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RESEARCH

A comparative investigation on the applicability of the actual precipitation index (API) with the standardized precipitation index (SPI): the case study of Aras Basin, Turkey

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Abstract
This study aims to analyze drought using precipitation data from 6 meteorological stations located in the Aras Basin, one of Turkey's 25 river basins. The precipitation data of the meteorological stations between 1969 and 2020 were used. Drought analysis were performed using the actual precipitation index (API), a new method, and the standardized precipitation index (SPI) based on the gamma distribution. The Kolmogorov–Smirnov test was used to determine the best distribution that fits the observed data. Three-, 6-, and 12-month periods are preferred. For Ardahan, Iğdır, and Kars stations, 3-, 6-, and 12-month API and SPI values are shown comparatively with graphics. Drought frequency values for all meteorological stations were obtained for 3-, 6-, and 12-month periods. Relative drought frequency values for both SPI and API are depicted in tables. According to the findings of this study, the driest station is Iğdır, while the wettest station is Ardahan. While extreme wet incidents are occasionally in the basin, extreme drought situations are observed. It has been determined that the climate of the basin is slightly arid.

1 Introduction

Drought events and their related impacts on society and environment are expected to increase because of changing climate (Bates et al. 2008; Dai 2011; Romm 2011). Due to the complex combination of various climatic factors, it is hard to predict exactly where or when natural disasters such as are droughts will occur. Determining the causes and nature of drought formations and identifying the various feed-forward and feedback mechanisms involved are topics of intense study (Cherenkova et al. 2015). Along with global warming, droughts, which have been frequently observed in the last decade, cause many changes in nature. The primary meteorological factors used to define drought are the precipitation deficit periods, the duration of dry periods, and the lack of productive soil moisture (Elizbarashvili et al. 2009). Due to physical and methodological issues, there is no consensus on a standard definition of drought. Although the mathematical interaction between them is difficult to describe, different geophysical scales are involved in drought formation. As listed in meteorological service guides, various drought criteria and threshold values make it harder to conduct a comparative analysis of drought formations and their associated negative consequences in different geographical areas (Kulikova et al. 2017).

The occurrence of drought is a critical problem in arid and semi-arid lands. Drought frequency increases in arid soils due to lack of precipitation. Drought also has significant consequences for the water resources, livelihoods, and food security of the creatures living in that region (Mesbahzadeh and Sardoo 2019).

The climate crisis played its part in deteriorative drought conditions in different parts of the globe. Schneider et al. (2011) described drought as "an extended period of deficient rainfall relative to the multi-year mean for a region." Four different drought types are introduced as follows: meteorological, agricultural, hydrological, and socio-economic drought (Hisdal et al. 2000). These are primarily affected by extreme rainfall deficits and a decrease in precipitation frequency. In addition to that, the influence of climatic factors

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and diverse external conditions might alleviate or worsen hydrological drought (Van Loon and Laaha 2015).

Today, the effects of natural drought are felt more frequently due to greater population density, lack of available water resources, and high-water consumption rates in industrially developed countries. Therefore, monitoring and predicting droughts is an essential issue, mainly because the number of extreme situations, such as droughts in the natural environment, has recently increased. The drought periods are becoming longer, and the intensity of droughts increases simultaneously (Burke et al. 2006; Arndt et al. 2010; Boczoń et al. 2016). Therefore, various mathematical methods were developed by hydrologists to provide information about the occurrence time, place, and duration of drought. With the help of these methods, the impact area and start and end times of drought in a region can be determined. Zargar et al. (2011) state that drought indices are quantitative measures for characterizing different drought levels by monitoring data from one or several variables (indicators) such as precipitation and evapotranspiration into a single numerical value.

The most widely used drought determination method globally is the standardized precipitation index (SPI) developed by (Mckee et al. 1993). This index is a prevalent method in practice because of its ease of calculation and because precipitation is the only meteorological parameter considered (Alamdarloo et al. 2020; Gao and Zhang 2016; Mallenahalli 2020; Park et al. 2019; Song et al. 2020; Topçu and Seçkin 2016; Vishwakarma et al. 2020; Zhao et al. 2020). Furthermore, the SPI might be calculated for timescales ranging from 1 to 24 months, depending on the area of interest. The SPI can simultaneously define wet conditions on one specified timescale and dry conditions on another timescale. However, the time-based responses of different drought systems such as water reservoirs and/or soil moisture are not well known. Therefore, separate detailed studies should be conducted for each specific application and region to associate different SPI values (calculated over different time scales) with the relevant variable (Blain and Meschiatti 2015).

Although not perfectly standardized with zero mean and unit variance, the calculated SPI results in a normalization of the original data. It is not possible to determine quantitative real drought characteristics at different levels, such as duration of dry periods, or magnitude or intensity in the SPI series, as the characteristics of the SPI data are not akin to those in the original data series. The dry and wet spell classifications are preferably based on the statistical standardization procedure for the quantification to work. Şen and Almazroui (2021) highlighted that SPI only gives reliable results when the original data series has a symmetrical or normal (Gaussian) probability density function. They introduced a new drought index, the actual precipitation index (API).

This study carried out a drought analysis for the Aras River Basin, located in northeast Turkey. Precipitation data from 6 meteorological stations in the basin between 1969 and 2020 were used. Standardized precipitation index and actual precipitation index were calculated.

The primary purpose of this study is to determine the applicability of the actual precipitation index, which is proposed as an alternative to the worldwide accepted and widely used standardized precipitation index (Sen and Almazroui 2021) for the Aras Basin. In addition, the results obtained by the two methods are examined in terms of similarities and differences. According to various climate scenarios and studies on drought in the Aras Basin, an increasing trend in temperatures while a decreasing trend is observed in precipitation (Aalijahan et al. 2021; Coşkun 2020; Khoshnoodmotlagh et al. 2020; MGM 2014; Mirzaei et al. 2020; SYGM 2016; Topçu 2022). Therefore, this study focused on the drought analysis of the Aras Basin. The paper is organized as follows. The analytical method is described in the next section, which is then followed by results and discussion. Our significant findings and observations are summarized in the concluding section.

2 Materials and methods

The monthly precipitation data used in this study were obtained from the Turkish State Meteorological Service (General Directorate of State Meteorology Affairs). The geographical characteristics of the six meteorological stations used are given in Table 1. The statistical properties of the precipitation data obtained from the meteorological stations in the basin are shown in Table 2. The selected meteorology stations reflect the characteristic climatic features of the Aras Basin. Only Iğdır station exhibits different climatic characteristics than the rest of the basin due to its lower altitude. The location of the study basin in Turkey and the settlements of the meteorological stations are depicted in Fig. 1.

