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Research article

Assessment of Hydrological Drought Index change over long period (1990–2020): The case of İskenderun Gönençay Stream, Türkiye

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Abstract: Recently, due to changes in the global climate, there have been significant increases in flood and drought events. The changes in wet and dry periods can be examined by various methods using hydrometeorological data to analyze climate disasters. In this study, Gönençay Stream in the Asi River Basin was chosen as the study area, which contains abundant underground and surface water reserves in Türkiye. Within this region, not only are the agricultural activities intense, but also hydraulic structure applications such as dams and reservoirs draw attention. Previous studies stated that meteorological and agricultural droughts have started to be noticed in the basin. Therefore, temporal variation analyses can positively contribute to assessing possible hydrological droughts in the following years. In this context, wet and drought periods were determined using the Streamflow Drought Index method at 3, 6, 9, and 12-month time scales with monthly average flow data observed between 1990 and 2020. At the same time, the number and probabilities of drought categories on a 12-month time scale, the first expected transition times between classifications, and the expected residence times between categories were specified. The study revealed that the most severe dry period occurred between 2013 and 2014 and was classified as Extremely Drought. The wettest period was around 2018–2019 and was classified as Extremely Wet. The largest expected time residence among all classifications was calculated for the Extremely Drought category with nine months, means that if the Extremely Drought period ever occurs, it remains for approximately nine months. While the Moderately Drought period occurred within one month following the Extremely Drought duration, and a Near Normal Wet period was observed three months after the Extremely Wet period. The most seen drought category for monthly calculations was the Near Normal Wet category, and was seen over 200 times with a 52.8% probability. Considering the Gönençay region, it is possible that any Extreme drought classification eventually regresses to normal.

Keywords: Hydrological Drought; Streamflow Drought Index; transition probabilities between drought classifications; Asi River Basin; Gönençay Stream (Türkiye)

1. Introduction

In the globalizing world, climatic changes and the time-dependent change in water consumption have significantly increased the number of natural disasters such as drought and floods. The incidence of these disasters can vary over the years, so it is critical to maintain water resources for their continuous use. Hydrological studies supplemented with historical data provide essential contributions to the preparation of water management policies more appropriately. In recent years, studies dealing with the long-term change of drought with various indices using hydrometeorological data have become more frequent, especially in arid and semi-arid areas. A common drought index is the standardized precipitation index (SPI). Unlike other indices, the SPI applies the observed precipitation measurements as the input data. The SPI method was developed by McKee et al. [1]. In the literature, there are many studies in which the SPI and meteorological drought are examined regionally [2–15]. With the SPI, the transition from dry to wet periods or vice versa can be studied during a certain period [16–19]. The index values provide a quantitative approach to the onset of drought and how it continues over time. Positive SPI values represent wet periods, while those with negative ones represent drought periods [18,20,21]. The fact that these transitions occur in large numbers affects the wet and drought formation. The streamflow drought index (SDI) method discussed in this study was developed by Nalbantis and Tsakiris [22]. Similar to the SPI calculation, only current data is used as the input data in the SDI method [23–30]. The SDI is independent of soil parameters or other properties, allowing this method to be the most practical side of this index. Additionally, wet and dry periods can be simultaneously considered. Furthermore, the practical application of the index allows researchers to examine more extensive areas as long as there are available discharge data.

Due to global climate change, problems such as decreasing precipitation and above-normal temperatures have begun to emerge. As a result, decreases in precipitation values also diminish the flow transferred to the basin, revealing hydrological, meteorological, and agricultural droughts. Consideringthe literature, many studies have focused on drought research specific to the Asi River Basin [24,31–34]. In these studies, it is stated that Extremely Drought periods are frequently observed around the Iskenderun region. While agricultural practices are a priority for the selected area, the number of water structure applications have also increased tremendously. Therefore, it is forecasted that in addition to meteorological and agricultural drought studies, examining hydrological drought indices over long periods will be helpful for feasibility evaluations. Moreover, the transition probabilities between drought classifications based on the hydrological drought approach for the Iskenderun region will significantly contribute to the literature. With the occurrence of a probability analysis, index outcomes become more understandable. Since agricultural and hydrological drought may cause significant adverse effects in this region, it is crucial to acknowledge and digitize the output of indexes. In this study, the Gönençay Stream in the Asi River Basin was determined as the study site by using the monthly average flow data between 1990–2020; wet and drought periods were investigated with the SDI method at 3, 6, 9, and 12-month time scales. In the literature, most drought indexes are examined by themselves. Without any further probability of occurrence studies, it is hard to visualize and foresee the possible drought expectancies. The prominent aspect of the study in the literature can be stated as the inspected historical or possible future drought occurrences. For a more detailed analysis, the occurrence probabilities of eight drought classifications for a 12-month time scale, the first expected transition times between classifications, and the expected residence times between categories were considered. With this additional feature, this study differs from the drought index researches made, especially in the Asi River Basin. Thanks to this part of the study, not only were wet and dry period investigations carried out, but also occurrence frequencies and probabilities of these periods were taken into account.

