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Drought Analysis with Two Different Indices in Yeşilırmak Basin

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Abstract: Reducing the negative effects of drought disaster, which is one of the most important parameters affecting the planning and management of water resources, has become very important today. Many methods have been proposed in the literature for the calculation of drought, which is used to express the periods when precipitation is significantly less than the average, and two of these methods, "Standardized Precipitation Index (SPI)" and "Reconnaissance Drought Index (RDI)" were applied to the Yeşilırmak basin in this study.12-month SPI and RDI analyzes were made and compared by using the monthly precipitation and evapotranspiration totals of 8 stations in the Yeşilırmak Basin for the period 1991-2020. The results show us that the SPI and RDI methods generally give similar signals for wet periods, but the RDI method defines more extreme dry periods than the SPI method in extreme dry periods. While the RDI method defines more extreme dry periods than the SPI method; It was observed that the SPI method defined more extreme wet periods than the RDI method. In drought analysis, using an index based on more than one meteorological parameter (such as the RDI) will give more reliable results instead of using an index based on a single parameter (i.e, SPI). It has shown in this study that the effect of evapotranspiration values in drought calculation is very important by comparing it with RDI analysis and SPI analysis.

Key Words: Standardized precipitation ındex, reconnaissance drought ındex, precipitation, yesilırmak basin

Yeşilırmak Havzasında İki Farklı İndeksle Kuraklık Analizi

Öz: Su kaynaklarının planlanması ve yönetilmesini etkileyen en önemli parametrelerden birisi olan kuraklık afetinin olumsuz etkilerinin azaltılması konusu günümüzde oldukça önemli hale gelmiştir. Yağışların ortalamadan önemli miktarda daha az düştüğü dönemleri ifade etmekte kullanılan kuraklığın hesabı için literatürde pek çok yöntem teklif edilmiş ve bu yöntemlerden ikisi "Standartlaştırılmış Yağış İndeksi (SPI)" ve "Keşif Kuraklık İndeksi (RDI)" bu çalışmada Yeşilırmak havzasına uygulanmıştır. Yeşilırmak Havzası'nda bulunan 8 adet istasyonun 1991-2020 dönemine ait aylık toplam yağış ve evopotranspirasyon kullanılarak 12 aylık SPI ve RDI analizleri yapılıp karşılaştırılmıştır. Elde edilen sonuçlar, SPI ve RDI yöntemlerinin ıslak dönemler için genellikle benzer sinyalleri verdiğini ancak aşırı kurak dönemlerde RDI yönteminin SPI yöntemine göre daha çok aşırı kurak dönem tanımladığını göstermiştir. RDI yönteminin SPI yöntemine göre daha fazla aşırı kurak dönemler tanımlarken; SPI yöntemi ise RDI yöntemine göre daha fazla aşırı ıslak dönem tanımladığı gözlenmiştir. Kuraklık analizinde tek parametreye bağlı bir indeks (örneğin SPI) kullanmak yerine birden fazla meteorolojik parametreye dayalı indeks (RDI gibi) kullanmak daha güvenilir sonuçlar verebileceği düşünülmektedir. Bu çalışma ile evopotranspirasyon parametresinin kuraklık analizindeki önemi RDI ile SPI indekslerinin karşılaştırılması ile gösterilmiştir.

Anahtar Kelimeler: Standartlaştırılmış yağış indeksi, keşif kuraklık indeksi, yağış, yeşilırmak havzası.

1. Introduction

Drought is a natural disaster that develops slowly, whose beginning and end cannot be determined precisely, and which has negative effects on the lives of living things. Drought is a problem with very important socio-economic consequences that complicate the planning and management of water resources, negatively affect economic life, and may cause a decrease in agricultural production, resulting in famine, hunger, death and migration. Since Turkey has very different climatic zones due to its geographical location and structure, the hydroclimatic parameters, especially the precipitation factor, which has the greatest effect on drought, show great temporal and spatial changes in our country (Şen, 2001).

When drought occurs, decreases are observed in many hydrological variables such as precipitation, stream flow, soil moisture, snowpack, groundwater levels, and reservoir storage (Öztürk, 2017). Drought is divided into different categories according to the types of environments in which the decrease occurs. For example, decreases in precipitation cause meteorological droughts, decreases in soil moisture cause agricultural droughts, and decreases in stream flow cause hydrological droughts (Dracup et al., 1980). While these reductions in different types/environments tend to be positively correlated and likely respond to the same trigger, they show different temporal and spatial scales. Therefore, generating a general drought indicator/index that covers reductions in many species and related temporal scales is difficult because of the complex dependencies in the variables used to characterize droughts. Given their uncertain nature, the status of droughts is often evaluated with various indices derived from hydrological variables (Dabanlı 2017).

Drought indices are key tools for measuring drought descriptions and implementing drought plans (Wilhite et al., 2007). Hydro-meteorological drought indices can be divided into three groups according to the number of applied hydro-meteorological variables. These are: univariate (eg Standardized Precipitation Index (SPI) (McKee et al. 1993), Streamflow Drought Index (SDI) (Nalbantis and Tsakiris 2009), bivariate (Reconnaissance Drought Index) (RDI) (Tsakiris and Vangelis 2007; Tigkas et al. 2013)) and multivariate (eg Aggregated Drought Index (ADI) (Keyantash and Dracup 2004)).

In this study, drought analyzes were performed using univariate Standardized Precipitation Index (SPI) and bivariate Exploratory Drought Index (RDI) methods using eight meteorological stations and monthly precipitation totals and average temperatures in the Yeşilırmak Basin for the years 1991-2020. These indices are preferred because they are the most preferred indices. For the 12-month precipitation totals for the basin, dry and rainy periods were determined and compared.

2. Materials and Methods

2.1. Data and Basin

The Yeşilırmak Basin, where the study was conducted, is a precipitation basin with an area of 39626 km^2, covering the Central Black Sea Region of Turkey, located approximately between the coordinates of 38^o-42^o North and 33^o-38^o East. A data set of at least 30 years is needed to perform SPI and RDI drought analyzes properly. Among the meteorological measurement stations in the basin, 8 (eight) stations have been identified that meet the requirement of having 30 years of precipitation, temperature and evopotranspiration (ET_0) data between 1991-2020. These stations are Samsun, Çorum, Amasya, Tokat, Zile, Turhal, Suşehri and Şebinkarahisar stations. Yeşilırmak basin and the stations used in the basin are shown in Figure 1. The basic statistical values of these precipitation stations are shown in Table 1.

