Response of hydrological drought to meteorological drought in the eastern Mediterranean Basin of Turkey (Postprint)

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Date: 2021-06-04T00:00:00+00:00

Abstract

The hydrographic eastern Mediterranean Basin of Turkey is a drought sensitive area. The basin is an important agricultural area and it is necessary to determine the extent of extreme regional climatic changes as they occur in this basin. Pearson’s correlation coefficient was used to show the correlation between standardized precipitation index (SPI) and standardized streamflow index (SSI) values on different time scales. Data from five meteorological stations and seven stream gauging stations in four sub-basins of the eastern Mediterranean Basin were analyzed over the period from 1967 to 2017. The correlation between SSI and SPI indicated that in response to meteorological drought, hydrological drought experiences a one-year delay then occurs in the following year. This is more evident at all stations from the mid-1990s. The main factor causing hydrological drought is prolonged low precipitation or the presence of a particularly dry year. Results showed that over a long period (12 months), hydrological drought is longer and more severe in the upper part than the lower part of the sub-basins. According to SPI-12 values, an uninterrupted drought period is observed from 2002–2003 to 2008–2009. Results indicated that among the drought events, moderate drought is the most common on all timescales in all sub-basins during the past 51 years. Long-term dry periods with moderate and severe droughts are observed for up to 10 years or more since the late 1990s, especially in the upper part of the sub-basins. As precipitation increases in late autumn and early winter, the stream flow also increases and thus the highest and most positive correlation values (0.26–0.54) are found in January. Correlation values (ranging between –0.11 and –0.01) are weaker and negative in summer and autumn due to low rainfall. This is more evident at all stations in September. The relation between hydrological and meteorological droughts is more evident, with the correlation values above 0.50 on longer timescales (12- and 24-months). The results presented in this study allow an understanding of the characteristics of drought events and are instructive for overcoming drought. This will facilitate the development of strategies for the appropriate management of water resources in the eastern Mediterranean Basin, which has a high agricultural potential.

Full Text

Preamble

Response of Hydrological Drought to Meteorological Drought in the Eastern Mediterranean Basin of Turkey

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Abstract: The hydrographic eastern Mediterranean Basin of Turkey is a drought-sensitive area that serves as an important agricultural region. It is essential to determine the extent of extreme regional climatic changes as they occur in this basin. Pearson's correlation coefficient was used to show the correlation between standardized precipitation index (SPI) and standardized streamflow index (SSI) values on different time scales. Data from five meteorological stations and seven stream gauging stations in four sub-basins of the eastern Mediterranean Basin were analyzed over the period from 1967 to 2017. The correlation between SSI and SPI indicated that hydrological drought experiences a one-year delay in response to meteorological drought, occurring in the following year. This pattern became more evident at all stations from the mid-1990s. The main factor causing hydrological drought is prolonged low precipitation or the presence of a particularly dry year. Results showed that over long periods (12 months), hydrological drought is longer and more severe in the upper part than the lower part of the sub-basins. According to SPI-12 values, an uninterrupted drought period was observed from 2002–2003 to 2008–2009. Results indicated that among drought events, moderate drought is the most common on all timescales in all sub-basins during the past 51 years. Long-term dry periods with moderate and severe droughts were observed for up to 10 years or more since the late 1990s, especially in the upper part of the sub-basins. As precipitation increases in late autumn and early winter, streamflow also increases, resulting in the highest and most positive correlation values (0.26–0.54) in January. Correlation values are weaker and negative in summer and autumn (ranging between –0.11 and –0.01) due to low rainfall, which is more evident at all stations in September. The relationship between hydrological and meteorological droughts becomes more apparent, with correlation values above 0.50 on longer timescales (12 and 24 months). The results presented in this study allow an understanding of the characteristics of drought events and are instructive for overcoming drought.

This will facilitate the development of strategies for appropriate water resource management in the eastern Mediterranean Basin, which has high agricultural potential.

Keywords: meteorological drought; hydrological drought; standardized precipitation index (SPI); standardized streamflow index (SSI); eastern Mediterranean Basin

