Evaluation of Streamflow Drought Index in Aegean Region, Turkey

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Abstract. Water is an invaluable substance of which ensures the life cycle and hydrological events across the world. In this respect, water deficit also known as drought is a natural disaster related to water scarcity in time and space. Although there is no solid definition for the phenomenon, the outcome of repeated wet and dry spells cause in economic, social, and political problems at regional, country-wide, and world-wide scale. In this study, drought associated with the streamflow in the Aegean region, which has an important economic, historical and socio-cultural role in the western Turkey, is investigated through the well-known streamflow drought index (SDI). Therefore, average discharge in the Çiçekli-Nif, Beşdeğirmenler-Dandalas, Bebekler-Rahmanlar and Koçarlı-Köprübaşı station respectively related to on Gediz, Büyük Menderes and Küçük Menderes basins were used. Then SDI with 1, 3, 6,12 months moving average are acquired to express the drought severity associated with the streamflow in the basins. Results showed that the SDI values in all of stations together with the 1, 3, 6, and 12-month moving averages depicts similar results and no abnormal situation exist during the study period.

Keywords: Aegean region · Drought · Streamflow drought index · Hydrology

1 Introduction

Water is the most vital commodity that ensures the life and hydrological cycle across the globe. For this, water deficit also known as drought can be distinguished as a natural disaster related to the long lasting dry spells across a region through time and space. To this end, there is no universally acceptable definition for the drought phenomenon mostly due to the diverse aspects and the outcome [1–3]. This disaster influences natural habitats, ecosystems, and various economic and social sectors, urban water supply, the modern multiple manufactories and from the agriculture to transportation [4]. Types of droughts have been classified under five categories respectively as meteorological,

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hydrological, agricultural, socioeconomic, and ecological. One of the most important types of drought is hydrological drought, as it affects many activities such as hydropower generation, industrial and urban water supply on surface water resources [5]. Several drought indices were developed to characterize hydrological droughts. Due to the index value indicates the level of drought severity, drought conditions is to use drought indices, because they provide a quantitative method for determining the onset and end of a drought catastrophe [4, 6].

In this study, drought associated with the streamflow in the Aegean region, which has an important economic, historical and socio-cultural role in the western Turkey, is investigated through the well-known streamflow drought index (SDI). Therefore, average discharge in the Çiçekli-Nif, Beşdeğirmenler-Dandalas, Bebekler-Rahmanlar and Koçarlı-Köprübaşı station respectively related to on Gediz, Büyük Menderes and Küçük Menderes basins were used. Then SDI with 1, 3, 6, 12 months moving average are acquired to express the drought severity associated with the streamflow in the basins.

2 Study Area

To this end, the Büyük Menderes, Küçük Menderes and Gediz Basin located in the west of Turkey are selected as the study area for further discussion (Fig. 1). Then, monthly streamflow time series in 4 hydrology stations during the 1973–2015 period are used, while the data were recorded at Beşdeğirmenler-Dandalas, Koçarlı-Köprübaşı, Bebekler-Rahmanlar and Çiçekli-Nif which are located Büyük Menderes, Küçük Menderes and Gediz basins respectively. Table 1, also details the location of the selected stations, position of the basins, names of the sub-basin and the study period.