Table 1. Statistics of precipitation stations
Tablo 1. *Yağış istasyonları istatistikleri*

	Average (mm/month)	Standard Deviation	Distortion	Maximum (mm/month)	Minimum (mm/month)
Samsun	60.65	39.62	1.28	269.80	0.00
Çorum	37.37	31.03	1.66	220.10	0.00
Amasya	39.16	29.16	0.90	144.60	0.00
Tokat	36.89	27.23	0.85	141.00	0.00
Zile	36.43	29.56	1.15	154.10	0.00
Turhal	36.53	29.16	1.03	143.60	0.00
Suşehri	34.54	26.69	1.12	164.20	0.00
Şebinkarahisar	46.85	33.36	0.78	170.40	0.20

2.2. Standardized Precipitation Index

The SPI method, which is accepted and widely used in the world for drought analysis, was developed by McKee et al. (1993). It is a dimensionless drought index that can be applied to regions with different climatic and geographical features in the world and that allows monitoring and comparison of droughts occurring in different periods. It is seen as a deficiency in that it can only be calculated based on precipitation data, but it also provides the opportunity to compare different regions together and interpret the results. The path followed in the SPI calculation can be summarized as follows: First, the best fit probability distribution is determined for the precipitation data obtained from the monthly precipitation totals. After the additive probability function is determined, the standard z-score value in the standard normal distribution corresponding to the probabilities of the precipitation totals gives the SPI value, which is the drought equivalent of that precipitation (Guttman 1998). Gamma distribution recommended by Thom (1958) is generally used in the literature as the most appropriate distribution in SPI calculations. In this study, however, this assumption was not followed and the most appropriate distribution for each station was determined separately.

In the SPI evaluation, negative values indicate dry periods and positive values indicate wet periods. It is recommended to use at least 30 years of complete monthly precipitation data for SPI analysis. The classification of drought classes given in Table 1 is used in the SPI evaluation (McKee 1993, Velmes 1998, Hınıs 2013, Yüceerim 2021, Eşit 2021, Zarei et al. 2021).

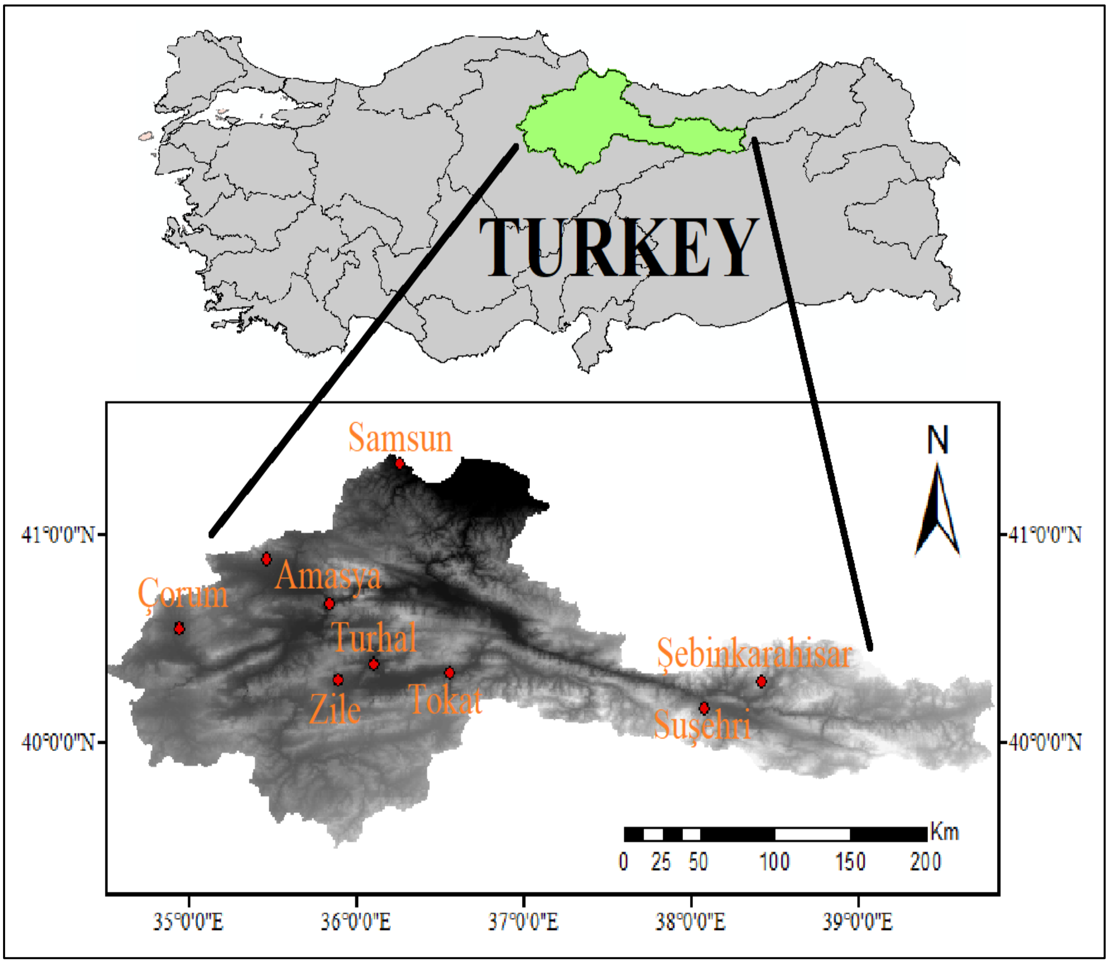

Figure 1. Yeşilırmak basin and stations used in the study
Şekil 1. *Yeşilırmak havzası ve çalışmada kullanılan istasyonlar*

2.3. Reconnaissance Drought Index

The α_k values required for the estimation of the values of the RDI index in the k-reference periods were determined from the following relationship.

$$\alpha_k^i = \frac{\sum_{j=1}^{3k} P_{ij}}{\sum_{j=1}^{3k} ET_{0_{ij}}} \quad i = 1 \ldots N \quad k=1,2,3,4 \qquad (1)$$

In Equation 1, P_{ij} and ET_{0ij} are the total precipitation and reference crop water consumption (ET_0) of the ith year and jth month. The RDI index is obtained by dividing the difference between the calculated (α_k^i) values and the calculated (α_k^i) values by the standard deviation of the calculated (α_k^i) values for a selected time period (k-reference period). The normalized RDI is obtained by Equation (2):

$$RDI = \frac{\alpha_i^k - \mu_\alpha}{\sigma_\alpha} \qquad (2)$$

μ_0 and σ_0, are the mean and standard deviation of α_k, respectively. In order to obtain RDI values from this relationship, α_k values should show a normal distribution (Tsakiris et al. 2007, Yürekli et al. 2010).