Mckee et al. (1993) reported the SPI index to monitor and evaluate drought. Fitting a gamma probability density to

Table 1 Geographical features of the meteorological stations

Station/no	Elevation	Latitude	Longitude	Period
Ardahan/17046	1827	41.1061	42.7055	1969–2020
Arpaçay/17656	1720	40.8539	43.3178	1969–2020
Doğubeyazıt/17720	1640	39.5396	44.018	1969–2020
Horasan/17690	1540	40.0383	42.1705	1969–2020
Iğdır/17100	856	39.9227	44.0523	1969–2020
Kars/17097	1777	40.6042	43.1073	1969–2020

Table 2 Statistical properties of precipitation data of meteorological stations

	Min (mm)	Max (mm)	Mean (mm)	Median (mm)	St. dev. (mm)	Skewness	Kurtosis
Ardahan	0.5	195.6	46.2	35.6	34.92	1.14	1
Arpaçay	0	223.9	38.15	30.3	33.13	1.55	3.32
Doğubeyazıt	0	226.6	27.65	22.4	23.81	2.23	9.98
Horasan	0	130.8	32.24	27.35	24.2	0.98	0.77
Iğdır	0	99.4	21.8	16.15	18.89	1.45	2.2
Kars	0	152.2	41.06	33.45	29.95	1.07	0.8

the total precipitation is essential to assess SPI indices. The gamma distribution function ($\partial(\alpha)$) is fitted to the dataset of precipitation involving a shape factor and a scale factor, termed α and β, respectively, which require an estimation for each year and time scale; hence, the maximum likelihood solutions are employed. If the amount of precipitation is represented by x, the cumulative probability ($G(x)$) can be assessed by

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^a \Gamma(a)} \int_0^x x^{a-1} e^{\frac{-x}{\beta}} dx \; x, a, \beta > 0 \tag{1}$$

If x is equal to 0, the gamma function is undefined and the precipitation distribution might contain zeros (Thom 1966), and the definition of cumulative probability ($H(x)$) becomes

$$H(x) = q + (1 - q)G(x) \tag{2}$$

where q is the probability of a 0, the cumulative probability is calculated to the standard normal random variable Z with a mean 0 and variance of 1, which is the value of SPI (Zarei and Mahmudi 2017).

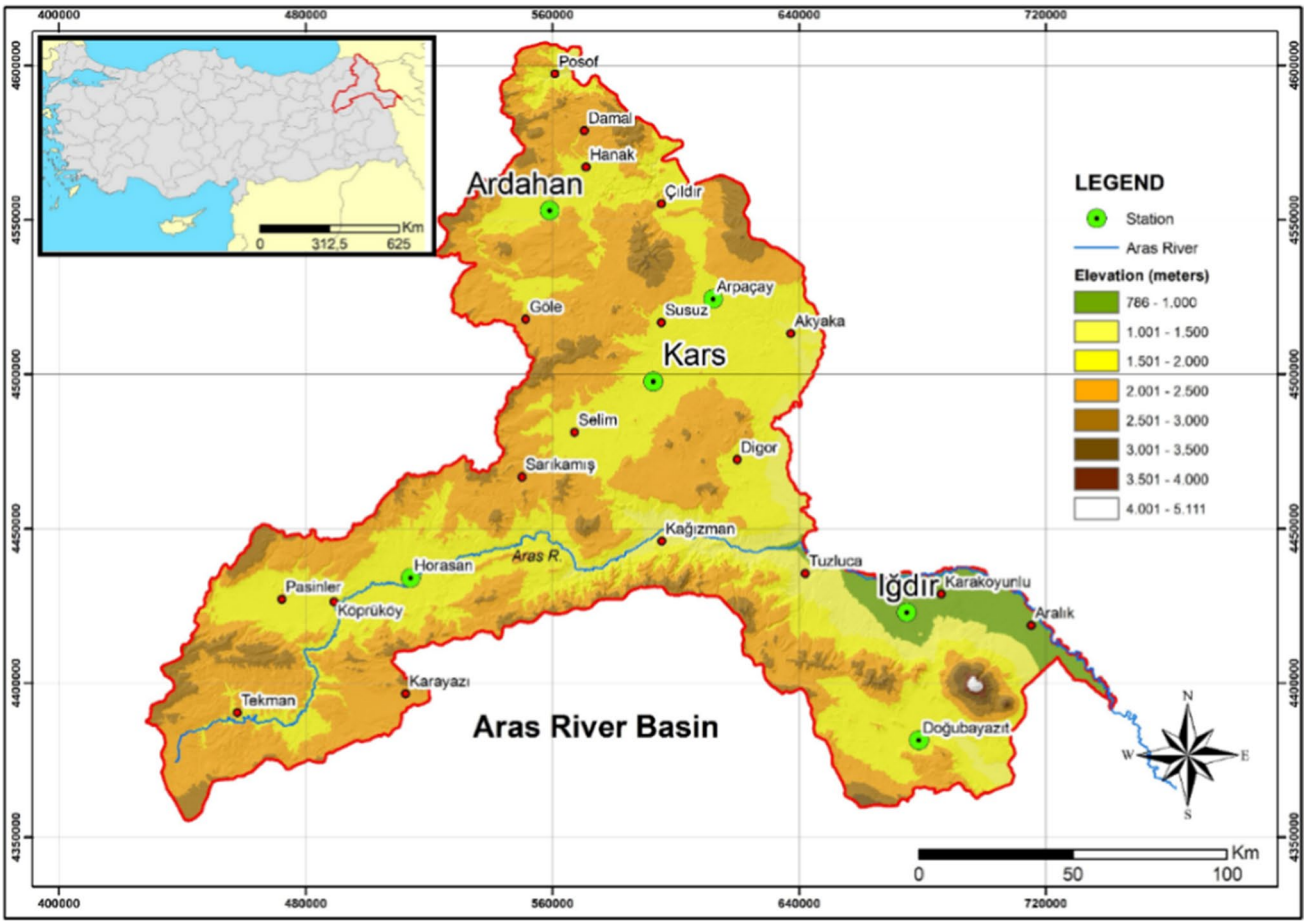


Fig. 1 The location of the study basin in Turkey and the layout of the meteorological stations in the study area

Table 3 SPI and API classification boundaries (Şen and Almazroui 2021)

Class	SPI, standard value	API, probabilistic value	Classification
1	> 2	> 0.9772	Extremely wet (EW)
2	1.50–1.99	0.9332 to 0.9772	Very wet (VW)
3	1.00–1.49	0.8413 to 0.9332	Moderately wet (MW)
4	0.50–0.99	0.6915 to 0.8413	Slightly wet (SW)
5	0.00–0.50	0.5000 to 0.6915	Normal wet (NW)
6	0.00 to − 0.50	0.0000 to − 0.3085	Normal dry (ND)
7	− 0.50 to − 0.99	− 0.3085 to − 0.1587	Slightly dry (SD)
8	− 1.00 to − 1.50	− 0.1587 to − 0.0668	Moderately dry (MD)
9	− 1.50 to − 2.00	− 0.0668 to − 0.0228	Very dry (VD)
10	< − 2	< − 0.0228	Extremely dry (ED)

Şen and Almazroui (2021) presented the actual precipitation index (API) method. This method provides drought classification and information independent of the underlying PDFs. Their paper aims to explain the main differences between SPI and API and to demonstrate that using API is the more reliable solution for classifying drought into five categories: "normal," "slight," "moderate," "severe," and "extreme." The application of the method is presented for two sets of precipitation data; one with exponential PDF monthly precipitation records from Istanbul City, Turkey, and one for NJ, USA, with an almost normal (Gaussian) PDF based on annual precipitation records. The results show that API applies regardless of the underlying PDF of the hydrometeorological data. It does not rely on the standard normal PDF conversion, but produces a true drought classification from the original data.

