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LONG-TERM HYDROLOGICAL DROUGHT ANALYSIS IN AGRICULTURAL IRRIGATION AREA: THE CASE OF DÖRTYOL-ERZIN PLAIN, TURKEY

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Abstract
In recent years, with the effect of the climate change, drought is accepted as one of the most important natural disasters. In the planning, development and management processes of water resources, studies on the analysis of past droughts and the decreasing of possible negative effects in the future, have become even more substantial. The best adaptation to drought risk can only be achieved by adopting holistic approaches. In this study, Dörtyol-Erzin Plain, which is located in the south of Turkey and covers the fertile agricultural lands of the Asi River Basin with a drainage area of approximately 7800 km^2, was preferred as the case study for hydrological drought analysis. In the literature, it is stated that there is a slow drought progress for the Asi River Basin. It is highlighted that decreasing trend in groundwater and increasing trend in evaporation and temperature parameters are remarked. Since the agricultural irrigation of Dörtyol-Erzin Plain is dependent on groundwater and surface resources, hydrological drought analysis over the long period will be beneficial for the future studies. Accordingly, Streamflow Drought Index (SDI) method was used for the hydrological drought analysis by using 35 years of flow data between the years of 1986-2020. The open source "SPI_SL_6.exe" program via National Drought Mitigation Center (NDMC) was operated in the calculations. Drought results were analyzed at different time scales of 3, 6, 12, 24 and 48 months, afterwards relevant graphs and tables were created. Consequently, the longest dry period has been determined between 2008 and 2012 water years, while the wet period has been evaluated between 2003 and 2007 ones. Furthermore, it is concluded that SDI values decreased as the monthly time periods increased, while the maximum indice values were obtained with SDI-3 in all drought periods. When all graphs are examined detailed, it can be expressed long-term droughts for certain water years are notable.

Keywords: Asi River Basin, Dörtyol- Erzin Plain, Hydrological Drought, Streamflow Drought Index.

1. INTRODUCTION

Drought is stated as a natural disaster that causes environmental, economic and social problems in a region as a result of low rainfall especially below the average values for long-term periods (Özfidaner et al., 2015; Yıldız, 2019). Lack of rainfall generally defines meteorological drought, and deficiencies in surface or groundwater determine hydrological drought (Gümüş, 2017; Özcan et al., 2019). Agricultural drought is explained as the decrease of these hydrological cycle components in terms of agriculture (Dai et al., 2020; Haghighi et al., 2020). It is of great importance to carry out planning studies on a regional basis in order to minimize the negative effects of the drought. Considering the classifications of the severity and magnitude of the drought, especially by making use of the observed past hydrometeorological data, will contribute greatly to the literature and emergency action plan studies for drought management in terms of future drought foresight.

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The most effective method of evaluating drought with numerical values is to benefit from drought indices. By this means, it will be possible to examine the drought in the sense of temporal severity, magnitude and spatiality (Sırdaş and Şen, 2003; Huang et al., 2015; Özfidaner and Topaloğlu, 2020). Many different indices are used to determine meteorological and hydrological drought. Standardized Precipitation Index (SPI) and Percent of Normal Index (PNI), which are generally calculated from precipitation data; Palmer Drought Severity Index (PDSI), De Martonne Index, Erinç Drought Index and Aydeniz Method, which include not only precipitation data but also many meteorological parameters such as temperature and humidity, are widely handled in drought analysis studies (Arslan et al., 2014; Said et al., 2019; Pandzic et al., 2020; Qaisrani et al., 2021, Jahangir et al., 2022; Ullah et al., 2022). Streamflow Drought Index (SDI) method, which has been examined within the scope of this study, exploits the observed flow data as input parameters (Yaltı and Aksu, 2019; Eroğluer and Apaydın, 2020; Prajapati et al., 2021; Junqueira et al., 2022; Turhan et al., 2022).
In this study, Dörtyol-Erzin Plain, which is located in the south of Turkey and covers the fertile agricultural lands of the Asi River Basin, was preferred as the case study for hydrological drought analysis. Because the agricultural irrigation of Dörtyol-Erzin Plain is dependent on groundwater and surface resources, hydrological drought analysis over the long period will be useful for the future drought prediction. Thus, SDI method was used for the hydrological drought analysis by using 35 years of flow data between the years of 1986-2020. "SPI_SL_6.exe" program via National Drought Mitigation Center (NDMC) was utilized in the calculations. Drought were investigated at different time scales of 3, 6, 12, 24 and 48 months quantitatively. With obtained values, relevant graphs and tables were created. It has been tried to reveal the changes of the indices calculated for long time periods in the time scales. The results can contribute on future studies with regard to measures to be taken for drought action plans.