2. Materials and methods

2.1. Study area and data used

The Asi River Basin is considered as one of the most crucial basins of Turkey in terms of water resource potential. This reserve consists of both underground and above-surface water resources. The fruitful agricultural areas of the Gönençay region also have a great importance for economic development. Although most of the water utilized is provided from underground resources, surface water can also be considered a primary resource in the future. With the scope of the study, data between 1990 and 2020 from the gauging station no. D19A016 on Gönençayı Stream near İskenderun were preferred (Figure 1). The D19A016 station is between 36º 26' 16" north latitude and 36º 01' 08" east longitude. The catchment area of the station is 94 km^2, and its elevation value is 240 m. During the observation period, the average monthly flow value was approximately 1.40 m^3/s. Additionally, the minimum discharge is 0.010 m^3/s, and the maximum flow rate is 78.40 m^3/s [35]. The data were divided into three periods, 1990–2000, 2001–2010, and 2011–2020, and analyzed in detail to determine the number of wet and drought years.

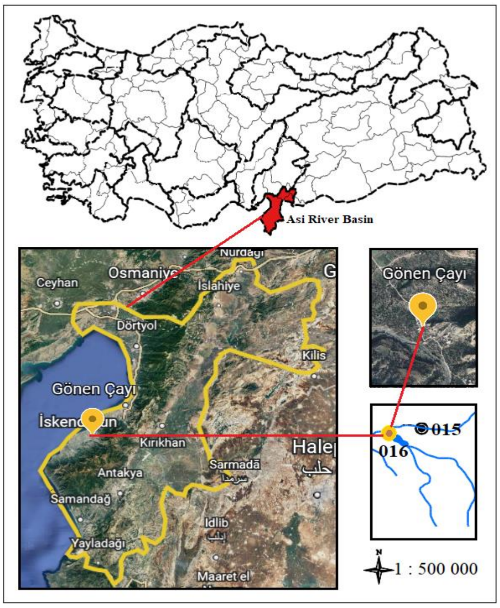

Figure 1. The location of the Gönençay gauging station (D19A016).

2.2. Streamflow Drought Index (SDI)

Although the SPI represents meteorological drought and the SDI represents hydrological drought, there are some similar features in both index computations, which are widely preferred in the literature for various time scales [1]. While the SPI method only accepts the observed precipitation data as variables, the SDI method applies discharge data as the input parameter [22]. In addition to both the SPI and DPI methods having common advantages, there are also some disadvantages. For example, both indices have a single type of data, and the precision of the results can vary depending on the length of this data series [36]. In addition, it is stated in the literature that effective results may not be obtained for indices that have only one input data and are calculated with probability distribution formulations unless the probability distributions are well determined. Therefore, this study calculated the indice according to the normal distribution, considered one of the most basic probability distributions [37]. The flow data specified in Equation 1 is shown as $Q_{a,b}$, where "a" represents the hydrological year, "b" means the month in a water year, and k symbolizes the reference period. Equation 1 expresses the way the cumulative flow volume is evaluated in the SDI method [26]:

$$V_{a,k} = \sum_{b=1}^{3k} Q_{a,b} \quad a = 1,2,\dots b = 1,2,\dots.,12 \quad k = 1,2,3,4 \tag{1}$$

In Equations 1 and 2, k = 1 represents the October-December period, k = 2 represents the October-March period, k = 3 represents the October-June period, and k = 4 represents the October-September period were implemented for the calculations. The SDI values for each k period of a hydrological year according to the cumulative discharge volumes are obtained as follows [26] (Equation 2):

$$SDI_{a,k} = \frac{V_{ak} - \overline{V_k}}{S_k}, k = 1,2,3,4 \tag{2}$$

$\overline{V_k}$ and S_k in the Equation 2 symbolizes the cumulative flow rate's average and standard deviation values, respectively. In Equation 2, V_{ak} is a streamflow value of specified time ("a" indice as water year and "k" as period of the year). Eight different classifications ranging from Extremely Wet to Extremely Drought were specified to examine at what level the results represent the wet and drought periods. The classifications are shown in Table 1 [29]:

Table 1. SDI method drought classification ranges [29].

