DROUGHT ASSESSMENT IN AYDIN AND IZMIR DISTRICTS IN TURKEY

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by
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İZMİR

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ABSTRACT

DROUGHT ASSESSMENT IN AYDIN AND IZMIR DISTRICTS IN TURKEY

Drought indices are widely used in order to track the severity, duration, and frequency of droughts, drought indices are frequently utilized. Turkey's Aegean region, which is expanding, has a range of water resources, including lakes, streams, lakes, and groundwater aquifers. In this study, the drought features in the Büyük Menderes, Küçük Menderes, and Gediz basins in the Aegean area of Turkey are investigated using long-term total precipitation and temperature records from 14 meteorological stations between 1973 and 2020 (47 years). For this, the Standardized Precipitation Index (SPI) and the Standardized Precipitation and Evapotranspiration Index (SPEI), and Discrepancy Precipitation Index (DPI) are used to investigate drought patterns, monthly and over 3-, 6-, and 12-month (annual) periods. The results reveal that the monthly indices show almost the same results for the whole study area, but the different indices differ in the severity of drought. As a common belief, moderate, severe, and extreme drought is observed at the end of the 1980s and around 2020, which is the closest year to the present. In addition, the trend analysis of the annual temperature (daily average) and total precipitation time series data collected from these 14 stations is examined. Sen test, Mann-Kendall test, and Spearman's rho test are used for trend detection. The Pettitt test is used to estimate the magnitude of the slope in the series and the Theil-Sen approach is used to detect the change point of the series. For precipitation, all stations showed a statistically significant increase in trends. In the temperature analysis, on the other hand, all stations show statistically significant increasing trends in daily average temperatures. The amount of precipitation increase determined by the Theil-Sen test is found to be between 4.2 and 7.9 mm/year.

Keywords: *Drought, Trend, Aegean Region, SPI, SPEI, DPI, Precipitation, Temperature*

ÖZET

AYDIN VE İZMİR İLLERİNDE KURAKLIK DEĞERLENDİRMESİ

Kuraklık endeksleri, kuraklıkların sıklığını, süresini ve şiddetini izlemek için yaygın olarak kullanılmaktadır. Ege bölgesi, deniz kıyıları, göller, akarsular ve yeraltı suyu akiferleri dahil ancak bunlarla sınırlı olmayan çeşitli su kaynakları ile Türkiye'nin gelişen bir bölgesidir. Bu çalışmada, Türkiye'nin Ege bölgesindeki Büyük Menderes, Küçük Menderes ve Gediz havzalarında kuraklık özelliklerini araştırmak için 1973-2020 (47 yıl) arasında 14 meteoroloji istasyonundan alınan uzun süreli toplam yağış ve sıcaklık kayıtları kullanılmıştır. Bunun için, kuraklık modellerini araştırmak için aylık ve 3-, 6- ve 12 aylık (yıllık) zaman periyotlarında Standardize Yağış İndeksi (SPI) ve Standardize Yağış ve Evapotranspirasyon İndeksi (SPEI) ve Yağış Aykırılık İndeksi (DPI) kullanılmaktadır. Sonuçlar, aylık endekslerin tüm çalışma alanı için hemen hemen aynı sonuçları gösterdiğini ancak, farklı endekslerin kuralık şiddeti hakkında farklılaştığını ortaya koymaktadır. Ortak kanı olarak, 1980'li yılların sonunda ve günümüze en yakın yıl olan 2020 civarında, orta, kvvetli ve aşırı şekilde kuraklık gözlenlenmiştir. Ayrıca bu 14 istasyondan toplanan yıllık sıcaklık ve toplam yağış zaman serisi verilerinin trend analizi incelenmiştir. Trend tespiti için Sen testi, Mann-Kendall, Spearman's rho testi kullanıldı. Serilerdeki eğimin büyüklüğünü tahmin etmek için Pettitt testi ve serilerin değişim noktasını tespit etmek için Theil-Sen yaklaşımı kullanıldı. Yağış için, tüm istasyonlar eğilimlerde istatistiksel olarak önemli bir artış gösterdi. Sıcaklık analizinde ise tüm istasyonlar günlük ortalama sıcaklıklarda istatistiksel olarak anlamlı artış eğilimleri göstermektedir. Theil-Sen testi ile belirlenen yağış artış miktarı 4,2 ile 7,9 mm/yıl arasında bulunmuştur.

Anahtar kelimeler: *Kuraklık, Eğilim, Ege bölgesi, Türkiye, SPI, SPEI, DPI, Yağış, Sıcaklık*

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ABBREVIATIONS

DIs: Drought Indices

SR: Spearman's Rho Test

MK: Mann Kendall

SPI: Standardized Precipitation Index

DPI: Discrepancy Precipitation Index

NMCC: National Meteorological Center of China

SPEI: Standardized Precipitation and Evapotranspiration Index

CHAPTER 1

INTRODUCTION

Drought is one of the most enormous challenges in the production and safety of agricultural products and foods. For this, the links between water and food bonds are getting more and more attention around the world. Turkey is among the countries that have serious concerns about water scarcity (Sokollu, 2014). In addition, the importance of Izmir as Turkey's third capital city, tourism center, and economic hub is undeniable.

Regarding this, SPI, EDI, Deciles Index (DI), PNI, DAI, PDSI, CZI, and the newly developed SPEI and Discrepancy Precipitation Index (DPI) are among the assessment tools in the evaluation for drought, while numerous studies have been conducted to investigate the aspects of these drought indices. (e.g., Svoboda et al. 2002; Morid et al. 2006; Webb 2016; Azmi et al. 2016; Montaseri et al. Amirataee 2017; Yacoub and Tayfur 2020).

1.1. Objectives of the Study

The province of Izmir has a great potential in terms of water resources including its coasts, lakes, streams (the main rivers: Küçük Menderes, Büyük Menders, and Gediz), and groundwater reserves. Likewise, the province of Aydın, located in the Aegean region within the scope of this study, has an increasing population, especially in summer, with tourism, just like Izmir. Manisa, Muğla, Denizli, and Uşak provinces, which are also within the scope of the study, are among the cities in Turkey that are constantly developing (and therefore increasing in population). For this reason, the measurement and evaluation of historical drought events are very important in the planning and development of the region. Because the usable water resources may decrease. It is utilized for a variety of things, including drinking, navigation, and irrigation. This study aims to shed light on the drought in the Aegean region in Turkey. The general objectives are the followings;

- determine the characteristics of drought such as duration, period, frequency, and magnitude
- identify the trends in precipitation and temperature in the region during the period of 1974-2020, and
- detect a single change-point in the precipitation and the temperature time series.

1.2. Thesis Structure

This thesis consists of six chapters in total. The sections are briefly described as below:

CHAPTER 1. INTRODUCTION: In this section, firstly the requirements for drought and trend analysis are defended, and the structure of the thesis is provided.

CHAPTER 2. LITERATURE REVIEW: The background information for the study is explained in this section. The definitions, categorization, and evaluation of drought are covered in the first section of this chapter, which is followed by a brief explanation of the techniques used to analyze drought. The second part describes the work done for data accuracy and reliability.

CHAPTER 3. DATA AND STUDY AREA: This section briefly tells the study area and data. In addition, the tests mentioned in the previous section and their results are also presented in this section.

CHAPTER 4. DROUGHT ANALYSIS: This section describes and discusses the methods to criticize drought in the region and their results.

CHAPTER 5. TREND ANALYSIS: This section first discusses the results of analyzes of annual temperature (mean) and annual total precipitation trends by applying five trend determination tests.

CHAPTER 6. CONCLUSIONS: This section summarizes the results, concluding the two issues of drought and trend analysis in general, and then emphasizes the importance of this study for the region studied.

CHAPTER 2

LITERATURE REVIEW

2.1. Drought Definitions

There is no universally agreed-upon conventional definition of drought as the occurrence of droughts increases internationally. Instead, there are growing arguments about the definition and viewpoints of drought. It might be challenging to come to a consensus on a single definition of drought, even among specialists. Drought is defined as a deficiency in precipitation from an estimated average within a time scale. In the most general definition, droughts are one of the major concerns in the production and security of food and agricultural goods. Accordingly, the continuously changing climate, regardless of the cause and effect of its situation, raises serious concerns. For this, the connections between water and food nexus are increasing to draw attention around the globe.

2.2. Classifications of Drought

Understanding the context in which the drought and its effects are described is crucial. Wilhite and Glantz (1985) discovered more than 150 instances of drought in the literature; these, as shown in Figure 2.1, can be further subdivided into four main categories:

- (i) meteorological droughts, tracked down as a decrease in precipitation;
- (ii) agricultural droughts, tracked down as a lack of moisture in the soil;
- (iii) hydrological droughts, tracked down as a decrease in stream-flows and runoffs; and
- (iv) socio-economic droughts.

According to these categories, there are many different and distinct realizations of drought types, each having a variety of repercussions on different industries.

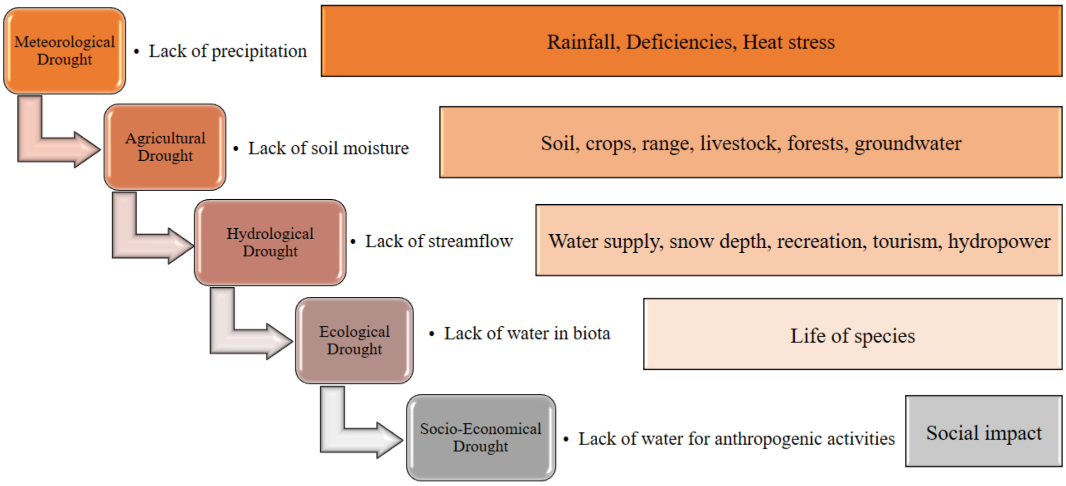

Figure 2.1: Types of droughts (Source: Yihdego et al., 2017)

2.3. Impact of Drought

All types of droughts begin with a decrease in precipitation over time and/or space; the early stages of this cumulative deficiency are often referred to as meteorological droughts. As a result, above-average temperatures, strong winds, and low relative humidity persist along with the phenomenon over time, having a significant impact on socioeconomic and environmental cycles. Due to the different climatic patterns seen in different places, changes in the local hydro-meteorological, geographical, and climatological conditions determine how meteorological droughts are articulated, and these changes are crucial to the definition of drought.

A drought in agriculture can also occur before the start of the growing season when the weather is unfavorable for planting. The term "hydrological drought" describes drought conditions that reduce the amount of water that is accessible in water resources (Eslamian 2014). Due to the length of meteorological droughts, the absence of surface flow caused by the area's dry soil starts to have an impact on the hydrology of the area. There are often lags that are distinct in both time and place. As a result, it was impossible to measure the hydrological effects of a drought immediately after it began. Frozen precipitation is collected for future runoff throughout the winter months, therefore a dry winter might lead to a hydrologic drought in the months that follow. The dry soil can prevent significant runoff even during precipitation events because it can absorb too much precipitation before it reaches rivers, streams, and other bodies of water. Heat and dryness will combine to reduce the amount of water that is accessible in a hydrological system.

When a hydrologic drought is a worry, water managers may decide to withhold water from some hydrological systems to lessen or modify potential effects in the future. Even if precipitation resumes its typical pattern, prolonged drought will have an impact on a region's hydrology if it is not properly recharged. A hydrological drought often develops slowly, and as a result, the recovery process might take months or even years. In terms of the components of meteorological, agricultural, and hydrological droughts, socioeconomic definitions of drought are linked to the relationship between supply-demand and economic commodities.

Other weather or climatic conditions can be used to explain socioeconomic drought or situations where demand exceeds supply, in addition to expressing why some items are rare. Depending on the severity of the impact and the value of the items affected, socioeconomic drought effects might start to manifest as soon as the drought hits a place and can last for quite some time. Ecological drought is also known as a lengthy and widespread shortage of naturally occurring water supplies, also known as changes in natural and managed hydrology, which put an ecosystem under a lot of stress. According to Liu et al. (2012), the occurrence of ecological droughts in the area can readily alter the ecological water level of a lake, which is the lowest water level required for the natural retention, integrity, and function of a lake ecosystem.

Given the difficulty in defining droughts, it is crucial to understand how they arise and what signs are available to identify those phenomena. Therefore, the initial step in researching droughts should be acquiring data regarding a region's main climatic and weather traits. A consistent climate pattern across time or space may also signal the beginning of drought in another area.

The most well-known types of droughts are conceptualized in generic terms in Figure 2.1 as a result. Therefore, any core observation must first address the local climate in order to determine whether the situation as it is now is likely to lead to a drought in the future. If a dry weather pattern is unusual, the chance of appropriate planning to lessen the effects of the likely drought would increase. Also, crucial to be fully ready for any drought event is a drought early warning system (DEWS) that monitors drought conditions. Without sufficient planning and readiness, the effects of drought could worsen or have even more negative effects on several sectors.

2.4. Assessment of Drought in the Study Area

When the case of Izmir is concerned, there are a few studies about the drought indices and indicators. Komuscu et. al. (1999) computed SPI values for 40 meteorological stations including Izmir station, in which SPI with 3-, 6-, 12-, and 24-month scales, covering 1940-1997 were evaluated. Results proved several categories of drought in the Izmir station. Pamuk et al. (2004) used SPI to evaluate drought in the Aegean region. It was concluded that in winter, near-normal drought patterns are observed. The drought susceptibility index (DSI) was utilized by Gunes et al. (2008) as a gauge of drought tolerance. The findings also showed that compared to drought-sensitive cultivars, drought-tolerant cultivars exhibited lower levels of RWL and membrane permeability but higher concentrations of RWC, ascorbic acid, and pro-line. Bacanli (2017) used fluctuation of the SPI at monthly intervals of 1, 3, 6, 9, 12, and 24. By using linear regression, the Mann-Kendall and Spearman's rho tests at the 5% level of significance, and linear regression, the trends of the 1, 3, 6, 9, 12, and 24 monthly SPI data were examined. Meteorological data from Kutahya, Izmir, Mugla, Manisa, Afyon, Denizli, Aydin, and Usak stations. At five stations, the annual precipitation dropped. In the SPI's analysis, droughts are seen as occurring more frequently but for shorter periods of time (such as three months), and as the period lengthens, the duration of the drought likewise lengthens but the frequency of it diminishes. In recent years, "severe" winter droughts have started to become more common. The highest intervals were in the normal and mild drought degrees when this study was conducted for various times based on SPI values in all stations. Extreme and severe droughts were also frequently and intensively observed. The trend in the drought index and precipitation was then compared. The outcomes of the drought study and the trend analyses of precipitation are parallel. Aksoy et al. (2019) used the Google Earth Engine (GEE) platform to analyze the spatiotemporal distribution of drought conditions in Turkey from February 2000 to January 2019 using several drought indices generated from MODIS satellite data. Turkey's Rize, Istanbul, Konya, Izmir, Sanliurfa, and Bursa were all assessed for drought using the VHI, NMDI, and NDDI, among other indices. It was determined that Izmir experienced a severe drought in 2007 and another one in 2008. The drought, which began in 2007, was more severe and lasted longer than it was in other provinces. The mild drought level in 2007 was displayed by the NDDI for Izmir, which has never been there for 20 years. In this respect other studies conducted by Özgürel et al. (2002), Özgürel and Kiliç (2003), Topçuoğlu et al. (2004), Sirdaş and Şen (2010), Khorrami and Gunduz, (2019) etc. can be suggested for the interested readers. There are also several drought assessment studies that considered the spatial and/or temporal drought patterns across Turkey and extended the results to apply to the Izmir district as well.

The evaluation of droughts is essential to the management and planning of water resources. Therefore, it is important to look at the origins of past droughts in the area, as well as their effects. Therefore, comprehending the various drought principles would aid in creating drought model. Unlike other natural catastrophes, droughts arrive gradually, making it possible to develop mitigation techniques to effectively deal with their impacts. Drought mitigation efforts should be carried out in three stages: pre-efforts, during, and post-efforts the drought. In this manner, the impacts would be considerably diminished at a low cost. Numerous techniques were created to evaluate and track the drought event as a result. Figure 2.2 shows the realization a drought process.

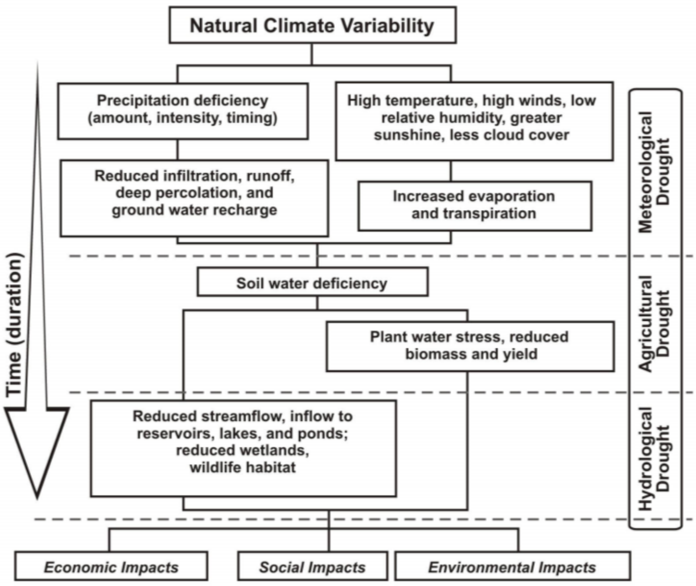

Figure 2.2. General realization of drought types (Source: Yihdego et al., 2017)

2.5. Drought Indices

The drought index is a metric used to assess the effects of drought and to describe its intensity, length, and severity, among other characteristics. The hydrological cycle's precipitation, streamflow, temperature, and other (measurable) factors are typically used to calculate drought indices. Because it is frequently possible to find long-term precipitation records, precipitation data are frequently utilized to calculate drought indices. The indices utilized in this study, which utilized data on temperature and precipitation, are explained below:

2.5.1. SPI

The SPI was developed by McKee et al. (1993) and is based on the typical standardization of a time series on the deviated values from the population mean, divided by the standard deviation. Generally, a 12-month moving average (MA) evaluation approach is used while a shorter or a longer-term is used to project the importance of the index and the period in which it lingers on a region. In this respect, a set of values for each period is derived and obtained results are evaluated based on the critical values.

2.5.2. SPEI

A similar index to SPI is called SPEI. The applicability is more advanced than SPI, though. It is a meteorological drought index that forecasts drought conditions in a region while also accounting for variations in precipitation, temperature, and (unlike SPI) potential evaporation.

2.5.3. DPI

In mathematics, the inconsistency theory observes how much a given distribution deviates from the ideal (Weyl, 1916). Tayfur (2021) developed a new drought index named Discrepancy Precipitation Index (DPI) to investigate the drought. The method uses precipitation data and does not use any probability distribution. The technique is based on the fact that the statistics surrounding the mean value are inconsistent. D-score values were used to categorize droughts. The technique is used to evaluate the drought in several stations spread throughout a variety of climatic zones, including desert Mauritania, semi-arid Afghanistan, and the Mediterranean climate (Turkey). The findings indicate that this index is a more effective drought assessment tool for regions with arid climates. It was asserted that DPI can be utilized in conjunction with other indices for places with Mediterranean climates.

2.6. Review of Trend Analysis

Global climate change has become a situation that affects the whole world in recent years. Studies on the impact of climate change are mostly followed by the changes in the trends of hydrometeorological variables (air temperature and precipitation). Evidence of an increase in temperature and precipitation over the past year has been demonstrated by many studies. In order to identify precipitation patterns, New et. al. (2001) gathered precipitation data from numerous nations. They came to the conclusion that daily precipitation rose in the 20th century. According to research by Jones et. al. (1999) on air temperature fluctuations over 150 years, the world's temperature rose by 0.32° between 1978 and 1997. In addition, Lettenmaier, Wood, and Wallis (1994) analyzed trend for precipitation at their station. In Oman, 27 years of precipitation records were used by Kwarten (2009) to examine trends. The results were determined to be reasonable and consistent with other studies. Van Beusekom (2015) came to the conclusion that trend analysis may also make sense of short-term precipitation patterns. To this purpose, the majority of earlier studies made the erroneous assumption that trying to monitor precipitation trends in short-recorded data was futile. Some decisions, however, cannot be put off for another 30 years, as evidenced by the recent fast shifts in precipitation patterns and climatic behavior. Chen, Kuo, and Yu (2009) used long-term precipitation records to explore historical patterns of meteorological dryness in Taiwan and found an increased tendency in the daily precipitation time series in the study region.

The majority of these trend tests fall under the category of parametric and non-parametric techniques. The parametric tendency test was found to be more effective than non-parametric testing. In order to identify patterns in hydrometeorological variables, nonparametric MK and SR tests are frequently used. These two tests are employed because they can spot monotonic (going up or down) trends in time series data. Şen (2011) introduced a brand-new (innovative) trend analysis technique that can pinpoint a time series' trend, particularly in terms of the low, medium, and high data values. This method is applicable regardless of the sample size, serial correlation structure of time, or non-normal probability distribution functions. Numerous studies use the Hirsch, Slack, and Smith-developed Theil-Sen method to estimate the absolute values of slope. Finally, the change points in time series are identified using Pettitt's test (1979). (Mu, Zhang, McVicar, Chille, & Gau, 2007).

CHAPTER 3

DATA AND STUDY AREA

3.1. Study Area

The Aegean Region, with an acreage of 90,251 km², is Turkey's 3rd smallest region but with high population density. This region is adjacent to the Central Anatolia Region in the east, the Marmara Region in the north, the Mediterranean Region in the southeast, and the Aegean Sea in the west (Fig.3.1).

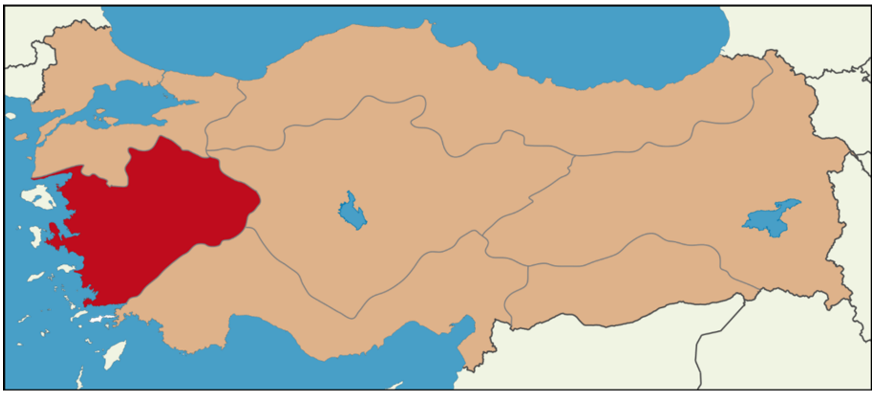

Figure 3.1: Aegean Region

The dominant climate type in the coastal Aegean Region is the Mediterranean Climate. In the climate of the region, summers are hot and dry, while winters are rainy and warm. Mediterranean climate is more common on the coast than inland. Located in the western part of Turkey, the Aegean Region has dry summers and rainy winters. Due to the land structure, the Mediterranean Climate Type can be seen up to the inner parts. The climate cover of the Aegean Region is the maquis, which is the vegetation seen in the Mediterranean Region according to the land conditions. We can state that there are forested areas in some regions. While the vegetation in the sections up to 400 meters is maquis, the vegetation seen in the areas above 400 meters is forested. It is the region where urbanization is very intense. Cities in the Aegean Region are mostly located on the edges of fertile plains and troughs where main roads pass; In the coastal part, it is located on the edges of the bays. Rural settlements are generally seen on the banks of streams in the plains and inside the valleys. About 1/8 of Turkey's population lives in the Aegean Region. More than half of this population (62.2%) is in cities. The average population density of the Aegean Region is above the average of Turkey. In terms of population density, it ranks second after the Marmara Region.

