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Drought Analysis Using Streamflow Drought Index Method of Goksu Basin, Turkiye

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Abstract: Drought is one of the most complex and long-recognised environmental disasters that can trigger environmental, social and economic problems. Drought assessment using drought indices is widely used for drought monitoring. In this study, Streamflow Drought Index (SDI) hydrological droughts were analysed at 3, 6 and 12-month time scales with the data provided from streamflow observation stations in Goksu Basin of Turkiye in 1980-2010. The distribution and magnitudes of the severity of wet and dry periods of the Goksu Basin were determined. In SDI analysis, the driest periods were found to be 2007, 2008 and 2010.

Keywords: Streamflow, Hydrological Drought, Streamflow Drought Index, Goksu Basin

I. INTRODUCTION

Drought is a prolonged period of water deficit and typically occurs when an area receives precipitation below normal levels for many months. Drought can develop during or after periods of low precipitation relative to normal conditions, and high temperatures exacerbate drought. Increasing drought severity and a persistent lack of precipitation can lead to dry conditions, low soil moisture, reduced reservoir storage, less groundwater recharge and low river flows [1].

Drought manifests as hydrological, agricultural, and socioeconomic drought, especially meteorological drought. A weather drought is a significant drop in precipitation below normal levels over an extended period. Agricultural drought is defined as a lack of soil moisture, especially during the growing season, and occurs when moisture is lost, and water resources are reduced. Groundwater resources and surface water are associated with precipitation during the wet season. Hydrological drought is defined as a prolonged reduction in precipitation, groundwater table, surface runoff and soil moisture [2].

Hydrological drought develops from meteorological drought (precipitation deficit), is usually slow to develop and can last for months or even years, severely impacting the ecosystem, environment, agricultural production, and water resources systems [3].

Drought indices are essential tools for monitoring and assessing drought conditions and are the basis for water resources management decisions during drought. Nowadays, many methods are proposed in the literature for determining meteorological and hydrological droughts. Drought indices such as the Standardized Precipitation Index (SPI) developed by McKee et al. [4] and the Standardized Precipitation Evapotranspiration Index (SPEI) developed by Vicente-Serrano et al. [5] are used to determine meteorological drought. In determining hydrological drought, indices such as Standardized Runoff Index (SRI) developed by Shukla and Wood [6], Streamflow Drought Index (SDI) developed by Nalbantis and Tsakiris [7], Standardized Streamflow Index (SSI) developed by Vicente-Serrano et al. [8] are used.

Tareke and Awoke [9] analysed hydrological drought in the study regions in Ethiopia using Streamflow Drought Index (SDI) in seasonal (3-month) and annual (12-month) periods and evaluated dry periods. Wabua [10] conducted a hydrological drought forecast using Surface Water Supply Index (SWSI), Streamflow Drought Index (SDI) and Artificial Neural Network (ANN). Hong et al. [11] calculated and evaluated SDI based on daily flow data on a 12-month time scale. They also analysed the effect of sample size on the sampling uncertainty of SDI using the Bootstrap method. Pathak et al. [12] conducted hydrological drought analysis using the Stream flow Drought Index (SDI) and Standardized Runoff Index (SRI) and a comparison of these two indices. Tareke and Awoke [13] analysed and compared two hydrological drought indices, the Modified Surface Water Supply Index and Streamflow Drought Index. Akbari et al. [14] conducted the meteorological and hydrological droughts of the Standardized Precipitation Index (SPI) and Streamflow Drought Index (SDI) in the Chenar Rahdar river basin.

In this study, hydrological droughts were analysed and evaluated with the Streamflow Drought Index (SDI) method by using the monthly average flow values of three streamflow observation stations in the Goksu basin for the period 1980-2010.