SDI Values	Classification
SDI ≤ −2	Extremely Drought (ED)
−2 < SDI ≤ −1.5	Severely Drought (SD)
−1.5 < SD I≤ −1	Moderately Drought (MD)
−1 < SDI ≤ 0	Near Normal Drought (ND)
0 < SDI ≤ 1	Near Normal Wet (NW)
1 < SDI ≤ 1.5	Moderately Wet (MW)
1.5 < SDI ≤ 2	Severely Wet (SW)
SDI > 2	Extremely Wet (EW)

3. Results and discussion

This study aimed to examine hydrological drought over time. In this context, the Gönençay Stream in the Asi River Basin was selected as the study area because of its abundant water reserves. From the recorded discharge data between 1990–2020, wet and drought periods were evaluated with the SDI method at 3, 6, 9, and 12-month time scales. In addition, the number and probability of occurrence, the first expected transition times between classifications, and the expected residence times between categories were also assessed in a 12-month time scale.

Considering the inferences obtained from the study, the most intense drought period occurred between 2013 and 2014 with the Extremely Drought classification [33]. Additionally, the wettest period occured between 2018 and 2019 with the Extremely Wet classification. In the first ten years, wet period numbers were predominant for 8 years, while in the last 20 years, there was an increase in the frequency of dry periods and wet periods counted as 12 out of 20 [31,34]. Moreover, wet and drought periods in the first ten years were generally at the Moderately level. However, for the last ten years, there was an increase in the severity of wet and drought periods because the SDI values in the Moderate category changed to Extreme (Figure 2).

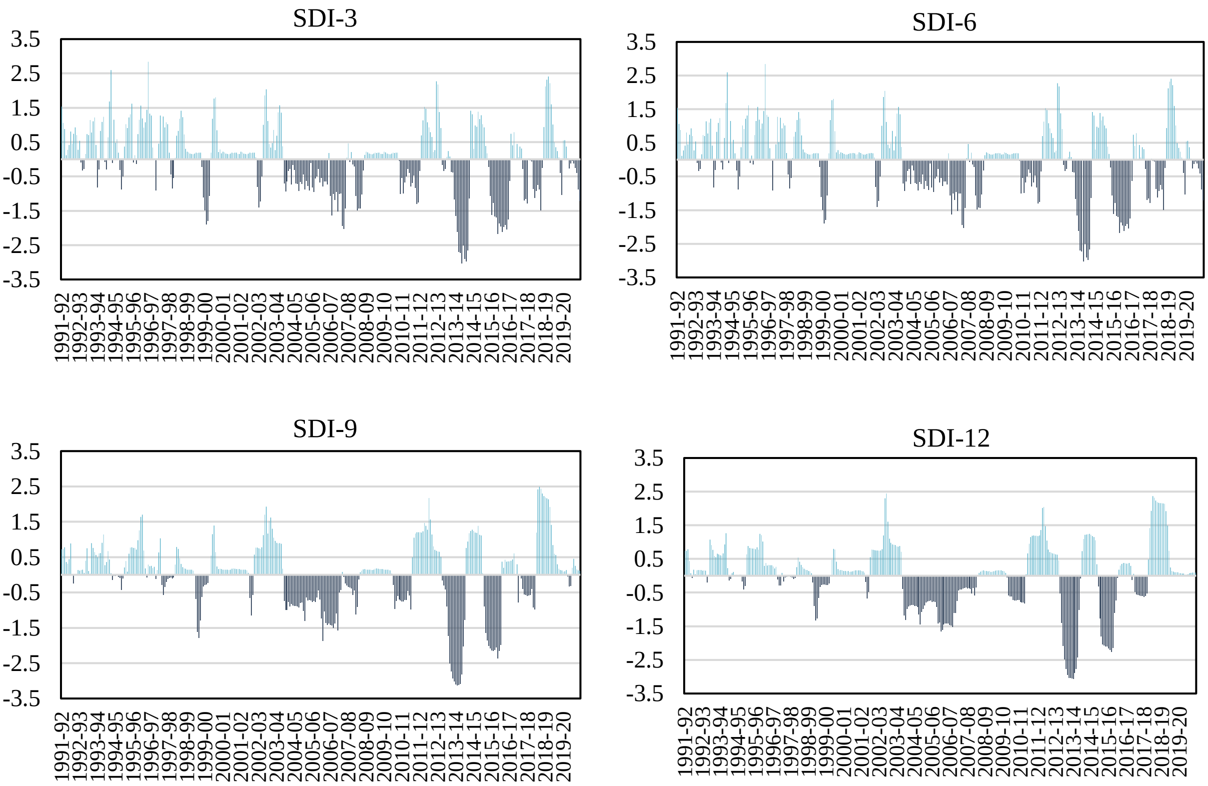

Figure 2. Change of monthly SDI values according to 3, 6, 9, and 12-month time scales.