3.2. Data

There are a number of large cities in the western Turkish Aegean region such as Izmir and Aydin. This region is shared by the three basins, utilized in the analysis, Kucuk Menderes, Buyuk Menderes, and Gediz (Fig. 3.2). There are 20 sub-basins in all, with 10 in the Buyuk Menderes basin, 5 in the Kucuk Menderes, and 5 in the Gediz basin.

Data on temperature and precipitation from 14 meteorological stations between the years 1973 and 2020 are used in this study. The locations of the stations are shown in Table 3.1. The data were collected at the Izmir, Cesme, Denizli, Yatagan, Nazilli, Kusadasi, Sultanhisar, Manisa, Salihli, Mugla, Seferihisar, Guney, Selcuk, and Usak stations. Tables 3.2 and 3.3 for the total annual precipitation and average annual temperature show statistical properties of the time series including mean, standard deviation, maximum (Max), kurtosis coefficient (K) and skewness (S).

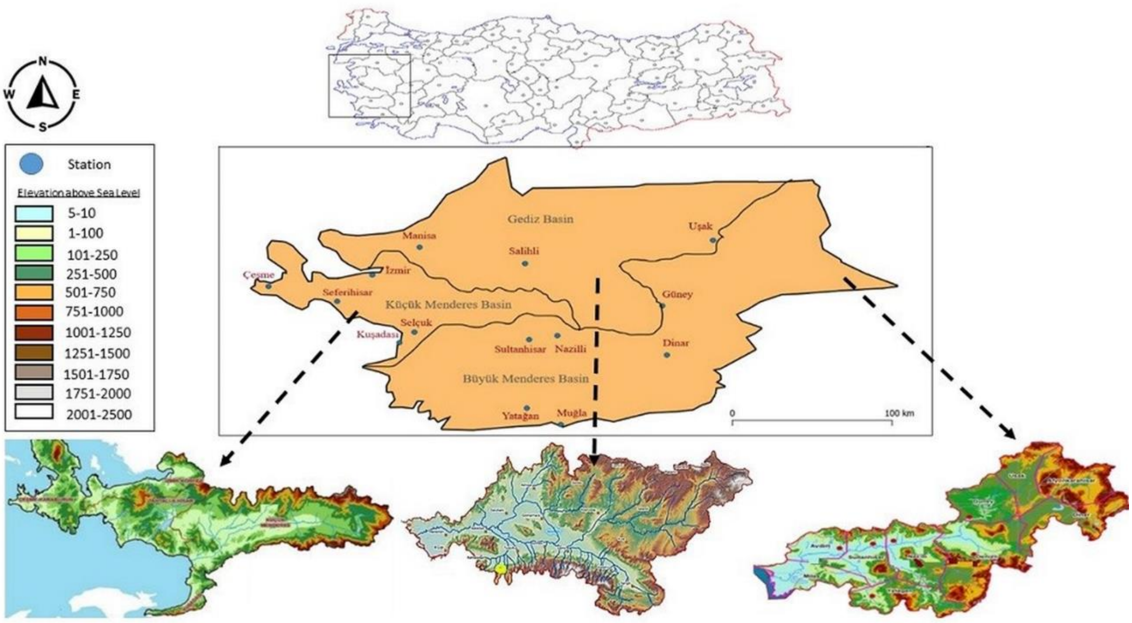

Figure 3.2. Meteorological Stations

Table 3.1: Information about the meteorological stations

Station	Basin	Subbasin	Location
Denizli	B. Menderes	Çürüksu	37°45'43.2"N 29°05'31.6"E
Sultanhisar	B. Menderes	Aydin Söke	37°53'03.5"N 28°09'01.4"E
Salihli	Gediz	Gediz	38°28'59.2"N 28°07'24.2"E
Selçuk	K. Menderes	K. Menderes	37°56'32.3"N 27°22'00.8"E
Çeşme	K. Menderes	Çeşme-Karaburun	38°18'13.0"N 26°22'20.6"E
Manisa	Gediz	Gediz	38°36'55.1"N 27°24'17.6"E
Uşak	B. Menderes	Banaz Çayi	38°40'16.4"N 29°24'14.5"E
Güney	B. Menderes	Buldan-Buharkent	38°09'05.4"N 29°03'31.3"E
Yatağan	B. Menderes	Çine	37°20'22.2"N 28°08'12.8"E
Muğla	B. Menderes	Çine	37°12'34.2"N 28°22'00.5"E
Kuşadasi	K. Menderes	Kuşadasi	37°51'34.9"N 27°15'54.7"E
Nazilli	B. Menderes	Nazilli Kuyucak	37°54'48.6"N 28°20'37.3"E
İzmir	K. Menderes	İzmir Körfez	38°23'41.6"N 27°04'54.8"E
Seferihisar	K. Menderes	Tahtali-Seferihisar	38°11'35.0"N 26°50'27.5"E

As seen in Table 3.2, the Muğla station has the highest average precipitation value among 14 stations. In addition, the maximum precipitation and the highest standard deviation values were reached at this station. On the contrary, the lowest average precipitation value among 14 stations was observed at Salihli station. In addition, the minimum precipitation and the minimum standard deviation value were also seen here.

Table 3.2: Annual Rainfall Characteristics

Station	Mean (mm)	S_d (mm)	*Max (mm)*	*K (mm)*	*S (mm)*
Denizli	583.88	111.18	784.2	-0.24	0.04
Sultanhisar	596.46	138.11	977.4	0.37	0.55
Salihli	476.7	83.11	669	0.15	0.03
Selçuk	664.89	152.19	1060.1	-0.145	0.029
Çeşme	573.83	146.61	869.7	-0.39	-0.34
Manisa	704.83	171.3	1081.6	0.009	0.1
Uşak	524.1	95.23	712.8	-0.6	0.19
Güney	507.1	99.42	783.2	0.7	0.31
Yatağan	648.94	150.27	1026	-0.04	0.2
Muğla	1135	271.51	1760.6	-0.03	-0.16
Kuşadasi	616.73	146.7	914.9	-0.85	0.17
Nazilli	571.14	126.74	856.2	-0.24	0.37
İzmir	696.84	175.24	1086.1	-0.219	0.339
Seferihisar	609.21	137.64	964.6	0.017	0.452

As seen in Table 3.3, the Uşak station has the lowest average temperature value among 14 stations. In addition, the maximum average temperature value was reached at this station. On the contrary, the highest average temperature value among 14 stations was observed in İzmir station at 18.077 C. In addition, the maximum average temperature value is also seen here. The highest and lowest standard deviation values (for T_{mean}) are at Kuşadası and Muğla stations, respectively.

Table 3.3: Annual T_{mean} Characteristics

Station	Mean (C)	S_d (C)	*Max (C)*	*K (C)*	*S (C)*
Denizli	16.41	0.97	18.44	-0.78	0.19
Sultanhisar	17.44	0.68	18.98	-0.78	0.31
Salihli	16.56	0.87	18.54	-0.71	0.46
Selçuk	16.85	0.84	19.17	-0.142	0.49
Çeşme	17.41	0.623	19.18	0.05	-0.36
Manisa	16.93	0.68	18.47	-0.22	0.3
Uşak	12.69	0.72	14.56	0.06	0.46
Güney	13.87	0.81	15.86	-0.12	0.51
Yatağan	16.37	0.69	18.05	-0.31	0.23
Muğla	15.2	0.62	16.7	0.11	-0.13
Kuşadasi	17.39	1.03	19.41	-0.82	0.071
Nazilli	17.52	0.65	19.13	-0.29	0.21
İzmir	18.077	0.739	19.67	-0.49	0.37
Seferihisar	17.14	0.85	18.92	-0.86	0.466

3.3. Data Analysis

The Turkish State of Meteorology services provides the precipitation data in the daily total precipitation formats. It is typical to encounter data abnormalities during hydrological investigations, such as data loss or deficits in precision mistakes, measurement errors, etc. To achieve this, a data repairment approach is typically utilized to recover the information that was lost in the supplied data.

3.3.1. The Double Mass Curve

The double mass curve is a technique for assessing how consistently the data from one station compare to those from the other stations in the research area. It can be used to adjust the inconsistent precipitation or temperature data from the records. For this, a cumulative set of values in the desired station is plotted against the cumulative average values of the remaining stations. Thus, any departure from the perfect fit line can be interpreted as the temporal inconsistency in the data records of the desired station and shall be used in rejection of the presentence of consistency or the removal of those inconsistencies from historical records. As can be seen from Figure 3.3, the cumulative data of a variable versus the cumulative data of the precipitation is a straight line (the variables have a constant ratio), so the data is consistent.

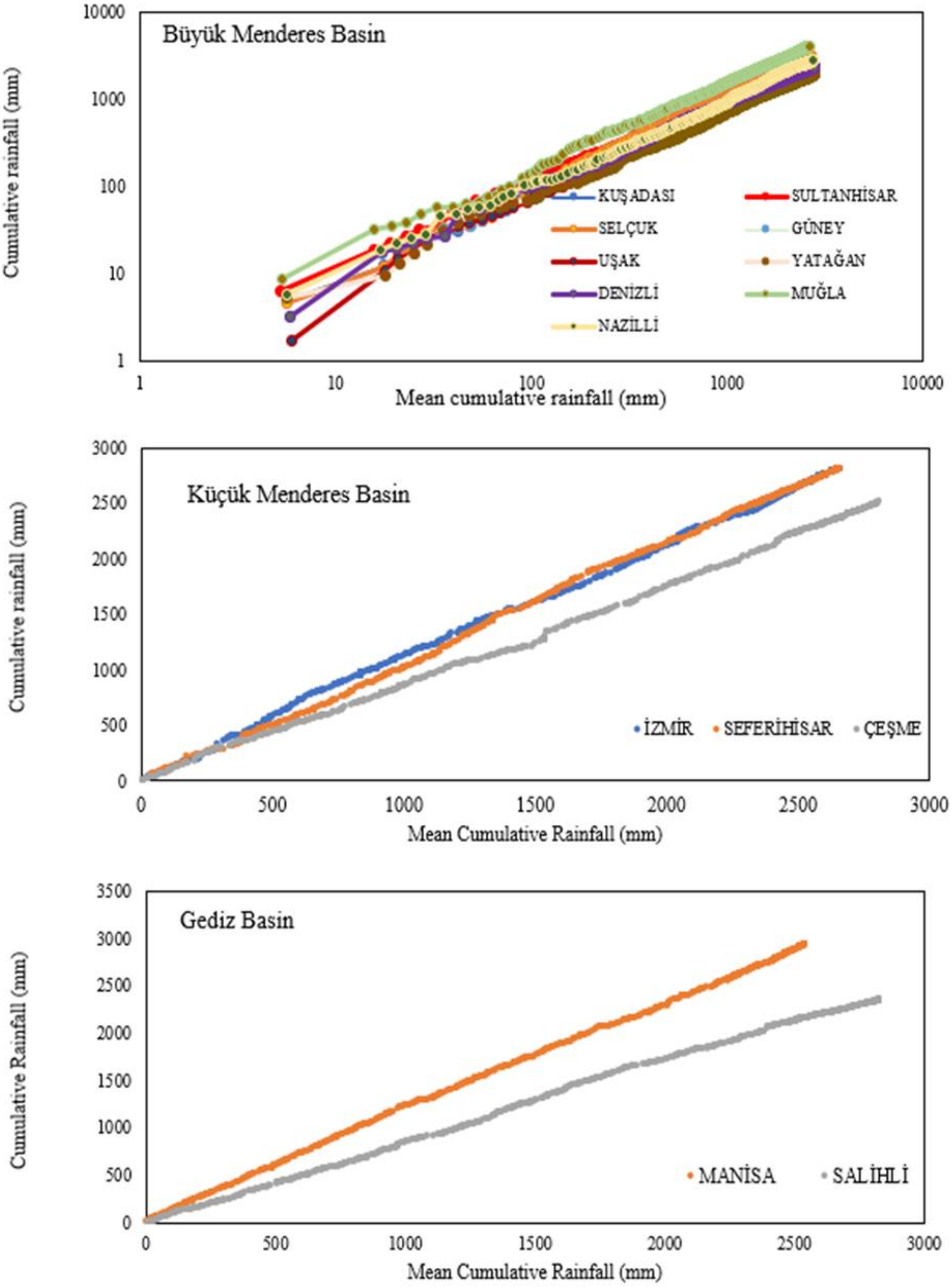

Figure 3.3: Double mass curve analysis for precipitation data at 3 basins

3.3.2 Run Test

The time series' temporal unpredictability is identified using the run test. Random behavior is known to be problematic since it can be difficult to foresee how it will turn out in the future. A statistical approach is used to determine if a collection of data inside a particular distribution was generated by chance. The run test is used to examine the occurrence of related events that are spaced apart by unrelated events. Because of this, it is crucial to ascertain whether an experiment's results are truly random, especially when random and sequential data have implications for later theories and analyses.

$$E = \frac{H+2H_aH_b}{H} \tag{1}$$

$$V = \frac{2H_aH_b(2H_aH_b-H)}{H^2(H-1)} \tag{2}$$

$$Z = \frac{R-(E)}{(S_d)} \tag{3}$$

where,

H is the data number, and E is the expected number of runs. H_a represents values that are below average, H_b represents values that are above average, variance is represented by V, run number by R, and test score by Z. The Z score must fall within the range of -1.96 $\leq Z \leq$ +1.96 in order to determine the randomness of the data with a 95% confidence level. The data cannot be randomly generated if the Z score is beyond the specified range.

Table 3.4 provides the Z values of the run test for the temperature and precipitation data. Z values must lie between -1.96 and +1.96 in order to have a 95% confidence level, and if they don't, it means that the data is not random. Table 3.4 demonstrates that the data is not random because the numbers do not fall inside that range for both temperature and precipitation (rainfall) data time series.

Table 3.4: The Run Test Results

Station Name	Z_{RTP}	Z_{RTT}
Nazilli	-60.40	-63.99
Çeşme	-61.32	-63.99
Manisa	-35.12	-64.02
Salihli	-58.27	-63.98
Muğla	-60.24	-64.01
Denizli	-34.18	-63.98
Yatağan	-58.11	-63.99
Uşak	-56.01	-64.01
Güney	-58.93	-63.98
Izmir	-60.01	-64.01
Selçuk	-62.16	-64.02
Sultanhisar	-58.18	-63.99
Seferihisar	-4.21	-64.01
Kuşadası	-10.73	-64.02

CHAPTER 4

DROUGHT ANALYSIS

4.1. Application

Typically, indicators are calculated numerical representations of drought severity evaluated using hydro-meteorological inputs. These indexes are assessed over a specific period of time to gauge the severity of droughts in various regions. The various forms of drought indices for drought evaluation within the region for periods of 1, 3 months and 1 year are based on daily precipitation and temperature records for 47 years collected from 14 meteorological stations. The characteristics of drought were clarified using applied methodologies.

4.1.1. SPI (Standardized Precipitation Index)

SPI values change when different kinds of statistical distributions are used since SPI is dependent on fitting the distribution to precipitation time series. Meteorological droughts may be detected by a 1-month SPI review, but 3-, 6-, 9-, and 12-month, SPI's are used to respectively project the seasonal estimation of precipitations or soil moisture, effectively representing the precipitation over distinct seasons and annual or hydrological water deficit. When assessing groundwater stage, climate, or local water resources, lengthier SPIs (i.e., 18, 24, 36, and 48-month SPIs) are used (WMO, 2012). Table 4.1 lists the SPI's categories for drought in this regard, and the following equation is used to fit the selected precipitation data to the Gamma distribution (Yacoub and Tayfur 2017),

$$g(x) = \frac{p^{\propto-1} e^{\frac{-p}{\beta}}}{\beta^{\alpha} T(\alpha)} \tag{4}$$

in which,

$$\propto = \frac{1}{4A}\left(1 + \sqrt{\frac{4A}{3}}\right) \tag{5}$$

of which,

$$\beta = \frac{\bar{x}}{\alpha} \tag{6}$$

when,

$$A = \ln(\bar{x}) - \frac{\ln(\bar{x})}{n} \tag{7}$$

where;

α is the parameter of the shape and β is the parameter of the scale, p is the amount of the precipitation, T is the Gamma-function by integration and n is the observation number.

4.1.2. SPEI

The SPEI is a meteorological drought indicator that forecasts drought conditions in a region by taking temperature and precipitation fluctuation into consideration. Finding the monthly potential evapotranspiration is the first step in computing the SPEI (PET). Then, the water balance equation is,

$$D_i = P_i - PET_i \tag{8}$$

where,

P_i is the total precipitation of i^{th} month.

Finally, a log-logistics distribution function is normalized and fitted to the developed explicit values. The SPI and SPEI drought categories are shown in Table 4.1, while the SPEI values for the i^{th} month are the standardized values of the probability (p) of exceeding a specified D_i and are derived by Eq. (9) (Mehr and Vaheddoost 2020).

$$\mathrm{SPEI_i} = \mathrm{W_i} - \frac{2.515517+0.802853W_i+0.010328W_i^2}{1+1.432788W_i+0.189269W_i^2+0.001308W_i^3} \tag{9}$$

while,

$$9\ \mathrm{W_i} = \begin{cases} if\ p < 0.5, & \sqrt{-2lnp} \\ if\ p > 0.5, & \sqrt{-2\ln(1-p)} \end{cases} \tag{10}$$

where,

p is the exceedance probability of calculated D_i values.

Table 4.1: Drought categorization for SPI and SPEI (Source: Barua, 2010)

Z-Index Value	Category
More than 2	Extremely Wet
from 1.99 to 1.5	Very Wet
from 1.49 to 1	Moderately Wet
from 0.99 to -0.99	Near Normal
from -1 to -1.49	Moderately Dry
from -1.5 to -1.99	Severe Dry
less than -2	Extremely Dry

4.1.3. DPI

This index's application is based on precipitation data's inconsistent mean value data. It is outlined in Eq. 11 (Tayfur 2021).

$$\text{DPI} = D_i = \log\left(\frac{Pi}{P}\right) \quad (11)$$

where,

D is the value of discrepancy (D-score) for the i_{th} precipitation, P_i is the i_{th} precipitation in the data series, and P is the mean value of the precipitation data series. Classification of the drought was done using the D-score values displayed in Table 4.2. According to Table 4.2, there is an acute drought if any precipitation number is less than about 75% of the typical amount. To be clear, the D-score is D = -0.6, which means extreme drought, if the average value is 1000 mm and the precipitation total is 250 mm. Similar to this, if the equivalent D-score is D = -0.4, severe drought is present, and lastly, if there has been 40% less precipitation than usual, the corresponding D-score is D = -0.2, signifying moderate drought.

Table 4.2: Drought Classification according to D-Scores (Source: Tayfur, 2021)

D-Score	Category	Remark
0 to -0,19	Nearly Normal	About 0-36% less than the mean value
-0,2 to -0,39	Moderate Drought	About 37-59% less than the mean value
-0,4 to -0,59	Severe Drought	About 60-74% less than the mean value
-0,6 or less	Extreme Drought	About 75% or more less than the mean value

4.2. Results

4.2.1. SPI Results

SPI-1 values calculated with one-month total precipitation values show almost the same results for all stations (in Appendix, Fig. A.1.1- Fig. A.1.14). During the years studied, moderate drought seasons were sometimes observed. In particular, extreme dry months were observed around 1980, and, between 1991 and 1995, and also after 2012. On the contrary, extreme wet periods were experienced in 1982, 2001 and 2002. Another remarkable situation is that SPI-1 values have decreased relatively compared to previous years, especially after 2005.

Seasonally generated SPI-3 values are shown in Fig. A.2.1 - Fig.A.2.14 (Appendix A). The periods are determined in quarterly periods according to the water year. In other words, it was calculated as October-November-December, January-February-March, April-May-June, and July-August-September. In general, moderate dry seasons prevail between 1979-1983 and extremely dry seasons between 1985-1990. In addition, extreme wet periods were experienced at Muğla, Salihli, and Denizli stations in 2005.

SPI-12 values (Appendix A, Fig.A.3.1. – Fig. A.3.14.), which are created by using the annual total precipitation values, are within normal limits in the general framework. However, extreme dry periods were observed around 1989-1992 and 2005-2008, and extreme wet periods were observed in 1981 and in 2010.

4.2.2. SPEI Results

SPEI-1 values calculated with monthly total precipitation and temperature values are shown in Figures B.1.1 - Fig.B.1.14 (Appendix B). In general, severe and extreme droughts were observed between 1980-1995 and also after 2005. There are also moderately wet periods regularly distributed between the study years.

Seasonally generated SPEI-3 values are shown in Fig. B.2.1 - Fig.B.2.14 (Appendix B). The periods are determined in quarterly periods according to the water year. In other words, it was calculated as October-November-December, January-February-March, April-May-June, and July-August-September. Just like with the SPEI-

1 endings, severe and extreme droughts were observed between 1980-1995 and also after 2005 and also there are moderately wet periods regularly distributed between the study years.

SPEI-12 values calculated using annual total precipitation and temperature values, as shown in Figures B.3.1 - Fig.3.14. All the stations exhibit similar behaviour. Moderate wetland between 1974-1979, normal between 1979--1985, severe drought between 1985-1995, moderate dryness between 1995-1998, a moderate wetland in 1999-2003, and moderate dry in 2018 and 2020. In the remaining years, normal conditions were observed.

4.2.3. DPI Results

DPI-1 values were not calculated since there are months that do not receive precipitation, especially in summer (P=0) in the region (since log0 is not defined). Seasonally generated DPI-3 values are shown in Figs. C.2.1 - Fig.C.2.14 (Appendix C). The periods are determined in quarterly periods according to the water year. In other words, it was calculated as October-November-December, January-February-March, April-May-June, and July-August-September. The moderate dry season was observed in all stations between 1981 and 1985, and extremely dry seasons were experienced between 1985 and 1990. In addition, moderate drought seasons and moderate drought seasons were experienced between 1990-1997, although severe drought was also seen. DPI-12 values created by annual total precipitation give moderate drought signals, especially for 2008 and 2020. In addition, there are moderate drought years between 1983-1995 for different stations.

4.3. Discussions of Results

Since the monthly index evaluations would take up a lot of space, the more common and functional annual evaluation based on stations is listed in Table 4.3. For each method, extreme, moderate, and severe drought years show the relevant years for all stations. In the table, the stations are indicated by numbers. (1= Çeşme, 2= Denizli, 3=Güney, 4=İzmir, 5=Kuşadası, 6= Manisa, 7=Muğla, 8=Nazilli, 9=Salihli, 10=Seferihisar, 11=Selçuk, 12=Sultanhisar, 13=Uşak, 14=Yatağan).

The results in Table 4.3 show that the drought occurred in the second half of the 1980s and the second half of the 2000s, and the year 2020, which is closest to the present. According to the table, there were no significant differences between the three indices. Drought-detected years are generally the same. However, there are differences in the drought category. Besides, unlike the other methods, the SPEI provides more reliable results because it uses not only precipitation but also temperature data. As can be seen from the related figures (Appendix B), SPEI values do not experience sudden increases or sudden decreases. This leads to a more realistic analysis.

In the Aegean region, droughts were recorded in 2006-2008, and 2020-2021. Autumn and winter precipitation both suffered significant drops. The meteorological drought has led to the development of hydrological, agricultural, and socioeconomic droughts. In large cities, there have been reports of agricultural product losses, a shortage of surface and subsurface water, insufficiency, and drinking water interruptions. The Aegean, Marmara, Mediterranean, and Central Anatolia regions were most severely affected, and drinking water was supplemented in several cities. As seen in Table 4.3, the drought determination indices for all stations reveal these drought periods in different categories (moderate, severe, extreme). This result reveals that there is no obstacle to the use of these methods for drought analysis in this region.