Using the SPI method, drought index classifications can be made quantitatively, whereas accurate data-based classifications in the actual precipitation index (API) can be calculated without standardization or normalization procedures. API considers the actual probabilities corresponding to the SPI values when examining the main differences between SPI and API methodologies. At the same time, the SPI depends on standard normal probability density function (PDF) values. Therefore, SPI values have zero mean, and unit variance for large samples is not valid in small sample cases.

Even though SPI implementation is not complicated, the corresponding probability values must be determined for the API application's 3-, 6-, and 12-month or year periods. Therefore, the following steps must be followed:

Determining PDF For each period, the matching empirical data point scatter diagram is created by sorting each series in ascending order and then adding the empirical probability, p, to each row using the well-known simple formulation below.

$$p = \frac{m}{n+1} \tag{3}$$

where n is the number of data and m is the rank in the order sequence,

Empirical probability diagram A non-decreasing scatter diagram is obtained by plotting the ordered data according to the corresponding probability value.

Theoretical PDF compatibility By placing the most suitable theoretical PDF in the empirical scatter diagram, the best PDF is created for the basic data. The goodness of fit is checked by chi-square and Kolmogorov-Simirnov tests (Stephens 1970).

Whether the observed data are suitable for any distribution is tested with the Kolmogorov–Smirnov test. In order to investigate whether the sample taken with this test comes from the main population with the said distribution, it is necessary to compare the cumulative frequency distribution valid below the expected distribution with the observed frequency distribution. First, the largest deviation between the two cumulative distributions is determined as the largest absolute difference during this comparison. Then, according to the sample distribution, it is investigated whether the difference in this extent can be obtained by chance (Bayazıt and Önöz 2008). Finally, D_{maxi} is obtained by Eq. (4).

$$D_{\text{maxi}} = \left| F(x_i) - F^*(x_i) \right| \tag{4}$$

Here, $F(x_i)$ is the ordinates of the selected distribution function corresponding to the same x_i's and $F^*(x_i)$ is the additive frequency distribution ordinate calculated from the observed sample. $F^*(x_i)$ is calculated by Eq. (5).

$$F^*(x_i) = \frac{i}{N} \tag{5}$$

The D statistic is the largest of the differences between the observed and theoretical additive distributions. The distribution of the D statistic is independent of the distribution of the

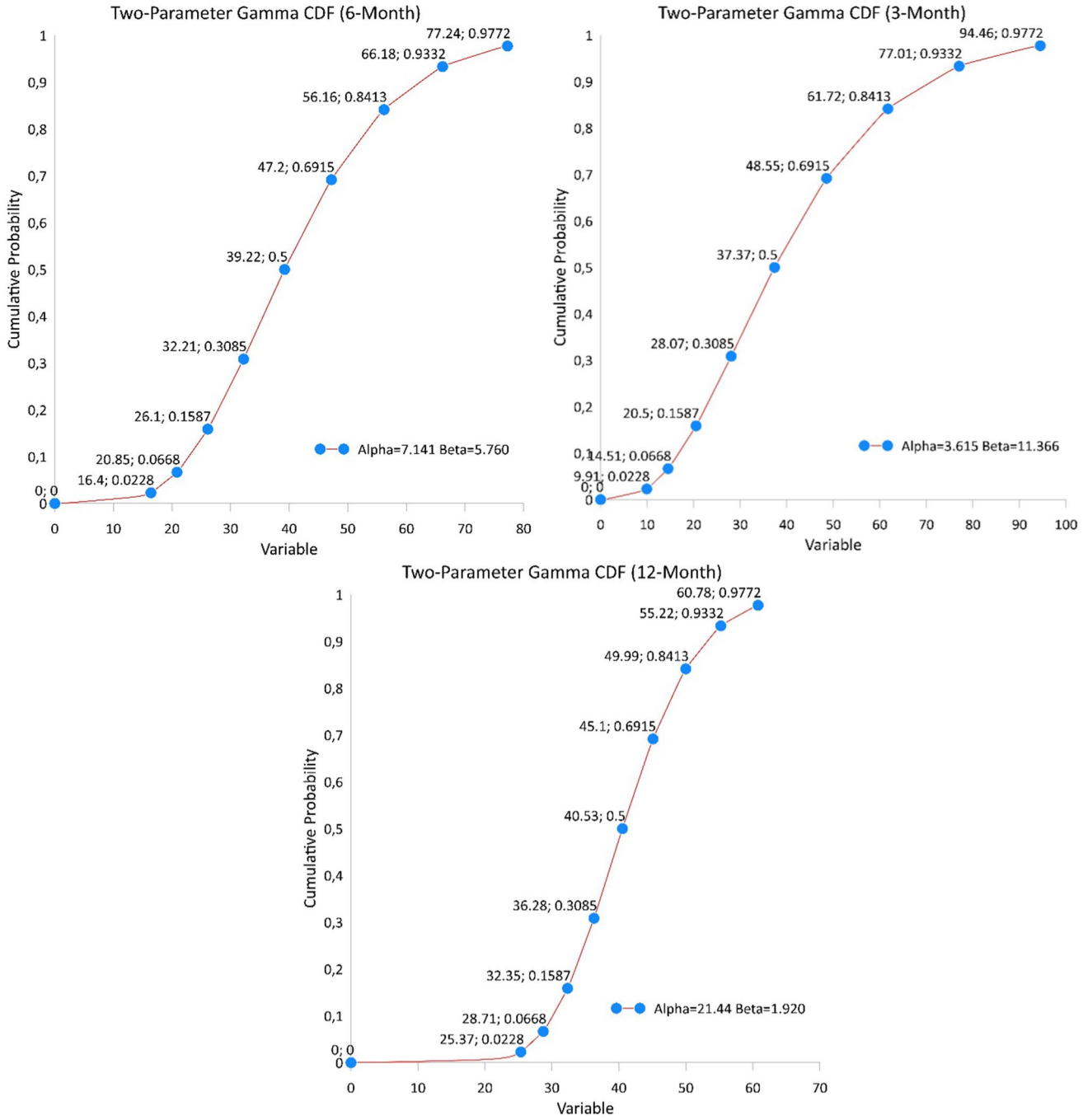


Fig. 2 The procedural structure of gamma CDF for API Kars 3, 6, and 12 months

Table 4 Kolmogorov-Simirnov *D* statistics results

	D statistics					
Distribution	Ardahan	Arpaçay	Doğubeyazit	Horasan	Iğdir	Kars
Pearson type III	0.0925	0.0642	0.136	0.0799	0.0868	0.0744
Gamma	0.0335	0.0357	0.0294	0.0536	0.0318	0.0278
Normal	0.1288	0.1327	0.1212	0.0897	0.1346	0.1109
Log-normal	0.0536	0.0739	0.0792	0.1024	0.0923	0.0878
Exponential	0.1152	0.0683	0.0847	0.0998	0.0694	0.1162