There was always a continuous drought period between 2003 and 2008 [29]. This drought duration was determined as the most extensive continuous period ever. Hence, from the trend change, it can be said that the SDI-3 July period is the most vulnerable duration (Figure 3).

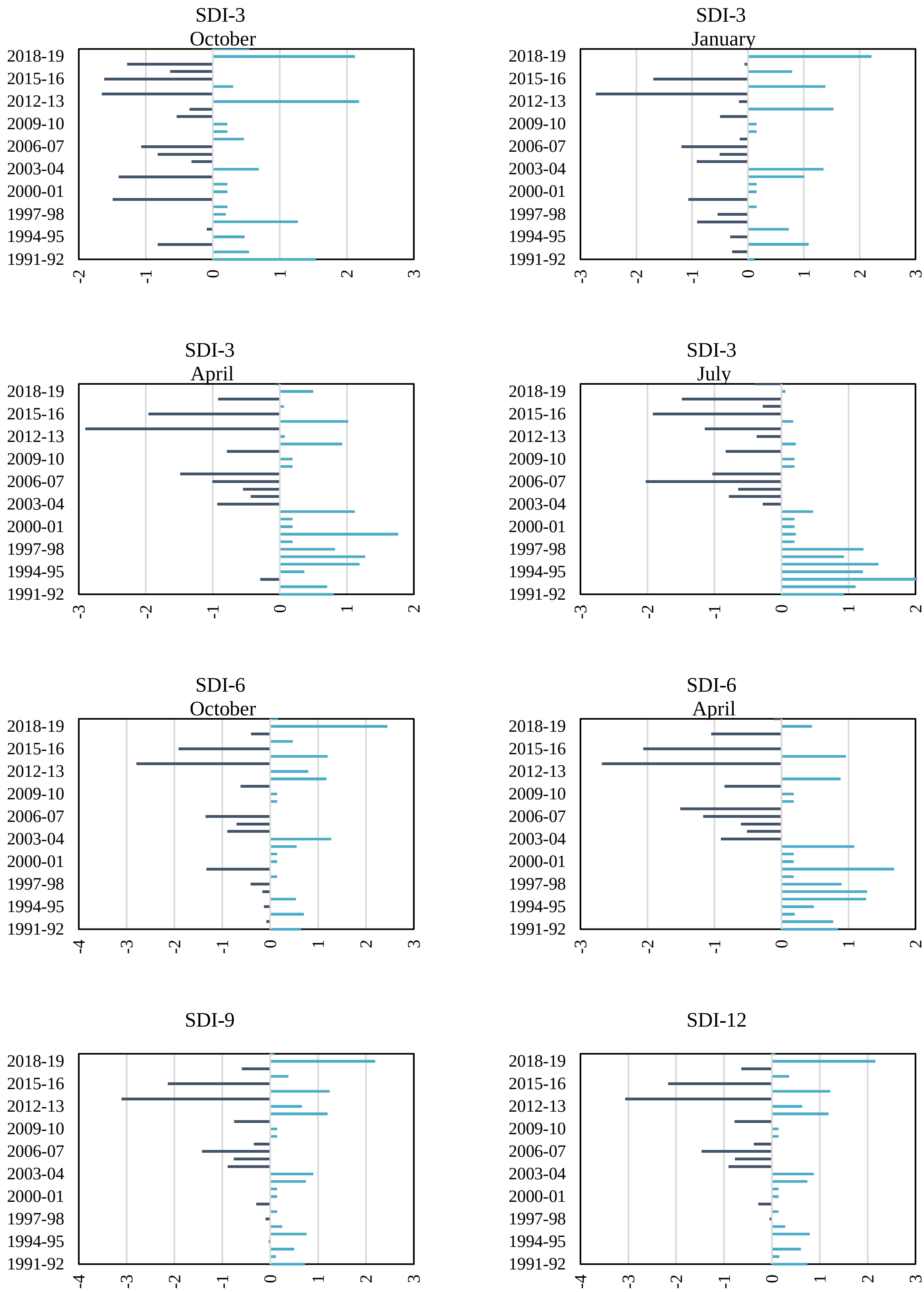

Figure 3. Change of annually SDI values according to 3, 6, 9, and 12-month time scales.

