



Determination of drought intensity in Seyhan and Ceyhan River Basins, Turkey, by hydrological drought analysis

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Abstract

This paper studied hydrological drought identified by the Streamflow Drought Index (SDI) at eight river-gauging stations in the Eastern Mediterranean part of Turkey for a roughly 43-year period covering from 1972 to 2014 (4 stations), from 1973 to 2015 (2 stations), and from 1969 to 2011 (2 stations). Results of SDI analyses indicate that the number of drought years was highest during the 3-month October–December period. A considerable part of the drought years was determined to be mild drought. Although moderate drought conditions were observed in all stations, moderate drought conditions were determined especially at Göksu-H in the Seyhan River Basin and Söğütlü and Savrun in the Ceyhan River Basin. Short-term fluctuations of dry and wet conditions are the dominant pattern for most of the stations; however, long-term persistent drought conditions are also prominent, especially at Tacin and Körkün in Seyhan Basin and Göksun in Ceyhan Basin. The starting point for the negative trend in the 12-month series was the years 1996, 1999, and 2000.

1 Introduction

Drought means a deficit in the expected available water in a given hydrological system (Sheffield and Wood 2011). Rivers are important water resources that supply water to rural and urban areas. Global climate changes, population growth, development of industry and technology, and lack of environmental awareness or irregular urbanization have all caused water resources to gradually decrease. Extreme rainfall deficits and the resulting periods of low flow can have severe effects on water management; thus, future increase in the demand for water will be most critical in periods of severe and extensive drought (Hisdal et al. 2000). For this reason, studies worldwide have focused on sustainable water management (Russo et al. 2014; OECD 2010; Taylor and Goldstein 2010; Sjödin et al. 2016). The common goal of research is generally to ensure the sustainability of water use in all areas (agriculture, industry, and cities) and to satisfy local and environmental needs.

In South Asia, studies of shrinking glaciers show that, in recent years, the rapid retreat of glaciers and the increasing demand for water resources for domestic and industrial use have caused concern over the reliability of water resources both in the present day and future for that region (Mathison et al. 2013, 2015). Most studies on streamflow in Europe indicate that there has been a systematic decrease, especially in minimum flows, since the 1970s, and that hydrological drought has become increasingly apparent (Douglas et al. 2000; Zaidman et al. 2001; Hodgkins et al. 2005; Fleig et al. 2006). In Europe, a regionally coherent picture of annual streamflow trends emerged covering the period 1962–2004 that showed negative trends in the south and east and generally positive trends elsewhere (Stahl et al. 2010).

The adverse effects of precipitation decrease on streamflow cannot be ignored. Precipitation directly affects streamflow through precipitation patterns, intensity, and spatial distribution; whereas the effect of temperature is mainly manifested through alterations to evapotranspiration and snowmelt (Berghuijs et al. 2014). Zhao et al. (2018) used the decomposition and climate elasticity methods in their study and detected that the contribution of climate change to streamflow reduction ranged from 14 to 47% on Loess Plateau in China. Barker et al. (2016) indicate that meteorological drought duration and severity characteristics showed little spatial variability; results showed that, at short accumulation periods, meteorological drought characteristics showed little spatial variability, while hydrological drought

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characteristics showed fewer but longer and more severe droughts in the south and east than in the north and west of the UK for the 1961–2012. Schneider et al. (2013) predicted that climate change in the future (i.e., the 2050s) will impact streamflow regimes in Europe. It was calculated that river flows would be much lower in all months of the year and that this change would be an additional threat to anthropogenic effects, especially in the Mediterranean climatic region.

Studies conducted on the variability and trends in the impact of climate parameters on streamflow in Turkey (Kahya and Kalaycı 2004; Durdu 2010; Türkeş and Acar Deniz 2011; Yerdelen 2013; Soydan et al. 2016; Tekkanat and Sarış 2015; Sütgibi 2015) indicate variability occurring in different patterns in different basins. For example, while no significant change was detected in the Eastern Black Sea basins (Sarış 2012a, b), annual mean streamflow and minimum streamflow (and some maximum streamflow) of rivers located in the western, central, and southern regions of Turkey exhibited a significant decreasing trend (Kahya and Kalaycı 2002, 2004; Cığızoğlu et al. 2004; Aksoy 2007; Bahadır 2011; Yılmaz and Alam Imteaz 2014; Gümüş 2017; Özfidaner et al. 2018). According to Gökmen (2016), the only consistent hydrological trend detected was an increase in evapotranspiration over the Mediterranean and Black Sea, with the magnitude especially considerable (up to 250 mm in total) over the Mediterranean coast in southwest Turkey. In addition, increasing evapotranspiration in the spring, summer, and autumn, high seasonality and year-to-year variability of precipitation totals, and significant increases in air temperatures are the biggest threats to regional water resources in northwest Turkey (Türkeş and Acar Deniz 2011). Almost all studies show that streamflow will significantly decrease in Turkish water basins in the future. According to Yılmaz and Alam Imteaz (2014), most steps taken to ensure adaptation are useful for a region regardless of the effect of climate change. Thus, even if climate change does not impact a particular region, it is beneficial to develop and apply measures to provide adaptability of the water resources in response to the natural variability of climate patterns.

The aim of this study was to determine the drought conditions for 3-, 6-, 9-, and 12-month periods by applying the Streamflow Drought Index (SDI) developed by Nalbantis and Tsakiris (2009). Data were derived from the monthly total streamflow measurements obtained from eight river-gauging stations in the Ceyhan River and Seyhan River Basins. Trend analyses were also employed to detect interannual variability in the streamflow series.