2. MATERIALS AND METHODS

a. Case Study and Observed Data

Hatay is a border province located at the eastern end of the Mediterranean Region in Turkey. Covering 0.7% of the total area of Turkey, the province area with a width of 5,403 km² comprises between 35˚52'-37˚04' north latitudes and 35˚40'-36˚35' east longitudes (Republic of Turkey Ministry of Agriculture and Forestry, 2019). It is stated that Hatay is one of the provinces that has an important position in the field of agriculture for Turkey and has a high potential respect to agricultural production in the future. A large part of the country's citrus production, about 12% of cotton, and a significant part of carrots and olives are produced in Hatay. The agricultural sector has different levels of significance in terms of many socio-economic criteria, considering the level of development in the country's economies (Semerci, 2018).
When examined in the sense of water resources, the Asi River Basin located in the south of Turkey is considered to be one of the basins with a high degree of substantiality due to its drainage area of approximately 7800 km^2 and its border with neighboring countries (Turhan et al., 2022). The Asi River is mostly used for agricultural irrigation and many rivers in the basin can dry up in the summer months. Mediterranean climate is dominant, with hot and dry summers and mild and rainy winters. The Asi Basin includes four sub-basins, and the Mediterranean sub-basin is only one of them (Figure 1). Dörtyol-Erzin Plain is located in the Mediterranean Sub-Basin. Dörtyol and Erzin districts have get famous for themselves with citrus cultivation. Nowadays, grain and vegetable cultivation and the greenhouse sector, which has been rapidly increasing, are also consideration economic resources.

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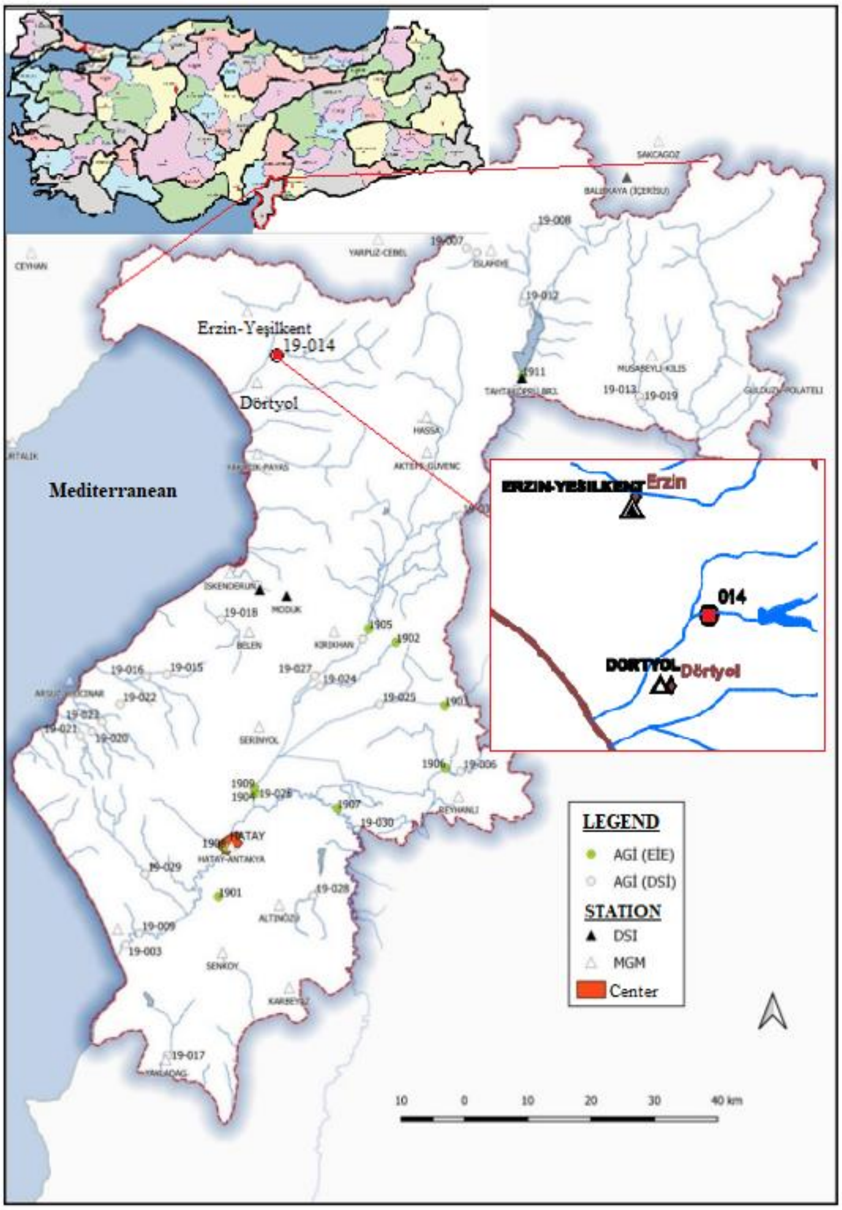

Figure 1. The location of the Dörtyol- Erzin Plain (Republic of Turkey Ministry of Agriculture and Forestry, 2019)

Currently, fluctuations in temperature and precipitation regimes and unusual climatic activities have threaten natural living environments. It is mentioned that there is a slow drought progress for the Asi River Basin. It is underlined that decreasing trend in groundwater and increasing trend in evaporation and temperature parameters are indicated (Dikici, 2019). Thus, the studies on the analysis of past droughts and the decreasing of possible negative effects in the future, have become significant. Because the agricultural irrigation of Dörtyol-Erzin Plain is related to groundwater and surface resources, hydrological drought analysis over the long period will be useful for the action emergency plans. In the Asi River Basin, there are many Stream Gauge Stations (SGS) operated by The State Hydraulic Works (knownly as DSI) since 1963. In this study, numbered D19A014 SGS, set around