Table 4.3: Characteristics of Historical Droughts

Method	Drought Intensity	Stations													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
SPI	Moderate	1977 2000 2006 2008	1989 2018	2004 2011 2013	1983 1985 2004	1975 1991 1993 2000 2020	1991 2004 2020	1991 2000	1992 2006	1985 1990 2008	1989	1985 1990 2007	2000 2004 2016	1987 1989 2006	1974
	Severe	1990 1992	1974 2016 2019	1977 1990 2020	1977 2008 2020	1985 1989 2006 2016	1985 1992 2008	1977 1990	2006 2008 2020	2004 2005	1977 2000 2020	1989 2006 2010	1992 2006 2008 2020	1977 2019 2020	1977 1989 1990 1991
	Extreme	1989	1976 1988 2007	2008	1990	1988 1992	2007	1992 2008 2020		1992 2018	2008	1992 2020		2008	1992 2008 2020
SPEI	Moderate	1985 1992 2017	1988 1990	2013	1985 2017	1989 1992 2020		1991 2017	1992 2016 2020	1985 1990 1992	1989 1995	1985 1989 1992 2020	1992 2016 2020	1987 1989	1974 1989
	Severe	1989 1992	1994 2018 2019	1990 2020	1985-1992 2018 2020	1985 1988 1990 2020	1985 1986 1990 1992	1990 1992		2018 2020	2018 2020	1990		2019	1991 1992 2020
	Extreme	1990	2020				2018							2020	
DPI	Moderate	1977 1990 1992 2000 2006	1974 1976 1989 2007 2016 2020	2008 2020	1977 1992 2020	1985 1989 1992	1991 1992 2008 2020	1977 1990 1991 1992 2008 2020	2006 2008 2020	1992 2008	1977 1989 1992 2000 2008 2020	1985 1989 1992 2006 2020	1992 2008	2006 2008 2020	1989 1992 2008 2020
	Severe	1989													
	Extreme														

CHAPTER 5

TREND ANALYSIS

5.1. Application

One of the most significant markers of global climate change is trend analysis. In this study, the major goal of trend analysis is to project the future using meteorological indicators from the past. In this case, the trend in temperature and precipitation time series was determined using 47 years of meteorological records. Mann Kendall, Spearman's rho, Innovative Şen trend test was used for trend detection in time series and Pettitt’s' test (Homogeneity analysis) was used for determination of breakpoint in time series. In addition, the Thiel-sen approach is used to estimate the trend in precipitation and temperature data.

5.1.1 M-K Test

The Mann-Kendall test is used to determine the trend of a time series. The purpose of the Mann-Kendall analysis in this thesis is to statistically determine whether the variable of interest has a monotonic upward or downward trend over time. A monotonic upward trend means that the variable is constantly increasing over time. Conversely, a monotonic downward trend indicates that the variable decreases continuously over time. In the results of this test, the null hypothesis (*H_0*) claims there is no slope, and the alternative hypothesis *(H_a)* claims there is a slope.

$$\mathrm{sgn}(x_i - x_j) = \begin{cases} 1; & \text{if } x_j > x_i \\ 0; & \text{if } x_j = xi \\ -1; & \text{if } x_j < xi \end{cases} \qquad (12)$$

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(x_i - x_j) \qquad (13)$$

where,

x_i and x_j indicate the data values at the time i and j, respectively. The n is the length of the data set. If the S value is greater than 0, the variable continously increases through time, conversely, if S is smaller than 0, the variable has a decreasing trend. Equation (14) can be used in cases where n is positive.

$$\text{Var (S)} = \frac{n(n-1)(2n+5)-\sum_{i=1}^{p} t_i(t_i-1)(2t_i+5)}{18} \tag{14}$$

where,

t_i is the number of the data points at the p^{th} group and p is the number of groups.

Then, the standard Z value can be found in Eq.15;

$$Z=\begin{cases} \frac{S-1}{\sqrt{Var\,(S)}} \ , if\ S>0 \\ 0\ , \quad if\ S=0 \\ \frac{S+1}{\sqrt{Var\,(S)}},\ if\ S<0 \end{cases} \tag{15}$$

The calculated Z value is compared with the standard normal distribution table using two-sided confidence levels. If the $|Z| > Z_{1-\alpha/2}$, H_o is rejected and H_a is accepted, so there is a significant trend. However, if the $|Z| > Z_{1-\alpha/2}$ condition is not satisfied, H_0 is accepted and H_a is rejected, meaning that there is no statistical trend. In this the study, a 5% significance level, which expresses $Z_{1-\alpha/2} = 1.96$ (from the standard normal distribution table), was used for this method.

5.1.2. SR Test

The significance of monotonic tendencies in time series of hydrometeorological data is assessed using the rank-based non-parametric statistical Spearman's Rho test. This test determines whether or not there are slopes in data time series and determines the trends side. In this test, the alternative hypothesis H_a shows there is a trend, while the null hypothesis H_o implies that the presented data are independent and uniformly distributed over time.

5.1.3 Şen's Innovative Trend Detection Test (2012)

This method divides the time series into two equal halves, in turn, ranks them from highest to lowest, and then graphs them relative to each other, with the first sub-series (X_i) on the X-axis. The other subseries (X_j) are located on the Y-axis based on the

Cartesian coordinate system. There is no trend when the data is collected on the 1:1 (45˚) straight line, and there is a decreasing trend in the time series when the data is in the lower triangle area of the 1:1 line, and there is an increasing trend in the time series when the data is in the upper triangle area of the 1:1 straight line, there is an increasing trend.

5.1.4 Thiel-Sen Approach

This method is used to calculate the magnitude of the slope of the trends found after trend tests. The Thiel-Sen approximation can be expressed by Equation 16:

$$\beta = \text{Median} \left(\frac{X_j X_i}{j-i}\right) \tag{16}$$

where,

X_i *and* X_j show the ordinal data of the time series in years *i and j*. The β value found is the calculated size of the slope of trend in the time series.

5.1.5. Pettitts' Test

Pettitt's test is used to figure out a single change-point hydrometeorological series with controversial data. For a time series of n times $\{X_1, X_2, \ldots, X_n\}$, let the time of the change point be m. The examples $\{X_1, X_2, \ldots, X_m\}$ *and* $\{X_{m+1}, X_{m+2}, \ldots, X_n\}$ can be derived by dividing the time series at time m.

The most important change point at the time t was accepted as $|Ut|$. Then, the approximate probability of significant change $P(t)$ for the change point can be expressed as;

$$P(t) = 1 - \exp\left(\frac{-6U_t^2}{n^3+n^2}\right) \tag{17}$$

The change point is considered to be a statistically significant α level when the approximate probability exceeds the value $(1\text{-}\alpha)$.

5.2. Results

5.2.1. Temperature

The Mann-Kendall, Spearman's Rho, Şen's Innovative Trend, and Pettitt tests were among the trend tests used to determine average annual temperature trends. In order to identify trends in temperature time series, the Mann-Kendall, Innovative-Şen trend test, and Spearman's Rho tests were utilized. The change point in the time series was identified using Pettitt's test. Table 5.1 and Figure 5.1 show that there was a rising frequency trend for 14 meteorological stations. When the Thiel-Sen technique was used to determine the slope's size, it was discovered that every ten years, the annual average temperature at the stations increased by between 0.2 and 0.35 C. Sudden changes in annual mean temperature were determined by the Pettitt test for the results at all stations (Table 5.1). The years in which the sudden change was detected are 2015 for Izmir station, 2016 for Manisa station, 2013 for Nazilli station, 2012 for Salihli station, 2016 for Yatağan station, and 2014 for Uşak station, and 2007 for all other stations. The Sen Innovative trend test was used to investigate the presence of trends in temperature data. The results show that there is an increasing trend in average temperatures at all stations (14 stations) (Fig. 5.1.a - Fig.5.1.b).

Table 5.1. Temperature trend analysis results

	Mann-Kendall Test		Spearmans' Rho Test	Thiel -Sen Approach	Pettits' Test
Station Name	Kendalls Tau (Z)	Trend?	(Z)sr	β (in C)	Change Point (year)
İzmir	4.800	Yes	5.79	0.3	2015
Manisa	4.380	Yes	5.64	0.25	2016
Nazilli	3.960	Yes	5.02	0.35	2013
Çeşme	4.220	Yes	5.66	0.3	2007
Salihli	4.91	Yes	6.68	0.3	2012
Muğla	4.42	Yes	5.54	0.2	2007
Denizli	5.25	Yes	7.14	0.25	2007
Yatağan	4.45	Yes	5.72	0.3	2016
Uşak	4.53	Yes	5.79	0.3	2014
Güney	4.34	Yes	5.69	0.2	2007
Selçuk	5.01	Yes	6.84	0.25	2007
Sultanhisar	4.96	Yes	5.87	0.3	2007
Seferihisar	4.76	Yes	5.75	0.2	2007
Kuşadası	4.99	Yes	5.72	0.2	2007

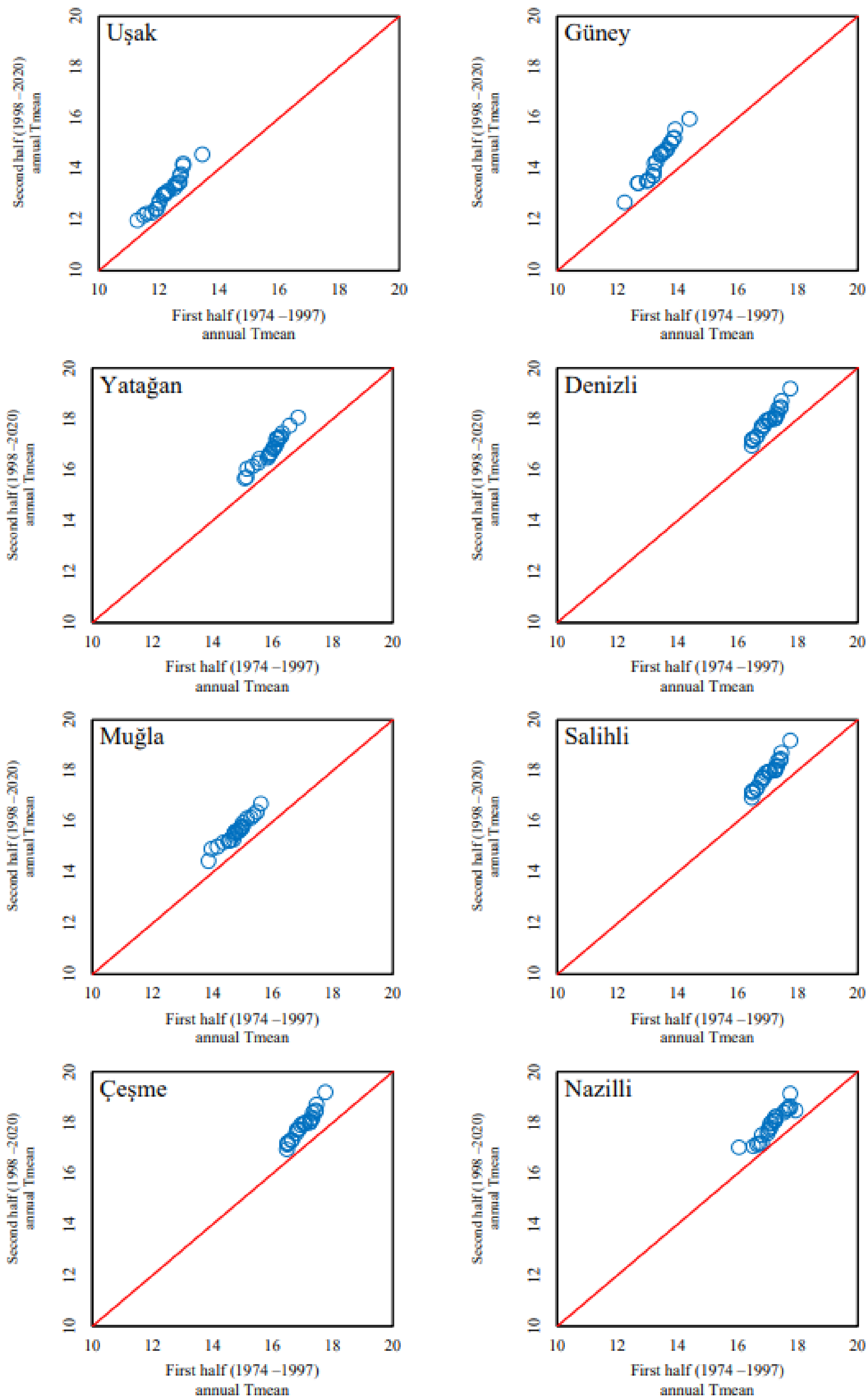

Figure 5.1.a: Şen’s Innovative Trend Analysis for annual average temperatures

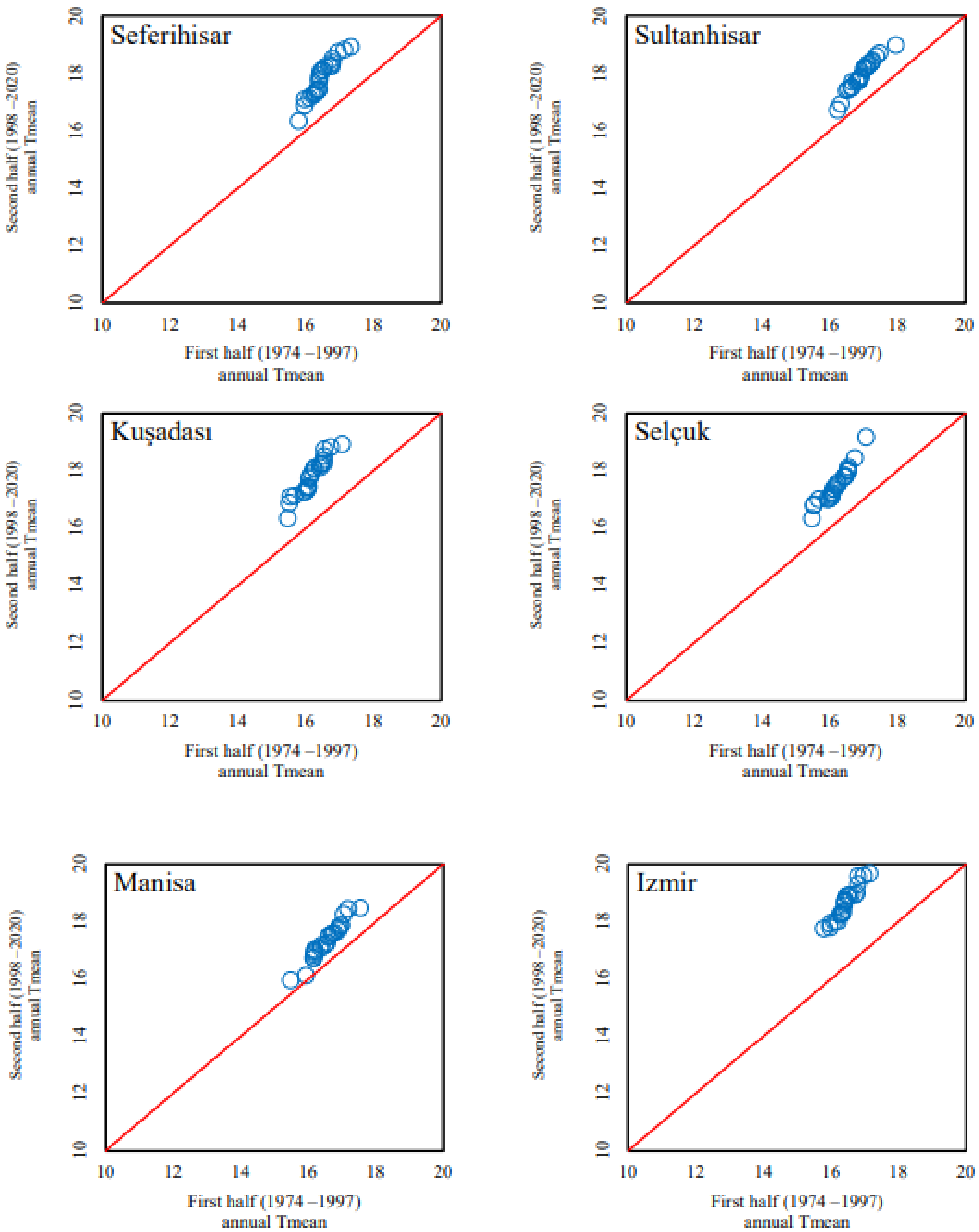

Figure 5.1.b: Şen’s Innovative Trend Analysis for annual average temperatures

5.2.2. Precipitation Trend

Mann-Kendall's shows yearly precipitation time series revealed no discernible patterns at the stations in Manisa, Salihli, Muğla, Denizli, Yatağan, and Uşak. The results of the Spearman's rho test confirmed this. The yearly rise in precipitation at the stations in Izmir, Nazilli, Çeşme, Güney, Selçuk, Sultanhisar, Seferihisar, and Kuşadası was calculated to be (+) 7.3, 6.8, 7.9, 4.2, 6.9, 5.5, 7.4, and 7.5 mm/year, respectively, using the Theil-Sen technique (Table 5.2). The transition years at all stations are 1998, as shown in Table 5.2.

Table 5.2: Precipitation Trends

	Mann-Kendall Test		Spearmans' Rho Test	Thiel -Sen Approach	Pettitt's Test
Station Name	Kendalls Tau (Z)	Trend ?	$(Z)_{SR}$	β (in mm)	Change Point (year)
İzmir	2.100	Yes	3.13	7.3	1998
Manisa	-0.940	No	-	-	-
Nazilli	2.008	Yes	3.1	6.8	1998
Çeşme	2.663	Yes	3.79	7.9	1998
Salihli	-0.19	No	-	-	-
Muğla	0.16	No	-	-	-
Denizli	-0.36	No	-	-	-
Yatağan	1.03	No	-	-	-
Uşak	0.32	No	-	-	-
Güney	2.14	Yes	3.18	4.2	1998
Selçuk	2.32	Yes	3.46	6.9	1998
Sultanhisar	2.62	Yes	3.77	5.5	1998
Seferihisar	2.88	Yes	4.12	7.4	1998
Kuşadası	2.31	Yes	3.43	7.5	1998

As can be seen, Şen Innovative test values also show similar results to the Mann-Kendall test. So, the results overlaps between trend test for both temperature and precipitation data time series analysis. The results are shown in Figure 5.2.a and Figure 5.2.b.

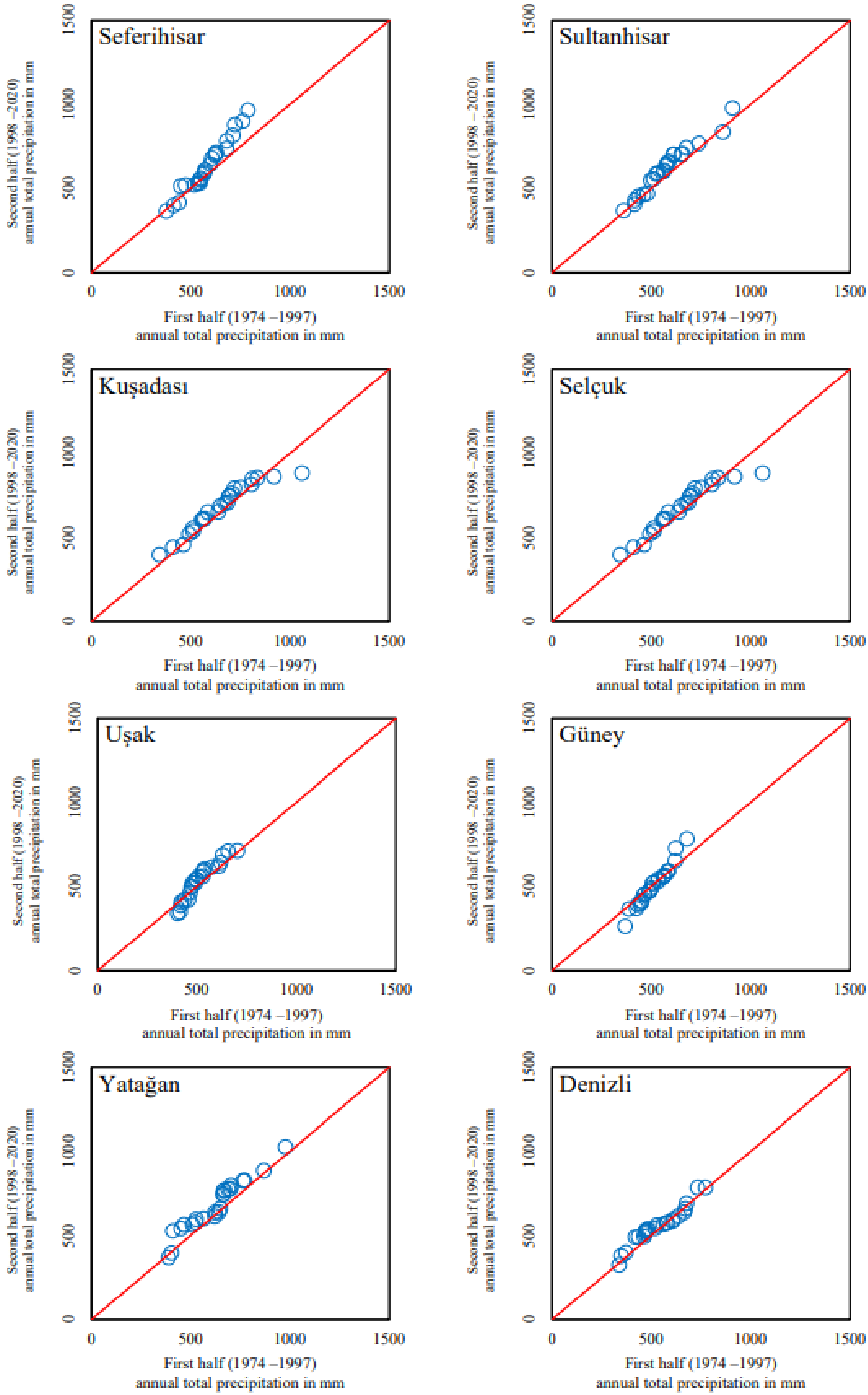

Figure 5.2.a: Şen's Innovative Trend Analysis for Annual precipitation

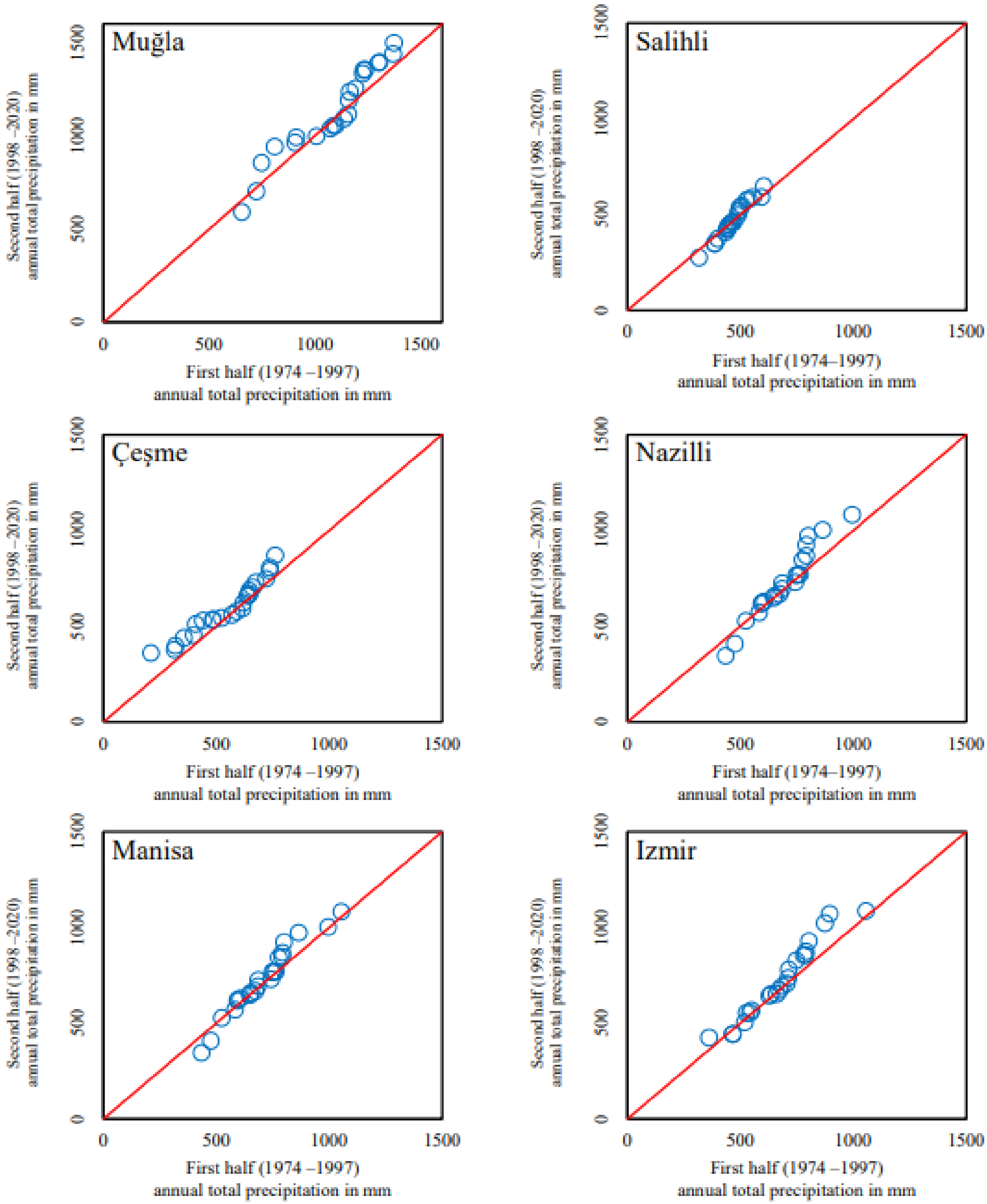

Figure 5.2.b: Şen’s Innovative Trend Analysis for Annual precipitation

5.3. Discussion of Results

Trends in temperature and precipitation in the years 1973-2020 were analyzed using various methods in the Aegean region, and these methods showed trends in precipitation and temperature over the study period. The annual average temperature at the stations has increased at rates ranging from 0.2 to 0.35 per ten year of time period. The Sen Innovative trend test also showed that average temperatures increased over the study period. Sudden changes in annual temperatures were observed at most stations in 2007, but changes were detected at Izmir station in 2015, Manisa station in 2016, Nazilli station in 2013, Salihli station in 2012, Yatağan station in 2016, and Uşak station in 2014.