1 Introduction

Complex environmental events that significantly affect agriculture, society, and ecosystems attract attention as large-scale droughts (Nkiaka et al., 2017). Wilhite and Glantz (1985) defined drought as insufficient rainfall for a long period of time and divided it into four main categories: meteorological, agricultural, hydrological, and socio-economic. The most recent report from the International Panel on Climate Change (IPCC, 2013) declared the Mediterranean as one of the most sensitive regions in the world susceptible to the impacts of global warming. The part of Europe that will be most affected by drought is the Mediterranean Basin, including Turkey, due to climate change (IPCC, 2007). Estimates show that 0.5×10^{6} people are likely to experience increased water resource stress by 2020 as a result of climate change (Aerts and Droogers, 2004). It is expected that population growth and increasing urbanization, especially in the coastal regions of the eastern and southern Mediterranean countries, will lead to both high water demand and further deterioration of water quality (MedECC, 2019). Bordi et al. (2009) also pointed out that the area where drought events occurred in Europe increased in the latter 50 years of the 20th century. An increase in drought based on decreasing precipitation in many countries within the Mediterranean Basin, such as Greece, southern Italy, and Turkey, has been documented (Kömüşçü et al., 2004; Sönmez et al., 2005; Livada and Assimakopoulos, 2007; Mendicino et al., 2008; Giannakopoulos et al., 2011; Caloiero et al., 2018). Drought trends are expected to progressively cause more damage until the end of the 21st century, leading to different results in drought frequency, duration, and severity (Spinoni et al., 2018).

A study on the relative contribution of changes in precipitation versus evaporative demand pointed out that the expansion of dry areas in the 21st century has been attributed to a widespread increase in potential evapotranspiration (Cook et al., 2014). Extreme climatic events such as increases in the number of very heavy rainy days and extreme rainfall events are predicted to inevitably affect the southern, central, and southwestern regions of China and Turkmenistan (Duan et al., 2016, 2019a, b). The IPCC (2007) report states that significant decreases will occur in precipitation with increasing temperatures toward the end of the 21st century. The magnitude and frequency of hydro-meteorological extremes such as heavy rainfall, flash floods, strong winds, storm surges, forest fires, and droughts accompanied by heat waves could significantly affect the ongoing climate in the Mediterranean region (Ducrocq and Gaume, 2016).

These conditions will be reflected mostly in the budget of streams as a negative decrease (Şen et al., 2013). Especially in the summer half-year (i.e., April to September), a reduction in precipitation is becoming more severe in Mediterranean countries, and as a consequence, evapotranspiration rates are likely to be higher, leading to decreased streamflow (Schneider et al., 2013). In addition, it is expected that streamflow droughts will become more severe and create an increase in drought in the Mediterranean and Alpine regions because of reduced snowmelt (Andreas et al., 2018). Studies conducted in recent years predict that climate change, extreme wet events, and human activities will cause adverse effects on water quality and water resources in Asian countries (Sun et al., 2015; Duan and Takara, 2020).

Due to the increase in average temperature worldwide, expansion of the high-pressure band around the 30° latitude toward the poles is the most important result of climate change (Quan et al., 2004; Frierson et al., 2007; Seidel et al., 2008; Johanson and Fu, 2009). The magnitude of this expansion has increased in the last 30–40 years (Grise and Davis, 2020). Warming of the Mediterranean Sea surface, spreading down to deeper layers, has been indicated by both global and regional climate models, which will influence the exchange of water and heat in the Strait of Gibraltar and the heat and salinity in deep layers of the North Atlantic Ocean (Ducrocq, 2016).

The central, southern, and southeastern regions of Turkey are under the effect of a semi-arid climate and face the risk of desertification (Türkeş, 2005; Türkeş and Tatlı, 2009; Bayer Altın et al., 2012; Bayer Altın and Barak, 2017; Bayer Altın and Altın, 2018). Climate change will further increase its impact in the near future, transforming the southern half of Turkey into a climate similar to that of its southern neighbors, Syria and Iraq. The central and humid northern regions will face an arid climate that currently prevails in the southern regions. For Turkey, this means that the risk of drought and desertification will increase in all regions (Şahin and Kurnaz, 2014).

Studies on the effect of low precipitation on streamflow and its correlation with the eastern Mediterranean Basin are limited. The majority of studies are related to meteorological drought analysis using the standardized precipitation index (SPI) and are based only on precipitation data from basins in the Mediterranean region of Turkey (Bahadır, 2011; Keskiner et al., 2016; Topçu and Seçkin, 2016; Oğuz et al., 2017; Çelik and Gülersoy, 2018; Çuhadar and Atış, 2019). A study on the potential future (2070s) impacts of climate change on the hydrology and water resources of the Seyhan River Basin detected an annual precipitation decrease of 157 mm (25%) and an annual runoff decrease of 118 mm (52%) (Fujihara et al., 2008). The study by Gümüş and Algın (2017) was the first related to hydro-climatological drought analysis of the Seyhan and Ceyhan river basins in the southern region of Turkey. The drought conditions of these basins, located east of the eastern Mediterranean Basin and sharing the same climatic conditions, were determined using the streamflow drought index (SDI) (Bayer Altın et al., 2020). Dabanlı (2018) investigated drought hazard and vulnerability based on hydro-meteorological and actual socioeconomic data for Turkey.