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II. Material and Method

A. Study Area and Data

In this study, drought analysis was carried out by considering the Goksu basin, which is dominated by the Mediterranean climate and whose borders are mostly within the borders of Mersin province (See Fig.1.). The basin consists of an area of 10400 km^2. The northern tributary of the basin is Gokcay, and the southern tributary is Gokdere, which has almost the same length. Both originate from the Geyik Mountains in the Taurus Mountains. The Geyik Mountains are between Antalya-Gundogmus and Konya-Hadim and are located about 50 km north of Antalya-Alanya. These two tributaries, after passing Karaman-Ermenek, merge south of Mersin-Mut and take the name Göksu. Göksu River, which constitutes the main tributary of the basin, is an important water source flowing into the Mediterranean Sea after Seyhan and Ceyhan rivers, and its length is 260 km [15], [16].

Fig. 1 Locations of Goksu basin and selected stations

The data from 3 current observation stations belonging to the Republic of Turkiye General Directorate of Electrical Power Resources Survey and Development Administration located on the Goksu River were used. Monthly average flow values of the selected stations Karahacili (1714), Kirkkavak (1719) and Hamam (1720) flow observation stations between 1980-2010 were used for hydrological drought analysis. The selected stations are given in Table 1.

TABLE I ANALYSIS, OBSERVATION AND GEOGRAPHICAL INFORMATION OF THE SELECTED STATIONS

Station ID	Station Name	Latitude (N°)	Longitude (E°)	Drainage Area (km^2)	Average Annual Streamflow (m^3/s)	Time Period (Years)
1714	Karahacili	36.4036	33.8155	10065.2	109	1980-2010
1719	Kirkkavak	36.5736	33.3113	3631	50.7	1980-2010
1720	Hamam	36.6358	33.3694	4304	43.5	1980-2010

B. Streamflow Drought Index (SDI)

Streamflow Drought Index (SDI) developed by Nalbantis [7] can be used to analyse the hydrological drought in a study region. Stream Drought Index (SDI) is calculated using monthly streamflow data ($Q_{i,j}$). Where i represents the hydrological year and j represents the month within the hydrological year, defined as the time between October and September. The cumulative flow volume is calculated as follows:

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$$V_{i,j} = \sum_{j=3(k-1)+1}^{3k} Q_{i,j}\,, \qquad k = 1,2,3,4 \tag{1}$$

$$V_{i,j} = \sum_{j=6(k-1)+1}^{6k} Q_{i,j}\,, \qquad k = 1,2 \tag{2}$$

$$V_{i,j} = \sum_{j=1}^{12k} Q_{i,j} \tag{3}$$

In Equations 1, 2 and 3, drought index values are calculated for 3, 6 and 12 months, respectively. The k in the equations refers to the reference period, and in Equation 1, k=1 represents October-December (SDI-3 October), k=2 January-March (SDI-3 January), k=3 April-June (SDI-3 April), k=4 July-September (SDI-3 July). In Equation 2, k=1 and k=2 refer to the first 6 months (SDI-6 October) and the last 6 months (SDI-6 April) periods, respectively, and Equation 3 refers to the annual drought index value (SDI-12).

The SDI for the reference period k and the i-th hydrological year is calculated as follows:

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

where V_k and S_k represents the mean and standard deviation of the cumulative stream volumes, respectively.

SDI values were expressed by Nalbantis in the class range from non-drought to extreme drought. This classification is given in Table 2.

TABLE II SDI VALUES CLASSIFICATION [7]

SDI Values	Classification
SDI < −2.0	Extreme Drought
-2.0 ≤ SDI < -1.5	Severe Drought
-1.5 ≤ SDI < -1.0	Moderate Drought
-1.0 ≤ SDI < 0.0	Mild drought
SDI ≥ 0.0	Non-drought

III. RESULTS AND DISCUSSION

The SDI values were calculated for 3-, 6- and 12-month time scales with the data obtained from 3 flow observation stations between 1980-2010 to determine the hydrological drought in the Goksu basin. All stations were analysed and evaluated separately.