While there was an extended wet period in 1990–2000, it is seen that the effect of Severely and Extremely Drought periods have increased since 2000. Although the Extremely Drought period in

2013 was noticed in all 3, 6, 9, and 12 time periods, it is noteworthy that the highest values are in SDI-9. In Figure 3, the SDI-9 panel displays an increase in drought periods in addition to the reduction in wet periods. Considering the comparison of the SDI values in the same period, which horizontal straight lines considered as the most compatible, it is seen that all drought category values of SDI-9 and SDI-12 have been in great accordance since 2000. However, according to the SDI-3 and SDI-6 values, it is noteworthy that the drought periods are more compatible than the wet ones (Figure 4).

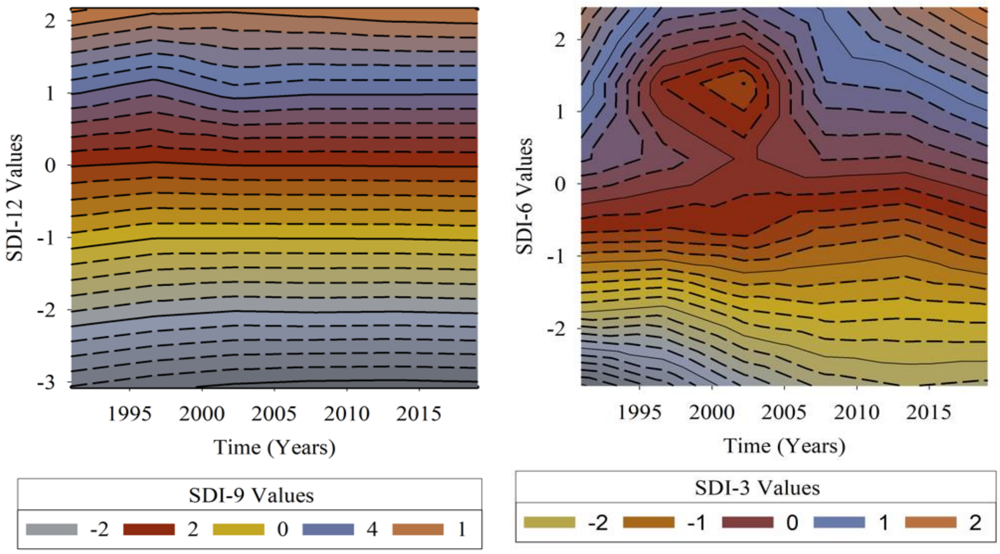

Figure 4. Contour plots indicate the harmony between the considered time scales. (a) SDI-12 and SDI-9 values, (b) SDI-6 and SDI-3 values.

Focusing on an annual basis, an upsurge is observed in the number of Near Normal periods, while there is no significant difference in the number of drought periods (Figure 5). It is assumed that this situation resulted in a decrease in the number of wet periods. From SDI-3 to SDI-12, it can be seen that the periodic effects diminish and partially turn into the Near Normal periods. For SDI-3, there is a drought period of 99 months, which gradually decreases to 90 by SDI-12. However, the opposite case was seen for normal periods, which were 118 for SDI-3 and 136 for SDI-12.

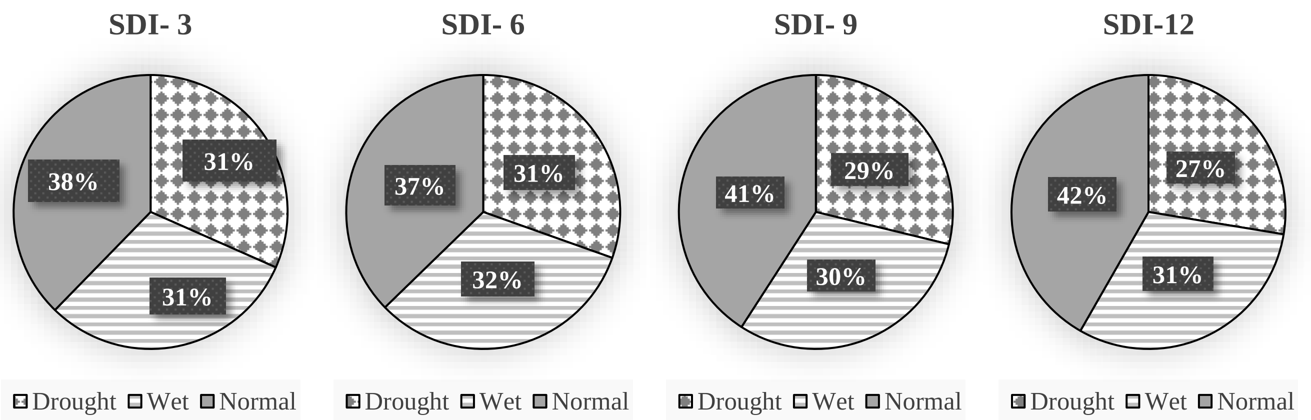

Figure 5. Percentage of occurrence of wet and drought and normal periods.