Previous studies (e.g., Sönmez et al., 2005; Türkeş and Tatlı, 2009; Kurnaz, 2014) have examined only either meteorological drought or hydrological drought (Bayer Altın et al., 2020). The difference between the current study and previous research (e.g., Bayer Altın et al., 2020) is the evaluation of meteorological drought together with hydrological drought. Another distinctive feature of this study is its temporal and spatial focus on the eastern Mediterranean Basin. Thus, the meteorological and hydrological drought values of the eastern Mediterranean Basin were compared and the accuracy of predictions was discussed.

The present study is the first to provide comprehensive drought analysis by taking into account streamflow and precipitation data obtained from the sub-basins of the eastern Mediterranean Basin. This study has two main objectives: (1) to investigate the causes of drought in the eastern Mediterranean Basin in light of hydrological and meteorological data; and (2) to determine hydrological drought in the sub-basins on short and long timescales. In addition, it focuses on the characteristics of propagation from meteorological to hydrological drought. Accordingly, based on meteorological and hydrological conditions examined spatially throughout the basin, this paper presents temporal variations of drought severity on 3-, 6-, 9-, and 12-month timescales.

2 Study Area

The eastern Mediterranean Basin is one of 25 hydrological river basins in Turkey. Located in southern Turkey [Figure 1: see original paper], the basin area includes the water collection areas of rivers between the Sedir River in the west and the Tarsus River in the east [Figure 1: see original paper]. In other words, the basin covers the area that discharges the water of the Göksu River and other rivers into the Mediterranean. The elevation of the eastern Mediterranean Basin varies between 0 and 2000 m a.s.l. and exceeds 3000 m a.s.l. on its ridges and peaks. It is bordered by the Ak Mountain in the west, the Taurus Mountains in the north, the Bolkar Mountains in the east, and the Mediterranean Sea in the south. The basin covers an area of 2.18$×10ˆ{4}$ km^{2}, with geographical coordinates of 36°00 –37°28 N and 32°06 –35°09 E (GDWM, 2016). Except for the Göksu and Tarsus (Berdan), the rivers are short and have steep beds. The basin lies completely within the Adana sub-region of the Mediterranean region. The locations of stream gauging stations (SGSs) and meteorological stations, with their geographical properties, are shown in Figure 1b and Tables 1 and 2.

In this study, stream-gauging data were obtained from the Göksu, Efrenk, Pamuk, and Lamas rivers. The most important river in the basin is the Göksu. Its two tributaries originate from the Middle Taurus Mountains, and it is named Göksu after these tributaries merge to the south of Mut District. The Göksu River, approximately 260 km long, flows south from its headwaters in the Taurus Mountains to the Mediterranean via a delta between Taşucu and Silifke.

Another important water source is the Lamas River, approximately 130 km long, which collects water between Mount Sakaryayla and Güzeloluk (GDWM, 2016). The Efrenk River (Müftü Creek) originates from the southern slopes of the Bolkar Mountains, is 100 km long, turns south in the Çağ vicinity, and flows into the sea through the city of Mersin. The Cehennem River, one of the tributaries of the Tarsus River, takes the name of Pamuk River while passing the city of Çamlıyayla. The river called Keşbükü in the Keşbükü gorge merges with the Kadincik River near the Çevreli village before arriving at the Muhat Bridge (GDWM, 2016).

Surface flow in the basin is high due to steep slopes, sparse forest cover, and high precipitation; therefore, river regimes are irregular (Topraksu, 1974). The length of the eastern Mediterranean Basin, whose total rainfall area is 2.18$×10ˆ{4}$ km^2, is 129 km. Average annual precipitation was 745 mm and average annual streamflow was 11.07 km^3/a for the period 1980–2016 (FDMD, 2018).

Agricultural lands in the eastern Mediterranean Basin occupy 4.96$×10ˆ{5}$ hm^2 and constitute 22.7% of the basin (GDWM, 2016). Dams and ponds on the Tarsus, Anamur, Göksu, and Lamas rivers, which are surface water sources, are used for agricultural irrigation and drinking water supply. Almost all of the rivers examined feed these dams and ponds.

The basin is generally under the influence of the Mediterranean climate. A typical Mediterranean climate is observed along the coast: summers are hot and dry, transitional seasons are clear, and winters are cool and rainy. However, approaching the Central Anatolia Region (e.g., Ermenek and Hadım) and toward mountainous areas, the effects of continental and mountain climates on the Mediterranean climate become more pronounced (Arınç, 2019).

3 Methods

A period of 51 years (1967–2017) was used for calculating indices such as standardized streamflow index (SSI) and SPI. The 1967–2017 reference period based on available hydrological and meteorological records was assessed in the present study. The main advantage of SSI is that it enables determination of the onset and end of a drought as well as the temporal relations of hydrological conditions of a river or set of streams. Months with drought events calculated by the SSI method were assessed in five categories (Table 3) for the seven SGSs operated by the General Directorate of State Hydraulic Works (Turkish acronym: DSI). These SGSs are located in the Göksu, Pamuk, Efrenk, and Lamas sub-basins of the eastern Mediterranean Basin. In addition, SGSs located behind dams were specifically chosen.