The Standardized RDI (RDIst) is calculated, assuming that the αo values fit the lognormal distribution. Similar to the SPI calculation method, RDIst is given by Equation 3 and Equation 4;

$$\ln(\alpha_i^k) = y_k \qquad (3)$$

$$RDI_{st(k)}^{(i)} = \frac{y_k^{(i)} - \bar{y}_k}{\hat{\sigma}_{yk}} \qquad (4)$$

$y_k^{(i)}$ expression isln $(\alpha_0^{(i)})$, $\bar{y}_k$ is the arithmetic average of $y_k^{(i)}$ and $\hat{\sigma}_{yk}$ is standart deviations (McKee 1993, Velmes 1998, Tsakiris et al. 2007, Eşit 2021, Zarei et al. 2021, Velez-Sanchez 2021).

Classification of RDI is similar to the SPI and given in Table 2.

Table 2. SPI and RDI classificaiton
Tablo 2. *SPI ve RDI sınıflandırılması*

SPI and RDI Values	Drought Categories
≥ 2	Extreme Wet (W3)
1,50 ~ 1,99	Wet (W2)
1,00 ~ 1,49	Moderate Wet (W1)
0,99 ~ -0,99	Normal (N)
-1,00 ~ -1,49	Moderate Drought (D1)
-1,50 ~ -1,99	Drought (D2)
≤ - 2	Extreme Drought (D3)

(McKee 1993, Velmes 1998, Tsakiris et al. 2007, Eşit 2021, Zarei et al. 2021, Velez-Sanchez 2021).

3. Findings and Discussions

3.1. Best Fit Probability Distribution

In order to conduct SPI drought analyses of (eight) stations determined in the Yeşilırmak basin, first of all, the best fit probability distribution functions were determined for the 12-month precipitation totals of these stations in the years 1991-2020. For this purpose, Matlab (2017b) program was used. The best fit distributions and stations identified are shown in Table 2. Kolmogorov-Smirnov (K-S) test and Chi-square test were used for the checking the suitability of the distributions, and the probabilities obtained from the K-S test are given in Table 3.

The best fit distributions determined for all stations in the basin were observed and the theoretical distribution results are shown in Figure 2 to 5.

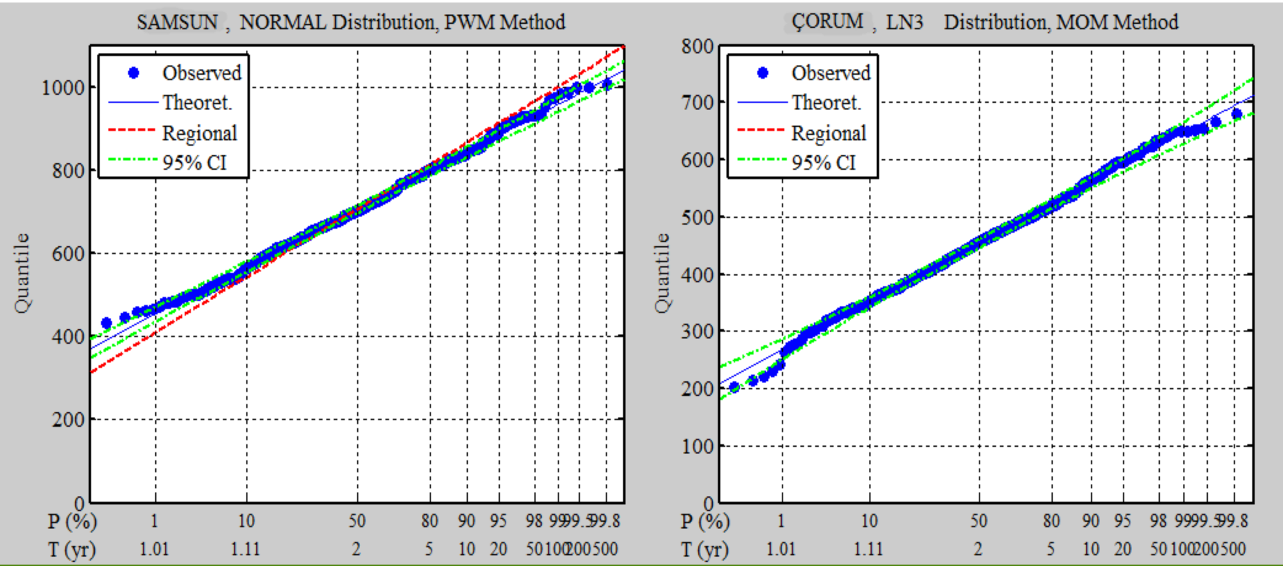

Figure 2. Observed and theoretical distribution funcitons for best fit distributions (Samsun, Çorum)
Şekil 2. *En uygun dağılımlar için gözlenmiş ve teorik dağılım çıktı grafikleri (Samsun, Çorum)*