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the Dörtyol-Erzin Plain, was preferred in order to evaluate hydrological drought analysis (DSI, 2020). Drought changes were investigated hydrologically at 3, 6, 12, 24 and 48 month time scales by using monthly average streamflow data between 1986 and 2020 years.

b. Streamflow Drought Index Method

Streamflow Drought Index (SDI) can be estimated using monthly average flow data. When these flow data are shown as $Q_{i,j}$, term of "*i*" represents the hydrological year, "*j*" shows the month in October and September, that is, the time in the water year, and *k* represents the reference period. In this method, generated by Nalbantis (2008), the cumulative flow volume can be specified as in Equation 1 below (Turhan et al., 2022):

$$V_{i,k} = \sum_{j=1}^{3k} Q_{i,j} \quad \mathrm{i} = 1,2,\ldots \quad \mathrm{j} = 1,2,\ldots,12 \quad \mathrm{k} = 1,2,3,4 \tag{1}$$

It is evaluated as k=1 for October–December, k=2 for October–March, k=3 for October–June, and k=4 for October–September. k=1 and k=2 show as SDI-October (6 months) and SDI-April (other 6 months) periods, respectively, and the annual drought index value decribes as SDI-12. Based on the cumulative flow volumes, the SDI value for each "*k*" of "*i*" hydrological years can be defined as follows (Equation 2):

$$SDI_{i,k} = \frac{V_{i,k} - \overline{V_k}}{S_k}, k = 1,2,3,4 \tag{2}$$

V_k and S_k in the Equation 2 show the mean and standard deviation of the cumulative flow volumes, respectively. SDI values are divided into eight different classifications between Extremely Wet and Extremely Drought. Drought classification created considering the SDI is denoted in Table 1 (Hong et al., 2015).

Table 1. Drought categories considering the SDI values (Hong et al., 2015)

SDI values	**Categories**
SDI≤-2	Extreme drought
-2<SDI≤-1.5	Severe drought
-1.5<SDI≤-1	Moderate drought
-1<SDI≤0	Mild drought
0<SDI≤1	Mildly wet
1<SDI≤1.5	Moderately wet
1.5<SDI≤2	Severely wet
SDI>2	Extremely wet

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3. RESULTS AND DISCUSSIONS

The changes of monthly average discharges of D19A014 numbered SGS over time is given in Figure 2 and also the flow duration curve is given in Figure 3.

