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COMPARING TWO STREAMFLOW-BASED DROUGHT INDICES

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Abstract
Analysis of drought in terms of water resources management is crucial. In the presented study, drought analysis in Küçük Menderes Basin in Turkey was carried out based on the streamflow measurements. Küçük Menderes Basin holds primary significance due to the role of agriculture as the biggest sector in the area. In the analysis, Standardized Streamflow Index (SSI) and Streamflow Drought Index (SDI) were used to model drought. SSI and SDI indices were computed at multiple time steps for the period 1972-2015 at selected streamflow gages in the basin. Prior to the computation of drought severity indices, homogeneity analyses, which included Standart normal homogeneity test, Buishand range test and Pettitt test were applied for homogeneity checks on the data set. Mann-Kendall non-parametric test was also used to detect possible trends in streamflow data. The results of the study enabled the evaluation of the basin status regarding drought as well as the selection of the most appropriate index for drought analysis in the basin.
Keywords: Standardized streamflow index, streamflow drought index, drought.

1 INTRODUCTION

Drought is a natural disaster, which has significant and widespread impacts especially on people and many economical sectors, and its severity and frequency are increasing due to the global warming. Drought affects very large areas and populations, causing economic and environmental problems, which can lead to irreversible damages (Spinoni et al., 2015; Vogt et al., 2011; Vogt and Somma, 2000). Analysis of drought in terms of water resources management is crucial. A good understanding of spatial and temporal characteristics of drought at a basin on regional and national level is required for efficient water resources management. In addition, determination of the severity, distribution and size of the drought and monitoring it by this way is of great importance for the strategic, planned and effective management of the drought.

Indices are the good way of monitoring the drougth and the data from which we calculate the indices are important. Data related to drought should be examined in a multidirectional way. In this research, the Küçük Menderes Basin in Turkey was selected as the study area due to its economical importance in agriculture where the irrigable agricultural lands are nearly %37 of the whole basin area and agriculture has a long-standing tradition in this region. Drought severity was analysed based on the Standardized Streamflow Index (SSI) and the Standardized Drought Index (SDI) in multiple time scales (3, 6 and 12-month) in the basin to define drought conditions and other related hydrological impacts.

2 MATERIALS AND METHODS
2.1 Study area

Küçük Menderes Basin is located between Büyük Menderes and Gediz Basin in the west of Turkey (Figure 1). The area of the basin is about 7000 km^2 and the main river of the basin, Küçük Menderes River, flowes into the Agean Sea. The mountains in the basin are the east-west direction and the east part is higher (between 1000-2200 m.) than the west coastal part (nearly between 100-400 m.)

The climate of the basin is typical Mediterranean climate known with hot and drought summers and mild winters with precipitation. The winters in the higher plains of the basin are snowy and cold. In the basin, mean annual precipitation is about 707 mm and the mean annual temperature is 16.8°C.

Agriculture is the main economic factor in Küçük Menderes Basin. This area is one of the most productive agricultural areas in Turkey. The main crops of the basin are olive, fruits, cotton which have high economic value in Turkish economy.