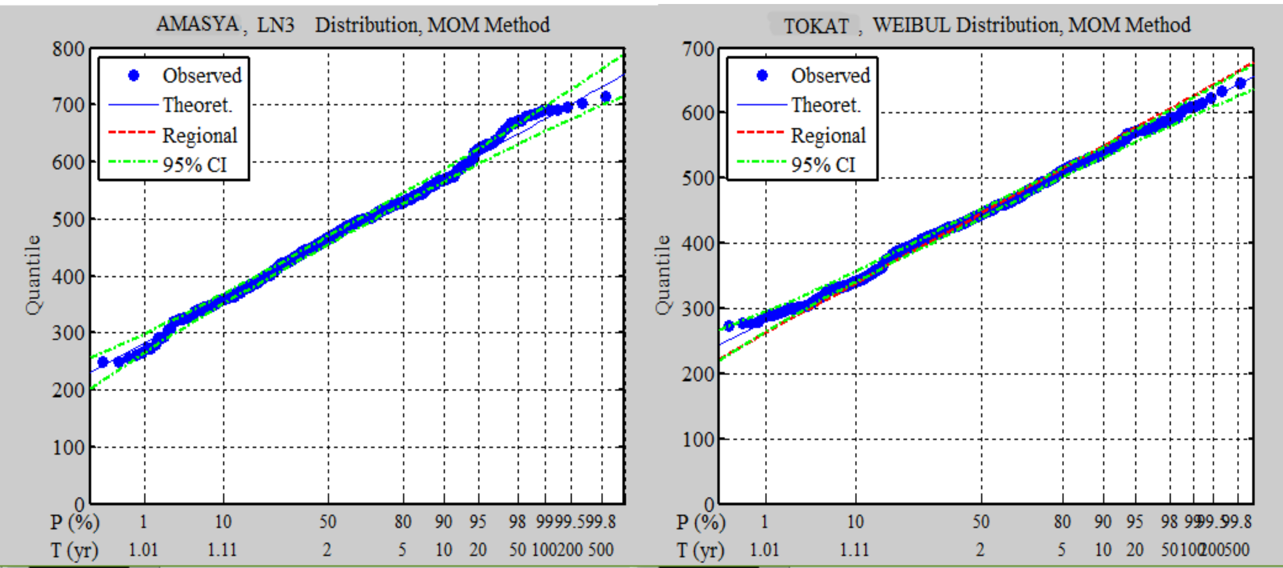

Figure 3. Observed and theoretical distribution funcitons for best fit distributions (Amasya, Tokat)
Şekil 3. *En uygun dağılımlar için gözlenmiş ve teorik dağılım çıktı grafikleri (Amasya, Tokat)*

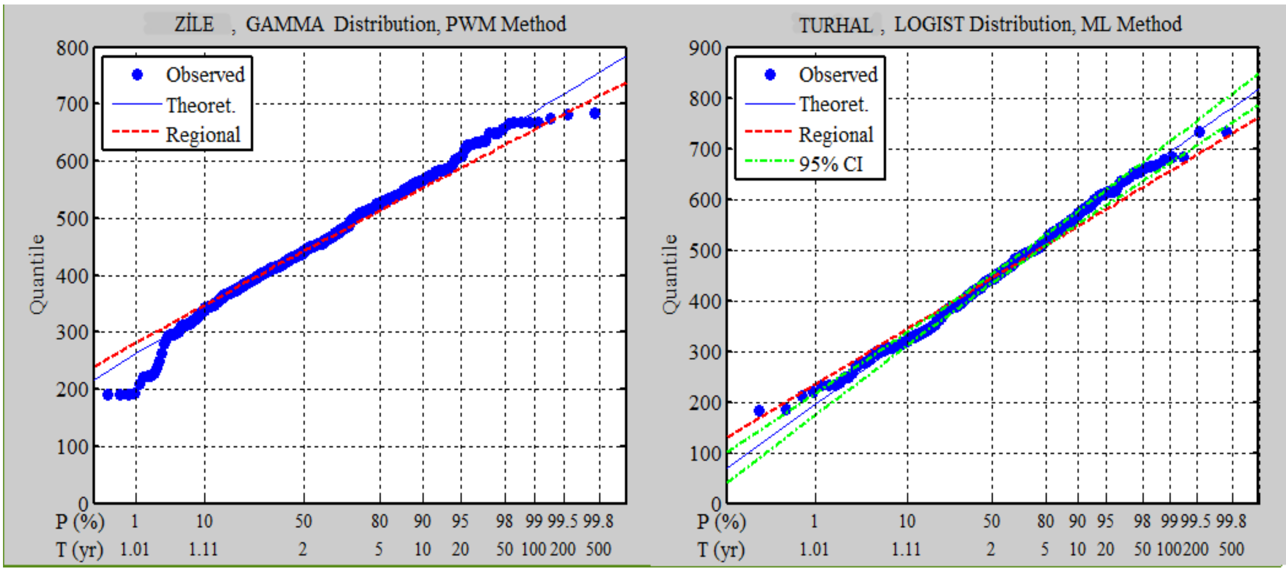

Figure 4. Observed and theoretical distribution funcitons for best fit distributions (Zile, Turhal)
Şekil 4. *En uygun dağılımlar için gözlenmiş ve teorik dağılım çıktı grafikleri (Zile, Turhal)*

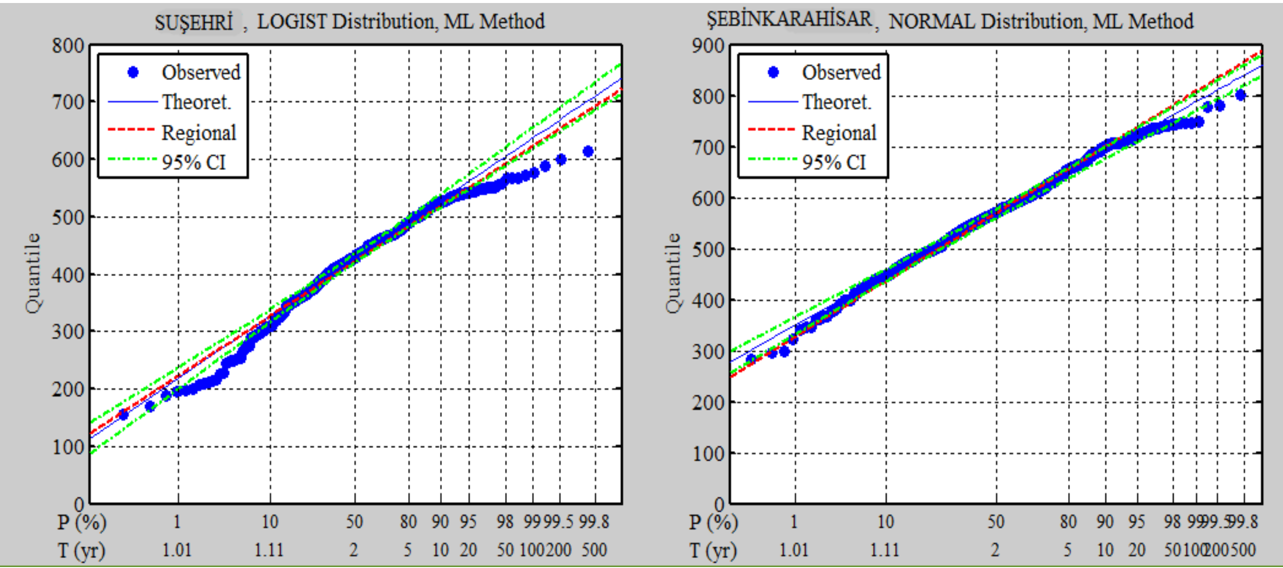

Figure 5. Observed and theoretical distribution funcitons for best fit distributions (Zile, Turhal)
Şekil 5. *En uygun dağılımlar için gözlenmiş ve teorik dağılım çıktı grafikleri (Zile, Turhal)*