The five meteorological stations are Hadim located in the upper section of the sub-basin, Mut in the middle section, and Mersin, Silifke, and Erdemli in the lower sections [Figure 1: see original paper]. Four SGSs are located in the Göksu River sub-basin at Gördürüp (D17A017), Kravga (D17A016), Hamam (E17A020), and Karahacılı (E17A014). Two SGSs (Kravga and Hamam) are in the middle part, while Gördürüp and Karahacılı SGSs are in the upper and lower parts, respectively. Efrenk (D17A011), Pamuk (D17A007), and Lamas (E17A017) are located in the lower part of the sub-basin with the same name.

SSI was developed by Shukla and Wood (2008) on the basis of SPI (McKee et al., 1993, 1995) to determine the effect of drought on water flow. The SSI and SPI are defined as follows: where x for SSI (m^3/s) and x for SPI (mm) are the streamflow and precipitation in a reference period, respectively; x (m^3/s) and x (mm) are the mean streamflow and mean precipitation, respectively; and σ is the standard deviation. The same approach was used for precipitation values in sub-basins where SGSs are located, resulting in the SPI. Its calculation is similar to SSI, and therefore SPI has the same features of simplicity and effectiveness, allowing comparison of meteorological and hydrological variables. Negative SPI and SSI values point to potential deficits of precipitation and streamflow, respectively. In drought assessment based on SPI and SSI values, the period with negative values is defined as a meteorological and hydrological dry period, respectively. The month when indices fall below zero is considered the beginning of drought, and the month when indices rise to positive values is considered the end. In other words, a dry period for a certain timescale can be determined from SPI and SSI value sequences by finding the first value lower than −1.

To calculate SPI values on different timescales, we first obtained the cumulative sum of precipitation amounts over multiple timescales (3, 6, 9, 12, and 24 months). The same method was applied to streamflow data for SSI. SPI and SSI were computed on four different multiple timescales: 3-month (October–December, identified as a short timescale with acronyms SPI-3, SSI-3, and Oct–Dec), 6-month (October–March, identified as a medium timescale with acronyms SPI-6, SSI-6, and Oct–Mar), 9-month (October–June, identified as a long timescale with acronyms SPI-9, SSI-9, and Oct–Jun), and 12-month (October–September, identified as a long timescale with acronyms SPI-12, SSI-12, and Oct–Sep). In addition, the data included in SPI-24 (2-year SPI) and SSI-24 (2-year SSI) are based on monthly precipitation and streamflow input data from 1967 to 2017.

The relationship between SPI and SSI is understood through Pearson's correlation coefficient (r). We calculated this correlation in two ways according to different timescales (1-, 3-, 6-, 9-, 12-, and 24-month) by taking into account sequential months in a year. If r values are between 0.7 and 1.0, 0.3 and 0.7, or 0.0 and 0.3, there are strong, moderate, and weak correlations, respectively. If the r value equals zero, it indicates no correlation (Ratner, 2009).

4.1 SPI and SSI Temporal Variations of Drought

In this study, we calculated SPI and SSI values based on meteorological and hydrological data from the eastern Mediterranean Basin for 3-, 6-, 9-, and 12-month timescales. The distributions of SPI and SSI on different timescales are shown in Figures 2 and 3. Although the climatic conditions of the sub-basins in which the gauging stations are located differ little from each other, SSI and SPI values calculated by month appear quite consistent. Since the topographic features, air masses, and precipitation data of these basins are quite similar, they are assessed together in terms of SPI and SSI values. The moderate drought threshold (–1.0) of SPI and SSI classes (Table 3) is also provided in Figures 2 and 3. Moreover, the threshold between –1.0 and 0.0 demonstrates the early stage of drought. As shown in Figure 2, values below the threshold of –1.0 indicate periods where indices are between moderate and extreme drought. It is possible to identify the probability of encountering moderate dry conditions on 3- and 6-month scales.