Nonetheless, considered on a monthly basis, the driest periods for the SDI-3 values occurred in the SDI-3 October period, and the wettest periods occured in the SDI-3 April duration. For the SDI-6 values, it is a crucial detail that while the SDI-6 April period is predicted to be drier, the Near Normal periods are more in number [18]. SDI-12 values were found to have the least number of drought periods (Figure 6).

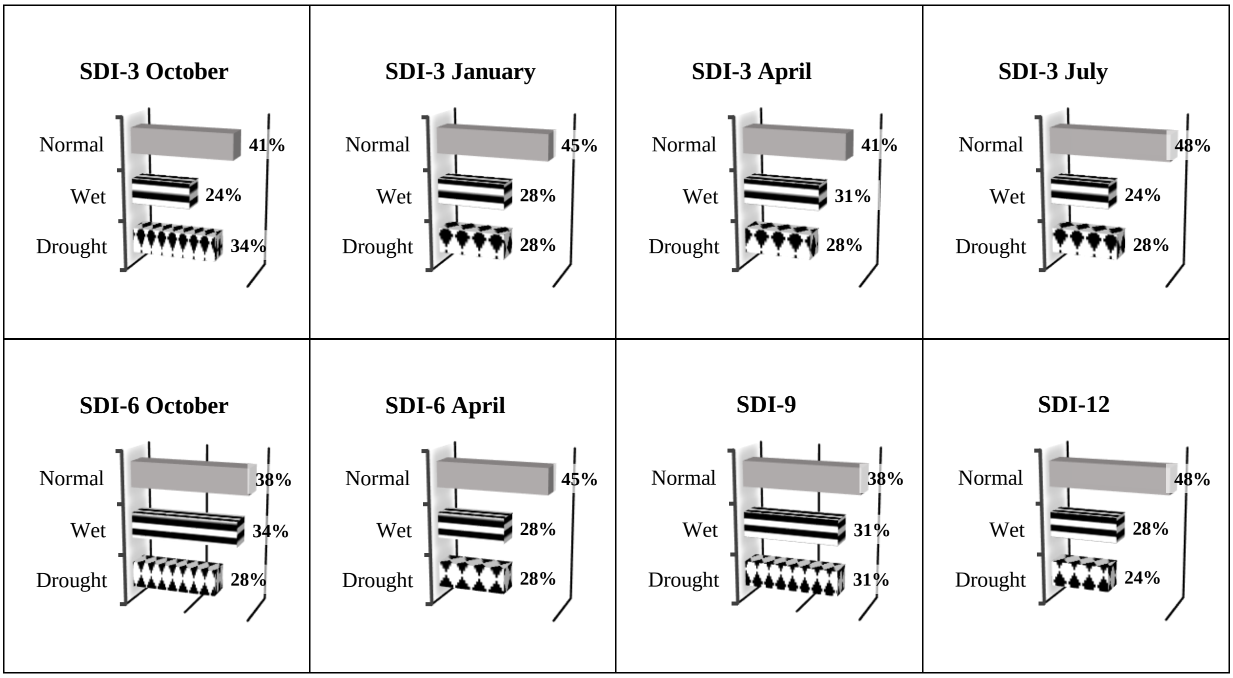

Figure 6. Percentages of wet and dry periods according to the determined time scales (%).

As stated in Table 2, the Near Normal Wet periods were the most frequent, with a 52.8% probability of occurrence and was observed 205 times. However, the Severely Wet period only occured three times, with an 8% percentage.

Table 2. The number and probability of specified drought classifications.