Table 3. Best fit probability distributions of stations in the study area for 12-month precipitation totals and probability of K-S test results
Tablo 3. *12 aylık yağış toplamları için çalışma alanındaki istasyonların en uygun olasılık dağılımları ve K-S test sonuçlarının olasılıkları*

Station No	Station Name	Method	Best Fit Distribuiton Function	Test	p-value
17030	Samsun	L-Moments	Normal	Kolmogorov-Smirnov	0,928
17084	Çorum	Moments	Log-Normal 3	Kolmogorov-Smirnov	0,968
17085	Amasya	Moments	Log-Normal 3	Kolmogorov-Smirnov	0,738
17086	Tokat	Moments	Weilbul	Kolmogorov-Smirnov	0,755
17681	Zile	L- Moments	Gamma	Kolmogorov-Smirnov	0,752
17683	Turhal	Maximum Likelihood	Logistic	Kolmogorov-Smirnov	0,885
17084	Suşehri	Maximum Likelihood	Logistic	Kolmogorov-Smirnov	0,528
17682	Şebinkarahisar	Maximum Likelihood	Normal	Kolmogorov-Smirnov	0,952

3.2. Drought Analysis

The standard z-score values of the cumulative probability values were transformed from the normal distribution and it was calculated and SPI was determined from the 12-month precipitation totals belonging to the 30-year (1991-2020) data set, the best fit probability distributions of which were determined.

The ET_0 values required for the RDI analysis of the

30-year (1991-2020) data set were used by the DRINC (Drought Index Calculator) program (URL1).

SPI_12 and RDI_12 drought indices of eight stations used in the study area calculated for 12-month precipitation totals are given in Figure 3-10 and the percentage values of the observed frequencies for each drought class obtained from these indices are given in Table 4.

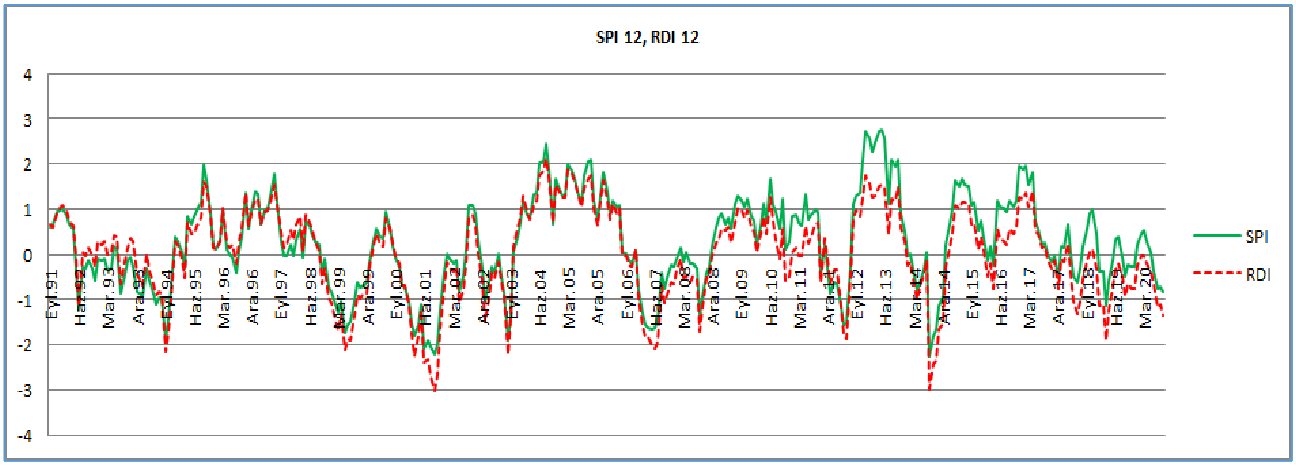

Figure 6. Drought analysis results for Samsun stations
Şekil 6. *Samsun istasyonu için kuraklık analiz sonuçları*

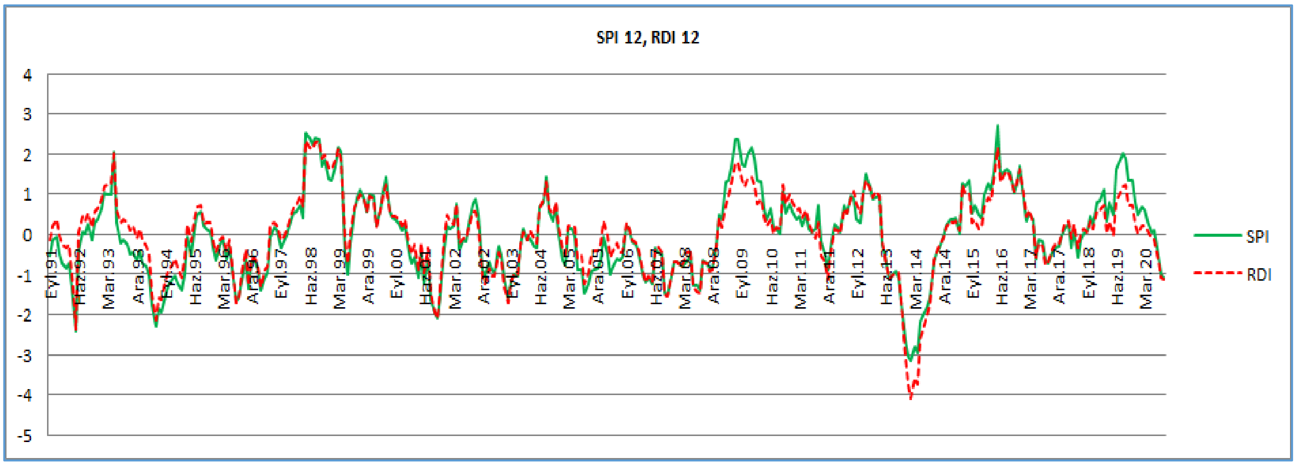

Figure 7. Drought analysis results for Çorum stations
Şekil 7. *Çorum istasyonu için kuraklık analiz sonuçları*