2 Location, current climate, and hydroclimate character of study area

The Seyhan and Ceyhan are major river basins located in the southern part of Turkey (Fig. 1) in the Çukurova Delta which reaches the Mediterranean in the province of Adana

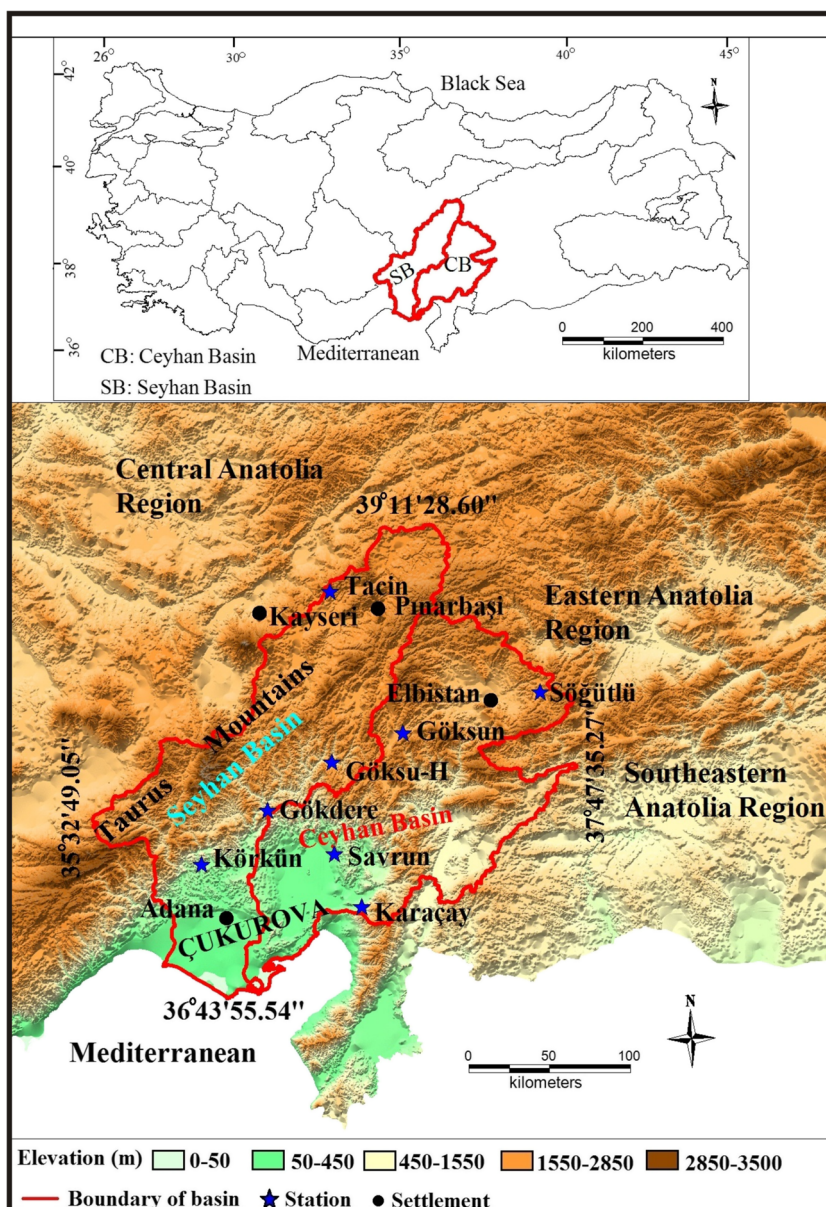
containing an important city with a population of 1.7 million (Fig. 1). Çukurova Delta is the largest delta plain in Turkey, and its fertile soil makes it one of the most agriculturally productive areas in the world. The total length of the Ceyhan and Seyhan rivers is 509 km and 560 km, respectively. The upstream of the basins extends into Central Anatolia and southern Eastern Anatolia, covering an area of about 22,110 km² and 21,470 km², respectively. Both basins lie in a south-northeast direction and include a quite large upstream area. The source of Ceyhan River is Söğütlü River in the area of Pınarbaşı, located in the transition zone between the Mediterranean and Southeast Anatolia. The Seyhan River originates from the northeastern part of Kayseri province, which can be considered a transition area between the Mediterranean and Central Anatolia.

The study area is under the influence of the Mediterranean Macroclimate. The Azores high pressure area and Mediterranean climate are affective during the summer, while in the winter descending Polar air to the south prevails in the region. The seasonally dominant pressure systems and oscillations controlling the spatial distribution of climatic conditions in the Mediterranean Basin are also affected by altitude and general orography, land-sea interactions, and smaller-scale processes (Lolis et al. 1999; Xoplaki et al. 2000; Trigo et al. 2002). This large basin represents a significant source of energy and moisture in development of the Mediterranean cyclone, and the complex topographic elements in the basin play an important role in directing air currents (Bartzokas et al. 1994; Trigo et al. 1999; Maheras et al. 2001). The Mediterranean climate is characterized by high temperatures in the summer and considerable precipitation during winter.

In the study area, while the downstream of the basins is largely influenced by the Mediterranean climate regime, upward of the basins is affected by the transition from Mediterranean to continental climates. Maximum rainfall in the basins is observed in the winter, and average annual rainfall is 539 mm upstream and 778 mm downstream. Minimum rainfall in the basins is observed in summer, and the average annual rainfall is approximately 9 mm upstream and 5 mm downstream. The two basins experience significant summer drought due to low rainfall and high temperatures (Bayer Altın and Barak 2012, 2017; Uzunkol and Kızılelma 2016). Generally, the climate is variable in both basins, with mean annual temperatures rising to 20 °C and 25 °C in the downstream environment and dropping to 8 °C and 7 °C upstream due to the higher elevation and distance from the sea (continentality). The hottest and coldest months are July and January, respectively. Mean temperatures in the summer months are 28 °C and in the winter months range from 9 °C (in the lowlands) to 4 °C (in the highlands).

The monthly observed streamflow data were obtained from eight river-gauging stations selected based on their location and length of observation period. River-gauging

Fig. 1 Geographic location of Seyhan and Ceyhan basins and spatial distribution of river-gauging stations



stations located behind dams were specifically chosen to remove any adverse impact of the dam on the natural streamflow. Data cover four stations (Göksun, Savrun, Karacay, and Tacin) from 1972–1973 to 2013–2014, two stations (Körkün and Söğütü) from 1973–1974 to 2014–2015, and two stations (Göksu-H and Gökdere) from 1969–1970 to 2010–2011. Elevation of the stations ranges from 102 to 1536 m. The location of the river-gauging stations is shown in Fig. 1, and their geographical coordinates are presented in Table 1. As shown in Fig. 2, there is no significant difference in regime among the stations. Gökdere is the station with the highest streamflow (56.3 m³/s) followed by Göksun-H with (27.6 m³/s). The station with the lowest streamflow is Tacin (average 1 m³/s). When the seasonal characteristics of the streamflow regime of the stations are examined, an

evident maximum in spring is observed and they reach their highest streamflow in April. Streamflows are fed especially by winter rainfall in the basins. The high streamflow in May shows that it is also affected by snowmelt and spring rains at Savrun, Körkün, and Gökdere stations. The number of days that the rivers are covered with snow upstream varies between 8 and 7 days in January and February, respectively. Therefore, snowmelt does not represent the primary streamflow generation process. Winter rainfall plays an important role in the rise of the streamflow.