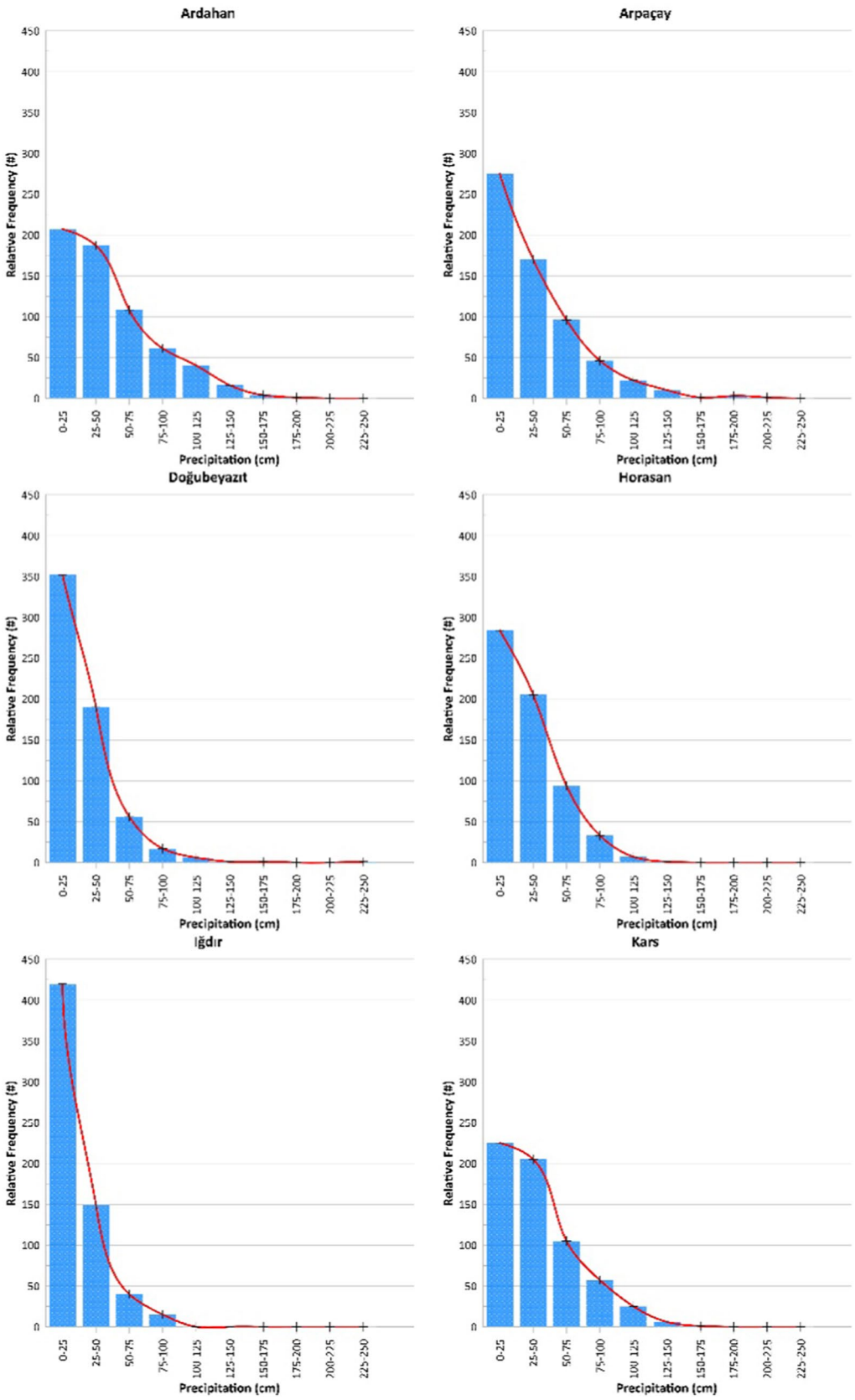


Fig. 3 Charts verify that Aras Basin stations PDF records demonstrates gamma PDF (y axis: relative frequency; x axis: precipitation (cm))

random variable and depends only on the number of *N* elements in the sample (Uçar 2010).

This study examines the compatibility of Pearson type III, gamma, normal, log-normal, and exponential distributions with the precipitation series of the stations in the basin. The *D* statistic determined the best fitting distribution. The reference on the use of gamma, log-normal, and exponential distributions in the calculation of SPI can be found in Guenang (2014), and the source on the calculation of SPI with the Pearson type III distribution in Blain (2011).

API value determination The theoretical PDF is utilized to verify the actual data values matching the API probability values given in the third column of Table 3 (Şen and Almazroui 2021).

Figure 2 depicts the procedural structure of 2-parameter gamma CDF for the API calculation. API possibilities are shown on the vertical axis, and corresponding API classification limits are on the horizontal axis.

All previous steps are repeated for 3-, 6-, and 12-month data sets and annual duration. PDFs are created, each with different parameters, so the API level values are different from each other. SPI and API classification limits are depicted in Table 3.

3 Results and discussion

In this study, detailed graphical analysis results are only highlighted for the Ardahan, Iğdır, and Kars meteorological stations because these stations are located in three important cities in the basin. The remaining Arpaçay, Doğubeyazıt, and Horasan stations are located within the district boundaries. The table of the district meteorological stations containing only API values and figures showing both SPI and API drought frequencies are included.

D values, which are Kolmogorov–Smirnov test statistics, are given in Table 4. According to Table 4, the gamma distribution is the best fit among five different distributions in all six stations in the Aras Basin. For this reason, the gamma distribution is based on the calculation of API and SPI.

PDF graphics in Fig. 3 highlighted that the distribution that best fits the precipitation series of the stations in the Aras Basin is the gamma distribution.