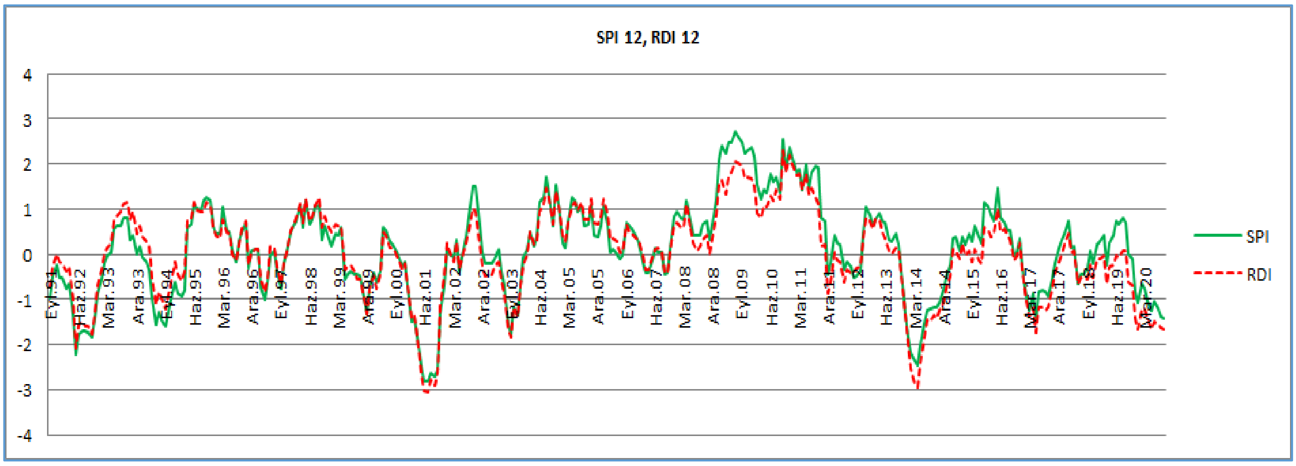

Figure 8. Drought analysis results for Amasya stations
Şekil 8. *Amasya istasyonu için kuraklık analiz sonuçları*

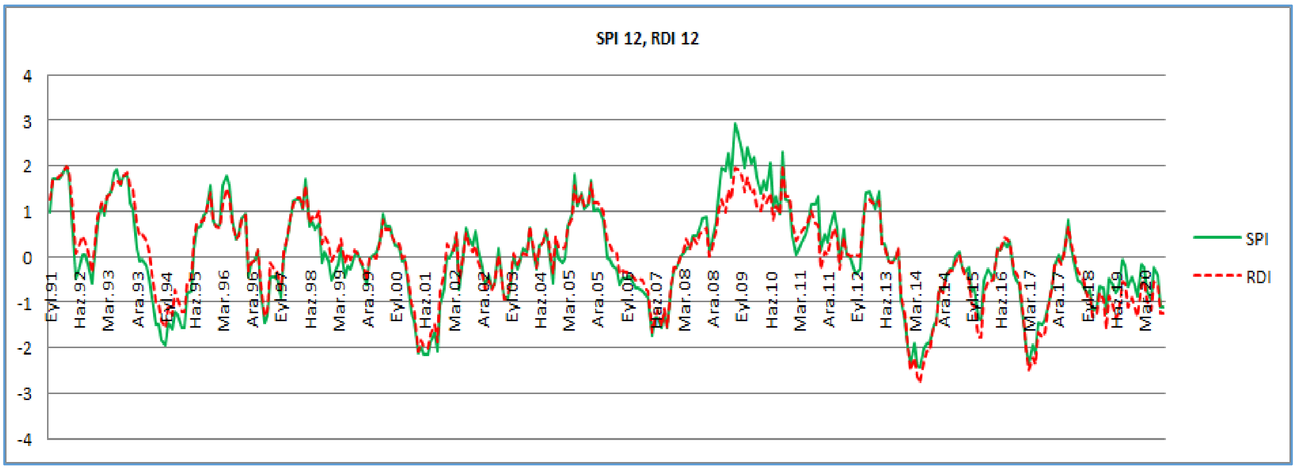

Figure 9. Drought analysis results for Tokat stations
Şekil 9. *Tokat istasyonu için kuraklık analiz sonuçları*

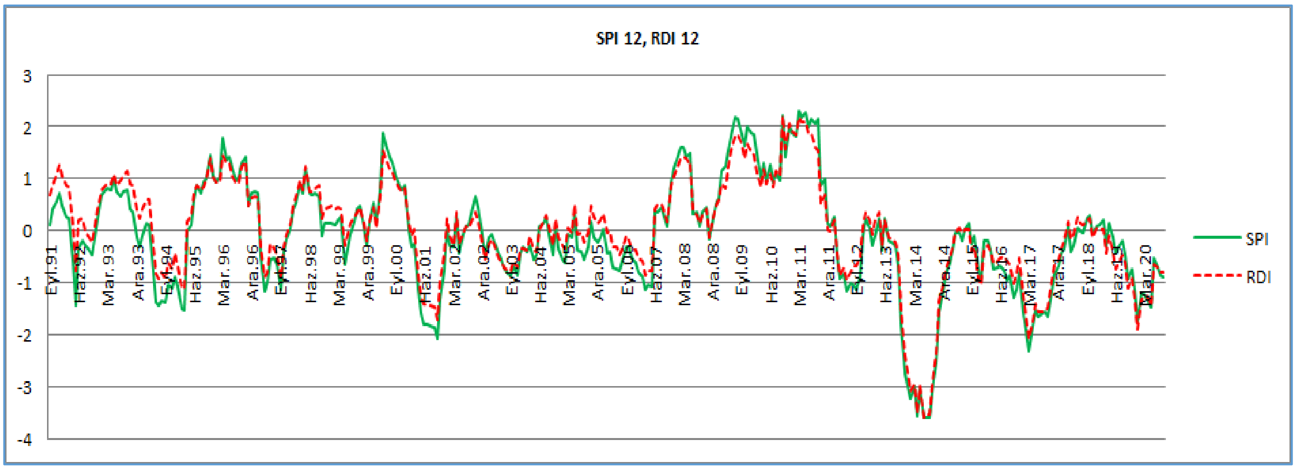

Figure 10. Drought analysis results for Zile station
Şekil 10. *Zile istasyonu için kuraklık analiz sonuçları*