Mild to extreme drought events for SSI-3 and SPI-3 generally occur at all gauging stations after 1990–1991 and 1991–1992, respectively, except at Lamas, where drought events appear after 2002–2003. Variation in SPI-3 values shows that extreme drought events (SPI value of –2.1) were determined only in 1999–2000 at Gördürüp, Kravga, and Hamam stations [Figure 2: see original paper], but extreme drought events for SSI-3 were not observed in this year. A moderate drought event occurred in the following year (2000–2001) at these stations with SSI values ranging between –1.6 and –0.5. A similar situation occurred at Karahacılı station, where moderate and mild drought events for SPI-3 (values of –1.4 and –0.1, respectively) were noted in 1999–2000 and 2011–2012. The same drought events were observed at this station with SSI values of –1.4 and –1.8 in 2000–2001 and 2012–2013, respectively. The mild drought observed in 2008–2009 for SPI-3 at Efrenk and Lamas stations became an extreme drought for SSI-3 in the following year [Figure 2: see original paper]; however, the moderate drought observed in 2013–2014 for SPI-3 at Pamuk station caused only a moderate drought for SSI-3 in the following year [Figure 2: see original paper].

Drought events for SPI-6 were observed from 1990–1991 at all stations, while drought events for SSI-6 appeared in the following year (1991–1992). An exception occurred at Efrenk and Pamuk stations, where drought events for SPI-6 began in 1984–1985. Variation in SPI-6, SPI-9, and SPI-12 values shows that an extreme drought event (SPI value below –2.0) was determined only in 2013–2014 at Gördürüp, Kravga, and Hamam stations [FIGURE:2 and FIGURE:3]. However, extreme drought events for SSI-6, SSI-9, and SSI-12 were not observed in this year but in the following year (2014–2015), when SSI values varied from –1.9 to –1.1. Variation of SPI-6, SPI-9, and SPI-12 values shows that a severe drought event (–2.0<SPI<–1.5) was observed in 2013–2014 at Karahacılı, Lamas, Efrenk, and Pamuk stations. SSI-6, SSI-9, and SSI-12 at these stations varied from –1.8 to –1.1 in 2014–2015. Accordingly, extreme and severe values of SPI for all timescales emerged as severe and moderate hydrological drought in the following year after the end of 1990.

Mild drought and wet conditions for SSI-3, SSI-6, SPI-3, and SSI-6 frequently alternated from the beginning of the 1970s to the mid-1980s [Figure 2: see original paper]. The longest wet duration for SSI-9, SSI-12, SPI-9, and SPI-12 was generally observed as a 17-year period initiated in 1973 at all stations [Figure 3: see original paper]. Severe and extreme drought events for SSI were observed on 6-, 9-, and 12-month timescales at all stations in 2016–2017, with SSI values varying from –2.4 to –1.1. The year 2001–2002 was a period of moderate to severe drought on these timescales. The year 2014–2015 experienced drought on all timescales and at all stations, though mild and moderate events dominated. The year in which mild and moderate drought events dominated for SPI on all timescales was 1999–2000. Moderate and severe drought events for SPI were observed in 2013–2014 at all stations.

In general, mild drought events were observed most frequently for SSI-3 and SPI-3, even in the driest years. Although an extreme wet event was observed in 1981–1982 at some stations in terms of SPI values, extreme wet conditions for SSI were not observed at all stations. Another extreme wet event for SPI was observed in 2001–2002 at some stations, with extreme wet conditions for SSI appearing in the following year (2002–2003). Accordingly, in all short and medium terms (3 and 6 months) and long terms (9 and 12 months), SPI and SSI values fluctuate further under the influence of each new precipitation and streamflow measurement because each new drought event has a greater effect on cumulative totals. This is more prominent for SPI-12 and SSI-12 values from 1994. According to SPI-12 values obtained from 1994 to 2017 (a duration of 23 years), severe and extreme drought events were frequently observed since the late 1990s at all stations (except Lamas). An uninterrupted drought period was observed from 2002–2003 to 2008–2009.

When SPI results are examined, they parallel findings from previous studies. Akbaş (2014) reported the presence of large areas with excessive humidity in the Mediterranean region of Turkey in July 1992, which is a dry month in terms of precipitation climatology for the period 1929–2009. This study also identified drought events in February 1991, known to be a humid period in the Mediterranean region, and in 2001 throughout Turkey. In a study on the impact of drought on agriculture for 2007–2008, the mean of total precipitation countrywide during the agricultural year was 596 mm, representing an 8.6% decrease in total precipitation relative to the norm, which created significant problems in food supply for wheat, maize, and rice production in 2007 (Şimşek and Çakmak, 2010), a finding supported by Akbaş (2014).