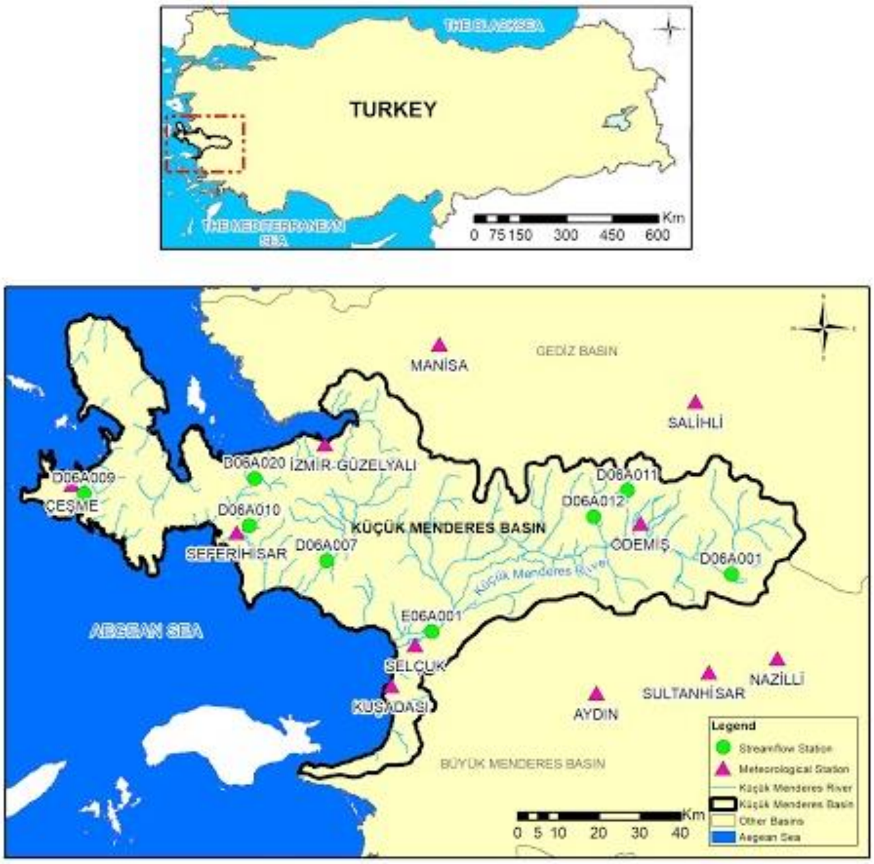


Figure 1. Location of Küçük Menderes Basin

2.2 Data

In order to calculate the SDI and the SSI, recorded monthly streamflow values are required as indicated by the World Meteorological Organization (WMO, 2016). In this study, the monthly streamflow data (m^3/s), covering the period of 1960-2014, was provided by the General Directorate of Turkish State Hydraulic Works (DSI). Eight streamflow stations were selected among 36 stations in the basin. The stations were chosen in a way to represent the whole basin relatively. The length of the streamflow data of each station was limited so as to omit the effect of the regulations such as dams in upstream. The purpose of the limiting the data of the stations is to have natural streamflow as much as possible. While Figure 1 shows the locations of the selected streamflow stations, Table 1 gives information on the streamflow stations, such as the length of streamflow series and the drainage areas of stations.

Table 1. Information on the streamflow stations

STATION NAME	STATION NUMBER	ELEVATION (m)	DRAINAGE AREA (km^2)	SELECTED PERIOD
Küçük Menderes N.-Beydağı Köp.	D06A001	171	445.0	1986-1999
Tahtalı Çayı-Dereboğazı	D06A007	19	512.9	1970-1988
Hırsız Dere-Alaçatı	D06A009	7	40.3	1970-1988
Yası Çay-Çukurköy	D06A010	92	41.0	1975-1990
Rahmanlar Çayı -Bebekler	D06A011	220	37.0	1991-2014
Aktaş Çayı-Bülbüller	D06A012	130	73.4	1985-2002
Çamlı Dere-Çamlı	D06A020	85	68.0	1991-2004
Küçük Menderes Nehri -Selçuk	E06A001	4	3255.2	1960-2007

2.3 Data pre-processing

Homogeneity and trend analyses were carried out before computing the drought indices. Homogeneity analysis was performed to ensure that the data used in the study have adequate quality. Standard normal homogeneity test, Buishand range test and Pettitt test were used for this purpose. These tests were performed by using “trend” package in R Studio software (Pohlert, 2016). The results of the homogeneity tests applied to streamflow data show that data at all stations except two stations numbered as D06A001 and E06A001, are not homogeneous at the %95 confidence level. Mann-Kendall rank correlation method was used for trend analysis (Kendall, M. G., 1962; Mann, H.B., 1945). Using Mann-Kendall test has some advantages, such as its robustness and accommodating to outliers (Helsel, D.R.; Hirsch, R.M., 1992; Yue, S.; Pilon, P.; Cavadias, 2002). Trend analysis identified a decreasing trend at stations D06A010 and E06A001. The results of the homogeneity and trend analyses are given in Table 2.