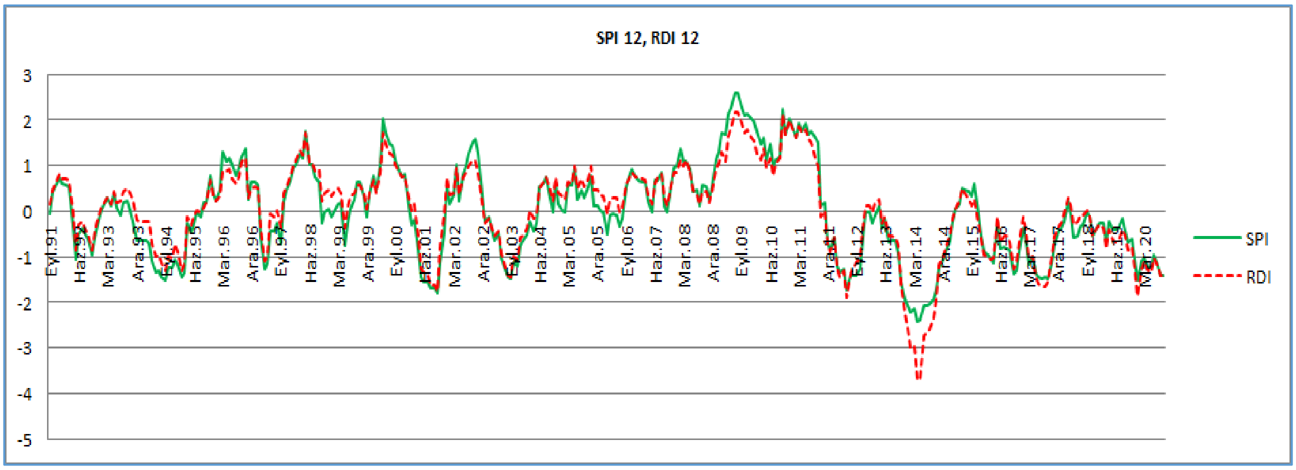

Figure 11. Drought analysis results for Turhal station
Şekil 11. *Turhal istasyonu için kuraklık analiz sonuçları*

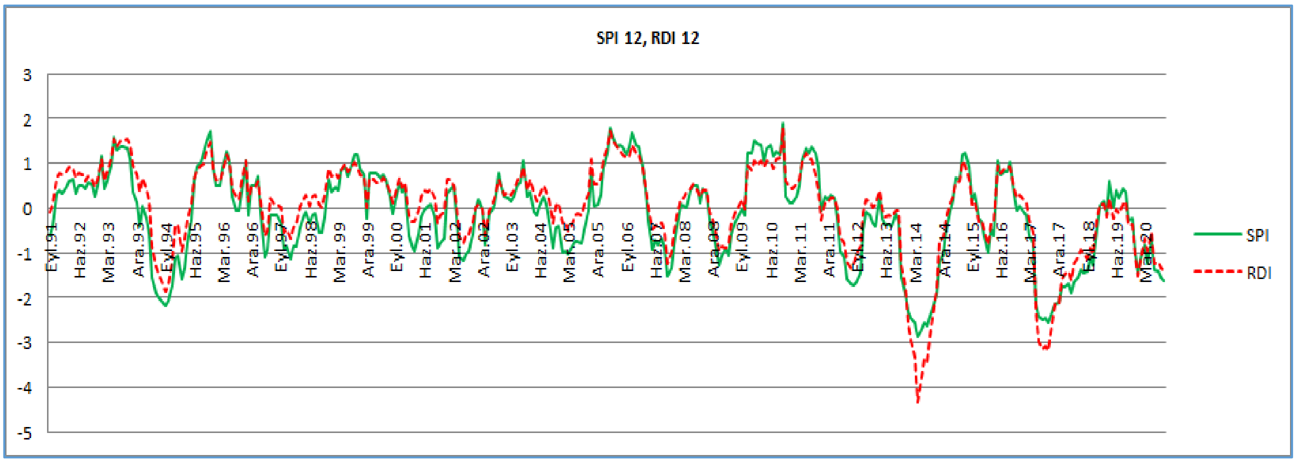

Figure 12. Drought analysis results for Suşehri station
Şekil 12. *Suşehri istasyonu için kuraklık analiz sonuçları*

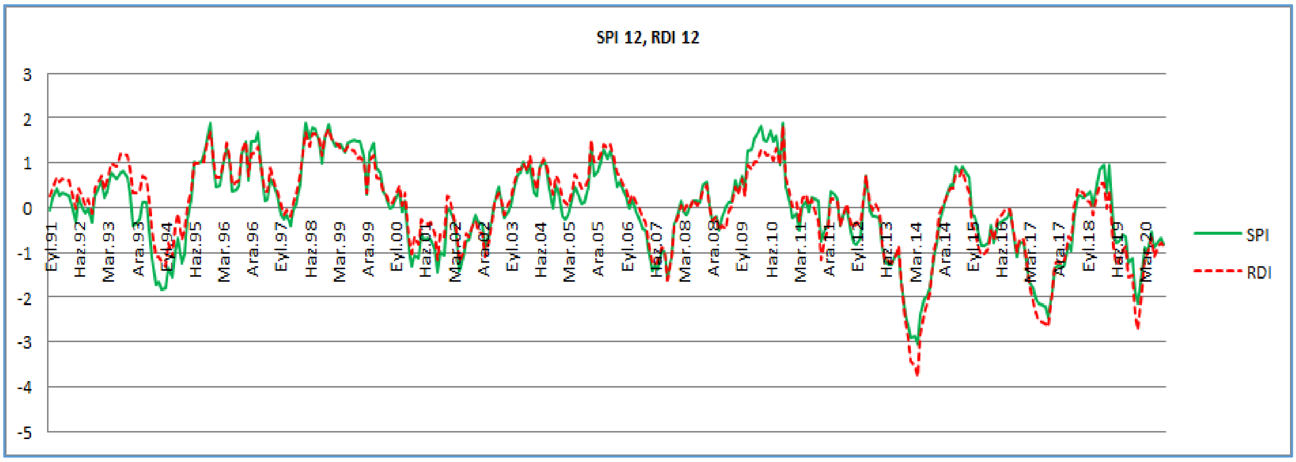

Figure 13. Drought analysis results for Şebinkarahisar station
Şekil 13. *Şebinkarahisar istasyonu için kuraklık analiz sonuçları*