Table 5 shows the gamma distribution parameters and API limit values for the different periods for all meteorological stations in Aras Basin. The values corresponding to the

Table 5 API values of wet and dry spells for different monthly periods in Aras Basin stations

SPI standard variants				2	1.5	1	0.5	0	–0.5	–1	–1.5	–2
API standard probability				0.9772	0.9332	0.8413	0.6915	0.5	0.3085	0.1587	0.0668	0.0228
Parameters												
ARDAHAN	Time	α (Alpha)	β (Beta)	API values (cm)								
	3-Month	3.08	14.99	112.22	90.29	71.23	55	41.4	30.27	21.41	14.57	9.5
	6-Month	6.04	7.67	91.19	77.26	64.75	53.64	43.86	35.35	28.05	21.86	16.73
	12-Month	24.19	1.92	67.18	61.34	55.83	50.66	45.81	41.28	37.07	33.16	29.55
ARPAÇAY	Time	α (Alpha)	β (Beta)	API values (cm)								
	3-Month	16.28	32.28	100.08	78.98	60.87	45.68	33.22	23.29	15.65	10	6.04
	6-Month	10.87	32.28	82.29	68.22	55.76	44.88	35.5	27.53	20.89	15.46	11.14
	12-Month	7.09	32.29	67.3	58.68	50.78	43.62	37.15	31.36	26.22	21.68	17.74
DOĞUBEYAZIT	Time	α (Alpha)	β (Beta)	API values (cm)								
	3-Month	16.28	32.28	66.64	53.7	42.45	32.85	24.79	18.19	12.92	8.83	5.79
	6-Month	10.87	32.28	53.8	45.72	38.44	31.96	26.24	21.26	16.96	13.31	10.25
	12-Month	7.09	32.29	45.36	40.19	35.41	31.01	26.99	23.34	20.03	17.06	14.42
HORASAN	Time	α (Alpha)	β (Beta)	API values (cm)								
	3-Month	16.28	32.28	72.1	59.19	47.84	38	29.59	22.53	16.73	12.07	8.44
	6-Month	10.87	32.28	57.27	49.75	42.88	36.67	31.08	26.09	21.68	17.8	14.45
	12-Month	7.09	32.29	47.9	43.46	39.29	35.4	31.77	28.39	25.27	22.39	19.75
IĞDIR	Time	α (Alpha)	β (Beta)	API values (cm)								
	3-Month	16.28	32.28	53.03	42.63	33.59	25.9	19.46	14.2	10.02	6.8	4.42
	6-Month	10.87	32.28	40.82	34.99	29.72	24.99	20.78	17.08	13.85	11.07	8.72
	12-Month	7.09	32.29	31.87	29	26.29	23.76	21.39	19.19	17.14	15.25	13.51
KARS	Time	α (Alpha)	β (Beta)	API values (cm)								
	3-Month	16.28	32.28	94.46	77.01	61.72	48.55	37.37	28.07	20.5	14.51	9.91
	6-Month	10.87	32.28	77.24	66.18	56.16	47.2	39.22	32.21	26.1	20.85	16.4
	12-Month	7.09	32.29	60.78	55.22	49.99	45.1	40.53	36.28	32.35	28.71	25.37

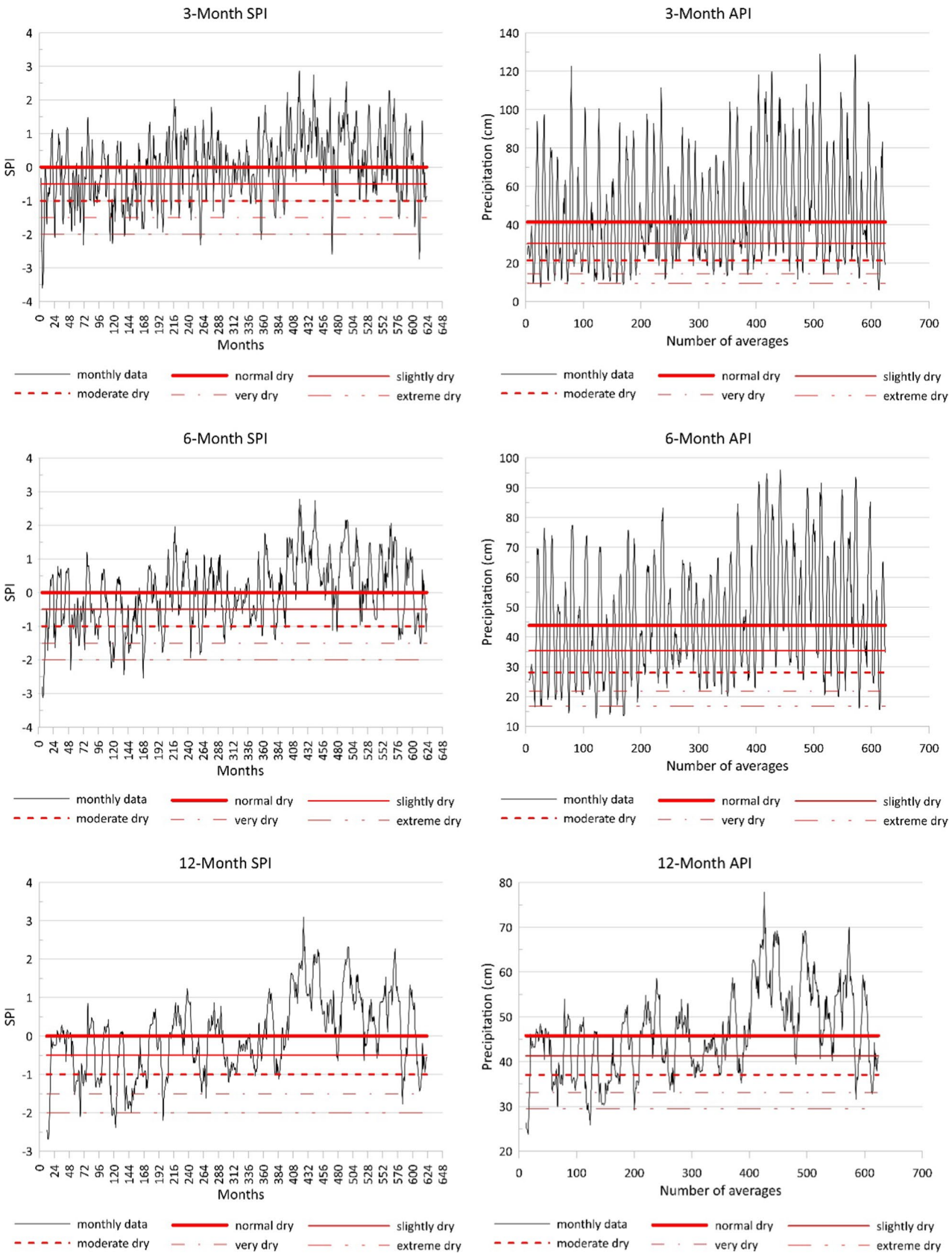


Fig. 4 Dry spell classifications of different durations for Ardahan station

drought limit values are indicated in bold type. For example, for Ardahan station over a 3-month period, precipitation between 30.27 cm and 21.41 cm falls into the slightly dry category, while precipitation less than 9.5 cm falls into the extremely dry category.

