation data were used as input parameters in all of these methods, drought analysis was performed using Potential Evapotranspiration (PET) according to monthly average maximum and minimum temperature values in addition to the calculation of the Reconnaissance Drought Index. Figure 2 shows the SPI drought analysis of the Ceyhan Basin according to the 12 months. Figure 3 shows the RDI drought analysis of the Ceyhan Basin according to the 12 months. Figure 4 shows the DI drought analysis of the Ceyhan Basin according to the 12 months.

In the SPI drought analysis of the Ceyhan Basin between 1989-2019, it was found that there was 1 extremely dry year (3%), 1 severe dry year (3%), 5 moderately dry years (17%), 17 years in the normal level class (57%), 5 moderately wet years (17%) and 1 very wet year (3%). Wet years constitute 20%, dry years 23% and 57% of the SPI analysis result according to the normal level classification. According to the result of SPI analysis, the driest years were 2014, 1994 and 1990, respectively. The most wet years were found to be 2010, 2004 and 1997, respectively. After 2013, it was observed that the number of dry years increased.

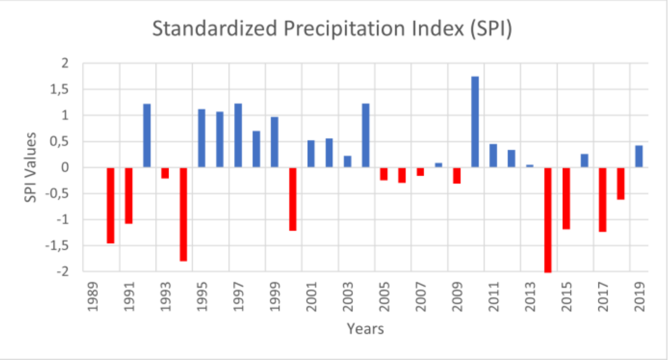

Fig -2: SPI drought analysis of Ceyhan Basin according to 12-month period

In the RDI drought analysis of the basin between 1989-2019, 1 extremely dry year (3%), 2 severe dry years (7%), 4 moderately dry years (13%), 16 years in the normal level class (54%), 6 moderately wet years (20%) and 1 very wet year (3%) were found. Wet years constitute 23%, dry years 23% and normal level class 54% of the RDI analysis result. According to the RDI analysis result, the driest years were 2014, 1994 and 1990, respectively. According to the RDI analysis result, the most wet years were found to be 2010, 1992 and 1997, respectively. The drought index value results have also changed slightly by calculating the temperature factor and obtaining evapotranspiration in the RDI analysis of the mentioned years.

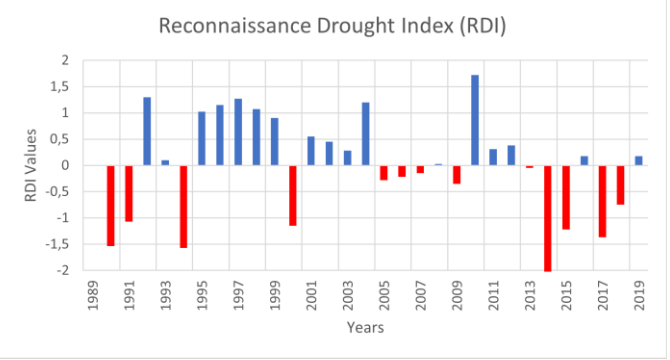

Fig -3: RDI drought analysis of Ceyhan Basin according to 12-month period

In the DI drought analysis of the basin between 1989-2019, it was found as 6 years (20%) very below normal dry, 6 years (20%) below normal dry, 6 years (20%) near normal, 6 years (20%) above normal wet, 6 years (20%) above normal wet and 6 years (20%) very above normal wet. Wet years constitute 40%, dry years 40% and near normal years 20% of the result of the DI analysis. According to the result of the DI analysis, the driest years were 2014, 1994 and 1990. According to the result of the DI analysis, the most wet years were found to be 2010, 2004 and 1997. It is observed that the results of the indices used in the study are compatible with each other.

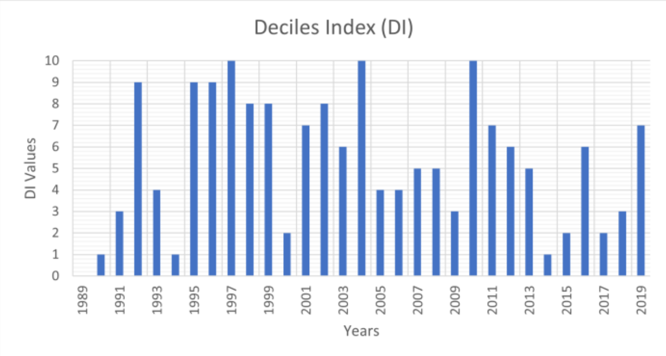

Fig -4: DI drought analysis of Ceyhan Basin according to 12-month period

4. CONCLUSIONS

The Deciles Index is a simple and useful method. However, it is also evident in the literature that it needs to be improved in its ability to evaluate and classify in more detail compared to the SPI and RDI methods. Since the DI method is in decile form, it cannot show the dry and wet years in more detail. In the SPI and RDI analyses, it is seen that the number of dry periods is higher in the years after 2013 and the early 1990sin its ability to evaluate and classify in more detail compared to the SPI and RDI methods. Since the DI method is in decile form, it cannot show the dry and wet years in more detail. In the SPI and RDI analyses, it is seen that the number of dry periods is higher in the years after 2013 and the early 1990s. In addition, the increase in the number of dry years in the study's last periods also indicates a risk of drought. The SPI and RDI methods yielded observation results closer to each other. When the graphs in the SPI and RDI analyses are examined, the effect of PET in 1993 and 2013 and the effect of the difference in values, albeit slightly, are seen. When all three different drought indices are examined, it is observed that the wettest year was 2010 and the driest year was 2014.

Analysing the studies conducted in the region as a whole, monitoring them with different indices, and making drought forecasts for future periods with the inferences from the results obtained can help drought risk management studies. Furthermore, determining the dry and wet period conditions can aid in the implementation of various measures to reduce the impact of drought on agriculture and water resources in the region.

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