Eight stations (Kusadasi, Izmir, Seferihisar, Nazilli, Cesme, Güney, Selçuk, and Sultanhisar) displayed significant positive trends, however no trends were found at the remaining stations after yearly precipitation time series analysis using Mann-Kendall and Spearman's Rho tests. However, the en test found somewhat encouraging trends at the stations in Mugla, Seferihisar, Nazilli, Ceşme, Manisa, and Izmir. On the other hand, the Thiel-Sen test findings revealed higher values in the trending stations between 4.2 and 7.9 mm/year. All (14) statioons showing a trend observed dramatic variations in yearly precipitation in 1998.

CHAPTER 6

CONCLUSIONS

Utilizing historical (precipitation and temperature) data between 1974 (by considering the water year) and 2020, three different drought indices and five trend tests were applied at 14 stations in the Büyük Menderes, Küçük Menderes, and Gediz basins in the Aegean region of Turkey. Following conclusions are drawn from this study:

- The drought indices gave nearly the same results for the drought analysis in the Aegean region. Drought periods are observed at the same time in terms of years. However, when the drought severity is considered, there are differences. To make it clear, a year that is severe drought by SPI is determined as moderate drought by DPI.

- The drought occurred in the Aegean region in the second half of the 1980s and the second half of the 2000s, and the year 2020.

- In the annual drought analysis; SPI shows higher drought severity than other indexes. The most optimistic picture (if it is the least severe) shows the DPI.

- The drought is not only depends on precipitation, SPEI values determined by calculating Potential Evapotranspiration, PET, using T_{mean}, T_{max}, *and* T_{min} values give more meaningful results, unlike SPI and DPI.

- As a result of the annual mean temperature time series analysis, changes in temperature between 1973 and 2020 highlight warming for the region in general.

- The temperature shows an increase of about 0.2 to 0.35 C for every 10-year periods.

- The majority of the stations recorded points of abrupt temperature fluctuations in 2007, however several stations also recorded these events in the 2010s.

- A positive trend (increase in precipitation amount) was seen in the rainfall time series data, ranging from 4.2 mm to 7.9 mm/year for certain stations and being low for others. Furthermore, it has been shown that similar abrupt shifts in the rainfall time series have happened every year since 1998.

- It is clear that the increase trend in temperature values is caused by the greenhouse effect due to the increasing carbon gas emission due to the increasing industrialization and urbanization. It is also thought that there is a link between rainfall and temperature changes.

The water resources in the Aegean region consist of groundwater, surface waters, and seawater. Rainfall plays an essential role as the main water supply (resource) for the region. In addition, the Gediz, Büyük Menderes, and Küçük Menderes rivers in the region are used for industrial and agricultural use. Therefore, it is very important to evaluate and monitor the drought in this region and analyze the meteorological trend.