Table 2. Results of homogeneity and trend analyses

TEST		D06A001	D06A007	D06A009	D06A010	D06A011	D06A012	D06A020	E06A001
BUISHAND	p-value	0.0009	0.1505	0.0764	0.0674	0.3529	0.1036	0.0087	0.0000
	homogeneity	NH	H	H	H	H	H	NH	NH
SNH TEST	p-value	0.0080	0.4085	0.6489	0.1053	0.5638	0.3382	0.3246	0.0000
	homogeneity	NH	H	H	H	H	H	H	NH
PETTITT TEST	p-value	0.1830	0.8233	1.0990	0.03038	0.9628	0.1421	0.2118	0.0000
	homogeneity	H	H	H	NH	H	H	H	NH
MANN KENDALL	p-value	0.5550	0.5466	0.9743	0.00542	0.7006	0.3376	0.4555	0.0000
	trend	NT	NT	NT	T	NT	NT	NT	T

Homogeneous (H); Non-Homogeneous (NH); Trend (T); No Trend (NT)

The data and the condition of the non-homogeneous station D06A001 has been checked out and found that some man-made changes have been carried out. The amount of the public irrigation in the upstream of D06A001 station is 3.85 hm^3 per year, which is intensive comparing to other public irrigation in that area (DSI and Suiş, 2012). The other non-homogeneous station E06A001 was also checked and it was clear that this station was also in the same effect of the public irrigation like the station D06A001. When the period of the data was taken from 2007 to 1985 where the public irrigation has began to effect the natural flow of the river, the homogeneity of the station has been provided. As a result, the limited period of the station E06A001 was used for the calculation of the drought indices but the data of the station D06A001 could not be used for the calculations due to the shortness of the data.

2.4 Drought indices

Nalbantis and Tsakiris (2009) developed SDI by considering monthly streamflow values (Qij), where i is hydrological year and j is month of the hydrological year. The procedure of SDI calculation is statistically similar to Standardized Precipitation Index (SPI).

$$V_{ik} = \sum_{i=0}^{k} Qij \qquad i = 1, 2, 3, ... \qquad j = 1, 2, 3, ..., 12, \qquad k = 1, 2, 3, 4 \tag{1}$$

In Equation (1), V_k is the i^{th} year volume of cumulative flow values. k=1 for October-December, k=2 for October-March, k=3 for October-June, and k=4 for October-September. By using the cumulative streamflow volumes, SDI is calculated for each k and for i^{th} hydrological year as given in Equation (2).

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

$\overline{V_k}$ is the mean and S_k is the standart deviation of cumulative flow values for k^{th} time period.

Hydrological drought classification based on SDI is defined through Table 3 (Nalbantis, 2008), which is identical with SPI classification. Five states are considered which are denoted by an integer number ranging from 0 (non-drought) to 4 (extreme drought).

Table 3. Drought classifications based on SDI

State	Description	Criterion	Probability (%)
0	Non-drought	SDI ≥ 0,0	50.0
1	Mild drought	-1,0 ≤ SDI < 0,0	34.1
2	Moderate drought	-1,5 ≤ SDI < -1,0	9.2
3	Severe drought	-2,0 ≤ SDI < -1,5	4.4
4	Extreme drought	SDI < -2,0	2.3

Modarres introduced Standardized Streamflow Index (SSI) in 2007, and Telesca et al. (2012) investigated it further. In this method, daily or monthly streamflow data can be applied and normalization is used associated with SPI as same as SDI calculation. SSI can be calculated for both observed and forecasted data and it can give a perspective for drought and wet periods (WMO, 2016). SSI is a probability-based index and this makes SSI sensitive to the aspects and assumptions that regulate probabilistic hydrology. Table 4 shows the range of SSI values along with their classifications (Nalbantis, I., Tsakiris, G., 2009).