The comparative 3-, 6-, and 12-month SPI and API values for the Ardahan station are depicted in Fig. 4. The SPI threshold values 0, − 0.5, − 1, − 1.5, and − 2 are constant. However, in API, drought threshold values are different for each station. This case gives an advantage to API over SPI because each station should be evaluated within its current climatic conditions. The lines on the graphs in Fig. 4 represent threshold values corresponding to each drought class. From the 3-month SPI chart, it is clear that Ardahan station is generally dry and occasionally slightly wet. The 6-month SPI graph shows that the wet-event frequency increased, especially from the 400th month. The 12-month SPI demonstrates that the Ardahan station experienced almost complete dry conditions up to the 400th month. However, similar to the 6-month SPI, moderate wetness occurred after the 400th month. The wet period continued, especially between the 400th and 463rd months.

In Tables 6 and 7, different drought frequency values for SPI and API stand out, especially in the normal wet class. For example in Ardahan station, the 3-month SPI is 20.3% for normal wet, while for 3-month API it is 12.9%. In the 12-month period, the SPI normal dry frequency is 15.7%, while the API normal dry frequency is 0%. In other words, according to the SPI, the frequency of normal dry is higher. Both SPI and API drought frequency values start to converge toward each other from the moderate drought class. The same drought frequency is observed thereafter, especially in the extreme arid class.

Table 5 displays API values for the Iğdır station, the driest station in the basin, and has the lowest precipitation threshold. In Fig. 5, the comparative SPI and API graphics for the Iğdır station are revealed. According to the 3-month SPI results shown in Fig. 5, an extreme drought occurred, while a less extreme drought was recorded in the 3-month API. Similar results are reported for the 6- and 12-month periods. Although Iğdır station is where the most severe drought is observed, moderate wetness can also be seen. In the 12-month SPI for the Iğdır station, the dry period between months 526 and 610 stands out.

API values for the Kars station are given in Table 5. After Ardahan station, Kars is the station with the highest API values. Figure 6 reports extreme drought at the Kars

Table 6 Drought frequency values of SPI for 3, 6, and 12 month periods

	Ardahan			Arpaçay			Doğubeyazit		
	Drought frequency (%)			Drought frequency (%)			Drought frequency (%)		
	SPI-3	SPI-6	SPI-12	SPI-3	SPI-6	SPI-12	SPI-3	SPI-6	SPI-12
Extreme wet	1.9	1.6	2.8	0.5	0.6	0.2	3.1	3.4	3.8
Very wet	4.2	5.0	4.7	3.1	3.1	2.5	2.1	3.9	4.7
Moderate wet	11.3	10.0	9.0	11.8	8.7	9.6	8.2	7.0	7.7
Slightly wet	14.8	15.2	13.6	15.8	21.5	22.2	16.1	13.9	10.6
Normal wet	20.3	18.1	21.9	20.6	21.4	26.8	24.5	20.6	18.6
Normal dry	16.1	17.5	15.7	23.0	20.9	13.9	17.4	21.7	21.1
Slightly dry	15.9	16.3	14.7	12.6	10.0	11.8	12.9	15.4	19.8
Moderate dry	9.0	10.2	12.3	5.8	4.4	3.6	9.8	8.4	8.2
Very dry	4.0	4.0	3.6	3.7	4.5	3.8	3.1	3.6	4.6
Extreme dry	2.4	1.9	1.8	3.2	4.9	5.7	2.9	2.3	1.0
	Horasan			Iğdir			Kars		
	Drought frequency (%)			Drought frequency (%)			Drought frequency (%)		
	SPI-3	SPI-6	SPI-12	SPI-3	SPI-6	SPI-12	SPI-3	SPI-6	SPI-12
Extreme wet	1.4	2.3	2.0	1.1	1.3	1.6	2.1	2.9	3.4
Very wet	4.0	3.6	3.8	5.8	6.3	4.7	4.0	6.0	7.8
Moderate wet	9.5	10.8	10.3	11.3	8.7	10.6	10.8	8.4	5.7
Slightly wet	18.0	12.5	15.7	11.9	14.6	12.7	15.3	12.6	10.5
Normal wet	20.1	22.7	19.3	20.8	22.0	21.2	19.8	17.0	20.3
Normal dry	19.2	19.9	19.1	18.0	17.5	18.0	16.7	19.4	18.5
Slightly dry	13.2	13.9	14.9	16.4	13.8	16.0	14.7	18.1	19.0
Moderate dry	7.9	8.1	9.2	6.9	8.4	8.3	10.1	9.5	9.5
Very dry	3.4	2.8	3.6	6.0	4.4	3.4	4.7	4.4	5.4
Extreme dry	3.2	3.6	2.3	1.8	3.1	3.3	1.8	1.6	0.0

Table 7 Drought frequency values of API for 3, 6, and 12 month periods

	Ardahan			Arpaçay			Doğubeyazit		
	Drought frequency (%)			Drought frequency (%)			Drought frequency (%)		
	API-3	API-6	API-12	API-3	API-6	SPI-12	API-3	API-6	API-12
Extreme wet	1.1	1.0	2.9	2.1	1.1	0.8	2.9	2.3	3.3
Very wet	6.8	6.3	4.6	4.7	5.5	4.4	4.3	5.7	4.7
Moderate wet	11.1	11.8	8.7	9.7	12.6	8.8	7.7	7.4	8.0
Slightly wet	14.5	14.2	13.7	17.7	12.8	22.2	13.4	13.8	10.0
Normal wet	12.9	0.0	0.0	15.1	0.0	0.0	19.5	0.2	0.0
Normal dry	17.6	32.5	15.8	19.5	37.2	13.1	23.5	39.8	22.2
Slightly dry	19.5	16.2	35.8	13.0	12.9	35.8	16.6	17.6	39.4
Moderate dry	10.5	10.5	13.2	10.0	8.9	4.2	7.1	8.4	7.5
Very dry	5.2	5.5	3.1	3.7	4.7	2.6	2.9	3.4	4.1
Extreme dry	1.0	1.9	2.1	4.5	4.2	8.0	2.1	1.5	0.8
	Horasan			Iğdir			Kars		
	Drought frequency (%)			Drought frequency (%)			Drought frequency (%)		
	API-3	API-6	API-12	API-3	API-6	API-12	API-3	API-6	API-12
Extreme wet	2.4	1.8	2.6	2.3	2.6	1.6	2.4	2.9	2.6
Very wet	5.5	4.0	3.6	4.8	4.9	5.4	5.3	4.2	7.7
Moderate wet	8.5	10.4	9.3	9.8	9.5	10.1	9.0	8.7	6.0
Slightly wet	14.5	17.3	16.3	14.5	13.9	12.6	14.3	16.3	10.9
Normal wet	17.4	0.0	0.0	17.9	0.0	0.0	16.4	0.2	0.0
Normal dry	20.6	35.6	18.1	18.4	38.3	18.3	18.8	35.0	19.4
Slightly dry	16.1	15.4	34.2	16.6	14.6	36.9	17.7	14.9	39.7
Moderate dry	8.7	9.2	9.5	11.3	9.4	7.7	11.0	12.3	9.3
Very dry	3.1	3.1	3.9	3.5	4.5	4.2	4.2	4.2	4.2
Extreme dry	3.2	3.2	2.5	1.0	2.3	3.1	0.8	1.3	0.0