The temporal change distributions of SDI values calculated at 3-, 6- and 12-month time scales according to the data obtained from station 1714 are given in Figure 2. The SDI 3-October was found to be 51.6% dry and 48.4% wet. In the SDI 3-October analysis, overall drought rates were found to be 1% extreme, 5.3% severe, 11.8% moderate and 33.5% mild drought. No extreme drought period was found in this SDI 3-October analysis. The overall drought rates in the SDI-3 January analysis were found as 4.3% severe, 10.9% moderate and 38.7% mild drought. In the SDI 3-January analysis, the driest years were determined as 1992 and 2008, and the wettest years were determined as 2002 and 1986. SDI 3-April analysis evaluation period was found to be 53.7% dry and 46.3% wet. No extreme drought period was observed in the SDI-3 January analysis. According to the results of SDI 3-April analysis, the evaluation of drought periods was found to be 3.2% severe, 12.9% moderate and 37.6% mild drought. In the SDI 3-April analysis, the driest years were 2007 and 2000, and the wettest years were 2002 and 1981, respectively. According to SDI 3-July analysis, this period was determined 52.7% wet and 47.3% dry. In SDI 3-July analysis, dry periods were found to be 1% extreme, 9.7% severe, 8.6% moderate and 28.0% mild drought. According to SDI 3-July analysis, the wettest years were 1981 and 1987, and the driest years were 2010 and 2007, respectively. SDI-6 October analysis showed that the study period was 46.4% wet

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and 53.6% dry. SDI-6 October analysis shows that no extreme dry period was determined. SDI-6 October drought period rates were calculated as 7.6% severe, 10.9% moderate and 35.1% mild. The wettest years of SDI-6 October were found to be 2002 and 1982, respectively. According to SDI-6 April analysis, showed that the study period was 48.4% wet and 51.6% dry. SDI-6 April dry periods were determined as 0.5% extreme, 3.8% severe, 12.5% moderate and 34.8% mild. The driest periods observed in the SDI-6 April analysis were 2007 and 2001, respectively. According to the SDI-6 April analysis, the driest years were 2007 and 2001, and the wettest years were 2002 and 1982, respectively. The SDI-12 analysis result was found as 51% dry and 49% wet. Drought rates in the SDI-12 period were found as 0.3% extreme, 8.9% severe, 9.1% moderate and 32.7% mild. The driest years of SDI-12 were 2008 and 1992, and the wettest years were 1982 and 1981, respectively.