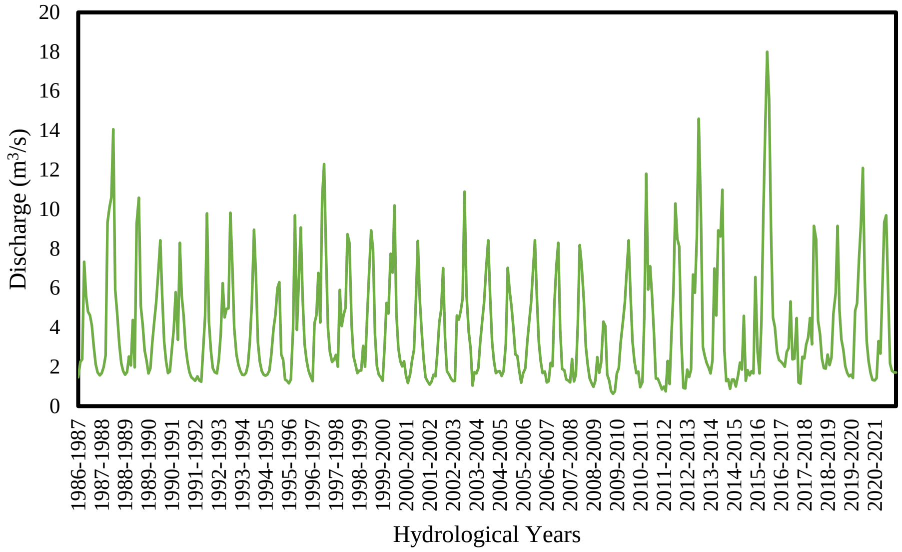

Figure 2. Graph of disharge value changing with time

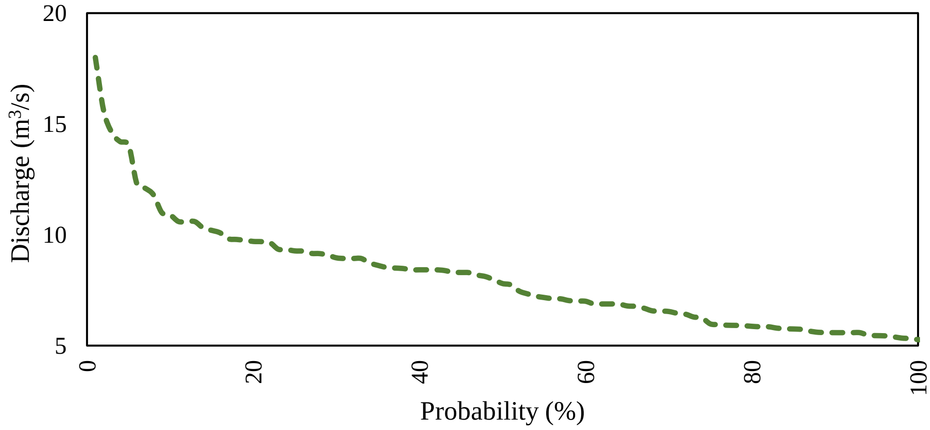

Figure 3. Flow duration curve for determined years

The year with the lowest flow value was 0.75 m^3/s between 2009-2010; and the year with the highest value was 18 m^3/s between 2015-2016. It is seen that the peak discharge values are close to each other between 1989 and 2013. As can be seen in Figure 3, 50% or more probability of exceeding occurs at low flow rates. In the study, the changing of the dry and wet periods according to the months was determined by 35 years of streamflow data (Figure 4). The longest dry period proceeded 10 months between 2008-2009, 2014-2015 and 2016-2017, and the wet period one interval continued 8 months

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in 1996-1997 and 2015-2016. It has been determined that the drought was significantly effective in the years of 2014-2015 and occurred at certain intervals for other time periods.

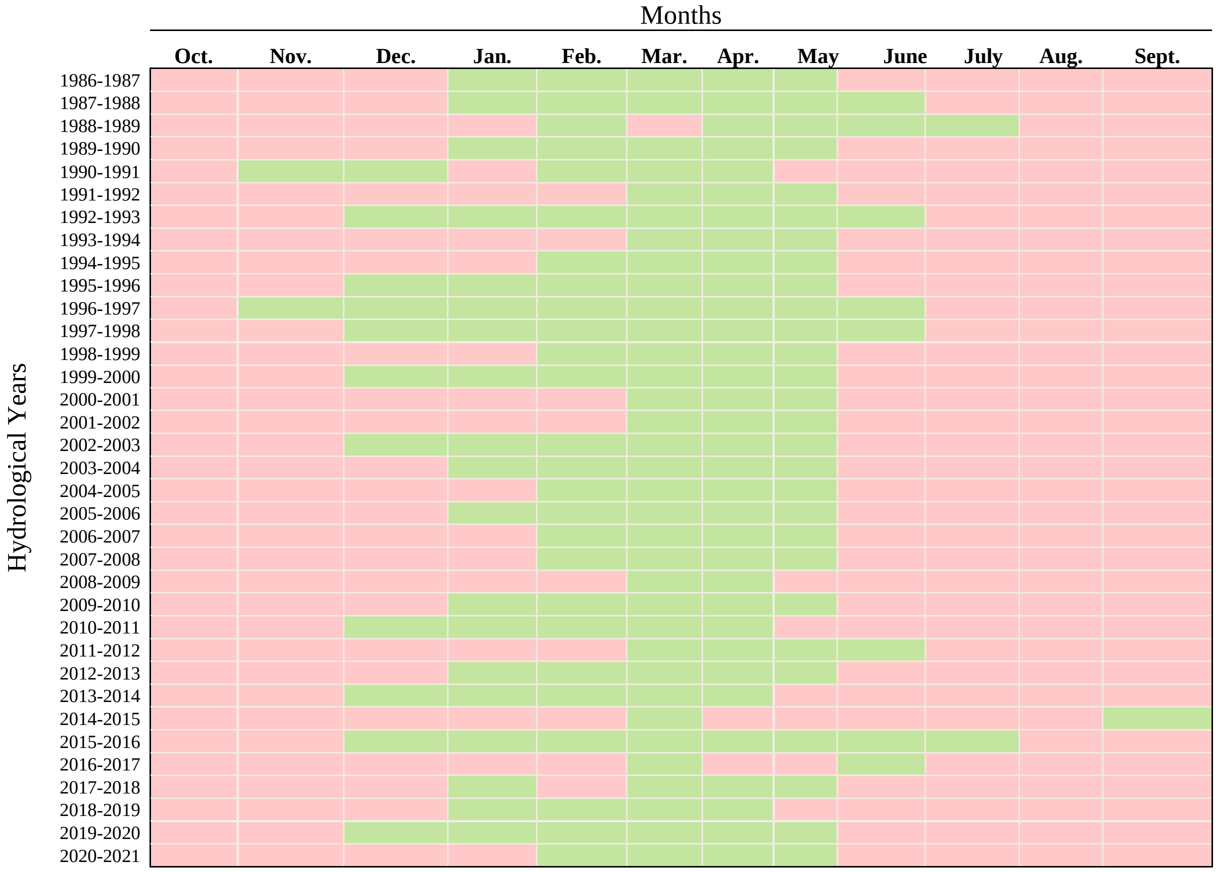

Figure 4. The changes of the dry and wet periods between 1986-2020 water years

In the above figure, the dry and wet months are shown according to the annual average flow values. Values lower than the average flow were predicted as dry period, while higher values were estimated as wet period. Thereby, while the most dry period has been specified in 2009 and 2017 water years with 10 months, but only a 2-month dry period has been observed in 1997 and 2016 water years. In the remaining 10 months, there are above-average flow data.