In a study investigating the spatial and temporal dimensions of meteorological drought for 1930–2002 in Turkey, it was detected that as the timescale increases, the frequency of severe droughts generally increases, especially on the Mediterranean coast and in some areas of Central Turkey (Sönmez et al., 2005). This result for inner regions is confirmed by Bayer Altın (2019a, b). In these studies, hydrological drought was determined by the SDI index. The SDI of the Konya Closed Basin (located in the Central Anatolia region) and SPI of the KOP region (including 8 provinces covering 63% of the Central Anatolian region and 12% of Turkey) were examined. In both drought analyses, severe and extreme droughts in the annual SPI were detected for 1950–2018, and 2013 and

2014 were determined to be the driest years of the last decade. In addition, according to SDI findings, the periods with the highest number of dry years are SDI-9 and SDI-12, which are also the periods when severe and extreme drought events were experienced from 2001 to 2014 in all sub-basins of the Konya Closed Basin (Bayer Altın, 2019a). The same findings for SPI-12 in 2002–2008 were detected by Gümüş and Algın (2017) for 1965–2010 in the Seyhan and Ceyhan river basins, and by Cook et al. (2016) for 900 years (1100–2012) in the Mediterranean Basin. In our study, an extreme meteorological drought was not observed as a hydrological drought in the same time period in the same year, but a hydrological drought was observed in the following year. It is apparent that the effect of meteorological drought on hydrological drought occurs one year later. The desynchronization of the two indices accords with findings for the Seyhan and Ceyhan river basins (Gümüş and Algın, 2017).

The percentages of drought events on different timescales based on SPI and SSI are shown in Figure 4. Both SSI and SPI consistently show moderate drought as the most common occurrence in the basin during the past 51 years, regardless of timescale. SSI analyses indicated that four stations (Gördürüp, Kravga, Hamam, and Karahacılı) show drought percentages above 50% for the 3-month timescale [Figure 4: see original paper]. The highest percentages of mild and moderate drought events were detected at Karahacılı station (49% and 55%, respectively). The longest drought duration appears to start in 2002–2003 and lasted for 14 years at this station, with exceptions in 2008–2009 and 2013–2014 [Figure 2: see original paper]. The lowest SSI value was −1.8 in 2012–2013, indicating a severe drought event.

SPI analyses indicate that four stations (Pamuk, Efrenk, Lamas, and Karahacılı) show drought percentages above 50%, and three stations (Gördürüp, Kravga, and Hamam) show nearly 50% for the 3-month timescale [Figure 4: see original paper]. Drought occurs in more than half of the 6-month timescales for SSI-6 at Karahacılı (51%), Lamas (55%), and Pamuk (53%) stations. Drought events are below 50% at other stations on this timescale. More than half of the 6-month timescales for SPI-6 experience drought at all stations except Lamas. Stations with drought below 50% on the 9-month timescale for SSI-9 are Gördürüp (47%), Karahacılı (49%), Lamas (47%), and Efrenk (41%). Drought occurs above 50% on the 9-month timescale for SSI-9 at Kravga, Hamam, and Pamuk stations. For SPI-9, drought occurs below 50% of the timescale only at Lamas station (43%). The proportion of drought with the lowest percentage for SSI-12 was observed at Efrenk station, covering approximately 39% of the 12-month timescale. A similar condition coincides with the percentage of SPI-12 for the 12-month timescale at Lamas station (49%). Drought occurs at more than 50% of the 12-month timescale for SPI-12 at other stations.

Figures 4c–i show the percentage of drought events based on SSI and SPI indices with different timescales in the sub-basins. Both indices consistently indicate moderate drought as the most frequent event in the sub-basins during the past 51 years, irrespective of timescale, followed by mild drought. Although moderate drought conditions were observed at all stations, the highest percentage for SSI-3 was detected at Hamam and Karahacılı stations (above 50%). The percentage of moderate drought events for SPI-3 was below 50% at Hamam station and 53% at Karahacılı station.

The highest percentage of moderate drought events for SSI-6 was detected at Lamas, Efrenk, and Pamuk stations (above 50%). The percentage of moderate drought events for SPI-6 was below 40% at Lamas and Efrenk stations and below 50% at Pamuk station. The percentage of moderate drought for SSI at Karahacılı station varies from 41% to 49% on 6-, 9-, and 12-month timescales. The percentage of moderate drought for SPI at Karahacılı station is just above 50% on the 9-month timescale. The percentage of moderate drought for SSI at Karahacılı station is only above 40% on the 6-month timescale and below 40% on other timescales at Gördürüp station. The percentage of moderate drought for SPI at Gördürüp station is below 40% on 6-, 9-, and 12-month timescales. The percentage of moderate drought for SPI and SSI at Hamam and Kravga stations varies from 41% to 47% on 6-, 9-, and 12-month timescales. The percentage of moderate drought for SPI at Efrenk station is above 50% on the 12-month timescale. Conversely, the lowest percentage of moderate drought events for SSI-12 was detected at Efrenk station (above 25%). A similar situation for this timescale was found at Pamuk station (35%). At other stations, the percentage of moderate drought for SPI and SSI shows close values in the long-term period (12-month), ranging between 35% and 49% for SSI and between 39% and 49% for SPI. Based on the distribution of SSI-12 index values in the sub-basins, the lower part is notable for having the shortest total drought duration (below 45% of the total 12-month timescale), while the middle and upper parts are identified as where droughts evidently lasted longer (above 45% of the timescale).