Table 4. Drought classifications based on SSI

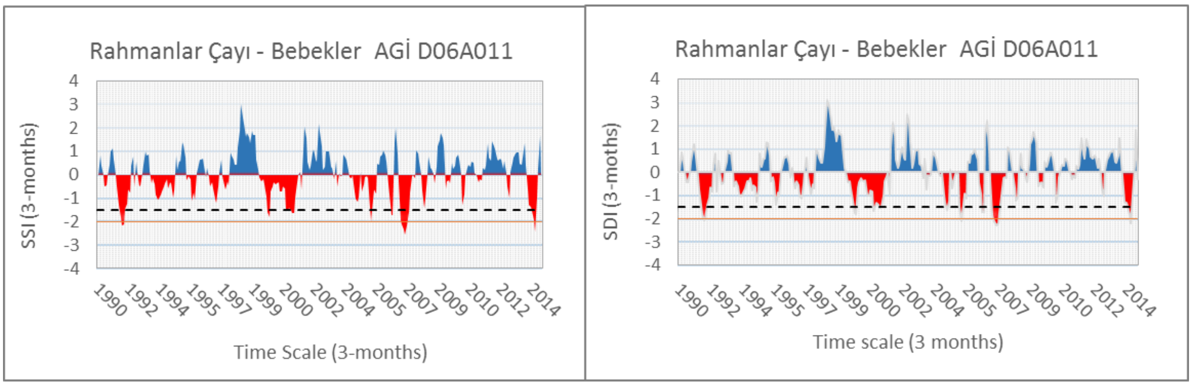
State	Categories	SSI Values
0	Extreme Drought	−∞, −2
1	Severe Drought	−2, −1.5
2	Moderate Drought	−1.5, −1
3	Slight Drought	−1, 0
4	Normal	0, +∞

As expressed by Vicento-Serrano et al. (2012), SDI and SSI are based on the same theory as drought indeces are calculated by transforming monthly streamflows into z-scores.

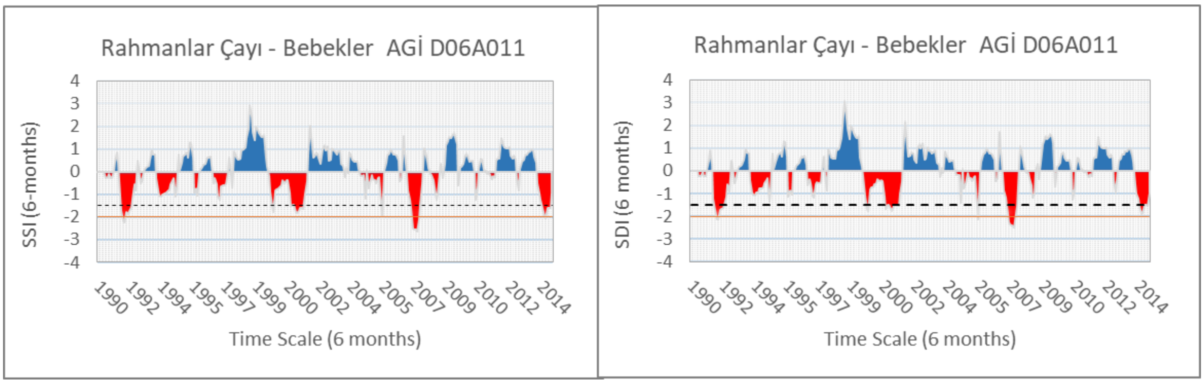
3 RESULTS AND DISCUSSION

SDI and SSI values were computed for 3, 6 and 12-month periods to define drought conditions for each station. SDI values were calculated by using DRINC (http://drinc.ewra.net/) and SSI values were calculated by using R-Studio software.