Regarding coverage of agricultural land and forest/semi-natural areas in the basins, this amounts to 40.6% and 37.19% in the Ceyhan Basin (OSB 2016b) and 40.4% and 56.8% in the Seyhan Basin, respectively (TUBİTAK-Marmara Research Center 2013).

Table 1 Details of river-gauging stations in Seyhan and Ceyhan basins

Station No.	Station	Location (basin)	Period	Years	Latitude (N)	Longitude (E)	Elevation (m)
E20A006	Göksun	Ceyhan	1972–2014	43	38° 01'	36° 34'	1389
E20A022	Sögütlü	Ceyhan	1973–2015	43	38° 15'	37° 32'	1502
E20A008	Savrun	Ceyhan	1972–2014	43	37° 21'	36° 05'	102
D20A008	Karaçay	Ceyhan	1972–2014	43	37° 2'	36° 16'	255
D18A008	Tac in	Seyhan	1972–2014	43	38° 49'	36° 4'	1536
E18A001	Göksun-H	Seyhan	1969–2011	43	37° 51'	36° 3'	665
E18A020	Körkün	Seyhan	1973–2015	43	37° 17'	35° 9'	167
E18A005	Gökdere	Seyhan	1969–2011	43	37° 36'	35° 36'	350

3 Methods

To characterize the hydrological drought conditions of the Seyhan and Ceyhan basins, mean monthly streamflow records

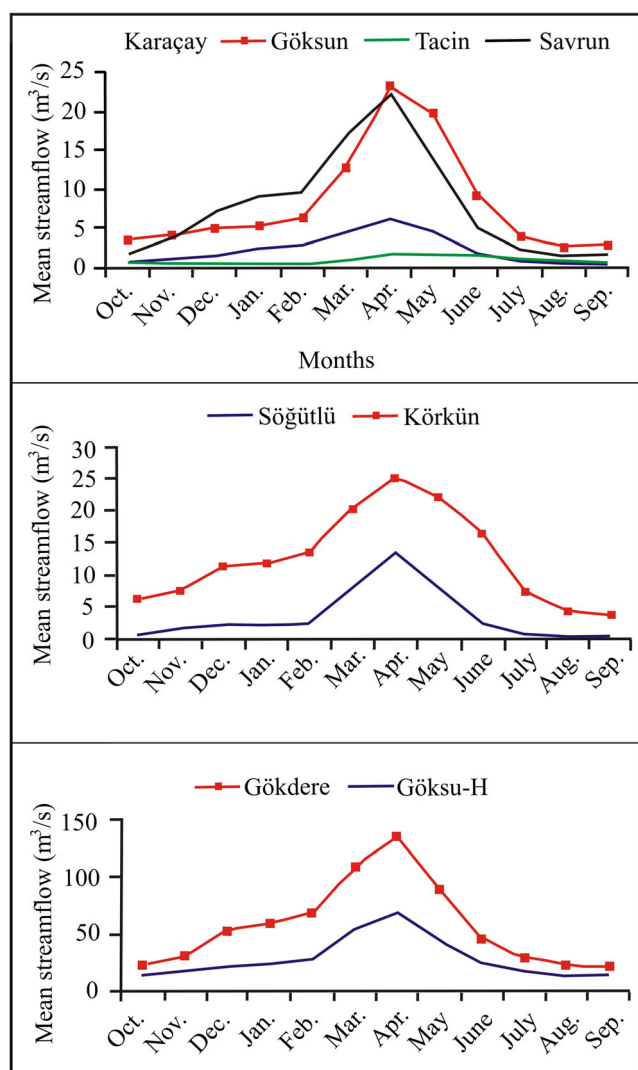


Fig. 2 Intra-annual streamflow variability of river-gauging stations in Seyhan and Ceyhan basins

were used and SDI was applied, as developed by Nalbantis and Tsakiris (2009). SDI analyses were undertaken for four different time scales within each hydrological year: 3 months October–December (Oct-Dec), 6 months October–March (Oct-Mar), 9 months from October to June (Oct-Jun), and the 12 months from October to September (Oct-Sep), in other words, a complete hydrological year.

SDI requires streamflow values of $Q_{i,j}$, where i denotes the hydrological year and j th the month within a hydrological year. $V_{i,k}$ represents the cumulative streamflow for the i th hydrological year and k th reference period (Eq. 1). Based on this series, we can therefore calculate:

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

$$SDI_{i,k} = \frac{V_{i,k} - \bar{V}_k}{S} \quad i = 1, 2, \dots, k = 1, 2, 3, 4 \tag{2}$$

where V_k and S are respectively the mean and standard deviation of the cumulative streamflow for the k th reference period (Eq. 2). The reference periods in this study are referred to as $k = 1$ for October–December, $k = 2$ for October–March, $k = 3$ for October–June, and $k = 4$ for October–September (Nalbantis 2008; Nalbantis and Tsakiris 2009).

Negative SDI values indicate a hydrological drought while positive values reflect wet conditions. Based on SDI, five states of hydrological drought are defined, which are denoted by an integer number ranging from 0 (non-drought) to 4 (extreme drought) (Nalbantis 2008; Nalbantis and Tsakiris 2009; Tabari et al. 2013). The five states are defined in the criteria of Table 2.