The index values obtained using the flow data are given in Figure 5. When this graph is examined, the effects of the low flow values mentioned for 2009 and 2017 water years can be clearly seen. Considering all periods, the driest periods have been seen between 2009 and 2017, and the Extreme Drought periods has been observed due to the SDI values exceeding the -2 limit value. In addition, Extremely Wet periods have been encountered in 2016. It is noteworthy that the Extremely Drought and Extremely Wet peak values seen in the SDI-3 graph gradually decrease in the SDI-48. Because the values at the Moderate Drought and Moderate Wet levels increase, the deviations for dry and wet periods in these graphs have been decreased considerably. Annual mean or average of SDI values are shown in Figure 6. Considering the peak values, the maximum ones have been obtained with the SDI-3 in 2016, which has been determined as the most wet year. The negative SDI values have been observed in the SDI-48 time scale in 1987 water year.

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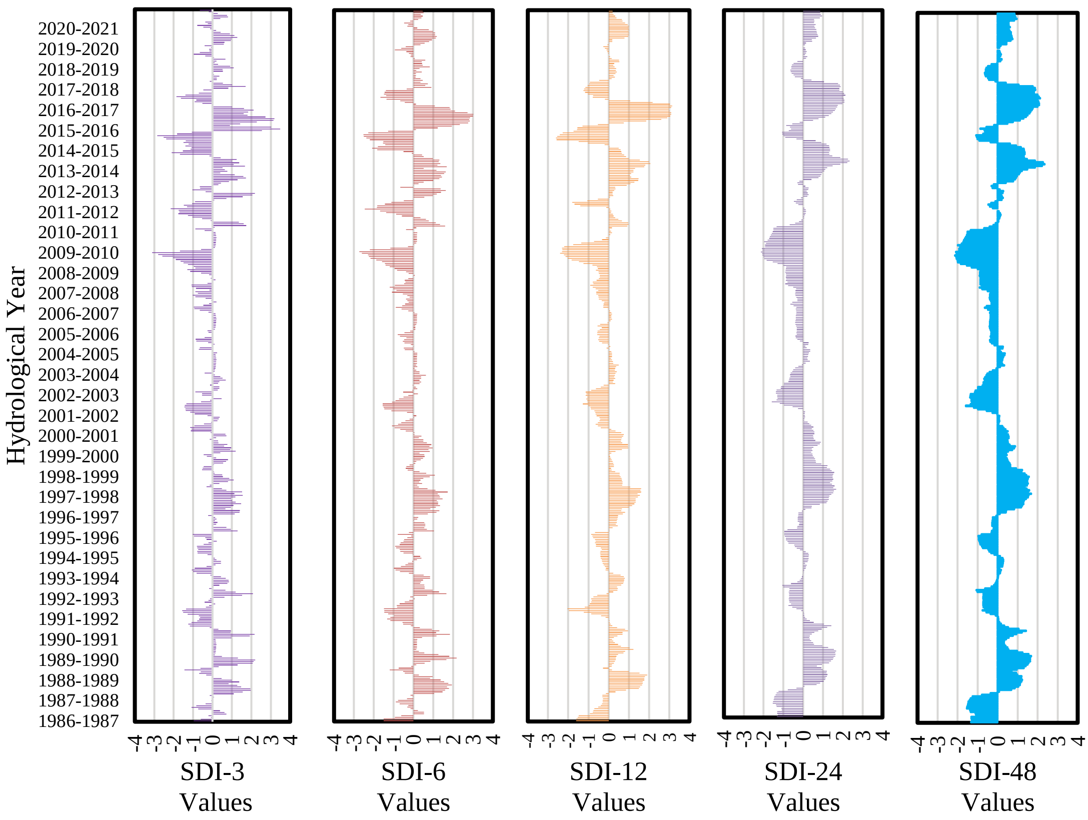

Figure 5. The results of the SDI values for different time scales in the determined water years

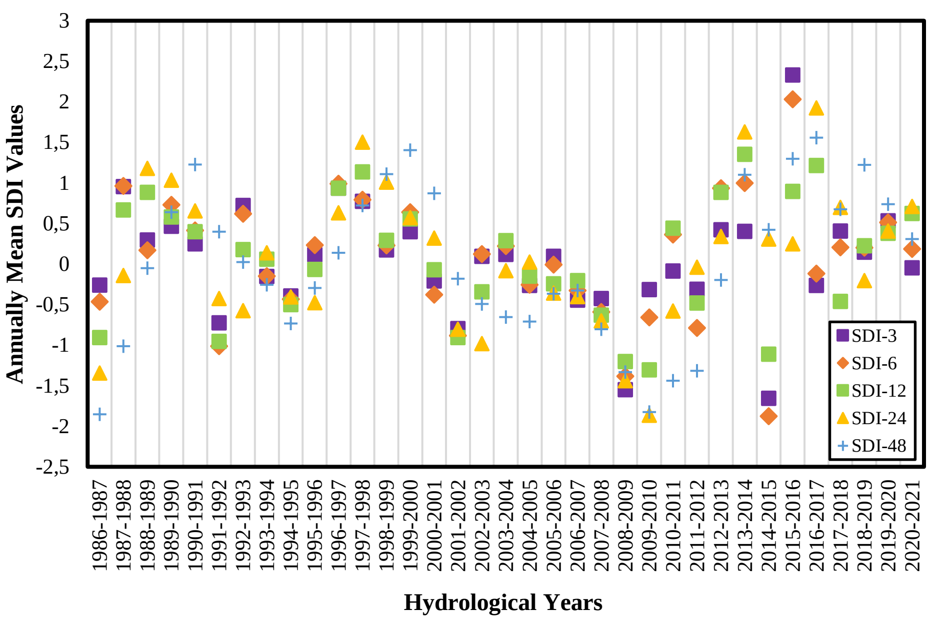

Figure 6. Annual average of the SDI values between 1986 and 2020 hydrological years