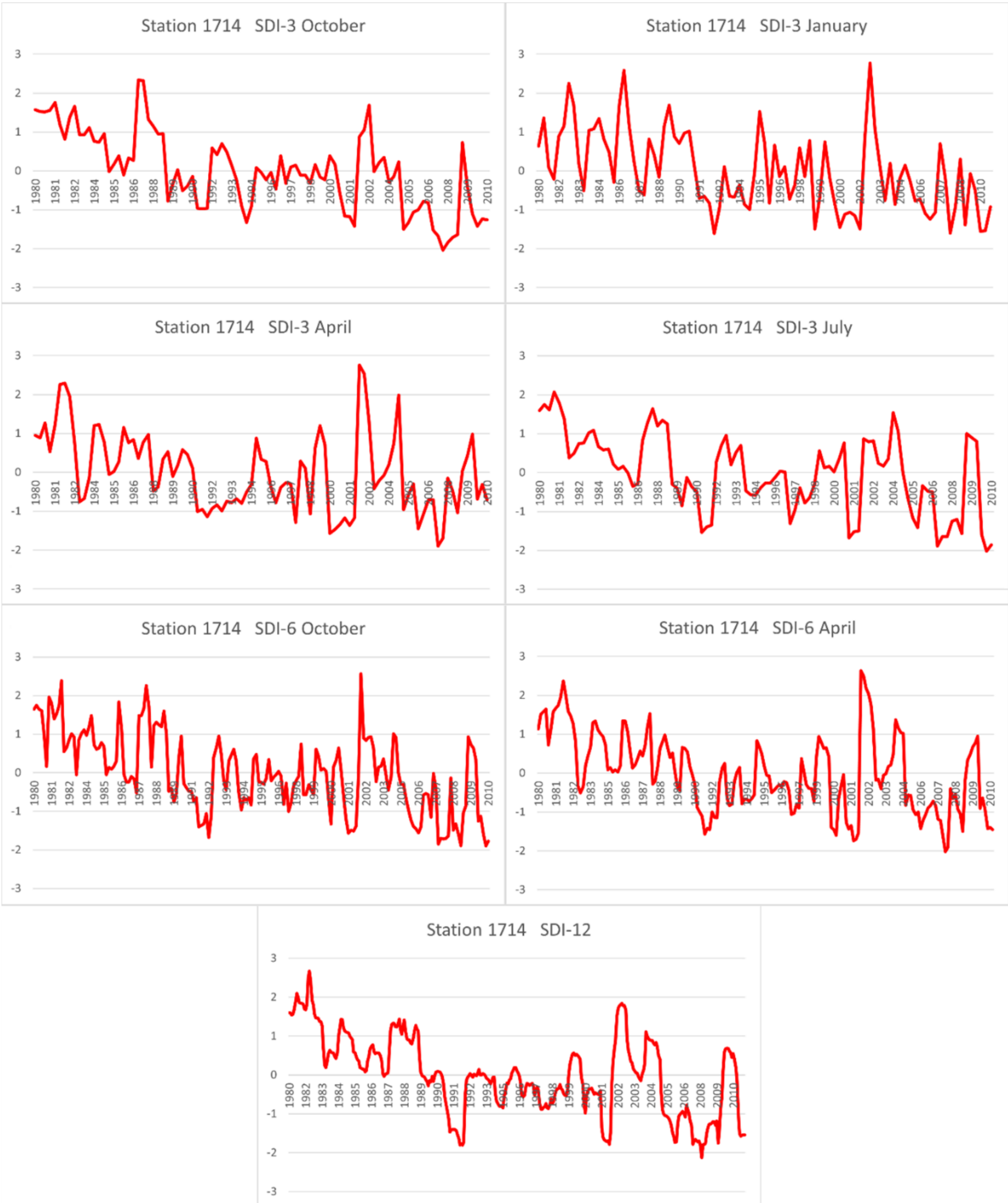

Fig. 2 Temporal variation of SDI values according to flow observation station 1714 in Göksu basin

Temporal change distributions of SDI values for station 1719 are given in Figure 3. SDI 3-October was found as 52.7% dry and 47.3% wet. Drought rates in the SDI 3-October were found as 4.3% extreme, 4.3% severe, 7.5% moderate and 36.6% mild dry. SDI 3-October analysis result reveals that the wettest years were 1987 and 1981, and the driest years were 2008 and 2010, respectively. According to SDI 3-January analysis, this period was found to be 54.9% dry and 45.1%

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wet. Drought rates in SDI 3-January period was found to be 3.3% extreme, 4.4% severe, 5.5% moderate and 41.7% mild. The driest periods in SDI 3-January were determined as 2010 and 1999, and the wettest periods were determined as 2002 and 1986, respectively. SDI 3-April evaluation was found as 53.8% wet and 46.2% dry. Overall drought rates in SDI 3-April period were found as 4,3% extreme, 8,6% moderate and 33,3% mild. For station 1719, no severe dry periods were found in SDI 3-April analyses. The driest years in SDI 3-April were observed in 2010 and 2007, and the wettest periods in SDI 3-April were found in 2002 and 1982, respectively. According to SDI 3-July analysis, the periods were found to be 56% wet and 44% dry. Drought rates in the SDI 3-July period were found as 3.2% extreme, 2.2% severe, 7.5% moderate and 31.1% mild. In this period, extremely wet periods were not encountered. In the SDI 3-July analysis, the wettest years were 1987 and 1981, while the driest periods were 2010 and 2007, respectively. According to the analysis results of SDI-6 October, 49,2% was considered wet and 50,8% a dry period. Overall, the drought rates of SDI-6 October analysis was calculated as 3.3% extreme, 1.6% severe, 10.4% moderate and 35.5% mild. The driest years of SDI-6 October were found to be 2010 and 2009 respectively. The wettest years of SDI-6 October were found to be 1988 and 1982. SDI-6 April was evaluated the period as 48.4% dry and 51.6% wet according to the calculated values. SDI-6 April analysis' drought periods were calculated as 3.2% extreme, 1.0% severe, 8.7% moderate and 35.5% mild. The driest years observed in SDI-6 April were in 2010 and 2007. SDI-6 April was found to be the wettest, mainly in 2002 and 1982. According to the SDI-12 analysis, the study period was determined as 51.3% wet and 48.7% dry. In general, drought rates in the SDI-12 analysis were found as 1.9% extreme, 3.6% severe, 8.8% moderate and 34.4% mild. The driest years in SDI-12 were evaluated as 2010 and 2008, and the wettest years were found to be 1982 and 2003, respectively.