station according to SPI in 3 different time periods, while extreme drought was observed in API only for the 3-month time period. As at Ardahan station, almost no wet conditions were experienced up to the 400th month, especially in the 12-month SPI. However, a moderate wet period was observed between the 400th and 463rd months. Figure 6 illustrates that extreme and very dry drought frequency is the same for 3-, 6-, and 12-month SPI and API values. In Fig. 6, the incidence of extreme dry and very dry events is similar for both SPI and API. However, while a normal drought is observed with a frequency of 16.7% in the 3-month period in SPI, a normal drought is observed with a frequency of 18.8% in the 3-month API.

Table 5 reports the scale and shape parameters of the gamma distribution for the Arpaçay station. API values are given in centimeters. According to the results, the 6-month SPI and API values give similar results in terms of normal drought frequency. Still in the 3- and 12-month periods, the SPI shows a drought frequency almost twice that of the API for the Arpaçay station. Similar differences can be seen in other drought categories. In SPI, extreme and very wet situations are not observed for all 3 periods, while extreme wet situations are observed in API 6- and 12-month periods. Regarding the frequency of extreme aridity, the API reports a higher frequency of aridity than SPI.

Table 5 also provides the gamma distribution parameters and API limit values for the Doğubeyazıt station. The 3-, 6-, and 12-month precipitation amounts obtained according to API at the onset of dry conditions are 18.19, 21.26, and 23.34, respectively. Tables 5 and 6 detail the comparative 3-, 6-, and 12-month SPI and API drought frequency values at the Doğubeyazıt station comparatively. According to the tables, the highest percentage of drought for the Doğubeyazıt station was 21.7% in the normal dry category in SPI-6, and 39.8% in the normal dry category in API-6.

Table 5 also summarizes the API drought threshold values for the Horasan station, while Tables 6 and 7 list its SPI and API frequency values. Extreme dry conditions start at or below 8.44, 14.45, and 19.75 cm for the 3-, 6-, and 12-month API, respectively. While extreme wet conditions are not observed frequently for SPI drought periods at Horasan station, wet conditions are observed for API drought periods. Therefore, when the frequency of extreme dry conditions is examined, the frequency of SPI drought periods is similar with the frequency of API drought periods.