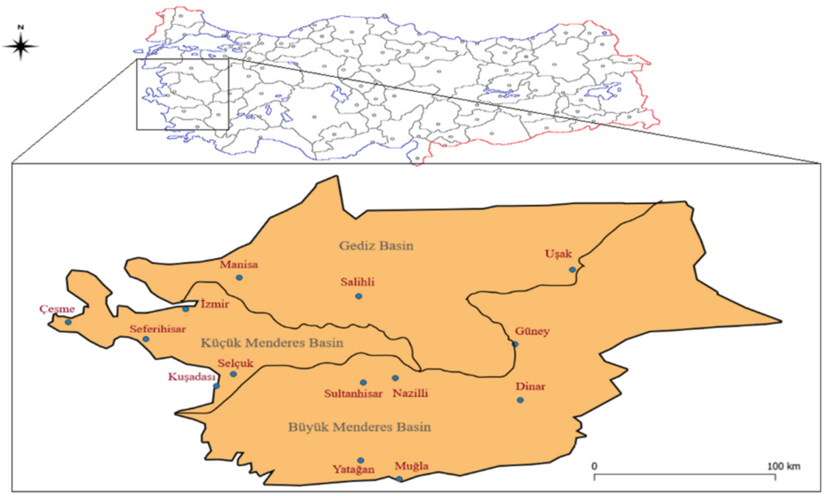

Fig. 1. Study area and location of the hydrology stations

Table 1. Observation times and geographical information of the selected stations

Station	Basin	Subbasin	Location
Çiçekli-Nif	Gediz	KemalPaşa-Nif Çayı	38°29′41"N 27°17′54"E
Beşdeğirmenler-Dandalas	B. Menderes	Akçay Havzası	37°48′18"N 28°34′48"E
Bebekler-Rahmanlar	K. Menderes	K.Menderes Havzasi	38°17′18"N 27°55′41"E
Koçarlı-Köprübaşı	B. Menderes	Aydın-Söke Havzasi	37°18′36"N 27°42′47"E

3 Quality of the Data

The streamflow time series data were obtained from the State Water Works in the daily total streamflow format. Afterward, consistency, randomness, and trends in the data were examined respectively with double mass curve, run test, linear trend test methods. Therefore, a set of complete and qualified time series are obtained to be used as the inputs to the drought analysis detailed below.

4 Streamflow Drought Index (SDI)

The SDI method is used to estimate the frequency and severity of the hydrological droughts based on the drought impact on the river basin. In this method, to compute SDI, it is assumed that a time series of monthly streamflow $Q_{i,j}$ is available where i stand for the hydrological year and j is the month within the same hydrological year. Cumulative streamflow volumes from varied time periods are used to investigate the variation and distribution of drought severity at different time durations, from which the frequency of drought occurrence of study region, occurrence of circle and drought severity are reached. In this way, it is estimated that the time series of monthly streamflow volumes ($Q_{i,j}$) are consecutive, that are accumulated according to the time duration of k. The cumulative streamflow volume can be obtained as

$$V_{i,k} = \sum_{i}^{3k} Q_{I,J} i = 1, 2, \ldots, 12, k = 1, 2, 3, 4 \quad (1)$$

where $V_{i,k}$ is the cumulative streamflow volume for the ith hydrological year with a period duration of k. Then the SDI for the ith hydrological year with period duration k is defined computing the cumulative streamflow volumes $V_{i,k}$ as follows:

$$SDI_{i,k} = \frac{V_{i,k} - \overline{V}_k}{S_k} i = 1, 2, \ldots, 12, k = 1, 2, 3, 4 \quad (2)$$

where $\overline{V}_k$ refers to long term mean of cumulative streamflow volumes and S_k refers to standard deviation of cumulative streamflow volumes.

When evaluating an SDI value, the data for analysis must follow a normal or log-normal distribution. Nonetheless, in small basins, streamflow may follow a skewed probability distribution, whose distribution pattern is alike that of the Gamma distribution. Thus, in this study, SDI values were calculated using gamma distribution with the help of DrinC software. DrinC software was improved at the Centre for the Assessment of Natural Hazards and Proactive Planning and the Laboratory of Reclamation Works and Water Resources Management of the National Technical University of Athens [7].

For each year the computed SDI values are categorized based upon the range for which varied drought severities are described. In this study, drought severity classification was used as a reference to the different drought severity developed by Al-Faraj et al. [8]. After which the SDI values are computed, results could easily be interpreted by means of threshold values given in Table 2.

Table 2. SDI values for drought severity classification

Index value	Description
SDI $\geq$ 2	Extremely Wet
2 $\geq$ SDI $\geq$ 1.5	Very Wet
1.5 $\geq$ SDI $\geq$ 1	Moderately Wet
1 $\geq$ SDI ≥ -1	Near Normal
$-1 \geq$ SDI ≥ -1.5	Moderately Dry
$-1.5 \geq$ SDI ≥ -2	Severe Dry
SDI ≤ -2	Extremely Dry

5 Result and Discussion

The consistency in the time series are checked using double mass curve and then *z*-values related to the run test are checked for the 95% confidence ($-1.96 \leq Z \leq +1.96$). Since the *z*-score associated with the selected time series are outside of the mentioned range, the time series considered not to be random (Table 3).