Severe drought for all timescales and the SSI index was observed at all stations. On all timescales of severe drought conditions, the most prominent stations are Efrenk and Karahacılı. Severe drought occurs in 10% of the 12-month period at these stations. About 6% of 3- and 6-month periods and 8% of the 9-month period experience severe drought at Efrenk station. At Karahacılı station, severe drought occurs in 8% of 3-, 6-, and 9-month periods and 4% of the 12-month period. Approximately 8% of the 6-month period experiences severe drought, varying from 2% to 6% at Kravga and Hamam stations. No extreme drought occurred at Hamam station for any timescale. At Gördürüp station, 8% of the 12-month period and 4% of the 9-month period have extreme drought, while at Kravga station, 4% of both 9- and 12-month periods experience extreme drought. Extreme drought occurs at Karahacılı station in only 2% of 6- and 9-month periods. At Lamas station, extreme drought was observed for 4% of the 6-month period. At Efrenk station, 2% of 3- and 6-month periods and 4% of 9- and 12-month periods have extreme drought. At Pamuk station, 2% of 6-, 9-, and 12-month periods experience extreme drought. In general, when duration is longer, the number of severe and extreme drought events increases in all sub-basins.

Severe and extreme drought for all timescales and the SPI index was observed at three stations: Gördürüp, Kravga, and Hamam. The percentage of severe and extreme drought varies from 2% to 6% at these stations on all timescales. In 10% of 9- and 12-month periods, extreme drought occurs at Lamas station. Neither severe nor extreme drought events were observed on the 3-month timescale at Karahacılı, Lamas, Efrenk, and Pamuk stations. However, the percentage of these drought events increases on other timescales, more evidently in the lower part of the sub-basins. This shows that the percentage occurrence tendency of meteorological drought events in the study area is substantially high in the lower part. Similar results related to spatial differences of SPI and SSI were obtained when comparing this study with previous research covering the Seyhan and Ceyhan river basins (e.g., Sönmez et al., 2005; Gümüş and Algın, 2017; Bayer Altın et al., 2020).

In terms of SPI values, extreme drought events occurred in the middle and south of the eastern Mediterranean Basin, while in terms of SSI values, they were encountered in the northeast of the Seyhan and Ceyhan river basins (Gümüş and Algın, 2017).

4.2 Correlation between SPI and SSI

Since the study area is located in a semi-arid climate zone, increasing the sustainability of water conservation and usage balance is of great importance. Effective water resource management can only be achieved by identifying hydrological drought occurrence and obtaining early warning information (Gümüş and Algın, 2017). Pearson's correlation coefficients (r values) based on SPI and SSI values in series on timescales from 1 to 24 months are shown in Figure 5a. For 1- and 3-month timescales, correlation is weakest, with coefficients varying from –0.08 to 0.18 and from –0.24 to 0.16, respectively. Correlation on the 6-month timescale is similar to that on the 3-month timescale, being weakly positive and varying from 0.11 to 0.47. On the 9-month timescale, correlation varies between 0.11 and 0.53. The correlation coefficient between SPI and SSI on the 12-month timescale is also similar to the 9-month value, ranging between 0.21 and 0.54. However, for the 24-month timescale, the correlation coefficient has a strongly positive value, varying from 0.42 to 0.79.

SPI and SSI for Gördürüp, Kravga, and Hamam stations located in the upper and middle parts have correlation coefficients of 0.79, 0.77, and 0.75 on the 24-month timescale, respectively, while for Karahacılı, Pamuk, Lamas, and Efrenk stations in the lower part, correlation coefficients are 0.53, 0.53, 0.49, and 0.42, respectively. This suggests that the relationship between SPI and SSI is stronger for longer timescales. Findings of SPI and SSI at longer timescales can indicate dry period duration in the basin, given that SPI responds slower as timescale increases and cycles of positive or negative SPI values become more visible. Furthermore, the period of occurrence and duration of dry years differ from station to station. Generally, results indicate that drought events are frequent at shorter timescales but last for shorter durations, while at longer timescales droughts are less frequent but persist for longer periods. SPI at longer timescales such as 12 and 24 months is suitable for representing droughts since these events usually take longer to become evident as SPI responds more slowly to short-term precipitation variation. These results are consistent with previous studies on river basins under Mediterranean climate influence (Loukas and Vasiliades, 2004; Vasiliades and Loukas, 2009; Lorenzo-Lacruz et al., 2013; Ljubenkov and Kalin, 2016; Bayer Altın et al., 2020). Using SPI and SSI analysis on 12-month and longer timescales, these researchers reported that streams tend to conform to the general pattern characterized by prolonged passivity in hydrological response to meteorological drought conditions. Results related to streamflow index having the strongest correlation with precipitation during longer timescales (12–24 months) were detected in other Mediterranean regions and countries (Ljubenkov and Kalin, 2016; Gümüş and Algın, 2017; Boudad et al., 2018). According to Salimi et al. (2021), in northern Iran, the high correlation coefficient between SPI and SSI for the 24-month period means that meteorological drought in the region immediately affects surface water. However, Lamas station has average correlation values, indicating that the lower channel of the Lamas causes rapid flow due to topographic features. This contrast between upper and lower parts may be explained by natural and artificial factors. The natural component of streamflow consists of precipitation from the water collection area located in the Taurus Mountains, which meets moist air masses from the sea. This area corresponds to the upstream sub-basins with small settlements. The artificial factor results from human activity requiring excessive water consumption for agriculture, urbanization, and animal husbandry in the lower sub-basins. It is evident that relief characteristics and artificial factors in the sub-basins influence the correlation between precipitation and streamflow indices at these stations. Therefore, correlation coefficients for watercourses can differ considerably among individual sub-basins of the eastern Mediterranean Basin. The combination of human activities alongside natural catchment and climate characteristics likely produces more divergent results (Barker et al., 2016).