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In this case, according to the whole water year of 1987, it can be concluded that Severe Drought periods are effective in general. The SDI results for the determined periods can vary, it can be stated that the SDI values are closer to each other regardless of monthly periods in water years with the low flow values. The frequency graph for examining the incidence of the SDI values obtained in this study is given in Figure 7. It is seen that the most common drought classification is Mildly Wet in the SDI-3 period.

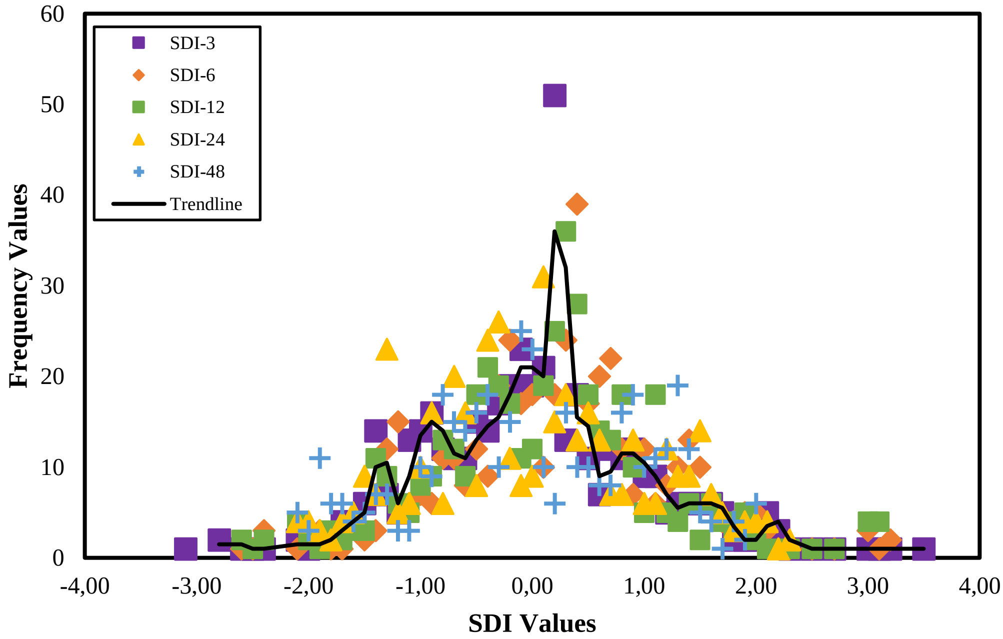

Figure 7. The frequency for the incidence of the SDI values at different time scales

Creating a trend line for the frequency values, it has been tried to determine at which values the frequency occurred. As a result, although the values in the wet category are higher, many SDI values have been determined at the Extreme Drought and Moderate Drought levels for the SDI-48 estimated over a 48-month period. The observed drought periods for all time scales are shown together in Figure 8. According to this figure, it has been seen that there is no drought period between 1997-2000 and 2003-2006 water years.

Although low discharges have been observed in these water years, it can be explained that partially wet periods have been occurred when it is evaluated in each period itself. Especially in 2008-2010 water years, it is observed that the drought severity has been increased remarkably. It can be said that the largest SDI scale occurs in the SDI-3 and the smallest one occurs in the SDI-48 period (Figure 9). Consequently, the longest dry period has been determined between 2008 and 2012 water years, while the wet period has been evaluated between 2003 and 2007 ones. Furthermore, it is concluded that SDI values decreased as the monthly time periods increased, while the maximum indice values were obtained with SDI-3 in all drought periods. When all graphs are examined detailed, it can be expressed long-term droughts for certain water years are notable. Generally, the obtained results are similar to many studies in the literature (Gümüş, 2017; Dikici, 2020; Topçu et al., 2022).