Mann-Kendall correlation test (M-K test) was applied to detect any possible linear trend in the values of the four overlapping time periods (Oct-Dec, Oct-Mar, Oct-Jun, and Oct-Sep) at the eight river-gauging stations. Serial values of $u(t)$ and $u'(t)$ from the progressive analysis of the Mann-Kendall test (Sneyers 1990) were plotted for selected stations (Türkeş et al. 1996). When there is no trend, the diagrammatic

Table 2 Description of streamflow drought classes based on SDI (Nalbantis and Tsakiris 2009)

State	Description	Criterion
0	Non-drought	$SDI \geq 0.0$
1	Mild drought	$-1.0 \leq SDI < 0.0$
2	Moderate drought	$-1.5 \leq SDI < -1.0$
3	Severe drought	$-2 \leq SDI < -1.5$
4	Extreme drought	$SDI \leq -2.0$

representation of $u(t)$ and $u'(t)$ shows curves that overlap several times. In the presence of a trend, the intersection of these curves enables the location of the beginning of the trend or change to be approximated (Sneyers 1990). M-K test was used for the temporal variation, and all trends showed a significance level of 0.05. When the value of $u(t)$ is significant, it can be determined whether it is an increasing or decreasing trend according to whether $u(t) > 0$ or $u(t) < 0$ (Türkeş et al. 1996). In other words, as $u(t)$ values become smaller, the significance increases in terms of drought.

Gaussian filter was used to examine the long-term fluctuations visually in the regional mean series as a low-pass filter (Türkeş et al. 1996) and applied to reduce fluctuations shorter than 10 years to aid understanding of long-term evaluation of the non-random characteristics of the series (WMO 1966).

4 Results and discussion

4.1 SDI results

Results of the SDI analyses indicated that the number of drought years was highest for k1 period (Oct-Dec) during the observation period of all stations (Table 3). Most of the stations show a percentage of drought years above 50% for the k1 period. A considerable part of the drought years was determined to be mild drought. The river-gauging stations where the dry conditions are most observed are Söğütlü and Göksun in the Ceyhan Basin and Körkün in Seyhan Basin. Although moderate drought conditions were observed in all stations, the

highest number of years was detected at Gökdere station in Seyhan Basin. Evident moderate drought conditions were also determined at Göksu-H, Söğütlü, and Savrun. Severe and extreme drought was observed at few stations. The most prominent stations in terms of severe drought conditions were Körkün and Göksun.

Extreme drought conditions were detected at only one station in both basins. Similar patterns were also found for other periods (k2, k3, k4). However, there was a shift from mild drought to moderate and severe drought in other periods. For the k2 period, the number of years characterized by mild drought was the highest at Tacin in Seyhan Basin, and at Söğütlü and Karaçay in Ceyhan Basin. The number of years for moderate drought was higher in the Ceyhan Basin stations. On the other hand, in Seyhan Basin (Tacin and Gökdere stations), severe drought was observed to be significantly higher but the number of extreme drought years is quite low. The results obtained for the k3 period are quite similar to k2 on a station-to-station basis. The Ceyhan Basin is striking for its extreme drought, although higher values were determined in the Seyhan Basin in the severe drought classification.

In the last period, k4, annual drought conditions were evaluated. Accordingly, mild drought is again the most dominant class, with the highest years at Tacin and Karaçay stations. Moderate drought conditions are significantly more common in the Ceyhan Basin while severe drought is more dominant in the Seyhan Basin. The maximum number of extreme drought years was determined in the k4 period (October–September). Extreme drought years were especially concentrated in the Ceyhan Basin.

Figures 3 and 4 show the interannual variability in calculated SDI series for the short-term (Oct-Dec, Oct-March) and long-term (Oct-June, Oct-Sep) periods, respectively. Short-term drought conditions exhibit high interannual variability (Fig. 3). Short-term fluctuations of dry and wet conditions are the dominant pattern. However, in the first and last decades of the observation period, it was determined that long-term fluctuations for dry and wet conditions followed one another. This persistent pattern stands out at Tacin station. A similar character was also detected at other river-gauging stations in Seyhan Basin. In these stations, dry conditions were seen from the beginning of the observation period until the early 1980s. Although there were

Table 3 Results of streamflow deficit index based on four periods

Basins	% drought years	k1 (Oct-Dec)	k2 (Oct-Mar)	k3 (Oct-June)	k4 (Oct-Sep)
Seyhan	Tacin	44.19	53.49	41.86	46.51
	Göksu-H	58.14	46.51	41.86	41.86
	Gökdere	53.49	48.84	41.86	44.19
	Körkün	55.81	46.51	46.51	44.19
Ceyhan	Söğütlü	60.47	48.84	48.84	44.19
	Göksun	60.47	55.81	44.19	44.19
	Karaçay	44.19	46.51	48.84	48.84
	Savrun	48.84	51.16	46.51	44.19