Fig. 3 Temporal variation of SDI values according to flow observation station 1719 in Göksu basin

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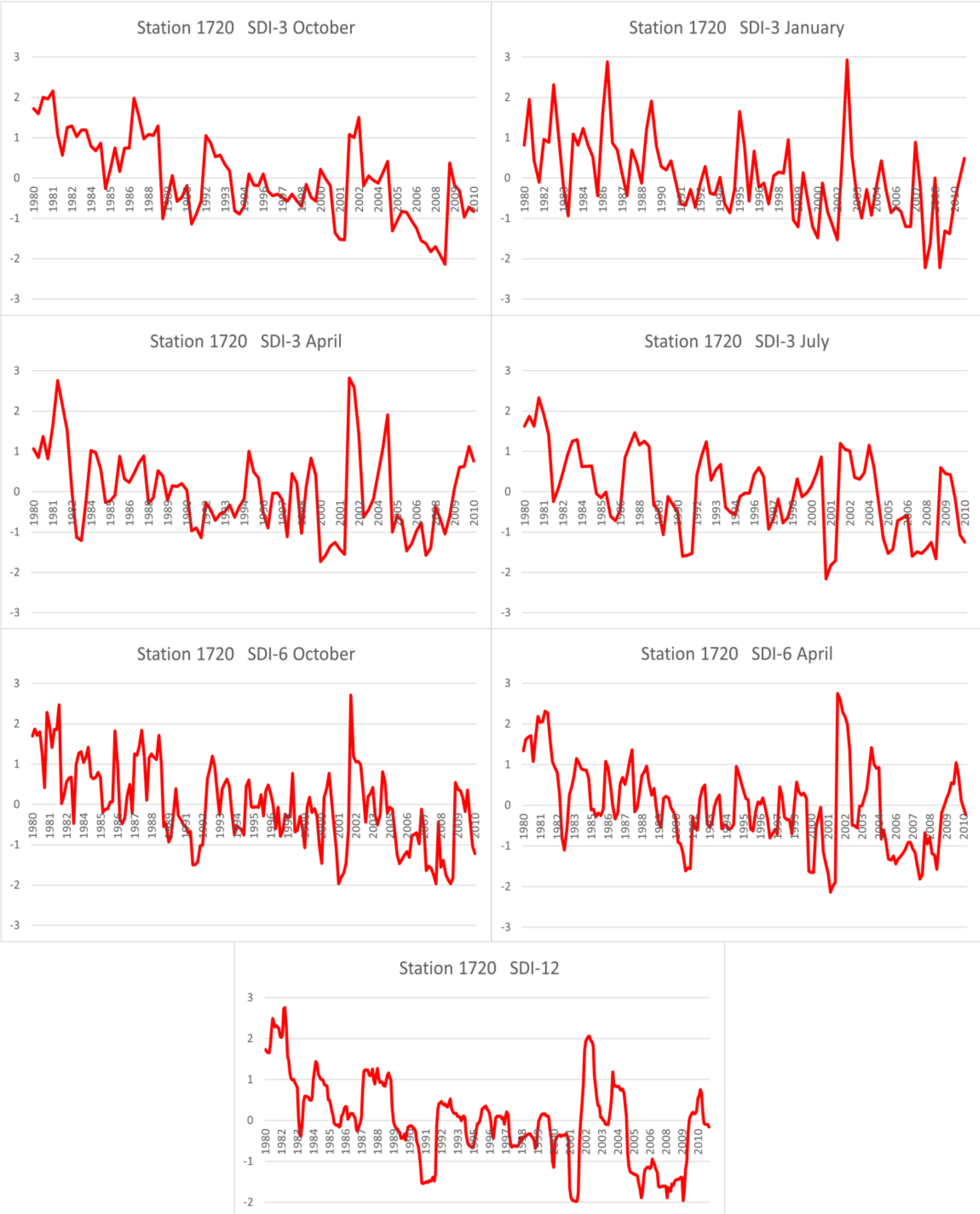