Table 4. Drought results frequency percentages for Yeşilırmak basin stations
Tablo 4. *Yeşilırmak havzası istasyonları için kuraklık sonuçları frekans yüzdeleri*

	Drought Categories	Extreme Wet	Wet	Moderate Wet	Normal	Moderate Drought	Drought	Extreme Drought
SAMSUN	SPI 12 (%)	4.3	6.0	12.9	65.6	4.9	5.2	1.1
	RDI 12 (%)	0.3	5.2	11.5	67.9	6.0	5.2	4.0
ÇORUM	SPI 12 (%)	3.7	4.6	8.0	66.5	10.0	4.6	2.6
	RDI 12 (%)	2.3	2.9	8.0	72.5	8.0	3.2	3.2
AMASYA	SPI 12 (%)	4.3	4.3	8.9	68.2	7.7	3.2	3.4
	RDI 12 (%)	1.4	3.4	10.0	69.1	8.3	4.3	3.4
TOKAT	SPI 12 (%)	2.6	6.9	8.6	66.2	7.2	5.4	3.2
	RDI 12 (%)	0.3	5.4	12.3	64.5	8.9	4.9	3.7
ZİLE	SPI 12 (%)	3.2	4.0	7.7	67.9	8.3	5.2	3.7
	RDI 12 (%)	1.4	3.7	9.7	73.6	5.7	2.3	3.4
TURHAL	SPI 12 (%)	3.2	5.4	8.3	63.0	14.0	3.7	2.3
	RDI 12 (%)	1.1	4.9	7.4	68.8	11.7	3.2	2.9
SUŞEHRİ	SPI 12 (%)	0.0	2.0	12.0	65.6	8.6	5.7	6.0
	RDI 12 (%)	0.0	2.0	9.2	75.1	6.0	2.9	4.9
ŞEBİNKARAHİSAR	SPI 12 (%)	0.0	4.9	10.3	67.9	9.5	3.7	3.7
	RDI 12 (%)	0.0	2.9	13.2	67.9	9.2	2.3	4.6

If it is accepted that the drought index calculated according to the 12-month precipitation totals can reflect the hydrological drought; In all of the stations given in Figure 3-Figure 10, it is seen that the year of the most severe hydrological drought in the Yeşilırmak basin was 2014.

When we look at the basin in general, it is seen that the drought analysis made according to both the SPI method and the RDI method at all stations are quite compatible with each other. Differences between RDI and SPI analyzes are seen in the occurrence of extremely dry and extremely wet periods. In the calculations made with the RDI method, it was seen that the extreme dry periods were seen more frequently than the SPI method, on the other hand, the frequency of the extremely wet periods was more frequent in the calculations made according to the SPI method compared to the RDI method. It is seen that normal and moderate dry periods are more common in the SPI method than in the RDI method at the Suşehri and Şebinkarahisar stations located in the easternmost part of the basin. In both drought methods, no extreme wet periods were observed until 2008 in the central part of the Yeşilırmak basin (Amasya, Zile, Turhal, Tokat stations).

Looking at Table3; While it is seen that normal periods give closer values each other in both drought index methods, it is seen that there are differences for other drought classes. In the Samsun station, extreme wet periods were observed in 4.3% of all times in the SPI analysis, while in the RDI analysis, extreme wet periods were calculated only in 0.3% of all times. On the other hand, in this station, according to the SPI method, extreme dry periods were observed at 1.1% of all times, while according to the RDI method, extremely dry periods were observed at 4% of all times.

When Çorum station results are examined, the number of normal periods calculated by SPI is higher than RDI. No significant difference was observed between the number of wet and dry periods in both methods.

It has been calculated that extreme dry and dry times, which are seen at all times in all stations except Suşehri and Zile, are seen more in the RDI method than in the SPI method.

In terms of extremely wet periods; In Suşehri and Şebinkarahisar, which are in the easternmost part of the basin, excessive wet periods were not calculated in both methods, but at other stations, more extreme wet periods were calculated in terms of time percentage in SPI method compared to RDI method. For example; Extreme wet periods for Amasya station were calculated as 4.3% for SPI and 1.4% for RDI at all times. The fact that the periods calculated with the SPI method are more than the periods calculated with the RDI method was also observed for the wet periods. For example; The percentage of wet period in Samsun station was 6% in SPI method and 5.2% in RDI method.

4. Conclusions

In this study, according to 12-month precipitation totals for Samsun, Çorum, Amasya, Tokat, Zile Turhal, Suşehri and Şebinkarahisar stations, which meet the requirement of having 30 years of monthly precipitation totals and ET_0 data between 1991 and 2020 in Yeşilırmak basin, two different drought indices (SPI and RDI methods) were used to analyze the drought RDI drought indices calculated using precipitation and evapotranspiration (ET_0) data with the SPI method calculated only based on precipitation data, and drought analysis in the Yeşilırmak basin were performed and the results of the two methods were compared.

When the results summarized in Figure 3-through Figure 10 and Table 3 are examined, it is seen that the RDI method calculates the extreme dry periods more severely than the SPI method; On the other hand, it has been observed that the SPI method calculates the wet periods more severely than the RDI method. For example, while the SPI index for Turhal station was calculated at about -2.5 in the period of April 2014, the RDI index was calculated at about -3.7 for the same period, emphasizing that the extremely dry period was more severe. Although both methods generally calculate the same signal for the same periods (dry-wet period) similarly, it was observed that the RDI index was calculated more severely for the dry periods. The calculation of drought values more severely directs scientists to calculate droughts with different indices. It is considered that calculating drought using at least 2 parameters gives more reliable results than calculating drought using only one parameter.The most important result of this study is that it has shown that the effect of ET0 values in drought calculation is very important by comparing it with RDI analysis and SPI analysis. Because drought suggests that not only the insufficiency of precipitation, but also other affecting hydro-meteorological parameters should be taken into account. To develop drought analysis, it is recommended to make calculations by using 2 or more meteorological parameters together, to detect trends and develop new methods.

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