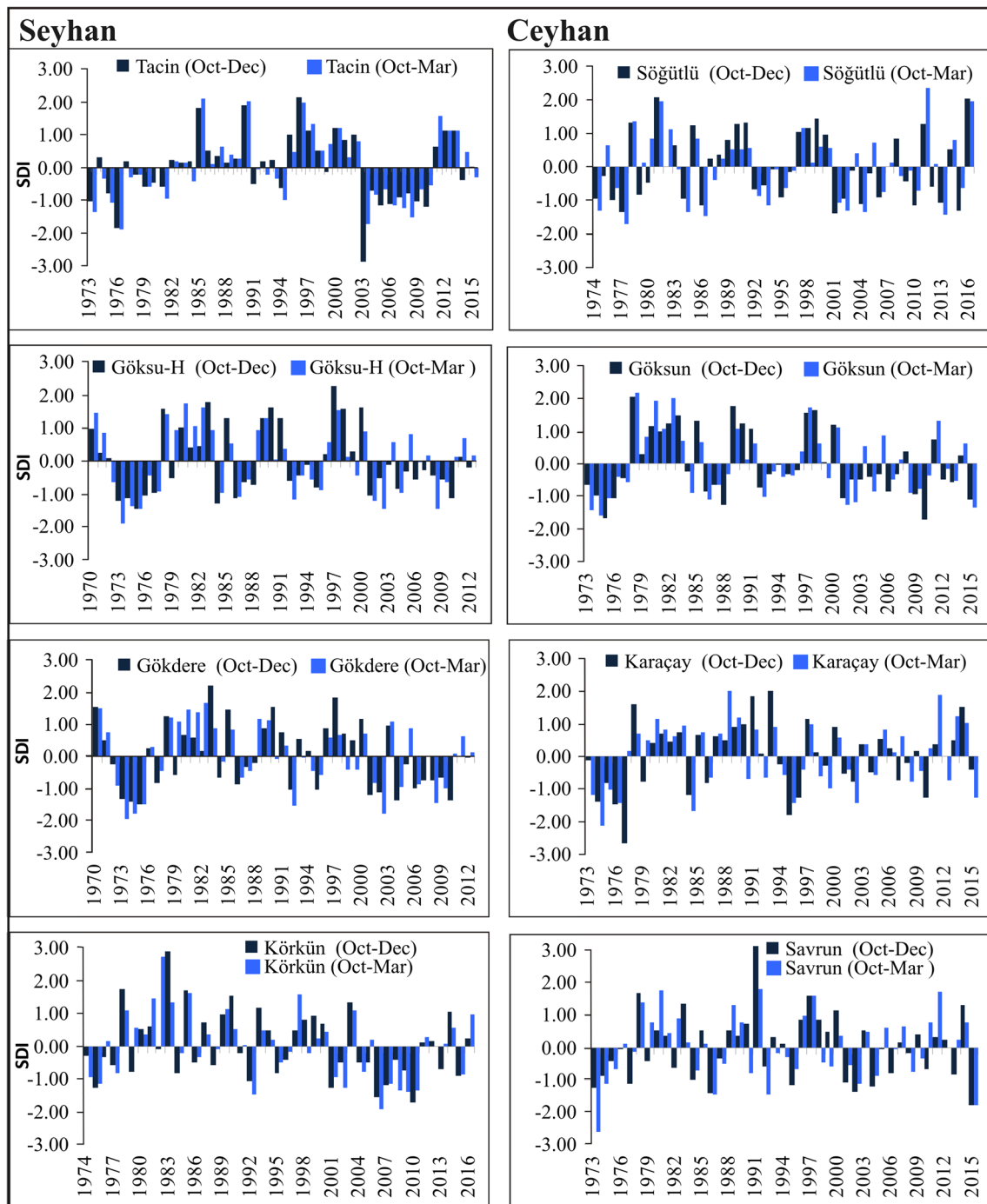


Fig. 3 Interannual variability of index values for k1 (Oct-Dec) and k2 (Oct-March) periods

short-term drought fluctuations from the 1980s to 2000s, humid conditions were dominant. From the beginning of the 2000s up to the present day, predominantly persistent dry conditions are noticeable. For the Ceyhan Basin stations, in the early years of the observation period, dry conditions were prevailing; however, there was a significant short-term fluctuation tendency in the following years, unlike the Seyhan Basin. In the Ceyhan Basin, a distinctive pattern was detected at Göksun where drought conditions were observed more persistently since the

2000s. When the k1 and k2 periods are compared, it can be said that there is no significant difference in the temporal variability of dry and wet conditions.

In terms of hydrological drought, the determination of long-term drought conditions is more important. Figure 4 shows the temporal variation of SDI values calculated for long periods, by which we mean the 9-month (k3) and 12-month (k4) periods. Precipitation patterns, soil moisture, and basin characteristics are all effective in the drought conditions

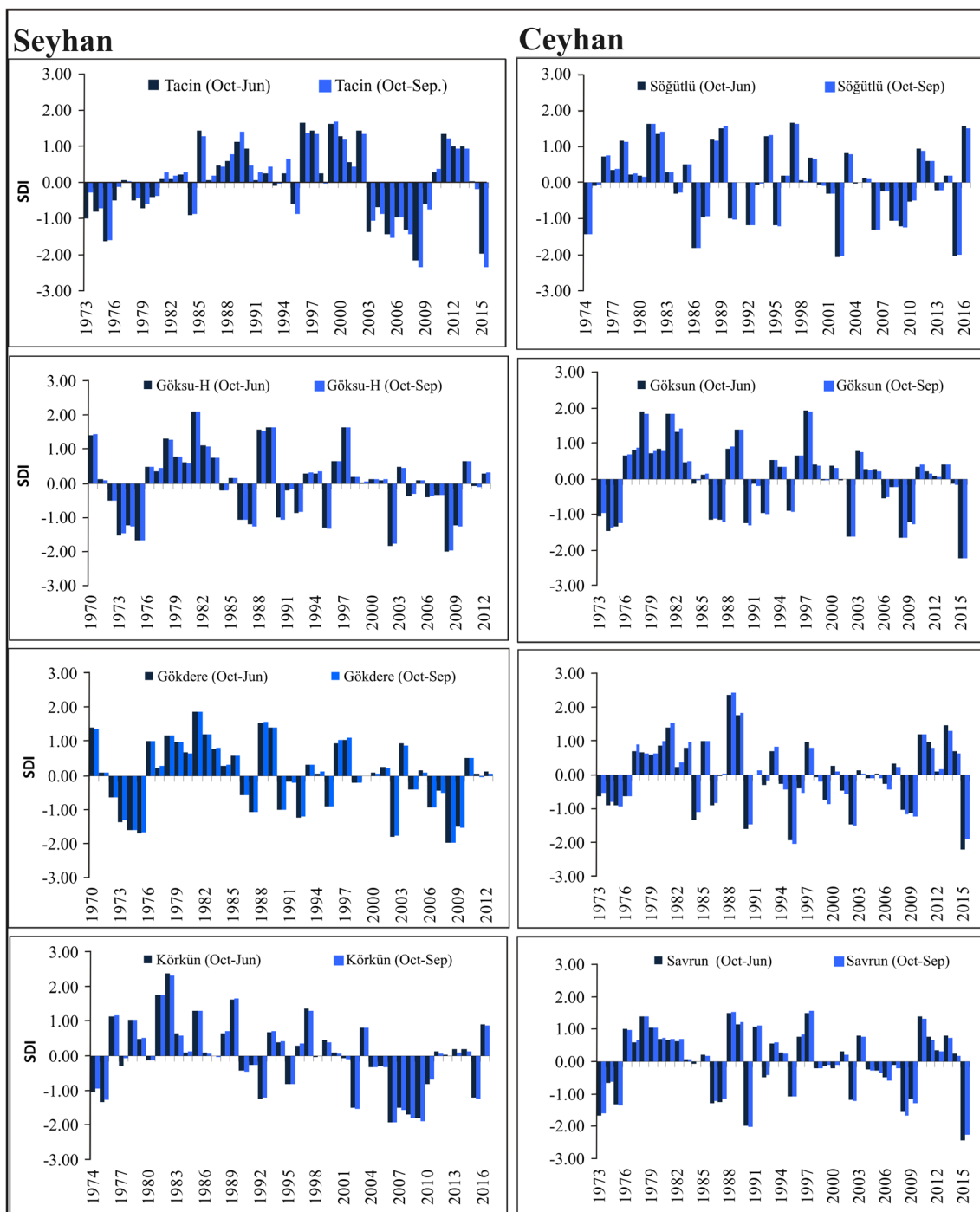


Fig. 4 Interannual variability of index values for k3 (Oct-June) and k4 (Oct-Sep) periods