Table 3. Z-Scores of the Run test for streamflow data

Station name	Streamflow
Çiçekli-Nif	−65.32
Bebekler-Rahmanlar	−60.36
Beşdeğirmenler-Dandalas	−57.15
Koçarlı-Köprübaşı	−58.99

The results of trend analysis also showed that, the Bebekler-Rahmanlar Station demonstrates negative direction among all stations, meaning that streamflow values decrease during the study period. However, no significant trend at the remaining 3 stations, are observed that means average streamflow values at these stations are constant.

Streamflow drought index values for each month were also calculated and evaluated by considering the average values of each month. SDI values results from time period of 1981–2015 belonging to observation stations of Çiçekli-Nif, Beşdeğirmenler-Dandalas, Bebekler-Rahmanlar and Koçarlı-Köprübaşı are obtained as shown in the Fig. 2. In this context, the highest and the lowest SDI-1 were respectively seen as 4.23 in Beşdeğirmenler-Dandalas and −3 in Bebekler-Rahmanlar stations. Similarly, the wettest and driest SDI-3 were respectively observed as 4.30 in Beşdeğirmenler-Dandalas station and −3.31 in Bebekler-Rahmanlar stations. The highest SDI-6 value was recorded as 4.36 at Bebekler-Rahmanlar station and the lowest SDI-6 value was -3.31 at Çiçekli-Nif station. Finally, the highest SDI-12 value was 4 at Bebekler-Rahmanlar station and the lowest SDI-12 value is −2.75 at Çiçekli-Nif station. Therefore, for all moving average values of all stations (1-, 3-, 6-, 12-month) based on general averages and for 1-month MA, no drought was detected, at 1981–2015.

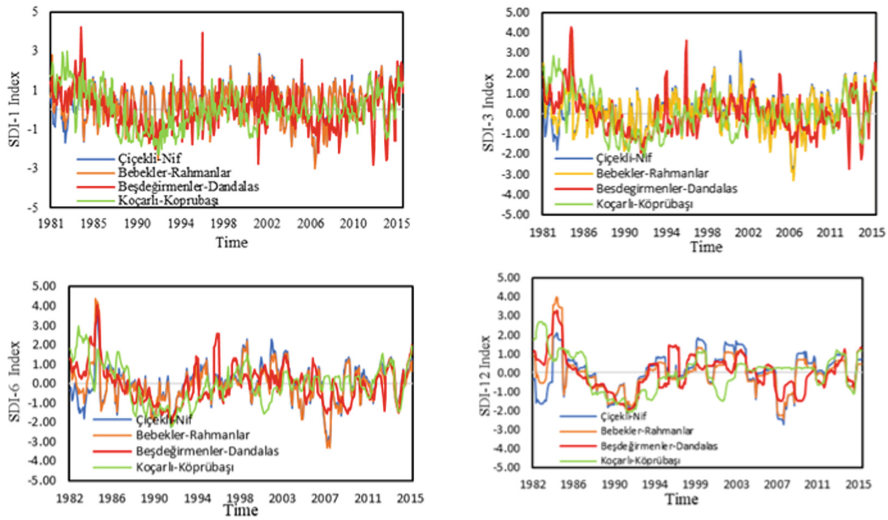

Fig. 2. SDI-1, SDI-3, SDI-6 and SDI-12 Graphs

6 Conclusion

The study area is a region where metropolitan cities such as Izmir and Aydın are located and whose population is constantly increasing. Agricultural activity is also very common. 34 years of streamflow records associated with 4 stations located in Büyük Menderes, Küçük Menderes, and Gediz basins were used to calculate the SDI drought indices on 1-, 3-, 6- and 12-month time scales. Initially, it was understood that the data was not random and consistent because of the tests applied. In addition, it was determined that there was no trend in streamflow with 3 stations and there was negative direction trend in just one station. Then, the spatial average of the historical SDI patterns was obtained separately to determine the drought events in the basins according to each index.

This study is limited to historical hydrological drought indices. Trends in drought indices could be extended to future periods based on anticipated outputs of global climate models to make an educated choice for sustainable watershed planning and management and to optimize the operating rules of current water resources. If future studies take into consideration meteorology, agricultural, and socioeconomic droughts, the findings will be more relevant.

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