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APPENDICES

APPENDIX A. SPI RESULTS

A.1. SPI-1

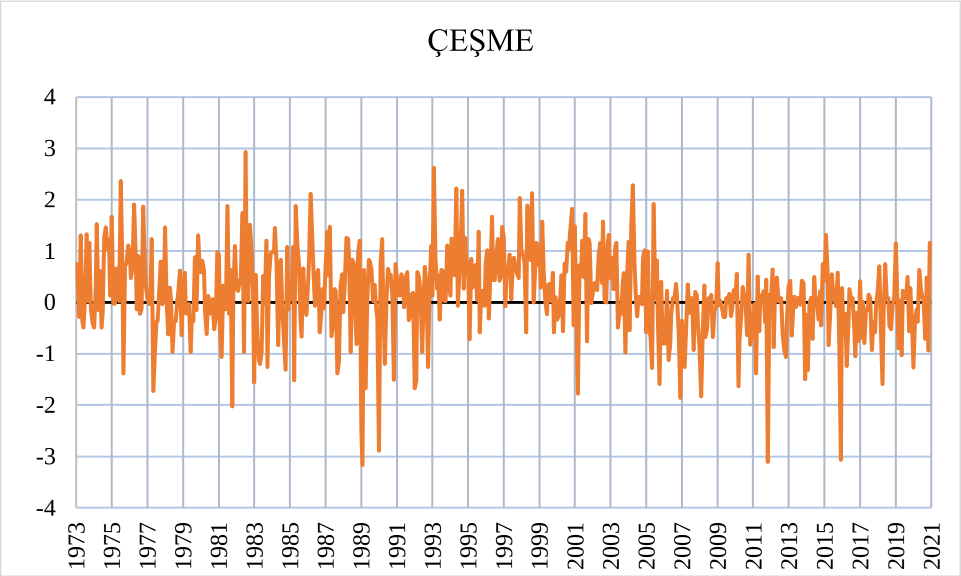

Figure A.1.1: Çeşme SPI-1 Results

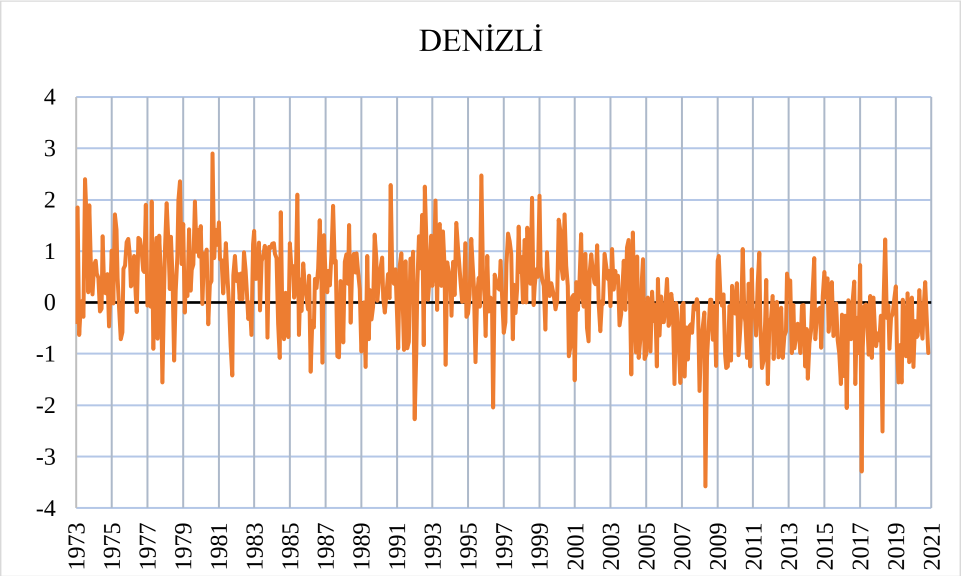

Figure A.1.2: Denizli SPI-1 Results

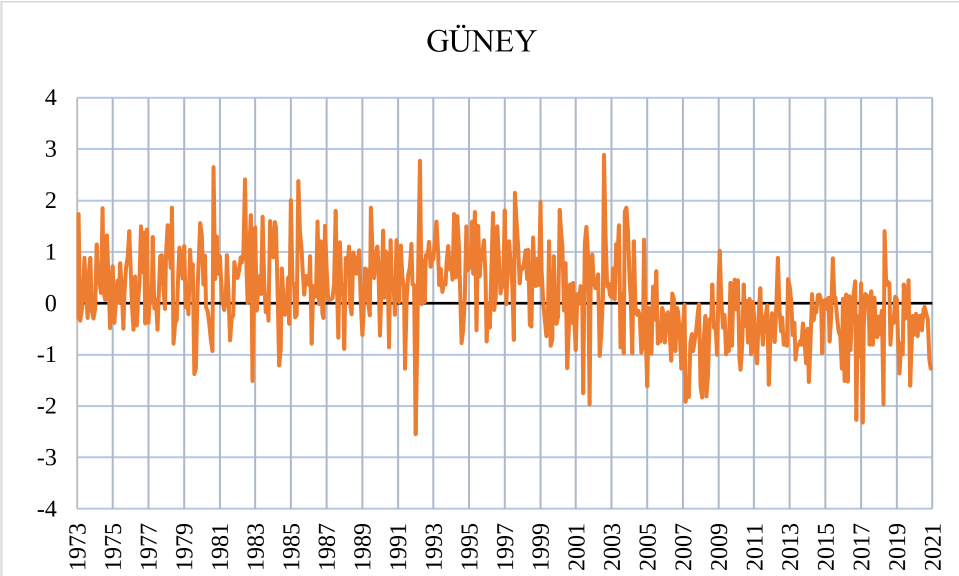

Figure A.1.3: Güney SPI-1 Results

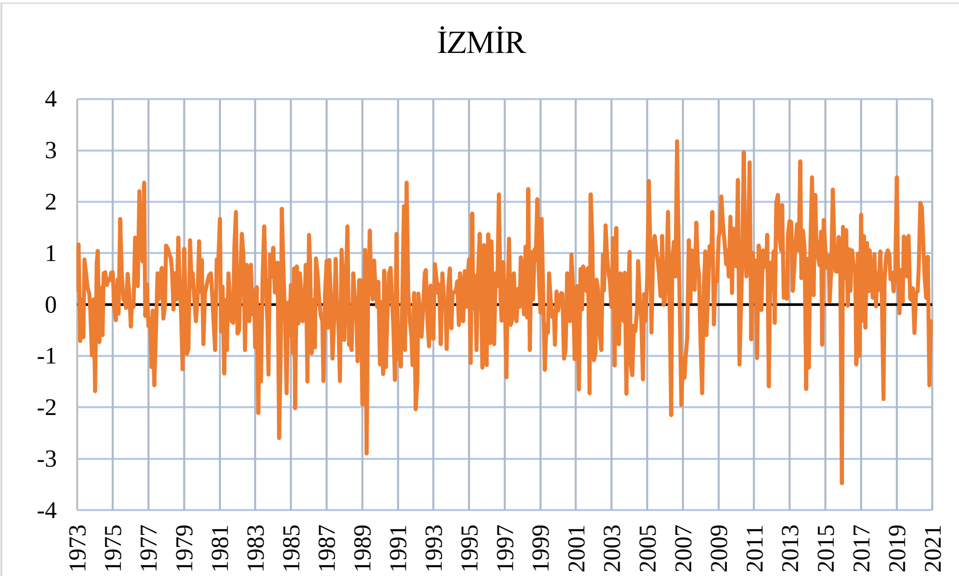

Figure A.1.4: Izmir SPI-1 Results

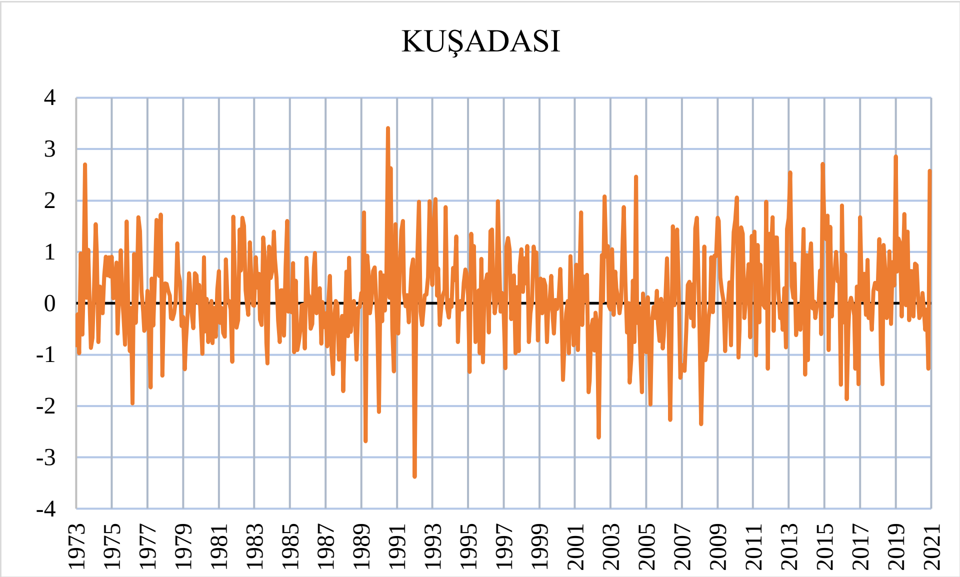

Figure A.1.5: Kuşadası SPI-1 Results

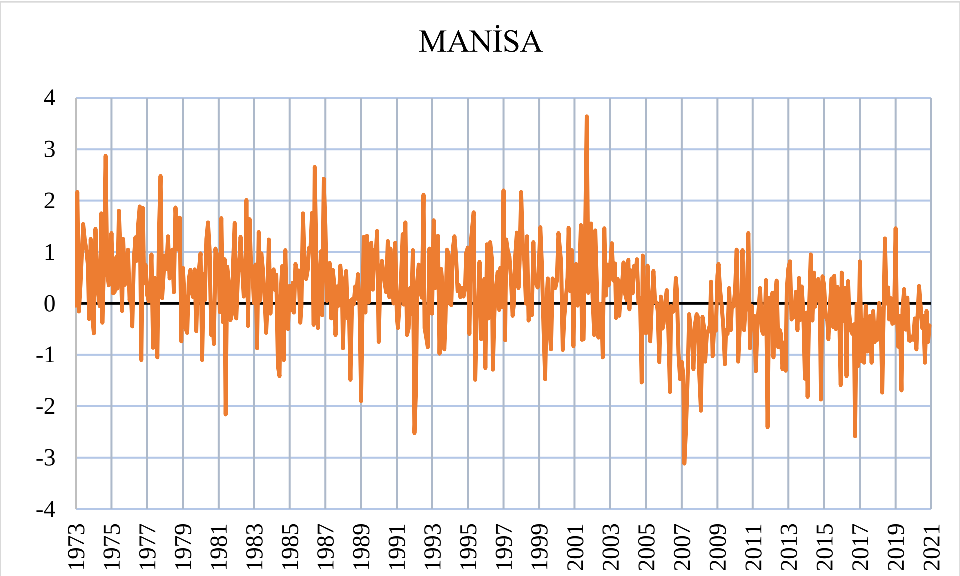

Figure A.1.6: Manisa SPI-1 Results

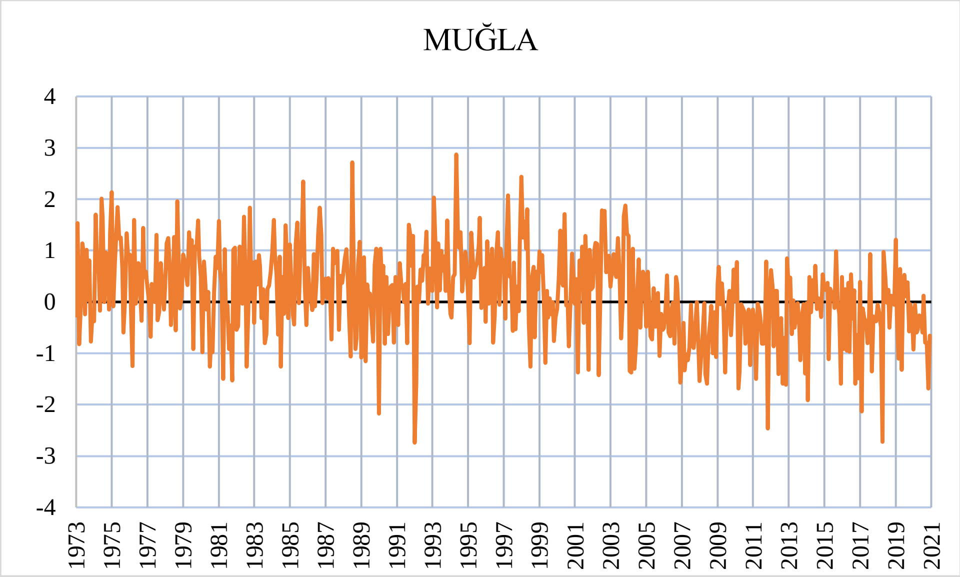

Figure A.1.7: Muğla SPI-1 Results

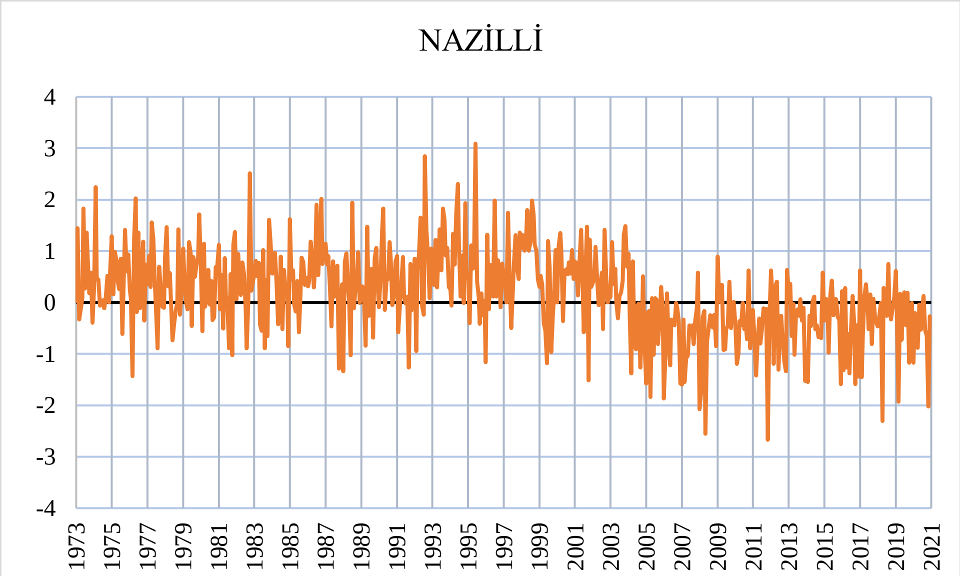

Figure A.1.8: Nazilli SPI-1 Results

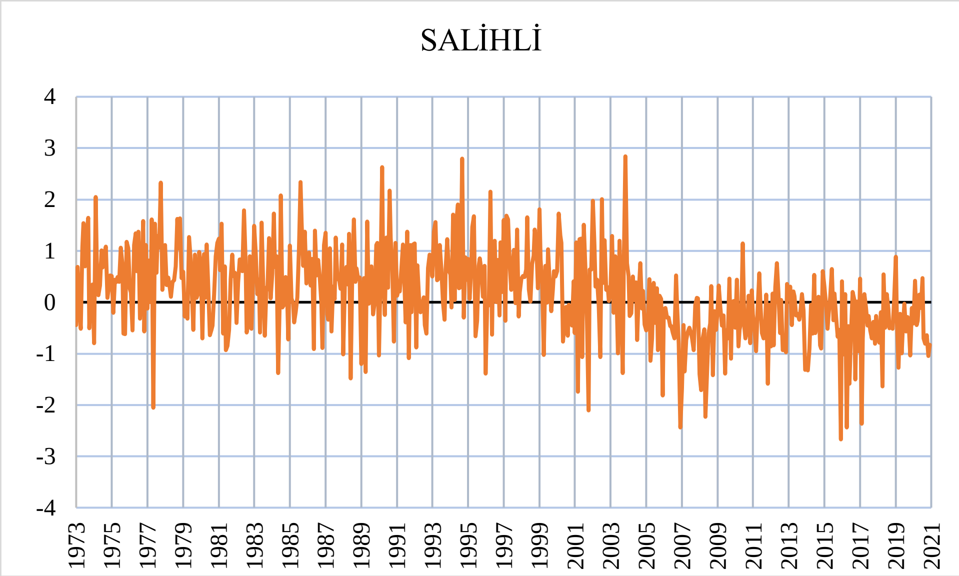

Figure A.1.9: Salihli SPI-1 Results

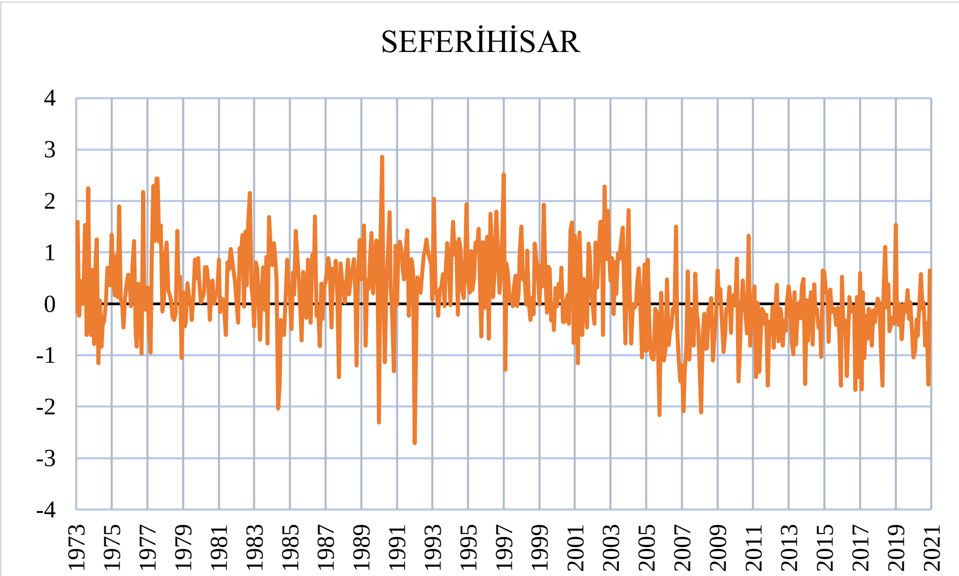

Figure A.1.10: Seferihisar SPI-1 Results

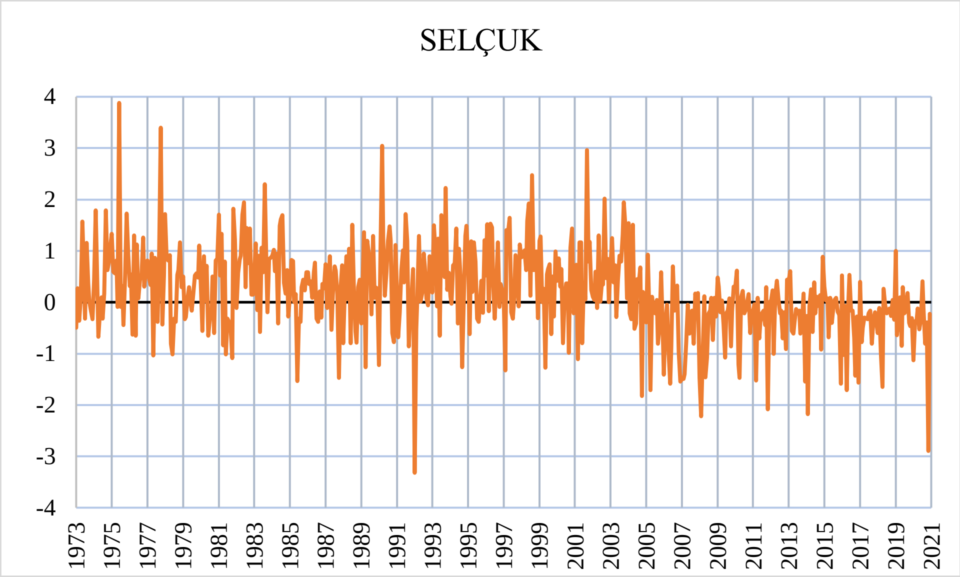

Figure A.1.11: Selçuk SPI-1 Results

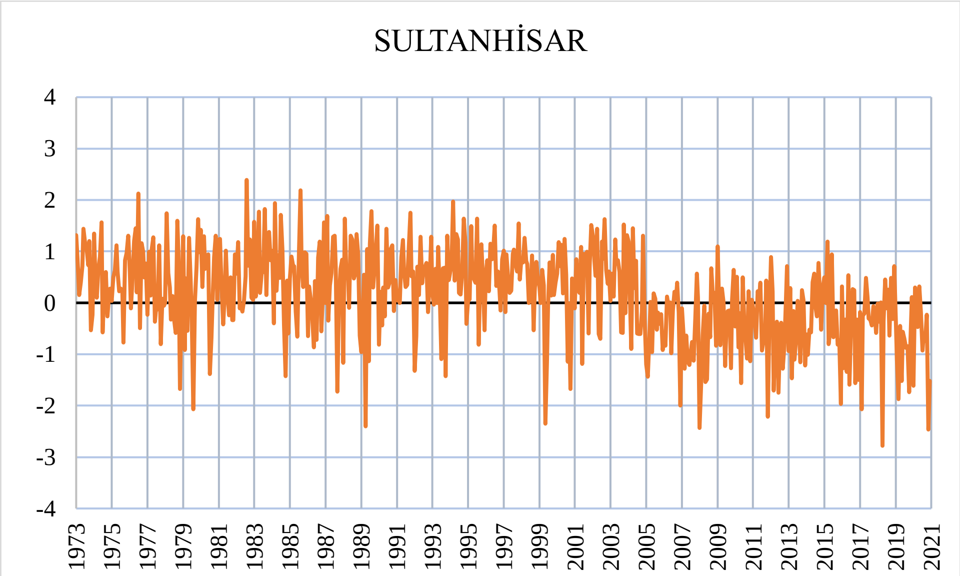

Figure A.1.12: Sultanhisar SPI-1 Results

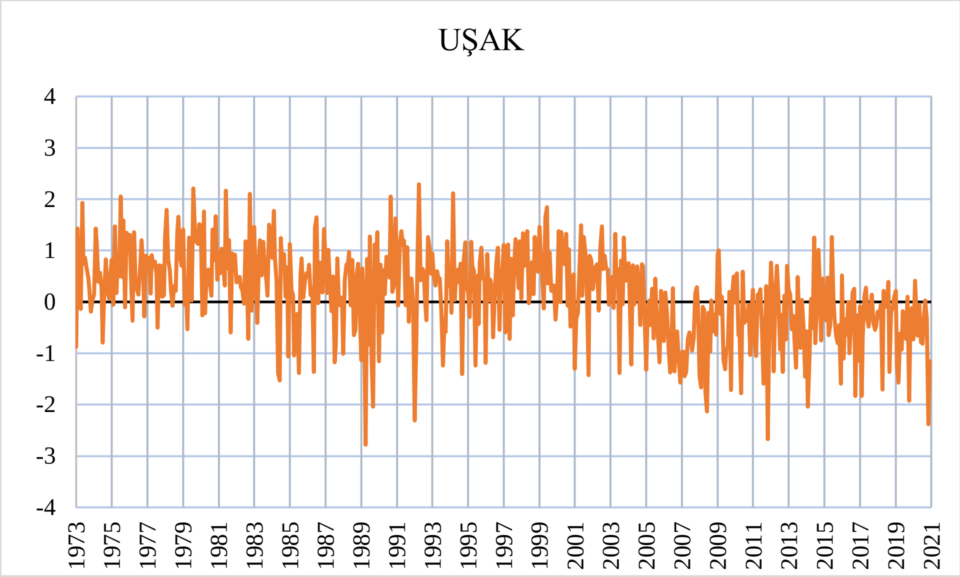

Figure A.1.13: Uşak SPI-1 Results

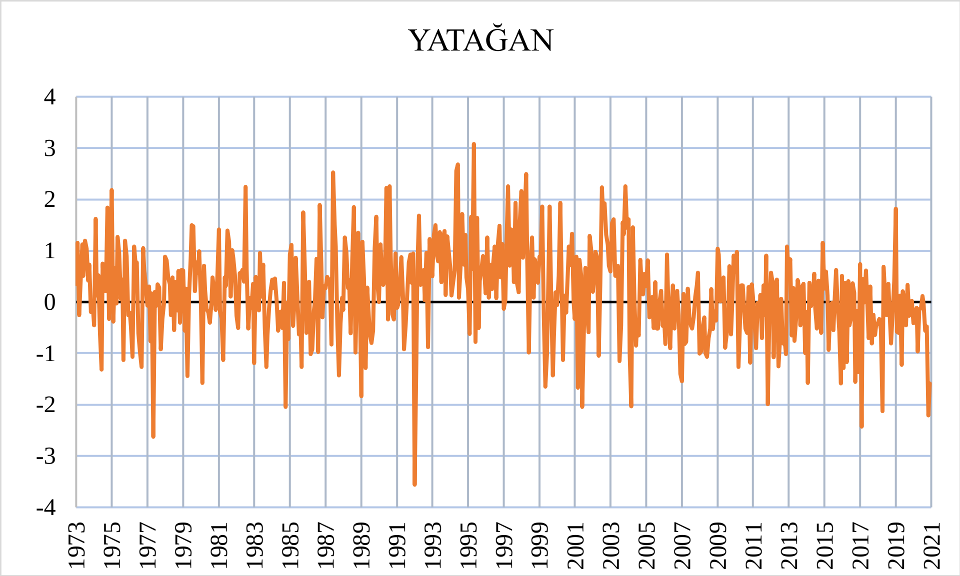

Figure A.1.14: Yatağan SPI-1 Results

A.2. SPI-3

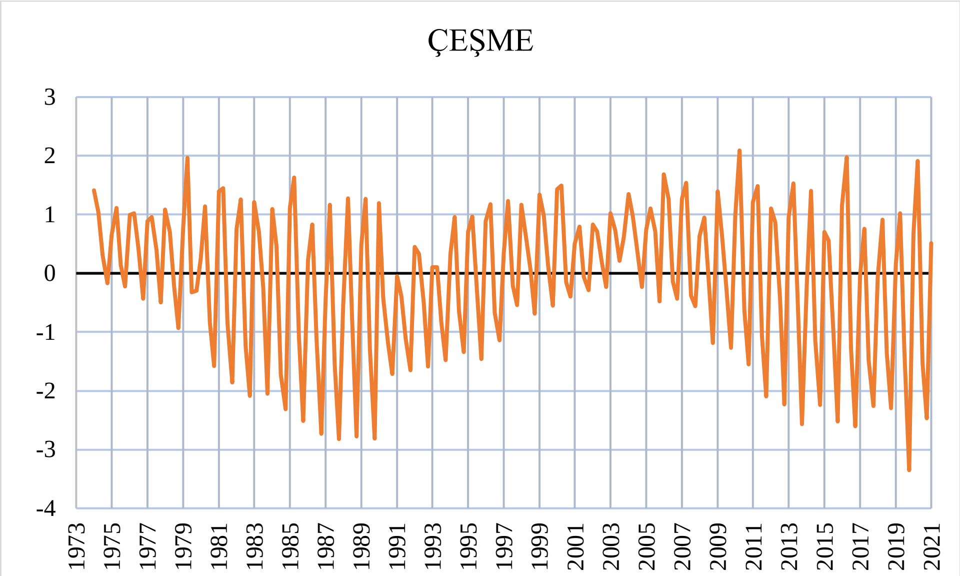

Figure A.2.1: Çeşme SPI-3 Results