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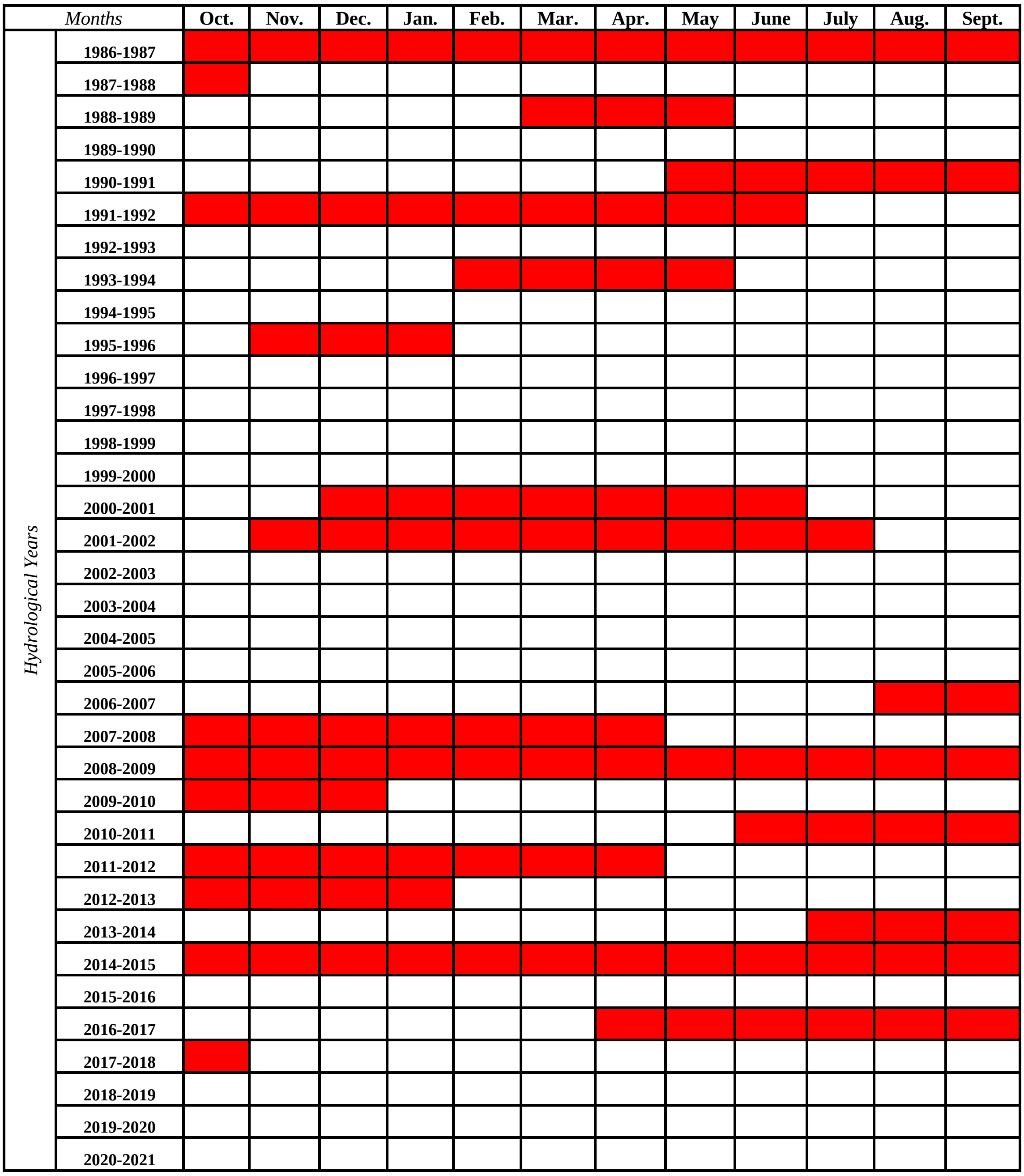

Figure 8. The observed drought periods for all time scales between 1986 and 2020 water years

Within the scope of the D19A014 SGS records, it can be stated that the wet period trend is observed in general, but drought periods are also occurred at regular intervals. In Figure 10, for various SDI time scales the categories of wet and dry period are shown using encolouring in Dörtyol- Erzin Region between 1986-1987, 2009-2010, 2013-2014, 2014-2015, 2015-2016, and 2016-2017 water years. Considering the SDI values calculated in the past years, the drought periods observed after successive wet years are remarkable, and it is also important to take precautions for agricultural activities against the occurrence of such these periods in the following years. These results can contribute on future works with regard to measures to be taken for current drought action plans.

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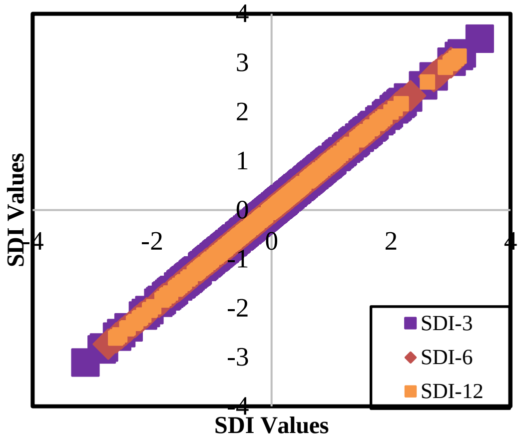