Fig. 4 Temporal variation of SDI values according to flow observation station 1720 in Göksu basin

According to the data obtained from Station 1720, the temporal change distributions of SDI values calculated in 3-, 6- and 12-month time scales are given in Figure 4. SDI 3-October analysis was found as 53.7% dry and 46.3% wet. In general, drought rates in the SDI 3-October period were found as 1% extreme, 7.5% severe, 7.5% moderate and 37.7% mild. The wettest years in SDI 3-October analysis were 1981 and 1980, and the driest periods were 2008 and 2007, respectively. SDI 3-January analysis was found to be 54,9% dry and 45,1% wet. In general, drought rates in SDI 3-January period were found as 2.2% extreme, 2.2% severe, 9.9% moderate and 40.6% mild. The driest years in SDI 3-January were 2009 and 2008, and the wettest years were 2002 and 1986, respectively. SDI 3- April analysis was found as 53.7% dry and 46.3% wet. In SDI 3- April analysis, no extremely dry periods observed. According to SDI 3-April result, the periodic rates of drought evaluations were found to be 4.3% severe, 13.9% moderate and 35.1% mild. The driest years of SDI 3- April were determined as 2000 and 2007, and the wettest years as 2002 and 1982, respectively. SDI 3-July analysis were found to be 52.7% dry and 47.3% wet. In this analysis, dry periods were found as 1% extreme,

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9.6% severe, 8.6% moderate and 33.5% mild. SDI 3-July was the wettest years determined as 1981 and 1980, and the driest years as 2001 and 2008. SDI-6 October analysis was evaluated as 46.5% wet and 53.5% dry. According to results of SDI-6 October analysis, no extreme dry period occurrence determined. SDI-6 October analysis dry periods were calculated as 7.6% severe, 9.8% moderate and 36.1% mild. The driest years of SDI-6 October were determined as 2001 and 2008, and the wettest years as 2002 and 1982, respectively. According to SDI-6 April analysis, the study period evaluated as a 46.2% wet and 53.8% dry. SDI-6 April analysis' dry periods were evaluated as 0.5% extreme, 7.0% severe, 8.7% moderate and 37.6% mild. The driest years observed in SDI-6 April were 2001 and 2007. SDI-6 April was found to be the wettest, mainly in 2002 and 1982. When the SDI-12 period was analysed on a 12-month time scale at this station, it was evaluated as 51% wet and 49% dry. In general, drought rates in the SDI-12 period were found to be 9.4% severe, 9.9% moderate and 29.7% mild. According to SDI-12 results, the driest years were 2001 and 2009, and the wettest years were 1982 and 1981, respectively.

IV. CONCLUSION

Considering the SDI temporal distribution graphs of all three stations in the Goksu basin, it was observed that the occurrence rates of mild dry periods were higher in terms of drought severity. In all SDI-3 periods, moderate dry periods are below 15%, severe dry periods are below 10%, and extreme dry periods are below 5%. Stations 1719 and 1720 had the driest periods, with a drought rate of 54.9% in SDI-3 January periods and the mildest dry periods. The lowest wet period was observed in the SDI-3 July station 1719, with a 56% wet period ratio. Severe dry values were observed in the SDI-3 periods, where the flow values were periodically high, in the following periods since 2008, and it was found that the wetness was high in 2002 and 1986.

The results of all periods of the 3 stations in the study were analysed, and 2002, 1982, and 1981 were determined as the wettest years, and the driest years were determined as 2007, 2008 and 2010, respectively. When the temporal change of drought is analysed in the graphs, it is observed that drought intensity has increased in recent years. Based on these results, appropriate measures and plans should be prepared to use existing water resources effectively. Considering the magnitude of the drought, the occurrence of hydrological drought after meteorological and agricultural drought indicates that basins may face water problems in the basins.

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