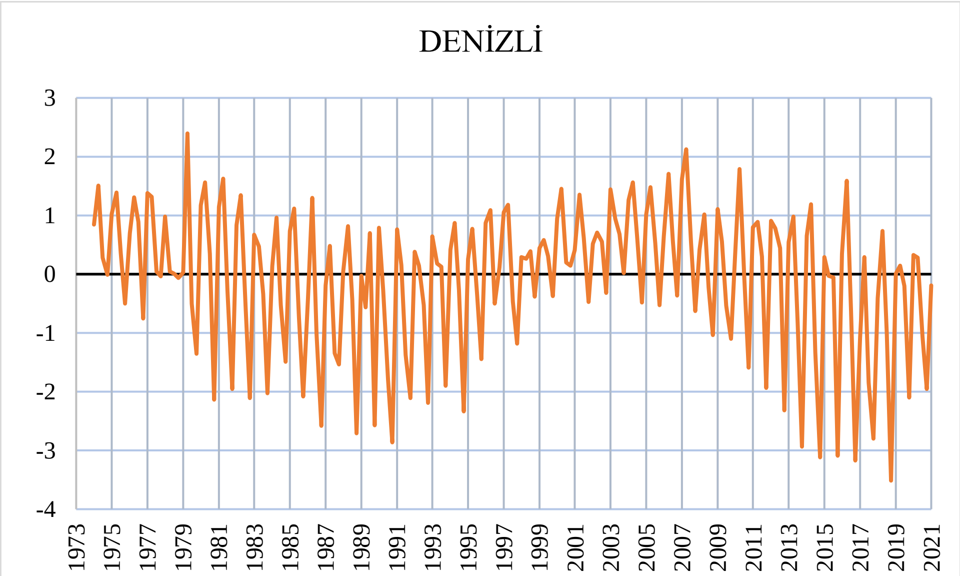

Figure A.2.2: Denizli SPI-3 Results

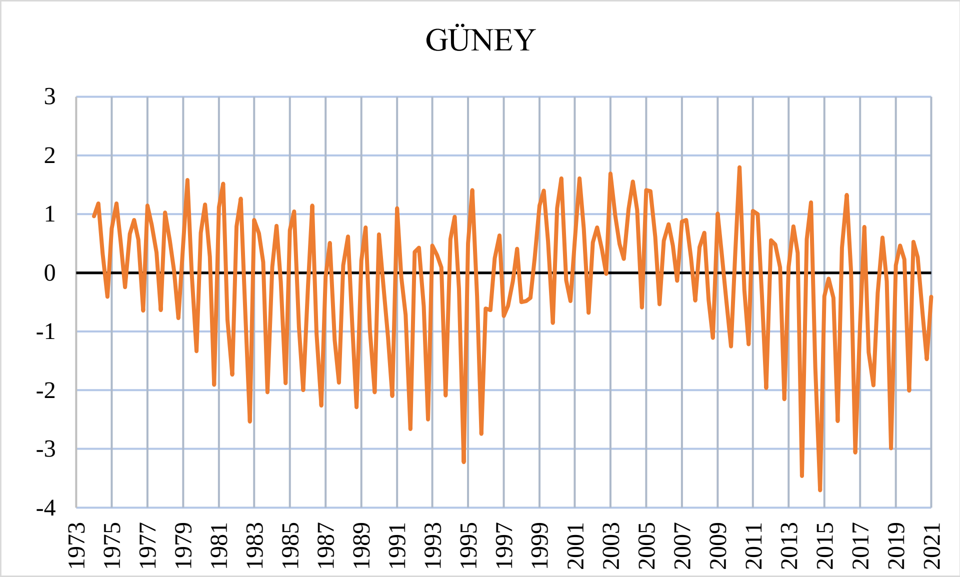

Figure A.2.3: Güney SPI-3 Results

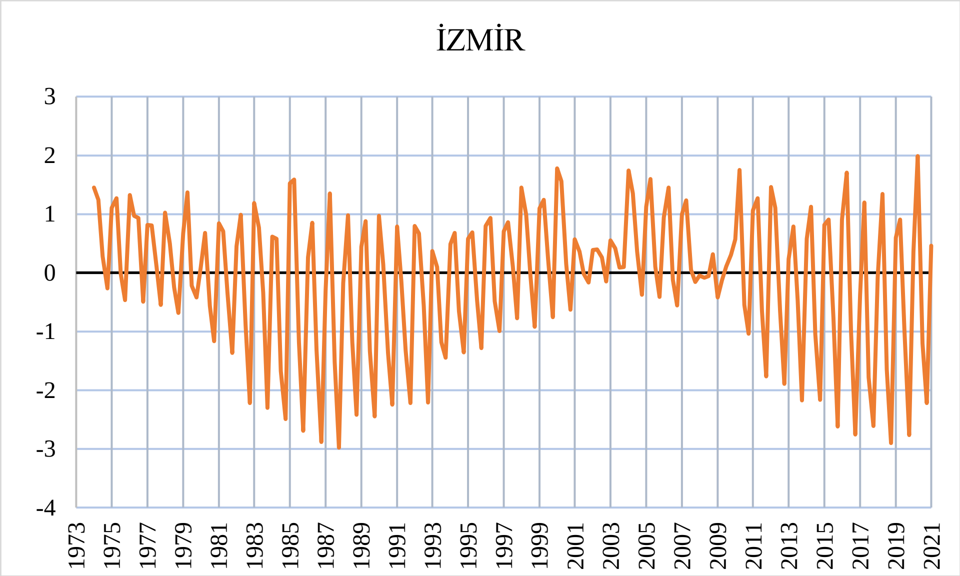

Figure A.2.4: Izmir SPI-3 Results

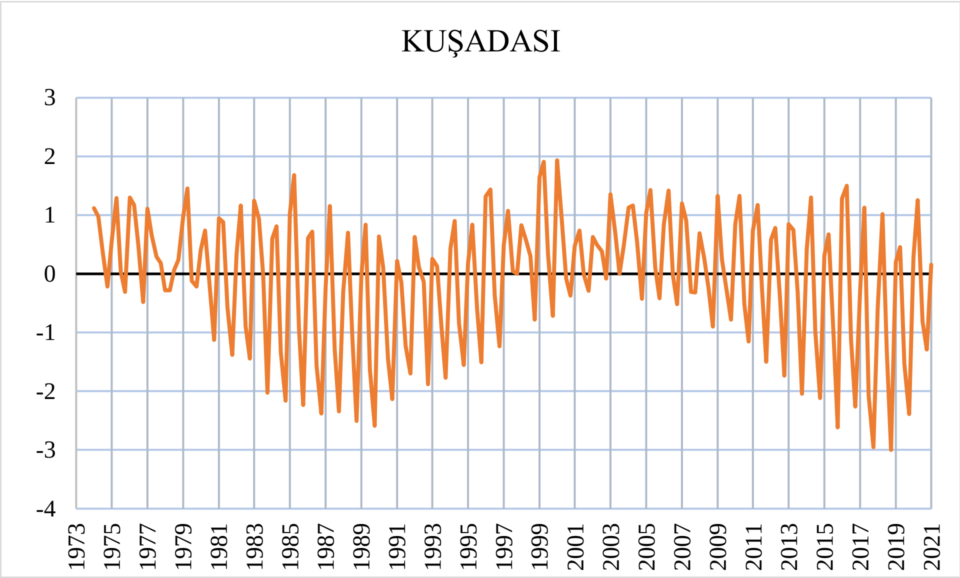

Figure A.2.5: Kuşadası SPI-3 Results

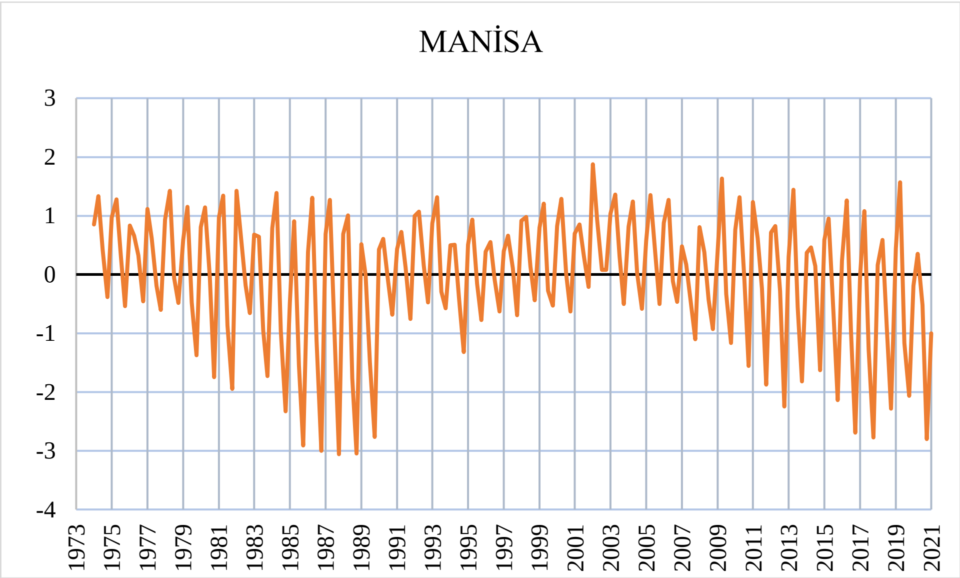

Figure A.2.6: Manisa SPI-3 Results

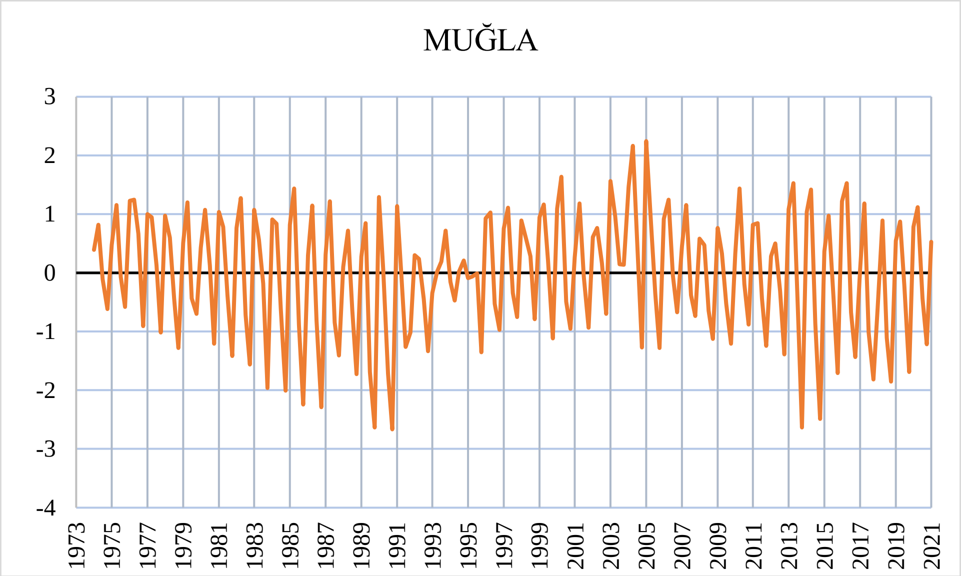

Figure A.2.7: Muğla SPI-3 Results

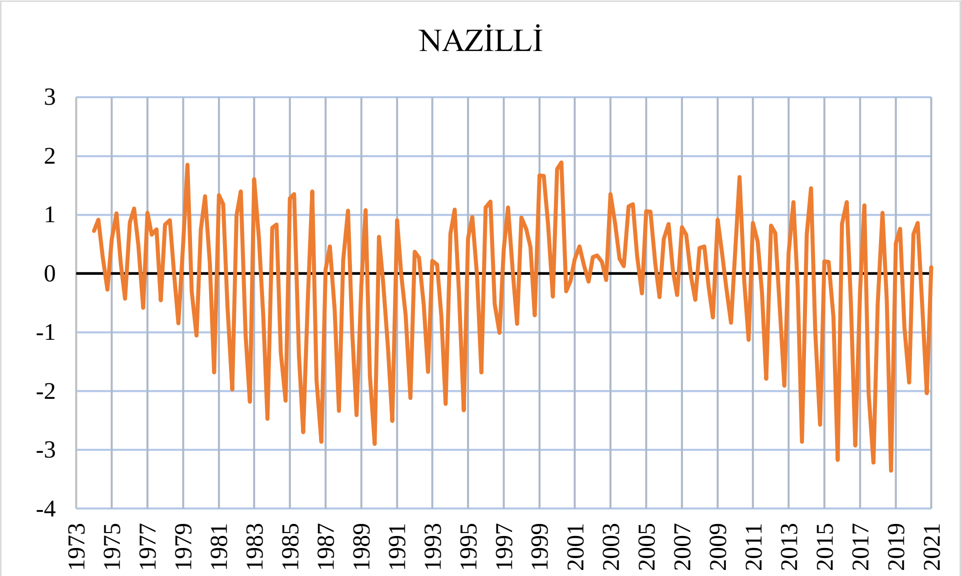

Figure A.2.8: Nazilli SPI-3 Results

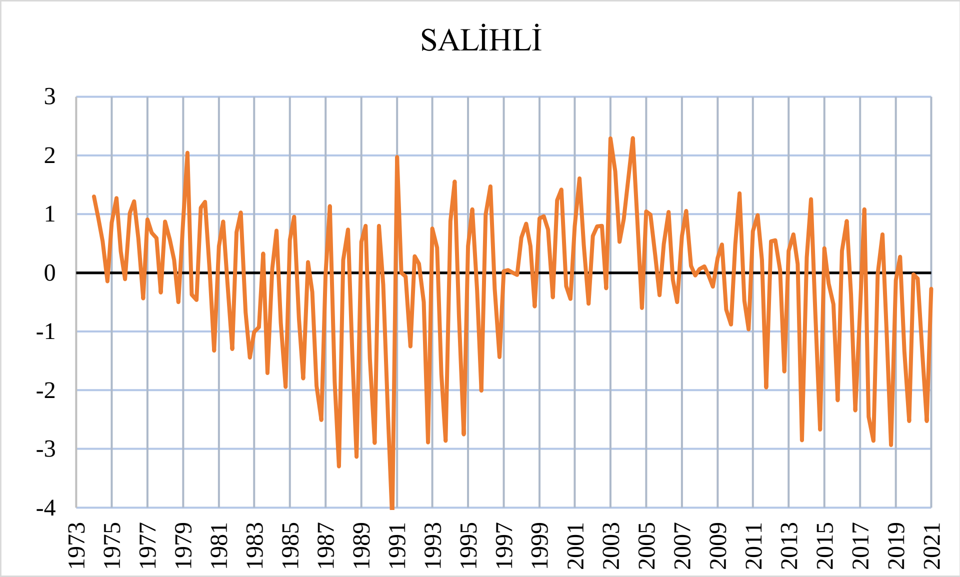

Figure A.2.9: Salihli SPI-3 Results

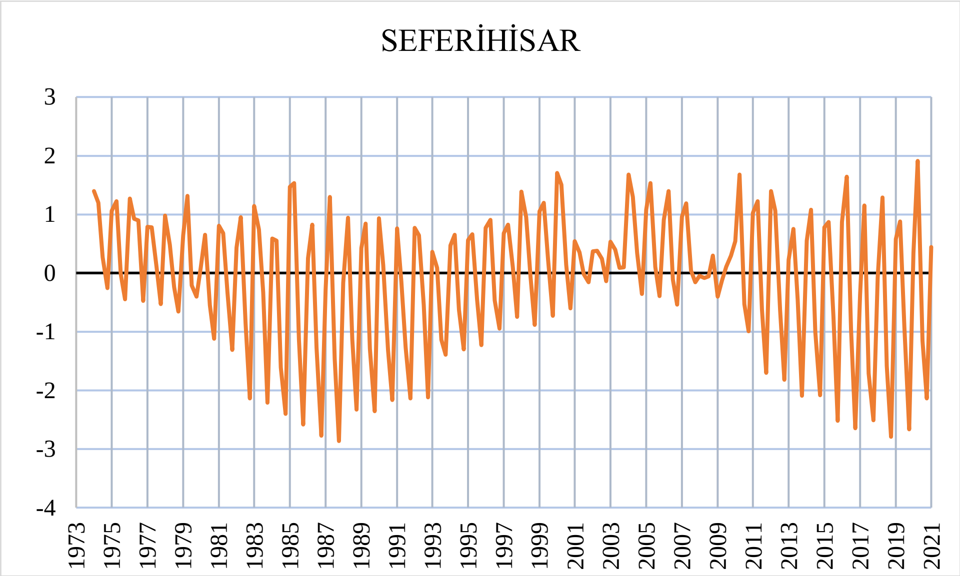

Figure A.2.10: Seferihisar SPI-3 Results

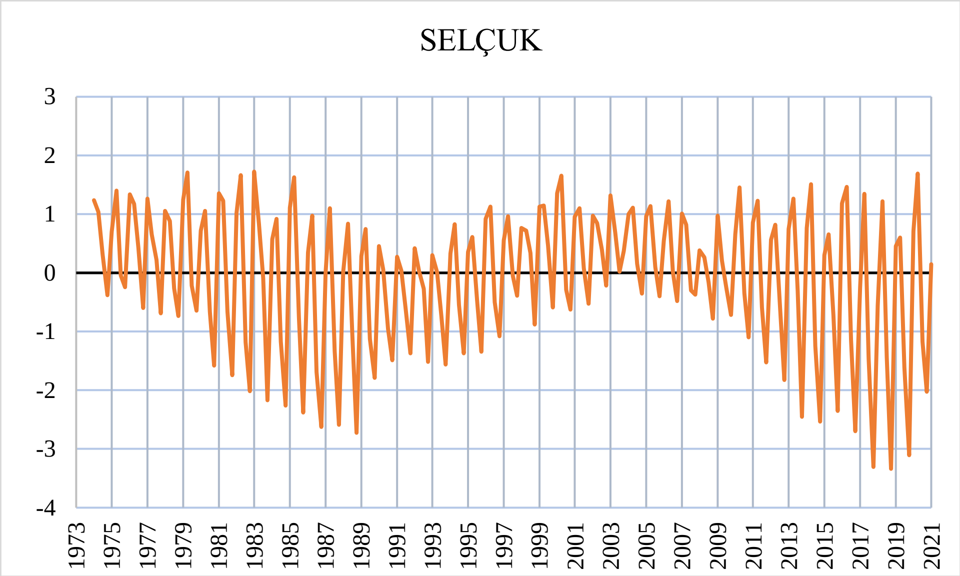

Figure A.2.11: Selçuk SPI-3 Results

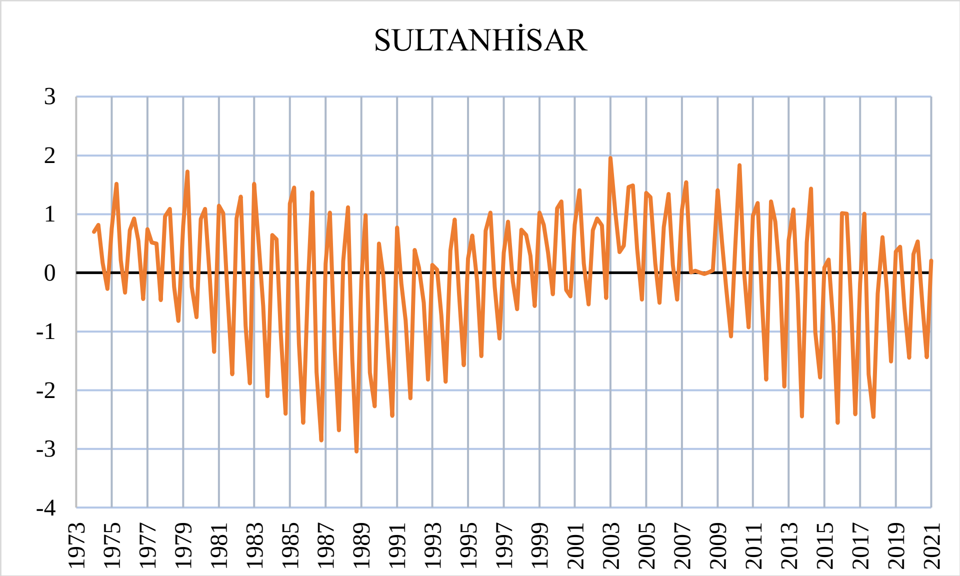

Figure A.2.12: Sultanhisar SPI-3 Results

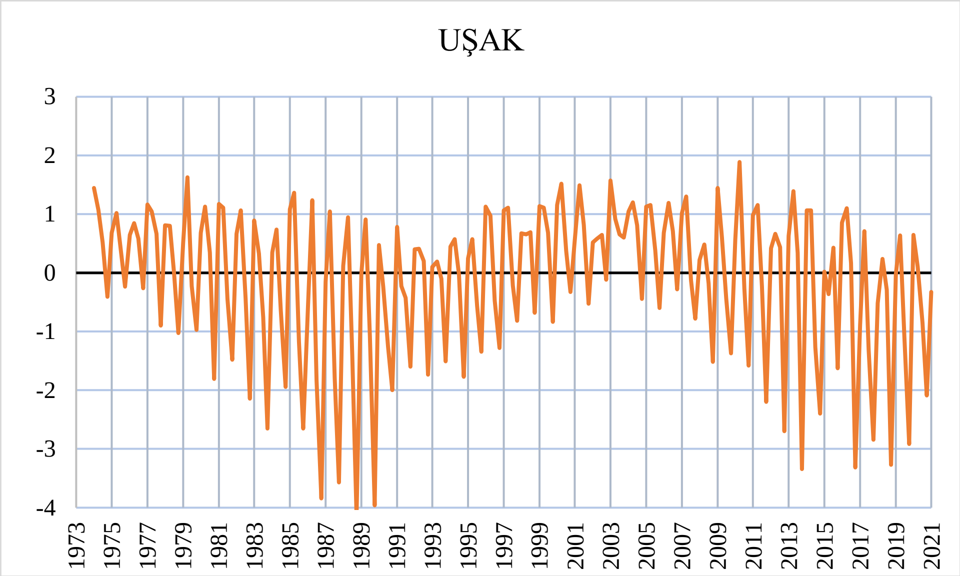

Figure A.2.13: Uşak SPI-3 Results

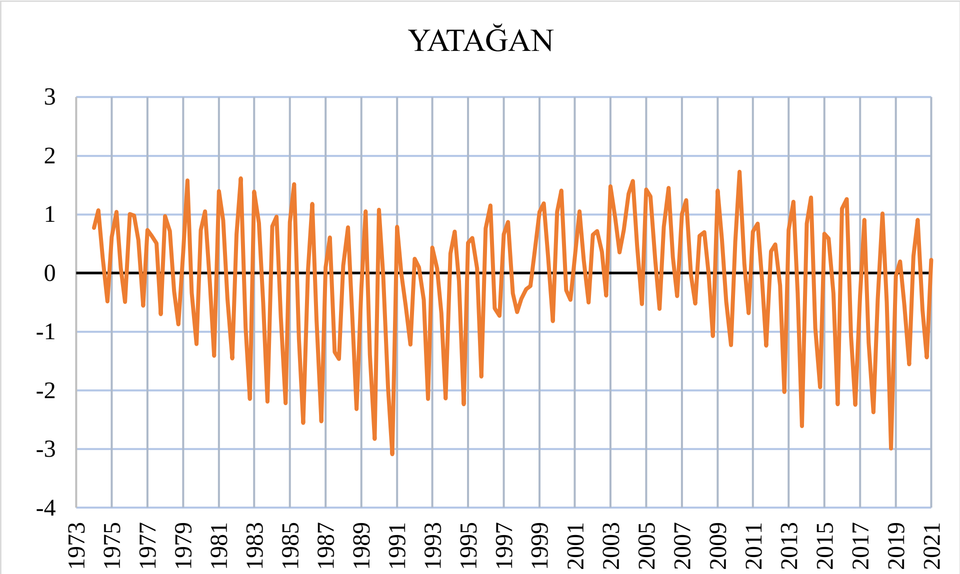

Figure A.2.14: Yatağan SPI-3 Results

A.3. SPI-12

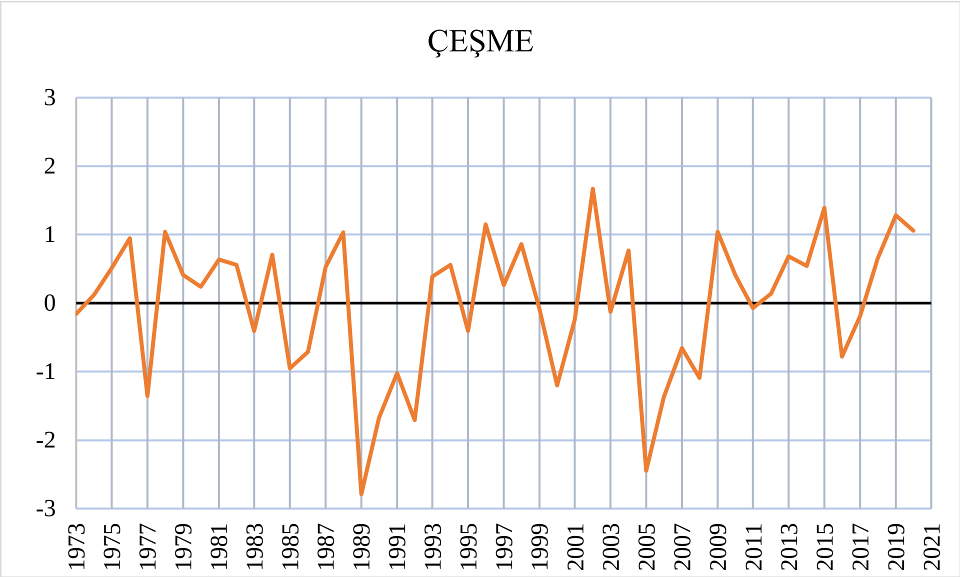

Figure A.3.1: Çeşme SPI-12 Results

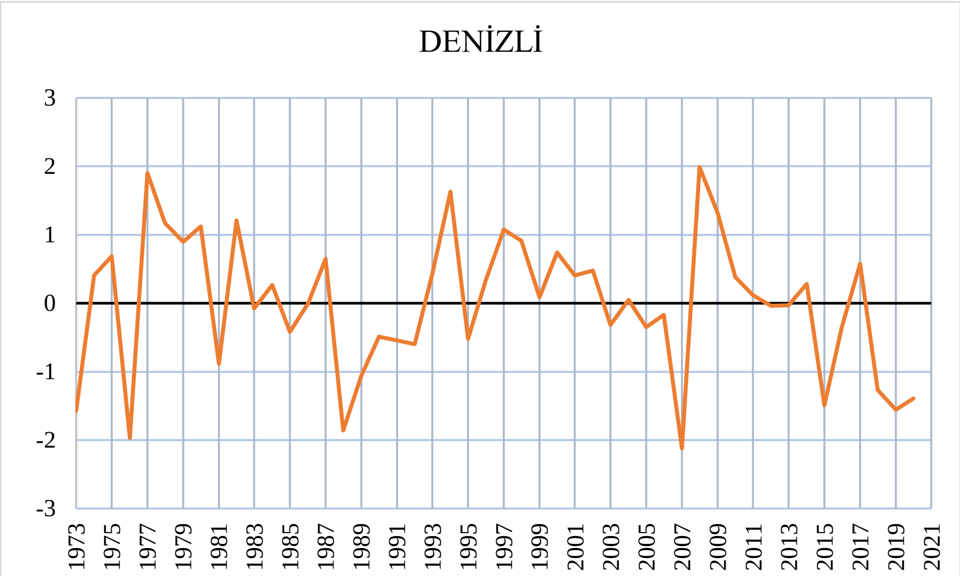

Figure A.3.2: Denizli SPI-12 Results

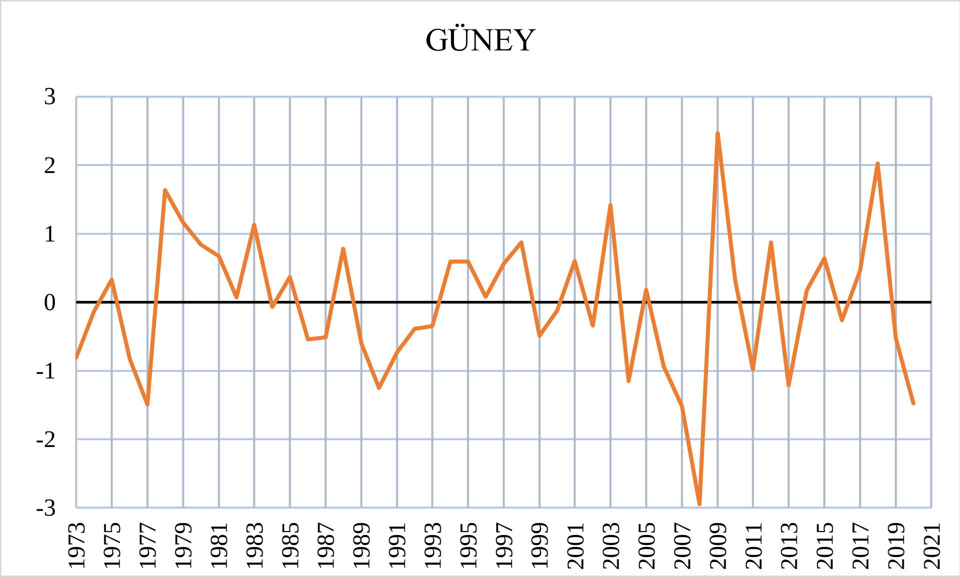

Figure A.3.3: Güney SPI-12 Results

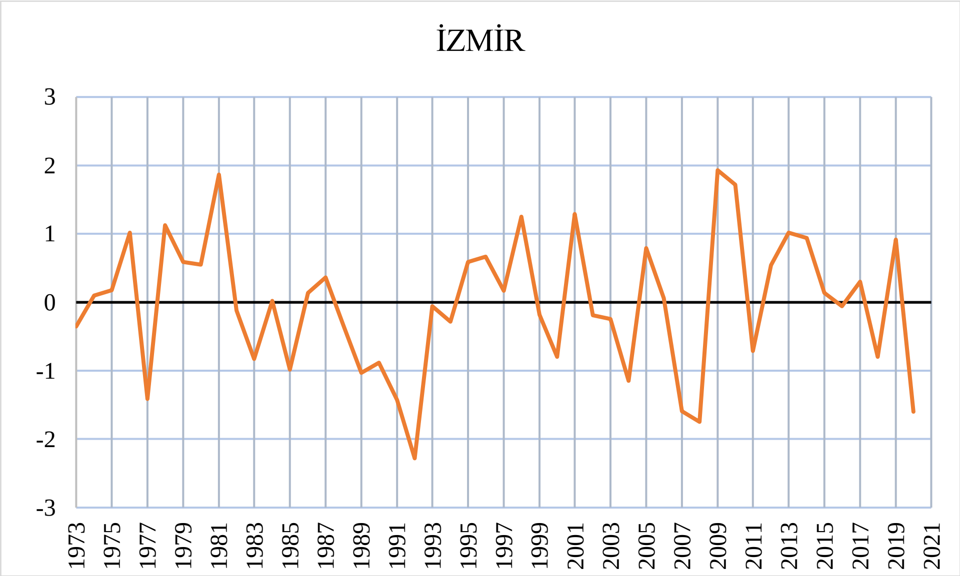