observed during the 9-month and 12-month periods. Significant dry conditions determined in the longer periods also indicate the temporal propagation of drought.

There is no significant difference between periods k3 and k4 in the temporal change of long-term dry conditions. In the Seyhan Basin stations, a short dry period in the first years of the observation period, except for Tacin, was generally followed by a wet period until the beginning of the 2000s.

During this wet period, there were also dry conditions characterized by short-term fluctuations. After the 2000s, the dominant trend is drought. At the Tacin station, successive dry and wet periods were found to be longer. The dry period between 1973 and 1983 was followed by a wet period until 2001. In the first decade of the 2000s, there was a severe dry period, which was also determined at the Körkün station. For the Ceyhan Basin stations, in the early years of observation, dry

Table 4 Results of Mann-Kendall (M-K) test. (–) decreasing trend. *Significant at 0.05 level

Basin	Station	Monthly period			
		Oct-Dec $u(t)$	Oct-Mar $u(t)$	Oct-Jun $u(t)$	Oct-Sep $u(t)$
Seyhan	Tacin	0.33	0.24	1.03	0.43
	Göksu-H	0.16	– 0.70	– 1.11	– 1.19
	Gökdere	– 0.84	– 1.22	– 1.53*	– 1.62*
	Körkün	– 1.16	– 1.64	– 1.89*	– 2.10*
Ceyhan	Söğütlü	– 0.08	– 0.16	– 1.15	– 1.20
	Göksun	0.99	– 0.40	– 1.69*	– 1.79*
	Karaçay	0.56	0.79	– 0.08	– 0.60
	Savrun	0.02	0.32	– 0.68	– 1.01

conditions were evident, except at Söğütlü. Similar to Seyhan Basin, this short-dry period was followed by a distinct wet period. In the following years, the main tendency of SDI values can be characterized as short-term fluctuations of wet and dry conditions. Only at Göksun station were drought conditions clearly observed in the last decade of the observation period. Gümüş and Algin (2017) investigated the drought intensity in the Seyhan and Ceyhan river basins for the period 1970–2005. They found that the highest extreme drought events were encountered in 2001 with an occurrence of 17%.

In terms of long-term persistent and considerable drought conditions, Tacin and Körkün in Seyhan Basin and Göksun in Ceyhan Basin become prominent. Tacin and Göksun stations are located at higher elevations of their catchment area, while Körkün is downstream in the Seyhan Basin. Intensifying

drought conditions for the Oct-Jun period (k3) upstream may signify either a variation in precipitation character (from snow to rain), amount, and duration, or a change in the runoff process caused by land degradation due to human impact. Both these reasons may also be affective in decreasing streamflow. For Oct-Sep (k4), hot and dry conditions cause both increasing evapotranspiration and more water to be withdrawn from the groundwater for irrigation and domestic use, which suppresses water availability in the streams.

4.2 Trend analyses

As the results show, there is no statistically significant increasing or decreasing trend in the different time scales for the streamflow data of Tacin, Savrun, Karaçay, Söğütlü, and

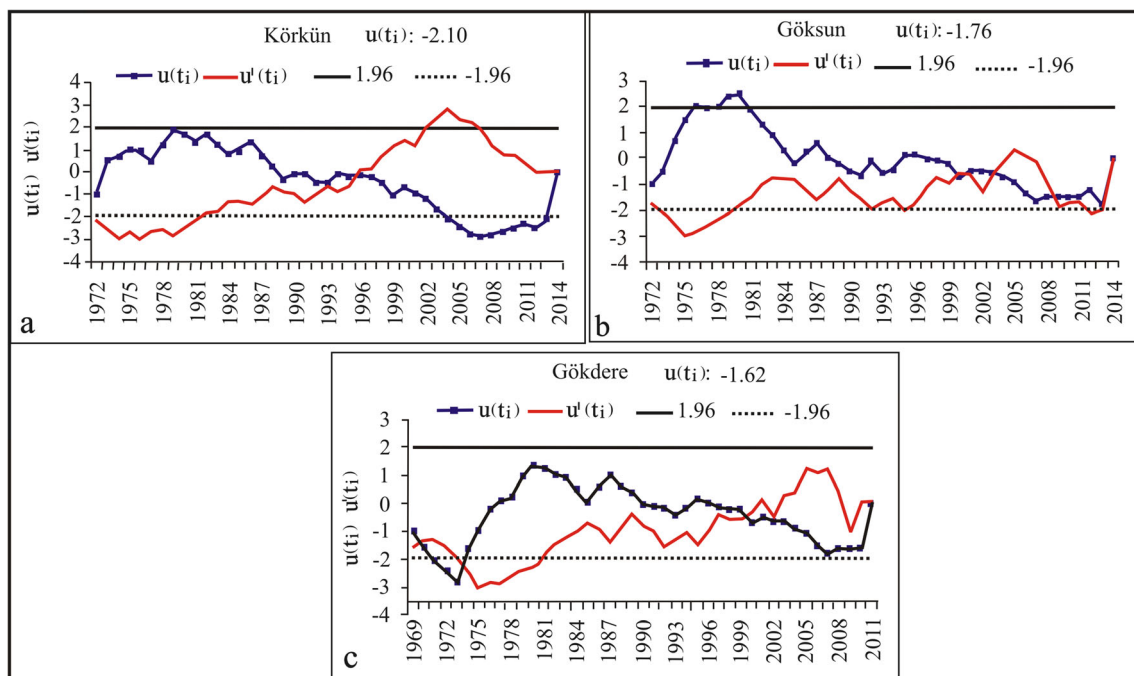


Fig. 5 Trend in time series of 12-month streamflow at Körkün, Göksun, and Gökdere stations for 43-year period obtained from M-K trend analysis, with critical significance value of ± 1.96 at 0.05 level