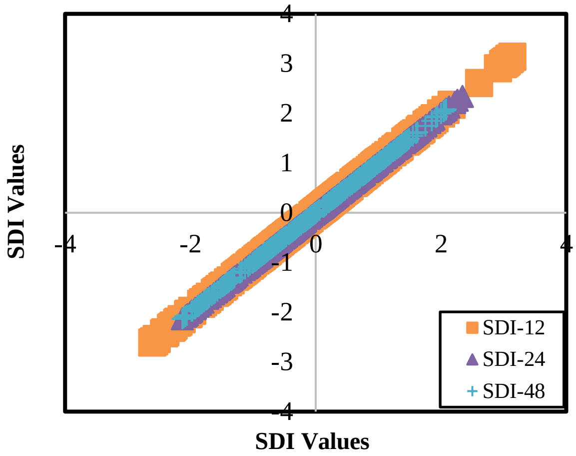
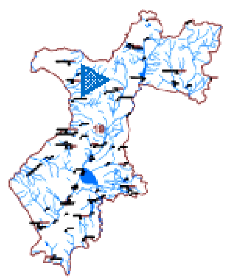
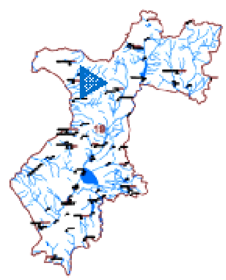
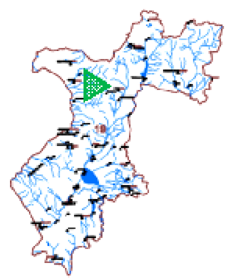
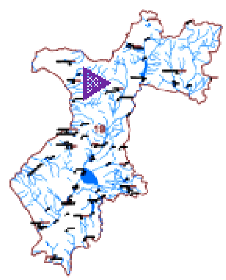
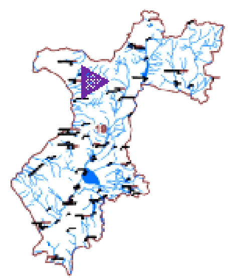
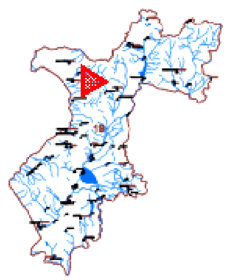
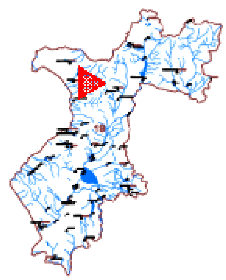
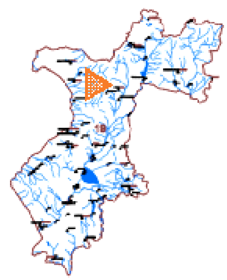
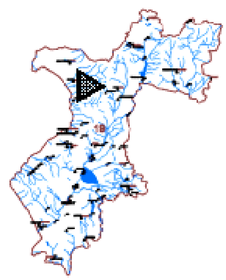
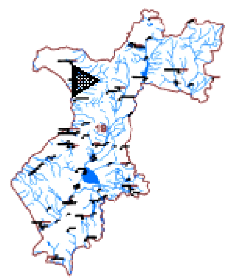


Figure 9. The correlation graphs of the SDI values for different time scales

SDI-48 Wet Period 1986-1987	SDI-24 Wet Period 2009-2010	SDI-12 Wet Period 2009-2010	SDI-6 Wet Period 2014-2015	SDI-3 Wet Period 2014-2015
				
SDI-24 Dry Period 2016-2017	SDI-24 Dry Period 2016-2017	SDI-12 Dry Period 2013-2014	SDI-6 Dry Period 2015-2016	SDI-3 Dry Period 2015-2016
				

(**Extreme Drought**; **Severe Drought**, **Moderate Drought**, **Moderately Wet**, **Severely Wet**, **Extremely Wet**)

Figure 10. The categories of wet and dry period at different time scales in terms of effective water years

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4. CONCLUSIONS

In this study, Dörtyol-Erzin Plain, which is located in the south of Turkey and covers the fertile agricultural lands of the Asi River Basin, was preferred as the case study for hydrological drought analysis. In recent years, fluctuations in temperature and precipitation regimes and unusual climatic activities have threaten natural living environments. It is mentioned that there is a slow drought progress for the Asi River Basin in the literature. It is highlighted that decreasing trend in groundwater and increasing trend in evaporation and temperature parameters are indicated. The studies on the analysis of past droughts and the decreasing of possible negative effects in the future, have become significant increasingly.

Because the agricultural irrigation of Dörtyol-Erzin Plain is dependent on groundwater and surface resources, hydrological drought analysis over the long period will be useful for the future drought prediction. Therefore, SDI method was used for the hydrological drought analysis by using 35 years of flow data between the years of 1986-2020. "SPI_SL_6.exe" program via National Drought Mitigation Center (NDMC) was utilized in the calculations. Drought were investigated at different time scales of 3, 6, 12, 24 and 48 months quantitatively.

Consequently, the longest dry period has been determined between 2008 and 2012 water years, while the wet period has been evaluated between 2003 and 2007 ones. Furthermore, it is concluded that SDI values decreased as the monthly time periods increased, while the maximum indice values were obtained with SDI-3 in all drought periods. The results can contribute on future studies with regard to measures to be taken for drought action plans. In future studies, the studies for a long period can be performed with different meteorological, hydrological and agricultural drought indices. In addition, the relationship between hydrological and meteorological observation data and the oscillation effects and consisttencies resulting from global climate change can be researched in detail.

5. ACKNOWLEDGEMENTS

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