Figure 5b and Table 4 show the relationship between SPI and SSI for each month. On a monthly scale, a moderate positive correlation ($0.20<r<0.50$) between SPI and SSI was observed in January, the coldest month, at all stations except Gördürüp and Lamas. This moderate correlation is weaker during winter months on shorter timescales. A negative correlation was encountered in September at all stations except Gördürüp. This month generally follows summer (especially August) and precedes autumn (October and November). In this case, correlations between SPI and SSI indicate seasonal differences on shorter timescales (e.g., 1 month). Correlations during winter and spring are moderate and weak but positive, related to the fact that most precipitation falls between January and May and snowmelt extends from January to June, with discharges especially in March, April, and May. In contrast, correlations in summer and autumn are weak and negative due to low precipitation prolonged from summer to the end of autumn. Thus, the lowest negative correlation coefficient values were encountered in September at all stations, ranging between –0.11 and –0.01.

The increase in precipitation at the end of autumn and beginning of winter also causes increased streamflow. Thus, the highest and most positive correlation values were found in January, ranging between 0.26 and 0.54. As timescale length increases, the correlation between precipitation and streamflow indices becomes clearer, indicating seasonal connectivity between hydrologic index and precipitation in sub-basins. Ljubenkov and Kalin (2016) stressed that water level has the strongest correlation (r>0.70) in winter and spring months for shorter timescales in Slovenia. Such information can guide water resources management by providing more exacting evaluation of watershed processes (Farjad et al., 2016).

5 Conclusions

In this study, hydrological and meteorological droughts based on SSI and SPI using monthly precipitation and streamflow time series were analyzed for four sub-basins in the eastern Mediterranean region of Turkey during 1967–2017. The percentage of drought events is more pronounced in the lower part of sub-basins at longer timescales, indicating that the percentage occurrence trend of meteorological drought events is significantly higher in the lower sub-basins. Extreme and severe SPI values for all timescales emerged as severe and moderate hydrological drought in the following year from the end of 1990. Extreme hydrological droughts were observed after 1990–1991. Meteorological drought causes decreased streamflow in the following year and is reflected as hydrological drought, which became more evident since the mid-1990s at all stations. SPI-12 values show that extreme and severe drought events occurred in 2013–2014, while drought events for SSI-12 appeared in the following year (2014–2015). The correlation between SPI and SSI is stronger in the upstream environment of sub-basins where the natural environment is preserved than in downstream environments. There is a strong positive correlation between SPI and SSI for longer timescales (9, 12, and 24 months), while correlation is negative and slight for shorter timescales (e.g., 3 months). The highest and most positive correlation values (0.26–0.54) were found in January because precipitation increases in late autumn and early winter, leading to increased streamflow.

These results can be applied in planning water resource use in the eastern Mediterranean Basin to achieve better water management and sustainability. For appropriate management of sustainable water resources, it is necessary to understand basin sensitivity to drought, which is especially important in the eastern Mediterranean basin where agriculture is the main livelihood. To determine drought tendencies in sub-basins and drought impacts on agricultural production, the findings of this research will guide decision-makers involved in the administrative structure of the region.

Acknowledgements: The authors are grateful to the Turkish State Meteorological Service for providing meteorological data (precipitation dataset) and the

General Directorate of State Hydraulic Works for providing streamflow data. We specially thank the anonymous reviewers for valuable comments and suggestions that improved article quality, and the journal editors.

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Note: Figure translations are in progress. See original paper for figures.