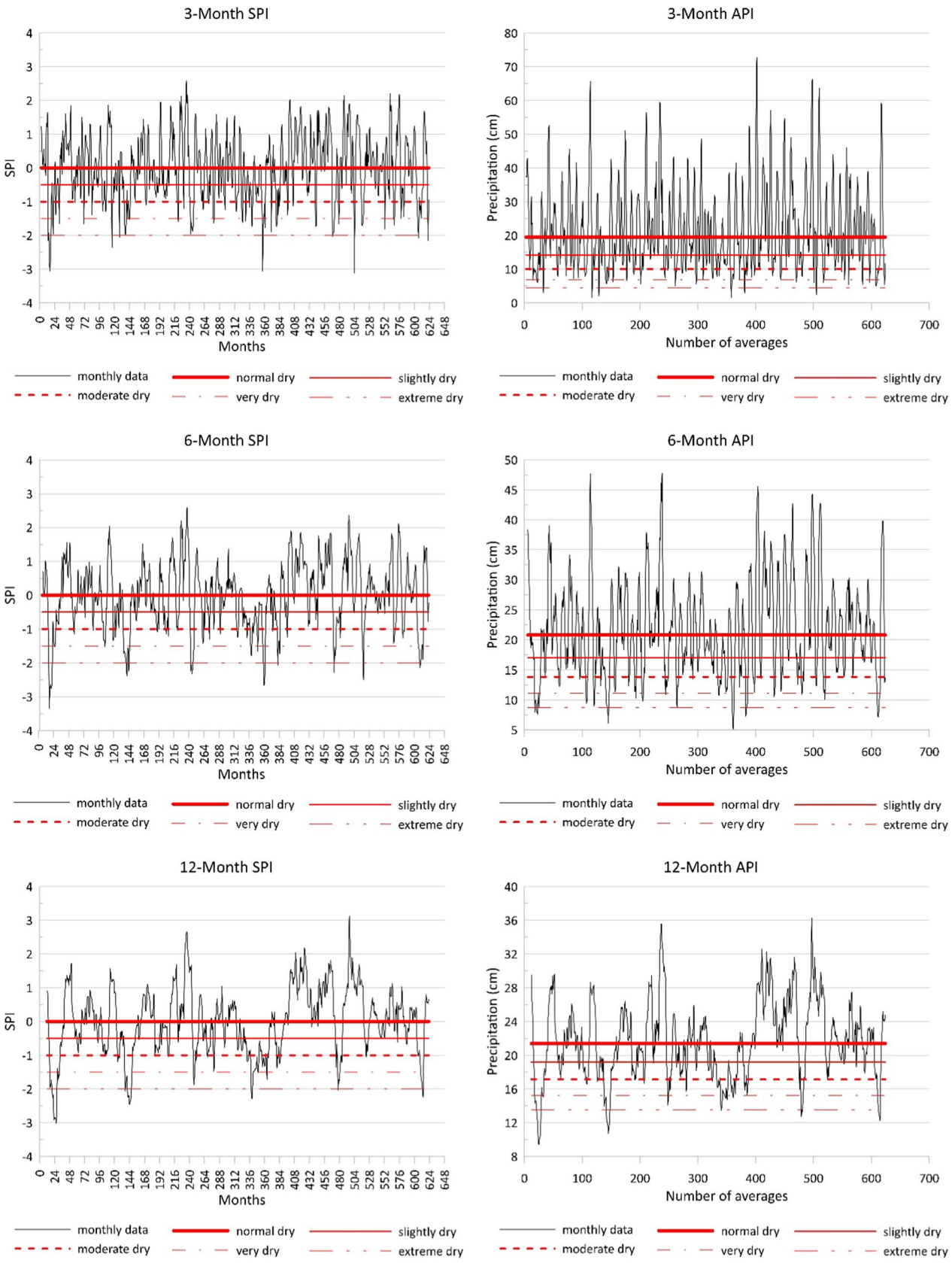


Fig. 5 Dry spell classifications of different durations for the Iğdır station

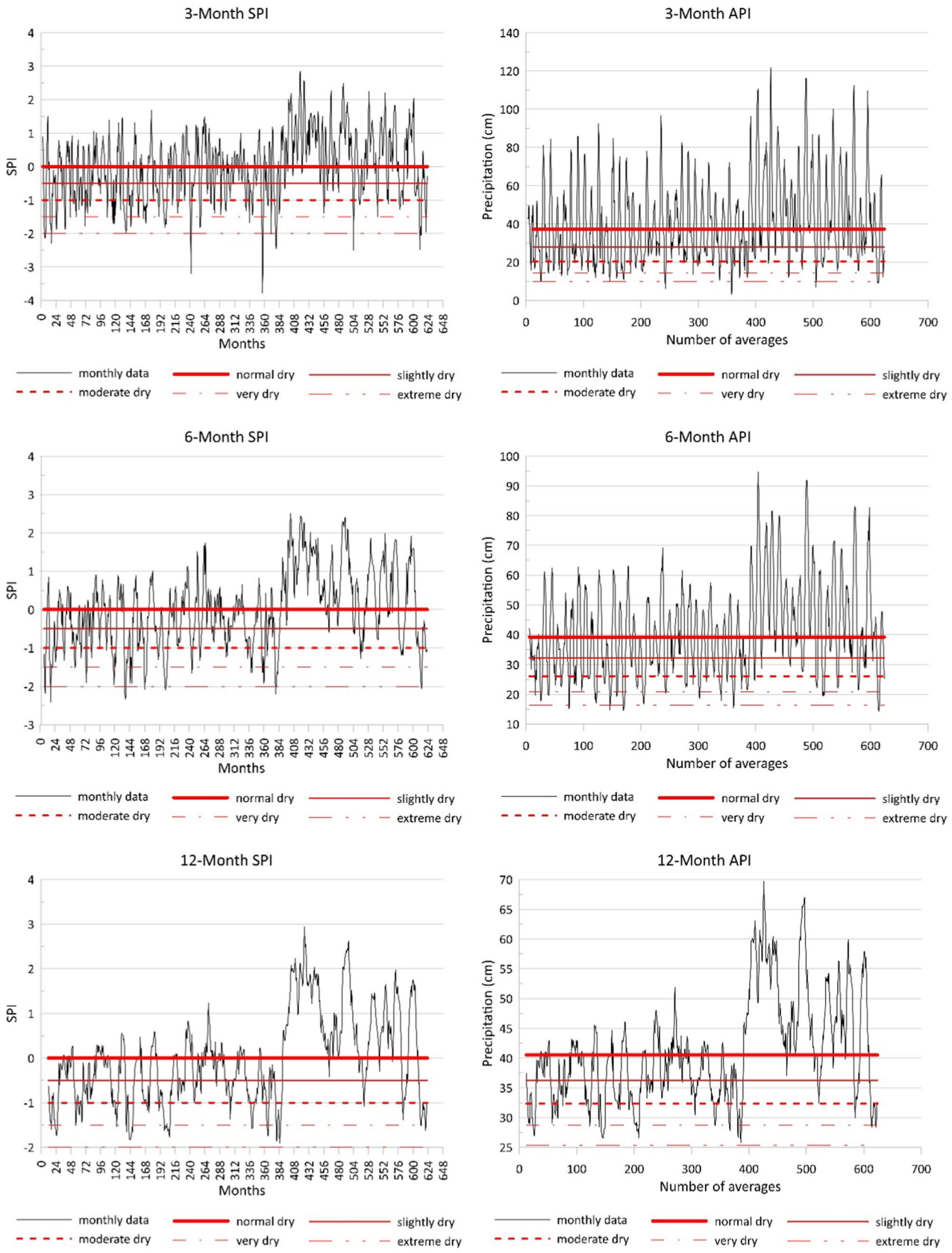


Fig. 6 Dry spell classifications of different durations for the Kars station

According to the SPI drought frequency values, while extreme wet conditions are observed at all stations in the Aras Basin, very wet conditions are observed at SPI-12 for Ardahan, Horasan, and Iğdır stations, and slightly wet at SPI-6 for the Doğubeyazıt station. The API drought frequency values show extreme wet conditions can occur at all stations except for Arpacay for API-3. Extreme dry conditions at the Ardahan station occur with the same frequency in both SPI and API. Similar patterns hold for the Kars station. For the remaining stations, the API drought frequency values are higher than the SPI frequency values for each drought period. Droughts experienced in the basin in recent years have been successfully detected by two drought indexes. Suppose SPI and API analysis results are evaluated in general. In that case, we can say that API values reflect more realistic results across the basin than SPI values because extreme dry conditions can be experienced from time to time throughout the basin.

4 Conclusions

In this paper, drought analysis was conducted over the Aras Basin, located in the coldest part of Turkey. The basin mainly consists of Ağrı, Ardahan, Erzurum, Iğdır, and Kars provinces and has an average altitude of 1900 m. The precipitation data from 6 meteorological stations in the basin were utilized. A severe continental climate prevails in the basin due to its elevation above sea level. Due to the continental climate, the most precipitation falls in the summer months. Therefore, SPI method using gamma distribution and API were preferred in the drought analysis.

The two methods yielded different results over short term (3-month) periods, while they gave similar results in longer periods (12 months). It is thought that this difference occurs due to the fact that the precipitation data in the short term are more irregular and the landforms in the region create different precipitation patterns. According to the study period, the basin receives about 500 mm of precipitation, in general. However in the southeast of the basin, these values decrease to 300 mm.

According to the drought frequency results, Arpaçay station experienced the most frequent extreme drought. In general, however, the driest station in terms of precipitation is Iğdır. Extreme wet conditions are rarely observed in the basin, while arid and slightly arid conditions are most commonly observed. We conclude that the basin is a slightly arid region based on these findings. Wet situations are less likely to occur. Results from 6 meteorological stations in the basin demonstrated that wet situations follow dry conditions and dry conditions follow wet situations. As a result of the comparative analysis, it was concluded that API can be used as an alternative to SPI and it gives more reliable results because it is applied to original precipitation data without underlying PDF of the data.

There are many dams and hydroelectric power plants in the Aras basin. In addition, due to the increasing population, livestock activities and the need for agricultural irrigation, and the amount of water taken from various water sources increases every year. At this point, studies on drought are vital because the results of such drought studies are taken as a basis for water resource planning. Therefore, the findings of this study should help with water resource project planning and management in the region.

Author contribution This study was conceived initially by Topçu and Karaçor. All authors contributed to observational design, instrument deployment and maintenance, data management, and quality control. Initial analysis and drafting of the manuscript were conducted by Topçu and Karaçor. The manuscript and analysis were further honed by all authors, including in the revision stage, and all authors read and approved the final manuscript.

Data availability The data used in this research will not be available.

Code availability Not applicable.

Declarations

Ethics approval There are no ethical issues in this study.

Consent to participate This research has been approved by all authors and signed on the signature.

Consent for publication The authors agree to the publication of this research and the copyright statement.

Conflict of interest The authors declare no competing interests.

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