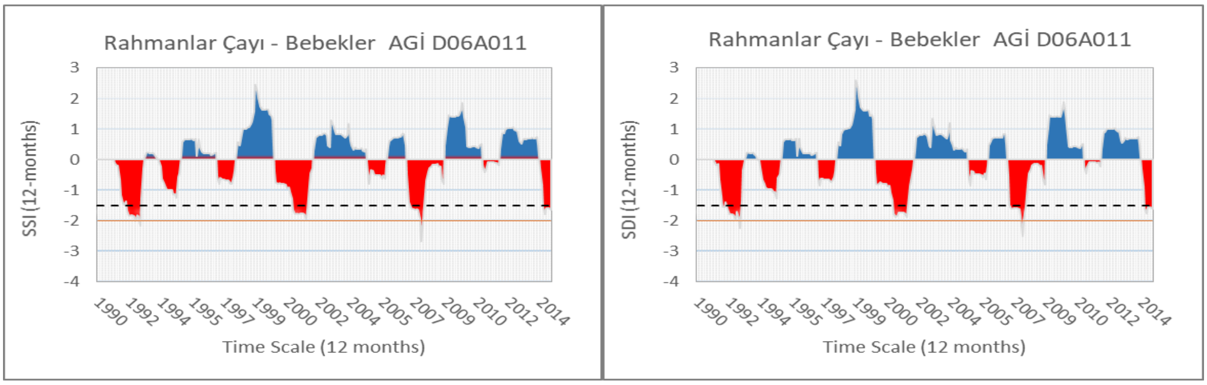
Unbiased probability weighted moments (ub-pwm) method was selected for computing the distribution function parameters, and Gamma distribution function was used to compute SSI values. The distribution function used for calculation of SDI values in DRINC program was chosen as Gamma distribution, as well. Because the best distribution function of streamflow data at almost all stations was determined as Gamma distribution. Figure 3 shows the temporal variations of computed SDI and SSI values for Rahmanlar-Bebekler Station as an example. It can be seen that SDI and SSI indices for multiple time scales over Küçük Menderes Basin prove to indicate similar behavior especially in 12-month values.



(a) (b)



(c) (d)



(e) (f)

Figure 3. SSI and SDI values calculated using the historical observed data (1991–2014) at Rahmanlar-Bebekler station:(a) 3-month SSI (b) 3-month SDI (c) 6-month SSI (d) 6-month SDI (e) 12-month SSI (f) 12-month SDI

Figure 3 also shows the most severe drought periods. The first period is 1991-1992, the second one is 1999-2001, the third one is 2005-2007, and the last period is 2013-2014. For most of the stations, the most severe drought years were identified as 1992, 2001, 2007 and 2014, respectively.

The correlation between two indices are also checked and it has been determined that there is a good correlation between SSI and SDI values. The determination coefficient between SRI and SDI is increasing with respect to duration (Figure 4).

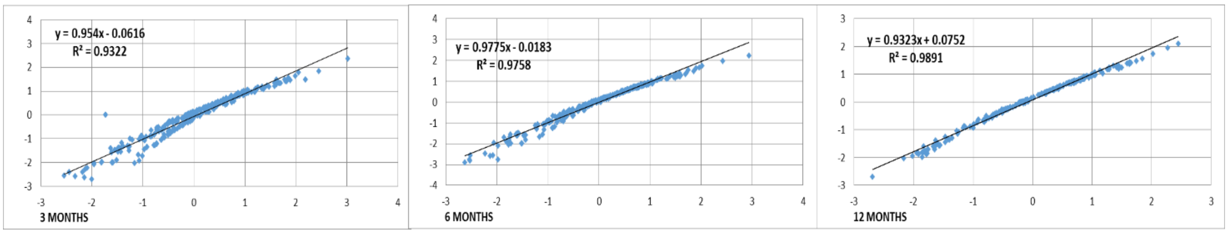


Figure 4. Correlation of SSI and SDI values for 3, 6 and 12-month time periods

Finally, trend analysis was carried out for SSI and SDI by using the Mann-Kendall rank correlation method. It was determined that there was increasing trend for 6 and 12-month time scale and no trend was analyzed for 3-month time scale.

4 CONCLUSION

In the presented study, SSI and SDI indices were computed and compared in Küçük Menderes Basin. Both of the indices indicate nearly same periods for severe and extreme drought in the basin. Correlation between two indices shows that there is no significant difference between SSI and SDI especially for longterm drought analysis. As the duration increases the tendency of similarity between SSI and SDI is rising. Therefore using these two indices for longer period of analysis will certainly be more confidential. Another outcome of the analysis is that there is an increasing trend in drought severity. Drought analysis using drought indices is of great importance where it provides very important information on drought severity, frequency and duration. Due to the importance of the Küçük Menderes Basin by means of agriculture, it is very clear that it will be affected by climate change significantly. Therefore, establishing drought management plan of Küçük Menderes Basin is urgent and following priority is to execute those plans on site as soon as possible.

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