	Occurence Properties	
	Number of drought classifications	*Probability of occurrence*
Drought Classifications		
Extremely Drought	19	0.049
Severely Drought	4	0.010
Moderately Drought	21	0.054
Near Normal Drought	95	0.245
Near Normal Wet	205	0.528
Moderately Wet	28	0.072
Severely Wet	3	0.008
Extremely Wet	13	0.034

The low incidence of the Severely Wet and Severely Drought periods indicates two circumstances, which are the transitions from the Moderately Drought period directly to the Extremely Drought period, and from the Moderately Wet to the Extremely Wet period. Since the wetness of the region turned into drought over the years, the 30-year data series was examined in 3 groups (Table 3). In the first group identified, between 1990–2000, maximum drought and maximum wet periods were spotted. There was a rapid increase in drought periods between 2001–2010 in the transition to the second time zone. For the third period, between 2011–2020, the number of wet periods seems to be the same as the 1990–2000 period, while there are significant differences between the dry periods in the two durations. According to the expected residence times in all classifications, the Extremely Drought period lasted the most, with a 9-month waiting period (Figure 7). Among the classifications, the Severely Wet period has the least expected residence time. Although the Near-Normal Wet and Near-Normal Drought periods seem more abundant, they occur less frequently compared to the Extremely Drought periods. It is thought that this situation mostly happened because the classifications accepted in the normal category are seen more frequently in a shorter time interval.

Table 3. Number of occurrences of wet and dry periods according to various time scales.

	Number of drought months				Number of wet months			
Years	*SDI-3*	*SDI-6*	*SDI-9*	*SDI-12*	*SDI-3*	*SDI-6*	*SDI-9*	*SDI-12*
1990–2000	10	8	6	4	53	47	34	30
2001–2010	52	55	33	34	9	18	24	30
2011–2020	37	35	54	52	34	39	40	40

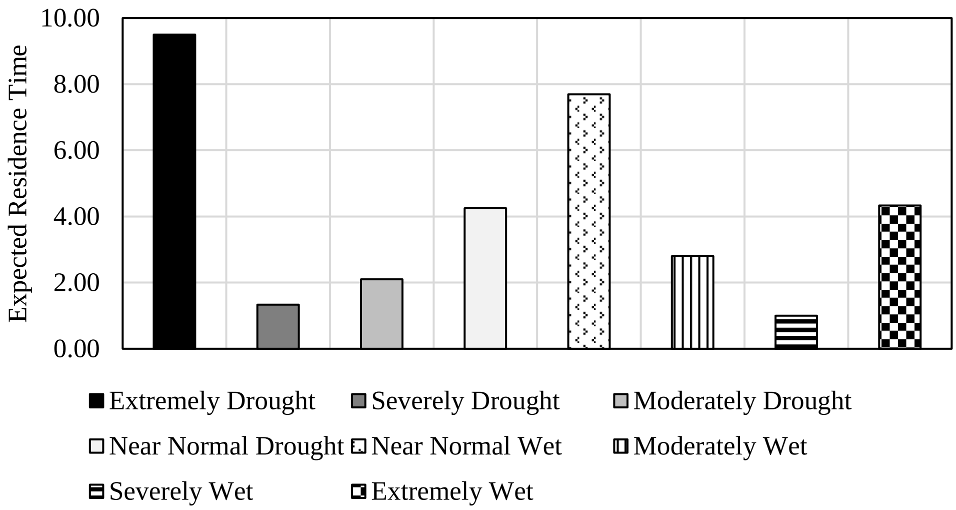

Figure 7. Expected residence times for specified drought classifications.

The expected transition period refers to the average time it takes to transition from a dry to a wet period (Figure 8). While the expected residence time for a Moderately Drought period is calculated as two months, its expected transition time is 27 months. In this case, it can be said that the transition to the wet period will take longer in the case of the Moderately Drought encountered. Considering the 1, 2, and 3 months after the end of the wet and drought period classifications, the Moderately Drought period was always observed one month after the Extremely Drought period. This inference supports the idea that the Severely Drought period does not follow the Extremely Drought period; instead, there is a direct transition to a Moderately Drought classification. Likewise, the occurrence of a Near Normal Wet period indicates a sudden conversion between the Extremely and Near Normal period classifications.

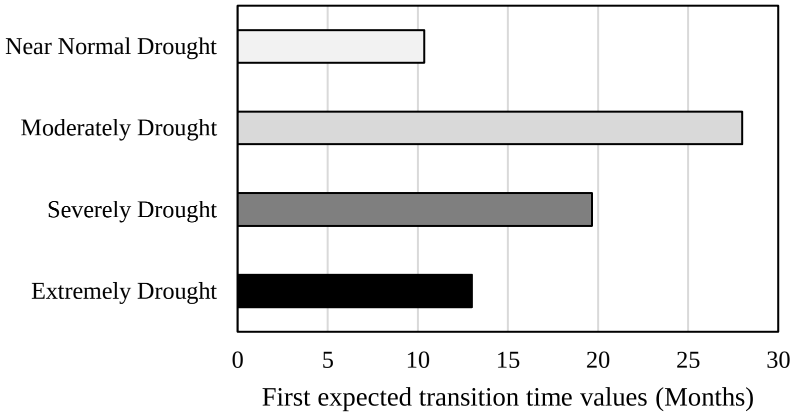

Figure 8. The first expected transition times according to drought periods.