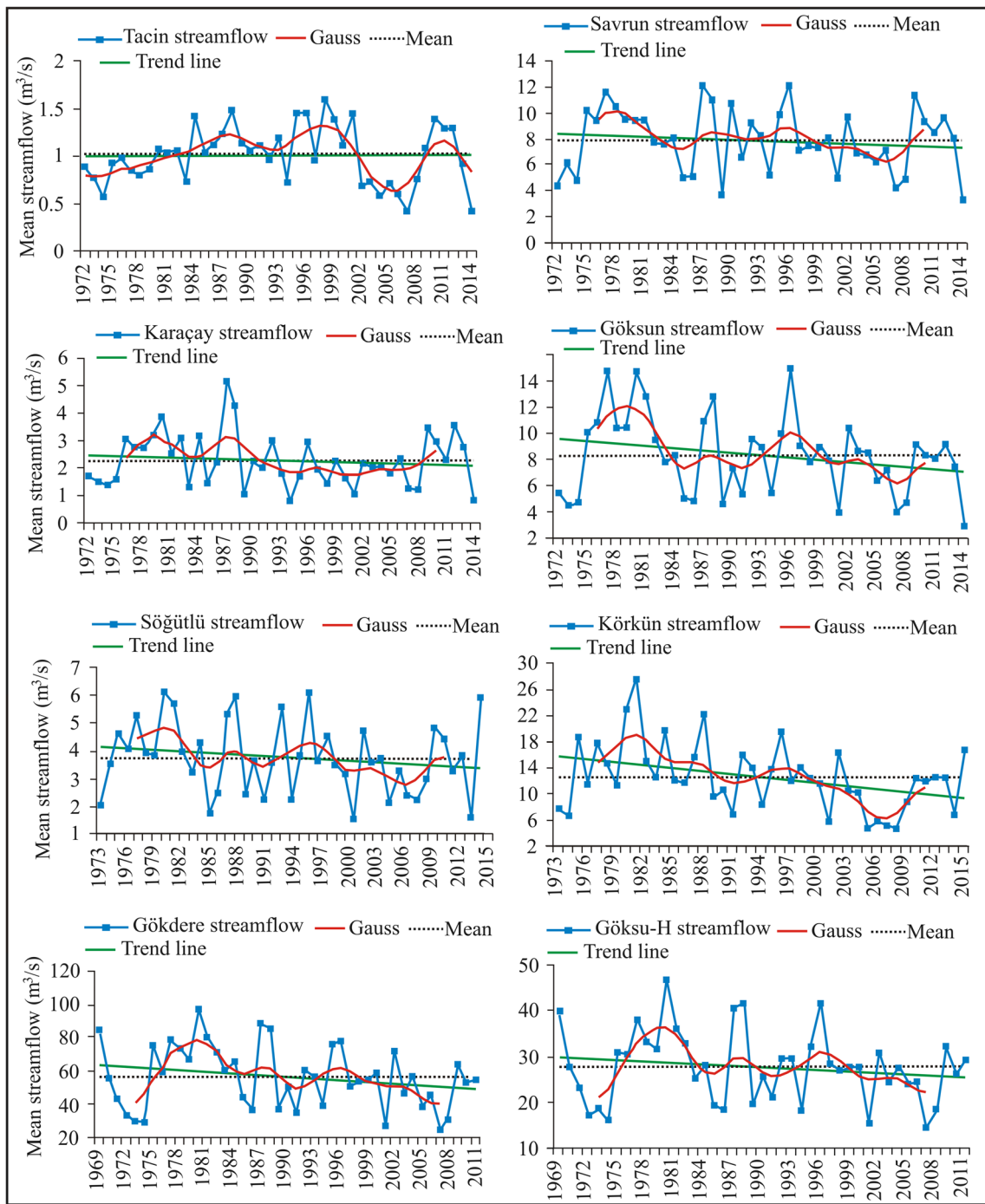


Fig. 6 Interannual variations in mean streamflow series of eight stations in Seyhan and Ceyhan basins for the 43-year period. Variations are illustrated with smooth line for 9-year Gaussian filter (red line), trend line

(green line), mean streamflow series (dashed black line), and streamflow series (dark blue line)

Göksun-H stations (Table 4 and Fig. 5a–c). However, a statistically significant decreasing trend at 0.05 level was detected for the October–June (9-month) and 12-month (full year) series of Körkün, Göksun, and Gökdere stations (Table 4 and Fig. 5a–c). This shows that the decreasing trend in summer streamflow plays an important role in amplifying the

decreasing trend of 12-month streamflows. According to results of the M-K test, the starting point for the detected negative trend in the 12-month time series at Körkün, Gökdere, and Göksun was 1996, 1999, and 2000, respectively (Fig. 5a–c). Bayer Altın and Sarış (2017) and Bayer Altın et al. (2019) also detected strong decreasing trends in streamflow in the Ceyhan

and Seyhan basins as observed in summer at 0.01 significance level and at 0.05 level in the autumn months. According to Bayer Altın and Sarış (2017) and Özfıdaner et al. (2018), the cause of the decreasing trend in streamflow in these basins is related to decreasing rainfall and increasing annual temperatures that accelerate evaporation.

The negative and positive trends in the time series (Fig. 6) of the mean streamflow correspond to almost similar periods. At all stations, there is an evident positive trend in the streamflow from the late 1970s to the end of the 1980s. Normal and near-normal values are observed from the 1990s to the early 2000s. This is followed by a long and strong negative trend from the early 2000s to 2011, 2014, and 2015. The negative trend is strongly evident at the Tacin and Körkün stations (Fig. 6a, f) from 2002 to 2009. The periods with a negative trend are longer at all stations except Tacin than periods showing a positive trend.