Figure A.3.4: Izmir SPI-12 Results

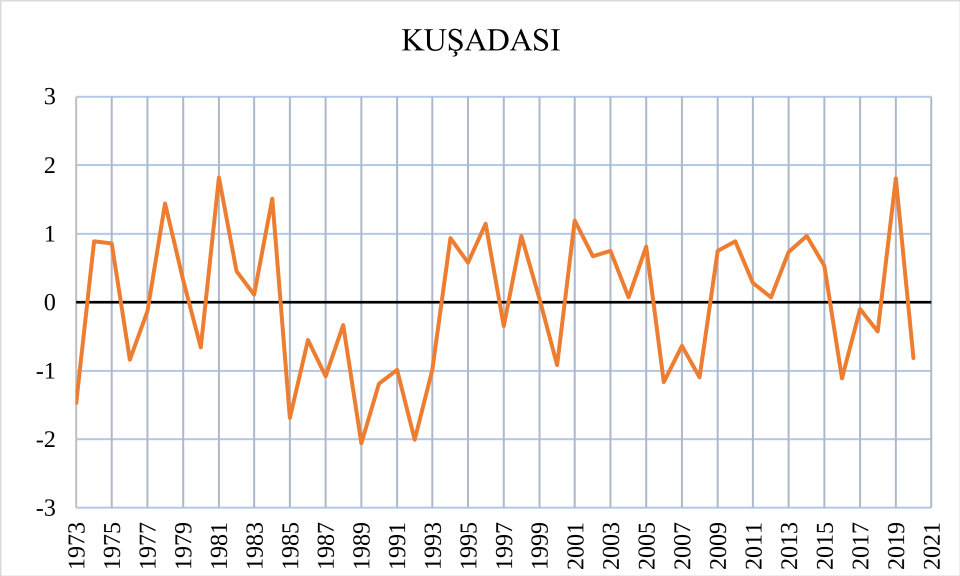

Figure A.3.5: Kuşadası SPI-12 Results

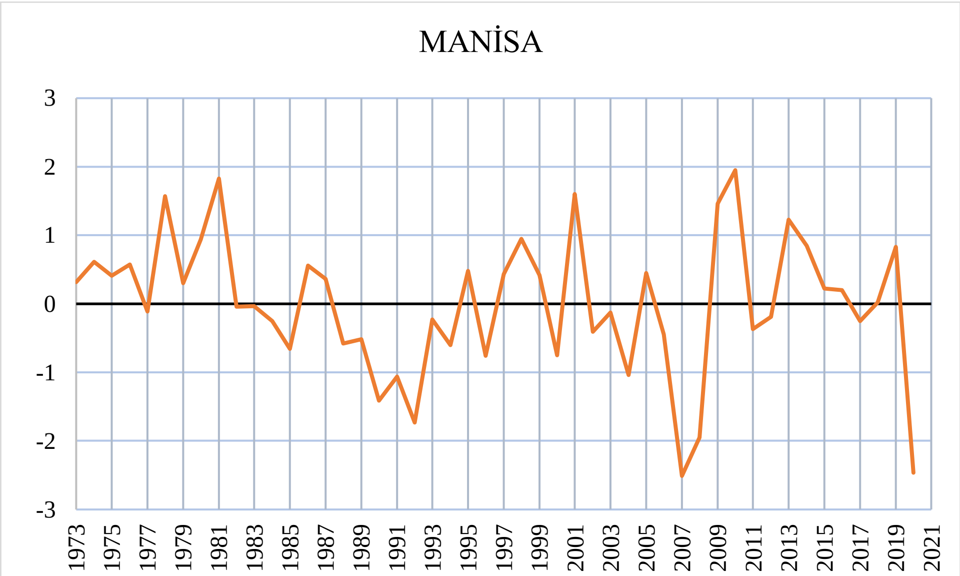

Figure A.3.6: Manisa SPI-12 Results

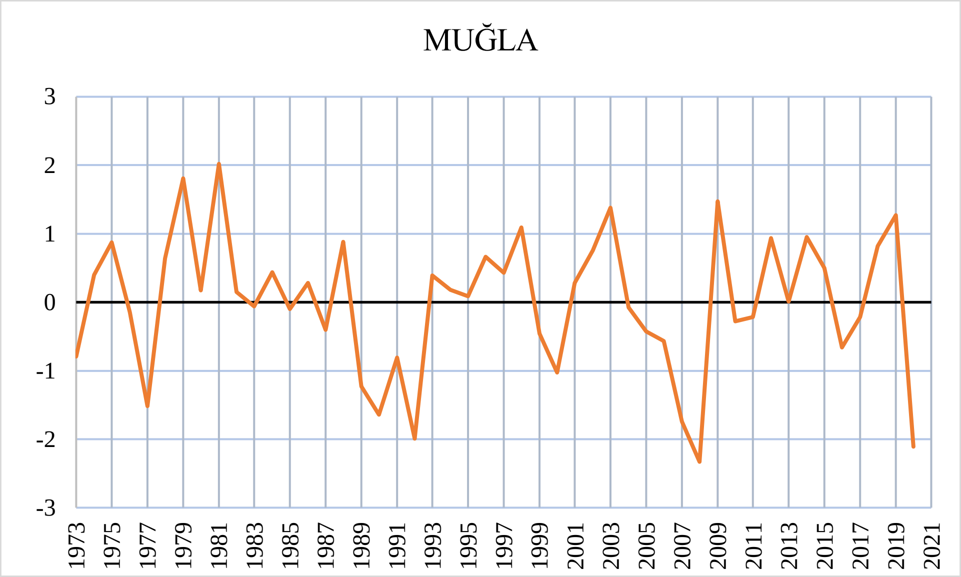

Figure A.3.7: Muğla SPI-12 Results

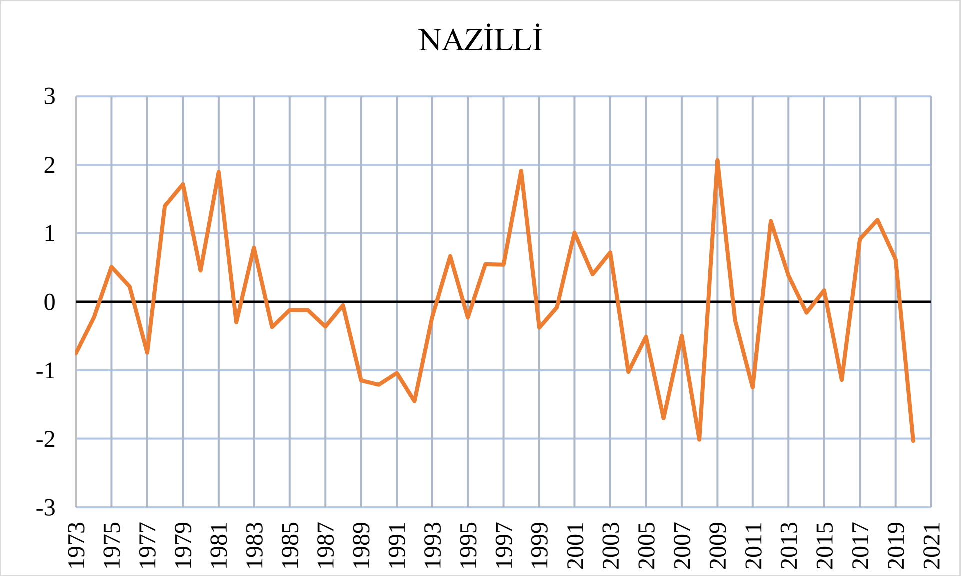

Figure A.3.8: Nazilli SPI-12 Results

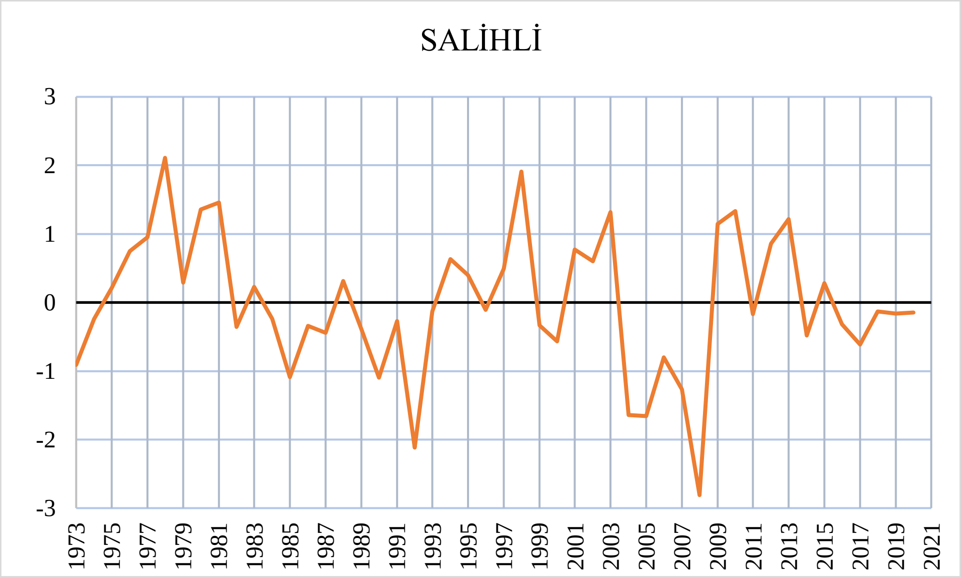

Figure A.3.9: Salihli SPI-12 Results

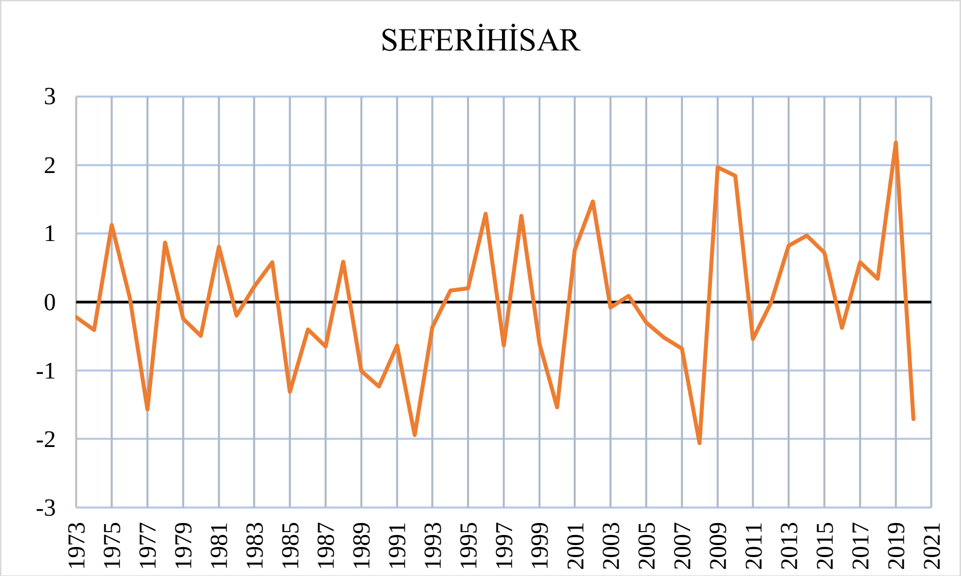

Figure A.3.10: Seferihisar SPI-12 Results

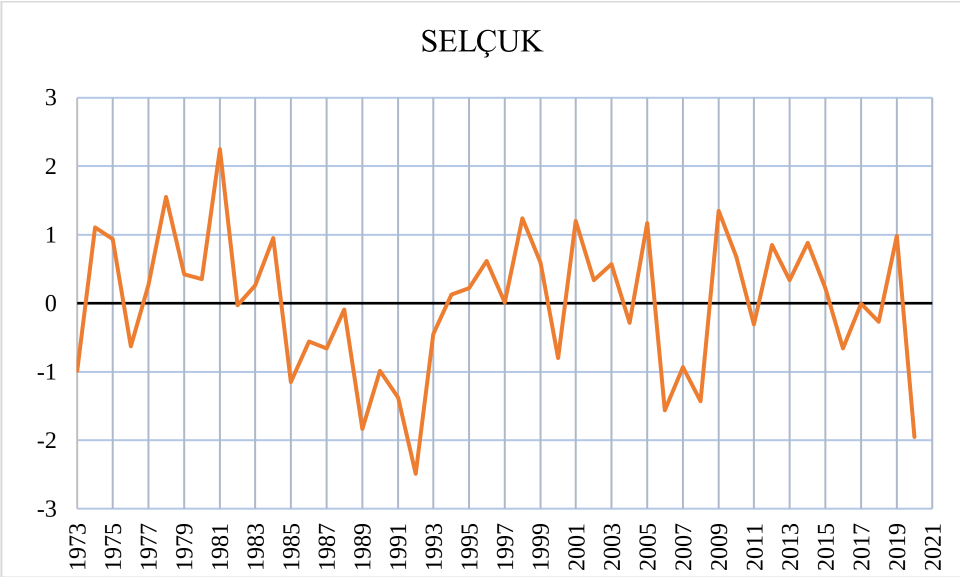

Figure A.3.11: Selçuk SPI-12 Results

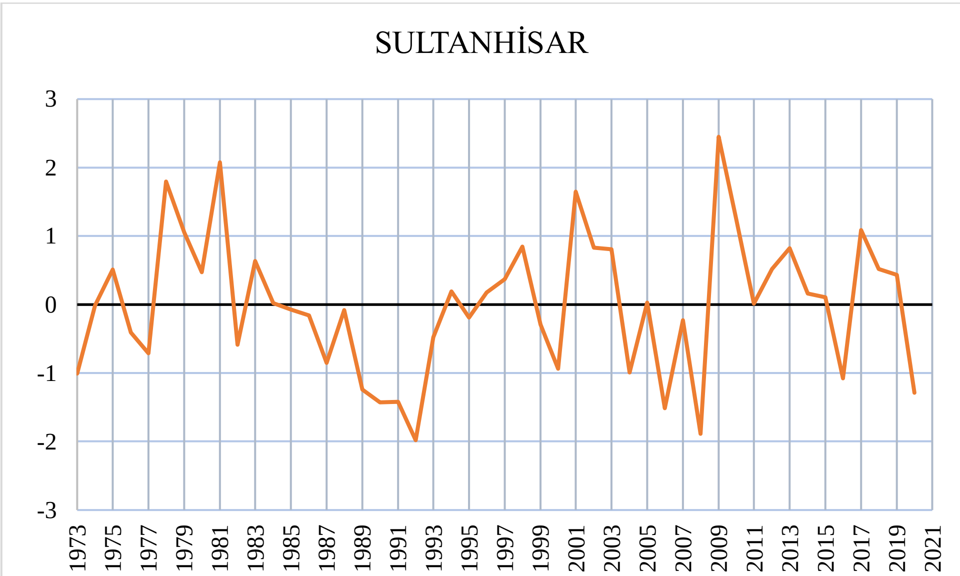

Figure A.3.12: Sultanhisar SPI-12 Results

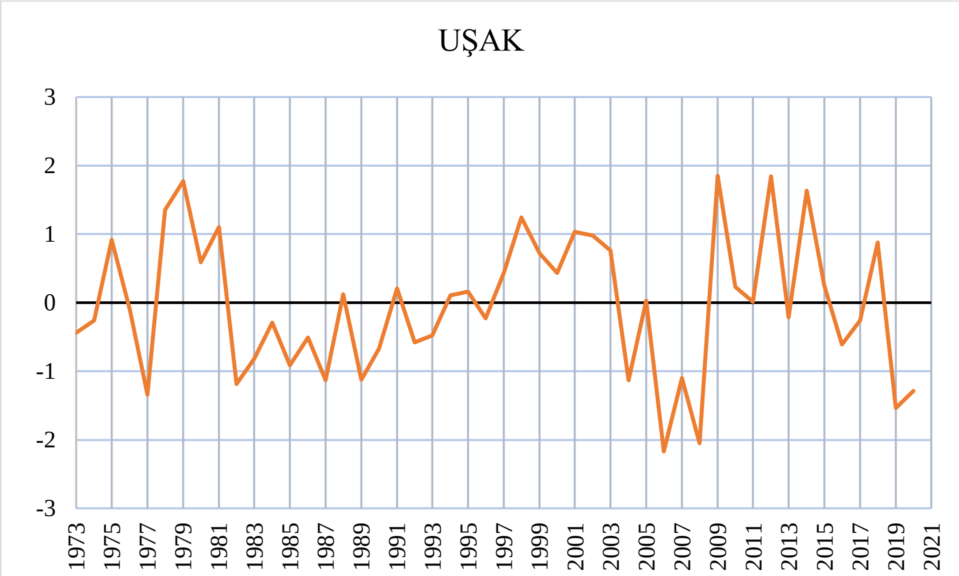

Figure A.3.13: Uşak SPI-12 Results

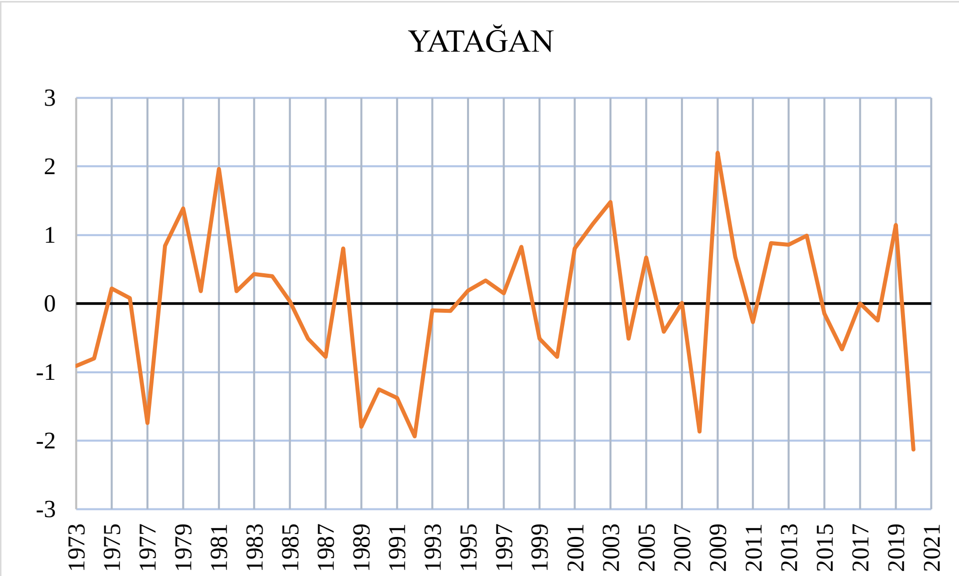

Figure A.3.14: Yatağan SPI-12 Results

APPENDIX B. SPEI RESULTS

B.1. SPEI-1

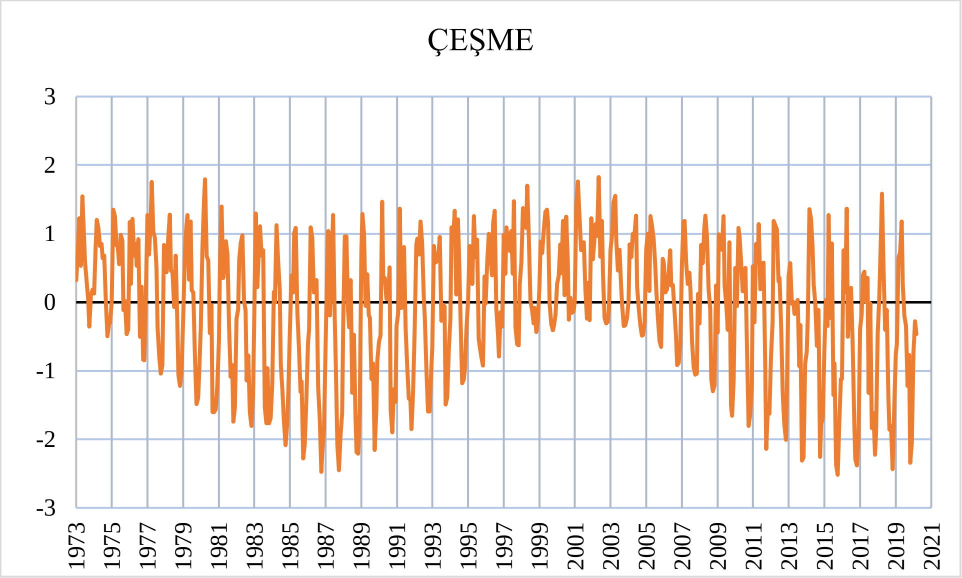

Figure B.1.1: Çeşme SPEI-1 Results

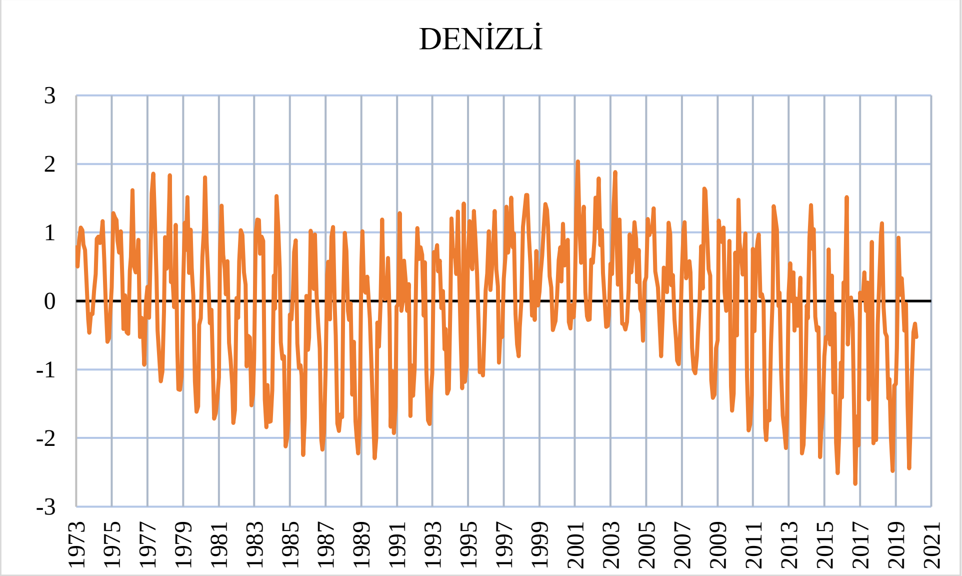

Figure B.1.2: Denizli SPEI-1 Results

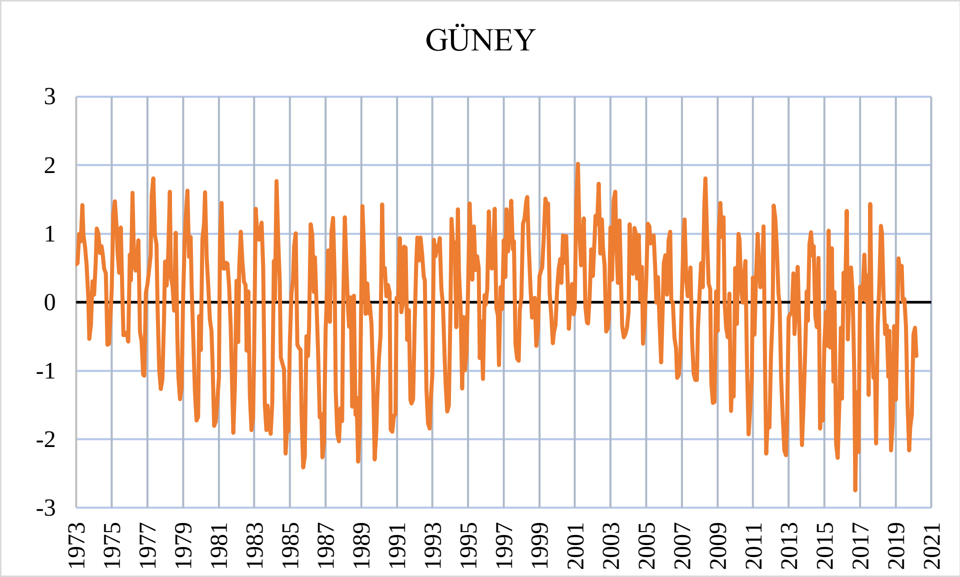

Figure B.1.3: Güney SPEI-1 Results

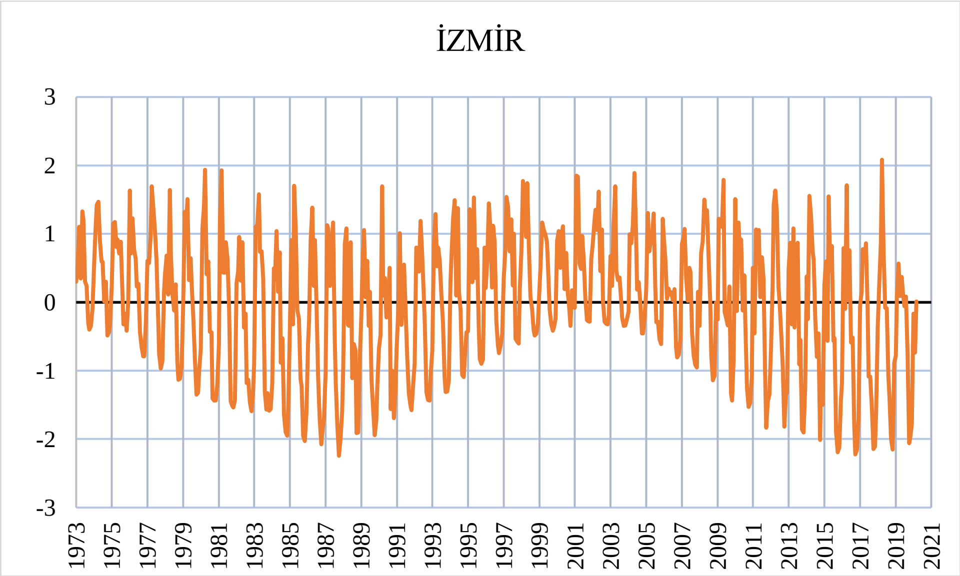

Figure B.1.4: Izmir SPEI-1 Results

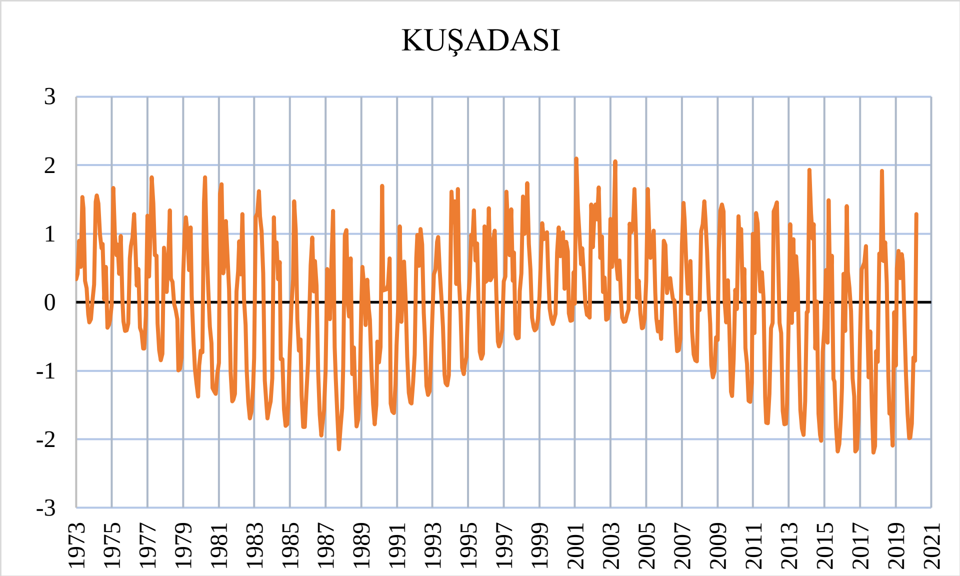

Figure B.1.5: Kuşadası SPEI-1 Results

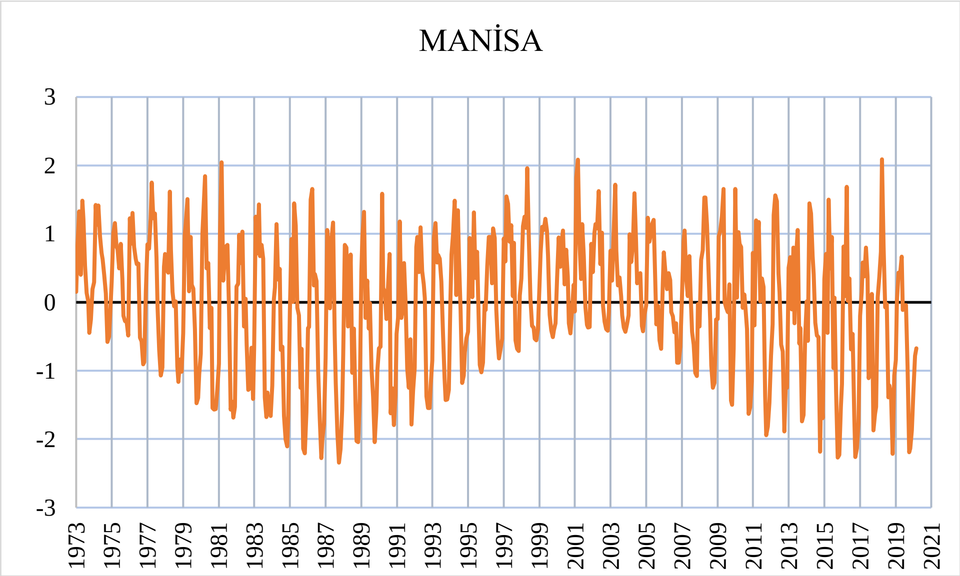