Table 4. Observed categories 1, 2 and 3 months after the current drought class.

	1 Month Later		2 Months Later		3 Months Later	
	Most Possible Category	Probability	Most Possible Category	Probability	Most Possible Category	Probability
Extremely Drought	Moderately Drought	1.000	Near Normal Drought	1.000	Near Normal Drought	0.500
Severely Drought	Moderately Drought	0.670	Moderately Drought	0.670	Moderately Drought	0.330
Moderately Drought	Near Normal Drought	0.570	Near Normal Drought	0.570	Near Normal Drought	0.570
Near Normal Drought	Near Normal Wet	0.700	Near Normal Wet	0.400	Near Normal Drought	0.700
Near Normal Wet	Near Normal Drought	0.670	Near Normal Drought	0.670	Near Normal Drought	0.670
Moderately Wet	Near Normal Wet	0.380	Near Normal Wet	0.380	Near Normal Wet	0.380
Severely Wet	Moderately Wet	0.670	Near Normal Wet	0.670	Near Normal Wet	0.670
Extremely Wet	Severely Wet	0.670	Moderately Wet	1.000	Near Normal Wet	1.000

The results of the study carried out with flow data from the Gönençay River, which stands out with its agricultural production in the Asi River Basin, can be summarized as follows:

- Most drought periods occured between 2013–2014; this finding is compatible with previous studies, as they mentioned extreme drought events that were seen in the Dörtyol and İskenderun regions of the Basin after 1990 [33].
- The wettest periods of the region occurred in the first ten years. This also makes sense with previous studies indicating a significant decrease in wet periods after 2000 [31–34].
- The number of drought periods increases significantly over time [31–34].

- A continuous drought period appeared between 2003–2008 for all time periods. Even though the SDI values between 2008–2010 turn slightly positive, they are still in line with other studies that address the Asi Basin [30–34].
- For all time periods, it is seen that the Near Normal durations are more in number. Additionally, as the time periods get larger, the SDI values ranges diminish, thence it is expected to see an increase in the number of Near Normal periods [18–29].
- Any Extreme drought classification seems to eventually regress to normal for the Gönençay region. The duration in question may vary from one to six months.

4. Conclusions

The incidence of natural disasters such as floods and droughts has been increasing recently. It is safe to say that this situation is mainly caused by global climate change, but it is also related to the malpractices of people in nature. Climate analysis with precipitation records will positively contribute to future forecasting studies to minimize the possible effects of these problems. In this study, the Gönençay Stream in the Asi River Basin, which has critical water resources in Türkiye, was chosen as the study area. Using observations between 1990–2020, wet and drought periods were analyzed by the SDI method at 3, 6, 9, and 12-month scales. Additionally, eight different wet and dry period classifications were divided for the 12-month time scale, and the number of drought occurrences and their probabilities, the first expected transition times between the classifications, and the expected residence times between the categories were analyzed.

Consequently, the most severe drought occured between 2013–2014 and were given the Extremely Drought classification. The wettest period occurred between 2018–2019 and was in the Extremely Wet category. While the drought period persisted between 2003 and 2008, there was also an uninterrupted wet period between 1990 and 2000. The expected residence times in all classifications were examined, and the longest residence time was detected in the Extremely Drought period with nine months. However, it has been concluded that the Near Normal Wet and Near Normal Drought periods occured with fewer residence times. While the Moderately Drought period occurred one month after the Extremely Drought period, the Near Normal Wet period was consistently seen three months after the Extremely Wet period. While the study area is crucial in terms of agriculture, water structure applications have developed rapidly in recent years. Therefore, various drought indices and long-term hydrological analyzes will provide essential knowledge for future feasibility studies. Addititionally, for upcoming studies, indices with more than one input parameter can be preferred if using only one kind of input data affects drought estimations; on the other hand, deep learning techniques and hybrid induce techniques may provide a different approach to the drought problem. Hydrometeorological evaluations and projection estimation models to with different drought indices should be utilized for future studies, which will be able to create solutions to current environmental problems.

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Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

The authors declare no conflict of interest.

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