Over the last four decades, the most severe and widespread drought events in Turkey were in 1971–1974, 1983–1984, 1989–1990, 2007–2008, and 2013–2014. During these periods, a considerable decrease in the amount of annual and winter precipitation is distinctive (Türkeş et al. 2009a, b; Türkeş 2014). Over half of Turkey's agriculture was affected by drought in 2006–2007 and 2007–2008 (Şimşek 2010) as well as the prolonged drought in 1996–2001 (Türkeş et al. 2009a). Serious diminution occurred in many agricultural products due to the drought of 2007. The loss rate of the products is as follows: 10.8% of cotton, 13.9% of wheat, 24.6% of sesame, 7.1% of orange, 5.9% of mandarin, and 8.3% of lemon (Şimşek et al. 2008). Almost half of these products are grown downstream of the Ceyhan and Seyhan basins. While the wheat production, a basic crop of Turkey, was 21,500,000 tons in 2005, it was 17,234,000 tons in 2007 and 17,782,000 tons in 2008 (Şimşek and Çakmak 2010). In addition, the water storage in 191 dams decreased to 14.76% according to data for 2008, which caused serious hardships for agricultural irrigation. This mostly began in the 1990s with a general decrease in the number of frosty and snowy days and an evident increase in hot days and nights, along with higher average night time minimum and daytime maximum air temperatures in the Eastern Mediterranean basins (Türkeş 2012).

Streamflow in the basins plays a key role in the water balance of dams as they are used for water supply, irrigation, energy generation, and flood control. Precipitation is also of great importance in the decrease/increase of streamflow values. Dikici et al. (2018) investigated drought years in the Seyhan Basin by using the Palmer drought severity index (PDSI). They found the most severe droughts were in 1970–1974, 1984–1985, 1989, 2001, 2004–2009, and 2013–2014. Uzunkol and Kızılelma (2016) discovered drought in the years 1984, 1993, 1999, and 1998 in Ceyhan Basin for the period 1963–2011. Predictions for the Seyhan and Ceyhan basins in the future vary, but precipitation is expected to decrease by 21% and 22%,

respectively (OSB 2016a, b) due to changes in seasonality, resulting in earlier snowmelt over the mountains (Selek et al. 2016). In addition, a significant decrease in the number of snowy days was observed at all stations located within the upper catchment of Ceyhan Basin (Bayer Altın and Sarış 2017). It was found that the beginning of the decreasing trend corresponded to 2009, 2012, and 2013. According to Selek et al. (2016), reservoirs that store and regulate river flow are essential to manage the impact of climate variability on water resources. However, efficient management, land use planning, and conservation measures must be applied to determine the equitable allocation of available water resources to all users under stress conditions (Tortajada 2016).

In the current study, significant differences were observed between different periods (e.g., between the 3-month and 6-month periods, and 6-month period compared with 9-month period). Especially after 2000–2001, there was a slight drought in the 6-month periods but a more acute drought in 3-month periods. This shows that much of the precipitation falls as snow in the Söğütlü, Göksun, and Tacin stations located at higher elevations during the 3-month period, whereas spring snowmelt alters the river flow regimes resulting in increased streamflow during the 6-month period. Similar results were detected by Tabari et al. (2013) for Northwestern Iran, Özfıdaner et al. (2018) for Seyhan Basin, Yürekli et al. (2009) for Sakarya Basin in Northern Turkey, and Gümüş (2017) for Asi River in Southern Turkey. Yücel et al. (2014), who assessed river discharge trends in the mountainous eastern region of Turkey, also reported that there were generally no statistically meaningful trends in river discharge (only 2 of the 15 stations showed evidence of a decreasing trend) over the study period (1970–2010), while the timing of the spring streamflow had significantly shifted to earlier in the year. Nalbantis and Tsakiris (2009) stated that the discrepancy is a result typical of the Mediterranean hydrological regime. Generally, discrepancies are only slightly significant when passing from the 6-month period to the 9-month period then disappear when passing from the 9-month period to the 12-month hydrological year. This shows that the longer the period, the greater the increase in the number and intensity of dry years. Such results were also observed by Öztürk et al. (2010) for Northeastern Turkey, where they found statistically that drought affected the full hydrological year in four out of eight stations during their most recent 5 years.

5 Conclusions

In this study, hydrological drought analysis was carried out for 43 years (1972–2014, 1973–2015, and 1969–2011) on streamflow data of the Seyhan River and Ceyhan River basins. Streamflow Drought Index (SDI), Mann-Kendal, and Gaussian filter statistical analyses were used for determining

the size, trend, and change in drought, respectively. In addition, hydrological drought analysis was estimated for 3-, 6-, 9-, and 12-month periods. Results of the statistical tests fit the results of the hydrological drought analysis based on SDI. According to M-K test, the beginning of the drought corresponds to the end of the 1990s and early 2000s at almost all stations. Gaussian filter results show that a strong negative trend was observed from the early 2000s to 2011, 2014, and 2015. Indeed, according to the results of the hydrological drought analysis, drought years are evidently more prevalent after 2000–2001. Similar results were observed for wet conditions. M-K test results showed a positive trend in streamflow from the late 1970s to the end of the 1980s at all stations. Almost the same dates for wet periods were detected by SDI. The SDI results indicate that the stations experienced extreme drought in different years. Extreme droughts occurred at Gökdere and Göksu-H stations during 2007 and 2008, at Karaçay, Savrun, Tacin, and Göksun stations for 2014–2015, at Körkün station during 2005 and 2006, and at Söğütlü station in 2001 and 2002. The most extreme streamflow drought occurred during the hydrological years of 2007–2008 and 2014–2015 at Tacin station. Drought events ranging from -1 to -2.3 of SDI values (varying from mild to extreme drought conditions) occurred in the last 10 years and 14 years. In general, after a wet period lasting 7 or 8 years, an interval in which dry years and wet years followed each other occurred in the basins, and this was then followed by a period of uninterrupted dry years.

In light of these results, appropriate policies and plans should be drawn up for the effective use of existing water resources. Considering drought propagation, hydrological drought occurs after meteorological and agricultural drought, hence pointing to a serious water deficit in these basins. This is an important issue to be resolved in basins such as those of the Seyhan and Ceyhan rivers, where agriculture represents an important livelihood for the population.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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