Figure B.1.6: Manisa SPEI-1 Results

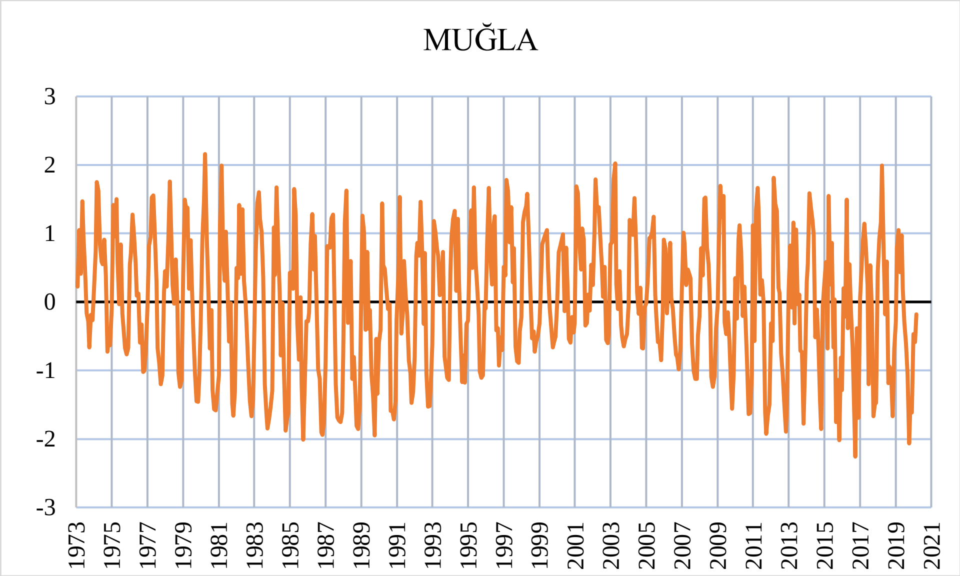

Figure B.1.7: Muğla SPEI-1 Results

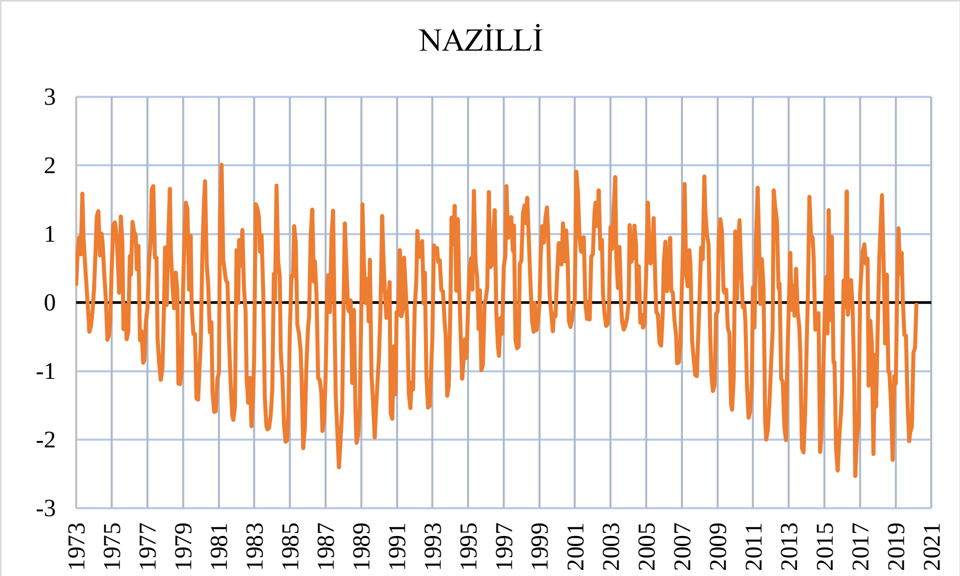

Figure B.1.8: Nazilli SPEI-1 Results

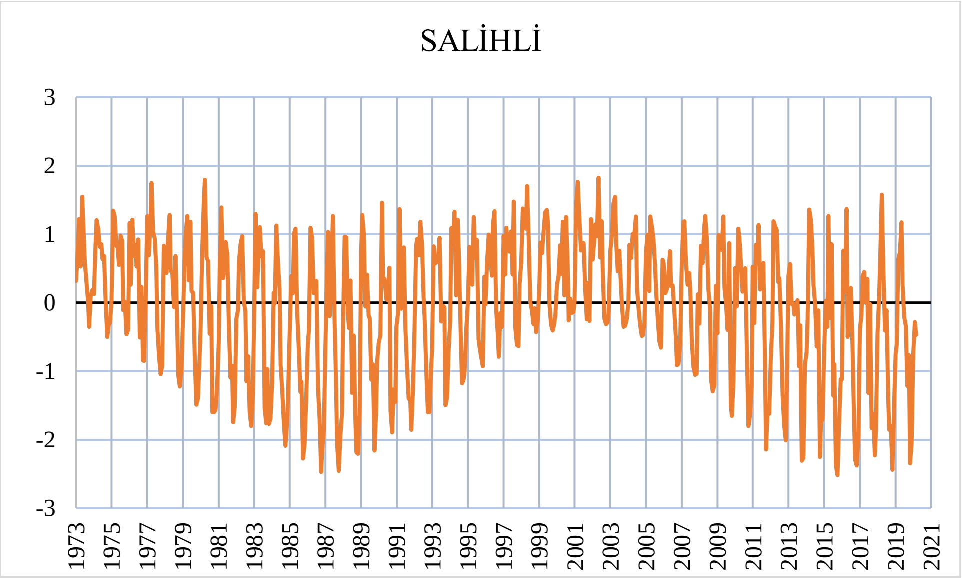

Figure B.1.9: Salihli SPEI-1 Results

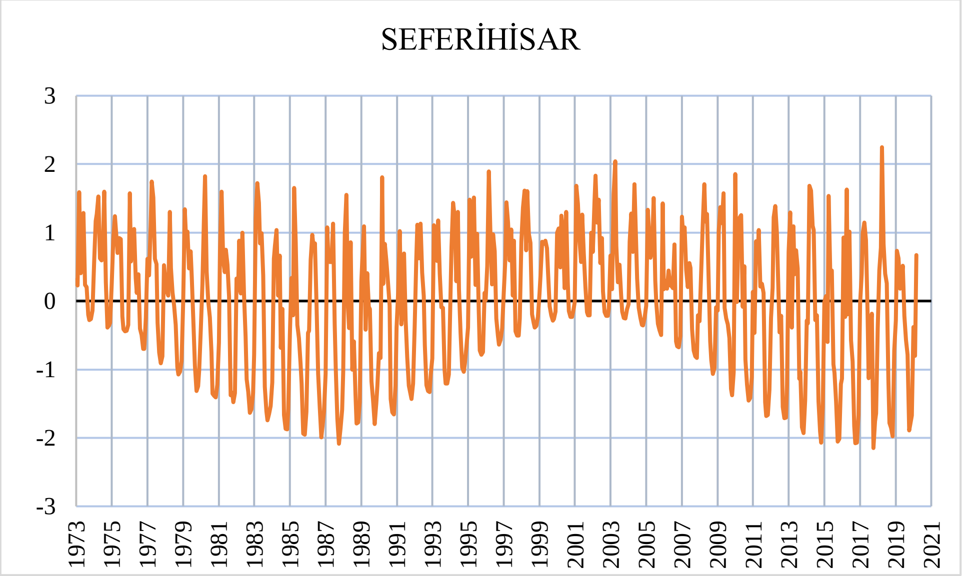

Figure B.1.10: Seferihisar SPEI-1 Results

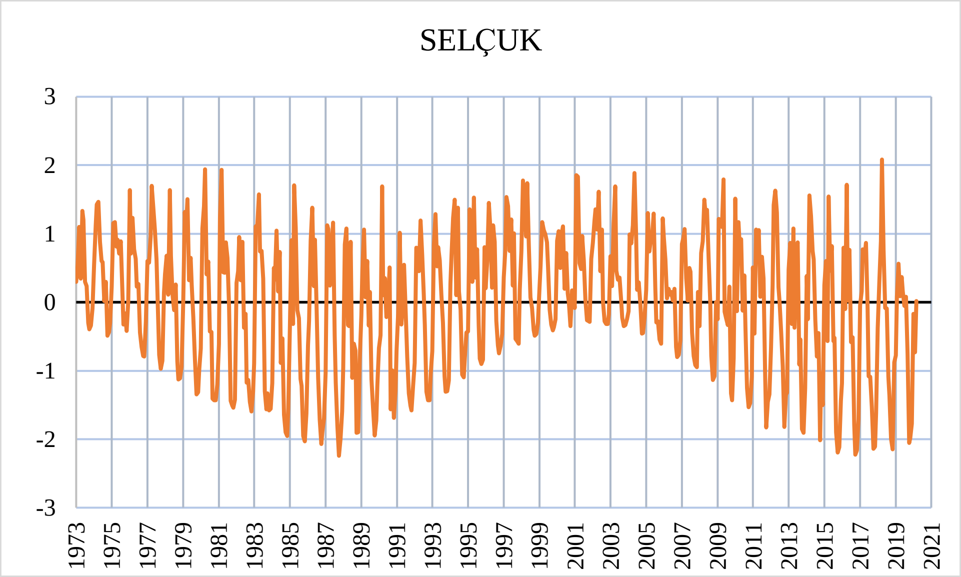

Figure B.11: Selçuk SPEI-1 Results

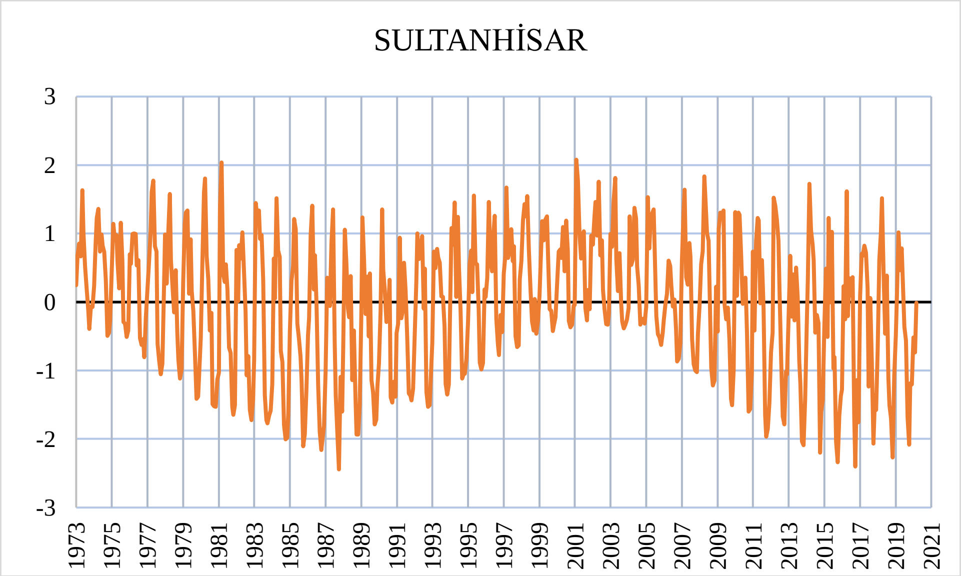

Figure B.1.12: Sultanhisar SPEI-1 Results

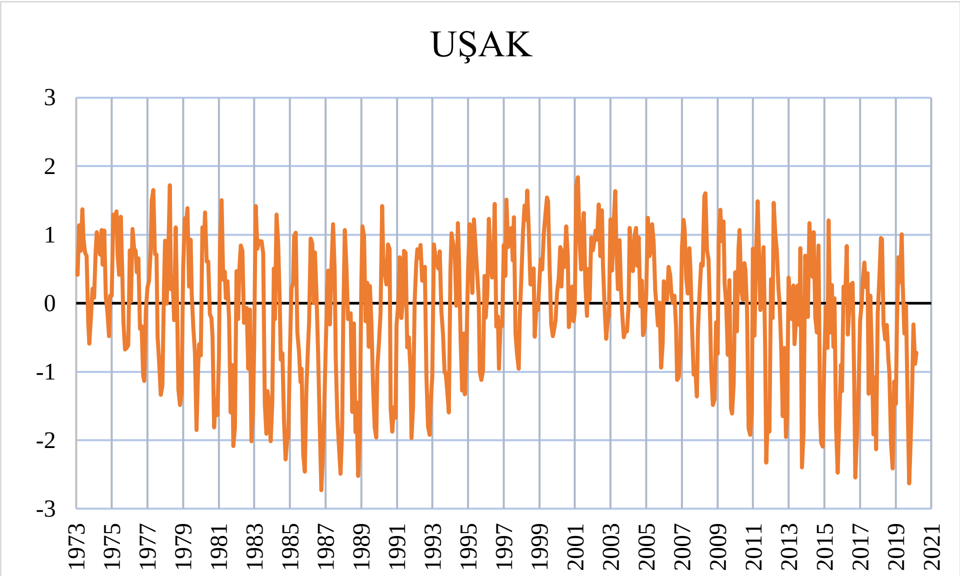

Figure B.1.13: Uşak SPEI-1 Results

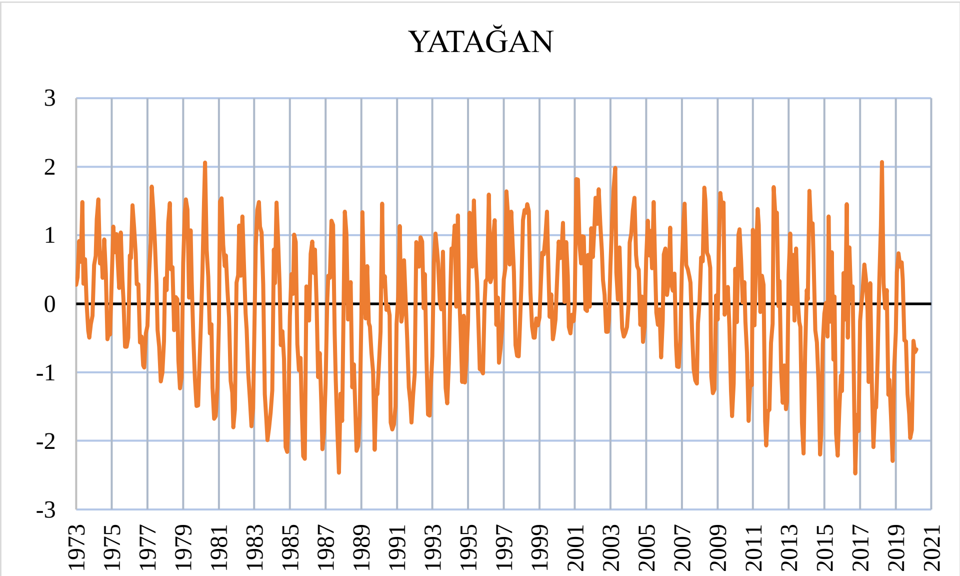

Figure B.1.14: Yatağan SPEI-1 Results

B.2. SPEI-3

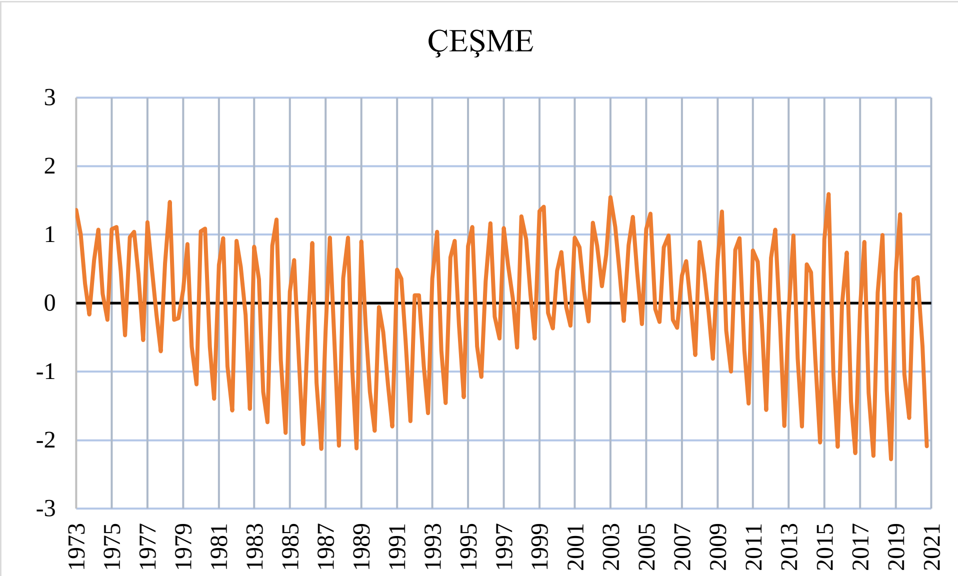

Figure B.2.1: Çeşme SPEI-3 Results

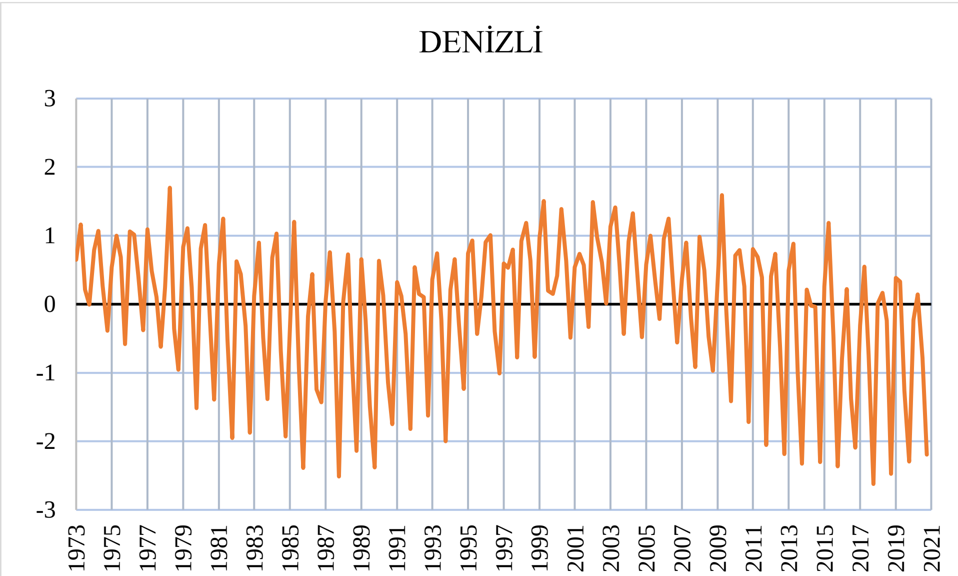

Figure B.2.2: Denizli SPEI-3 Results

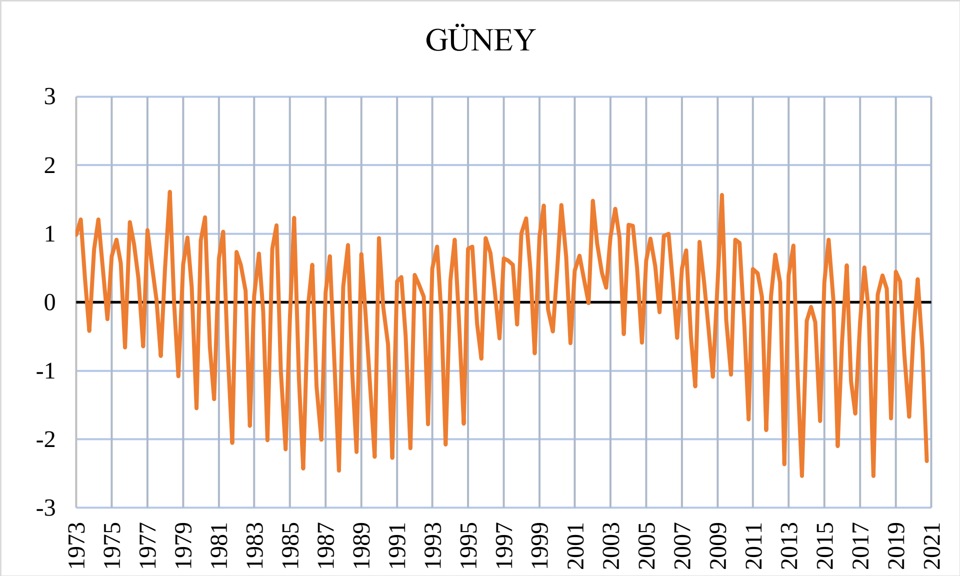

Figure B.2.3: Güney SPEI-3 Results

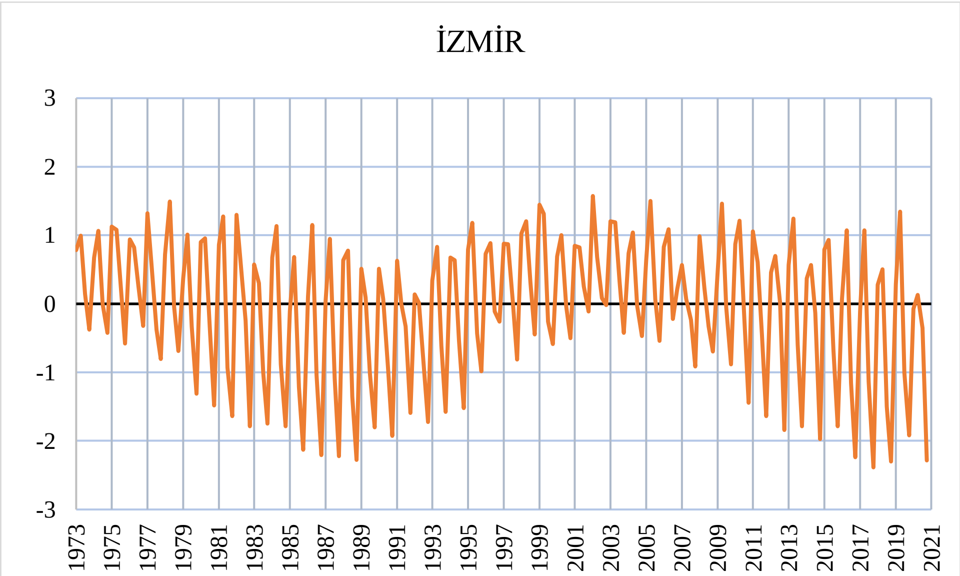

Figure B.2.4: Izmir SPEI-3 Results

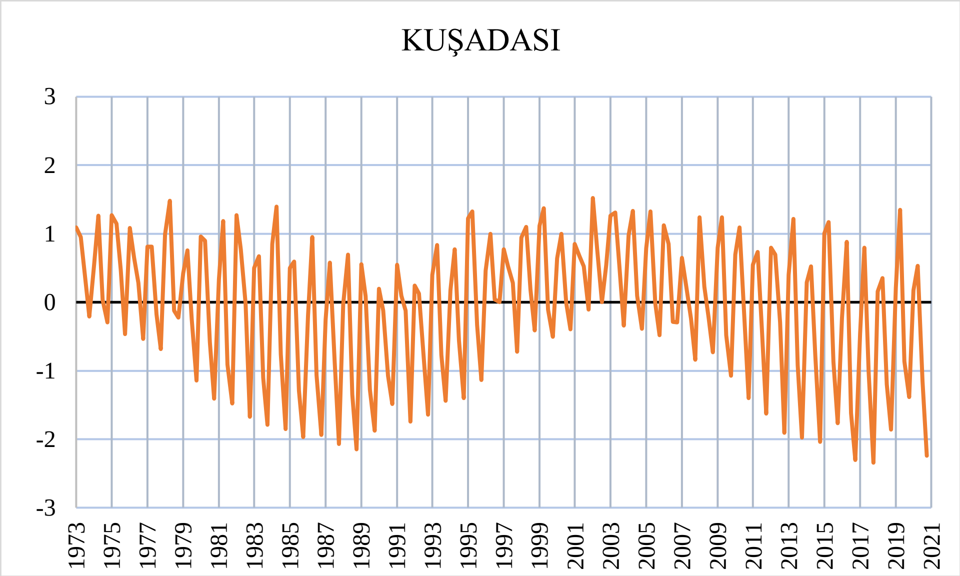

Figure B.2.5: Kuşadası SPEI-3 Results

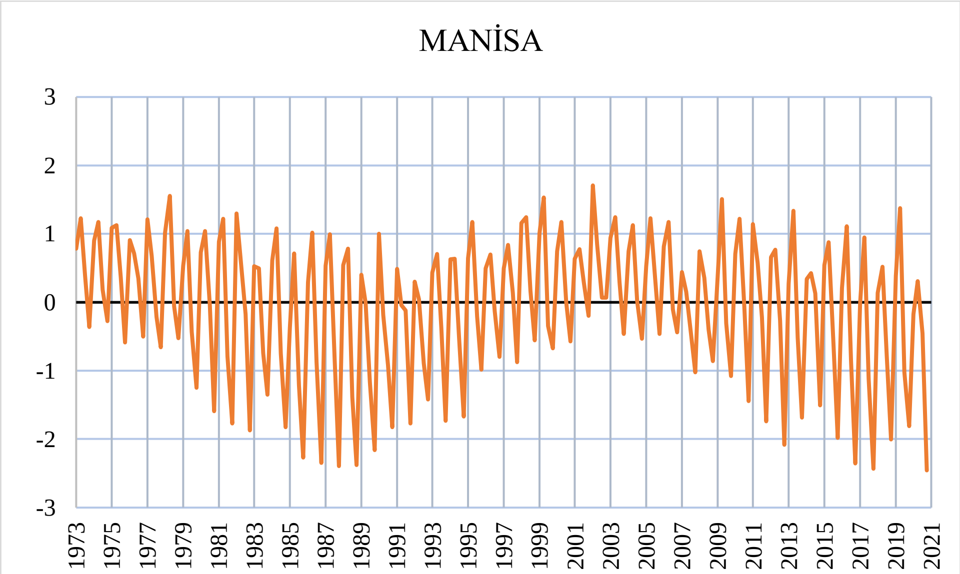

Figure B.2.6: Manisa SPEI-3 Results

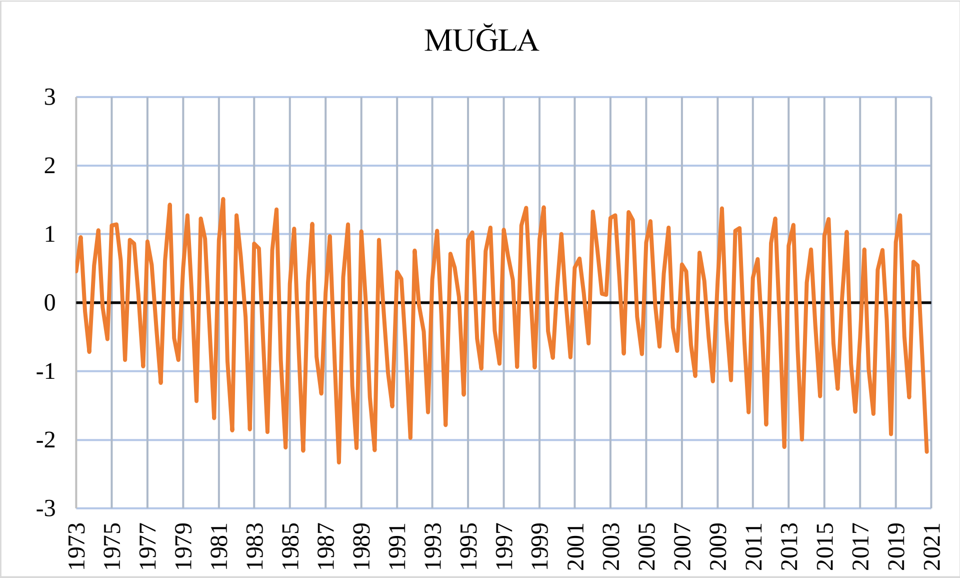

Figure B.2.7: Muğla SPEI-3 Results

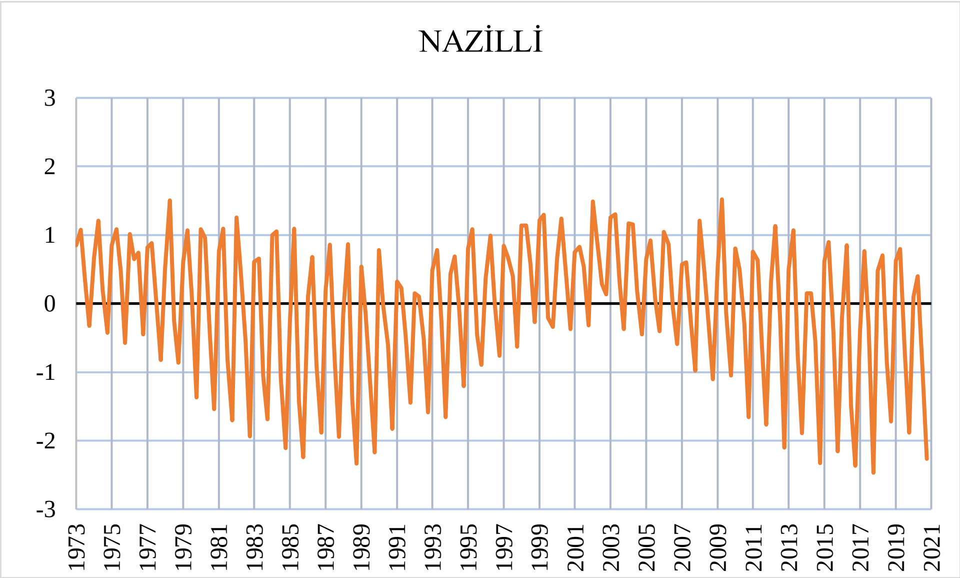

Figure B.2.8: Nazilli SPEI-3 Results

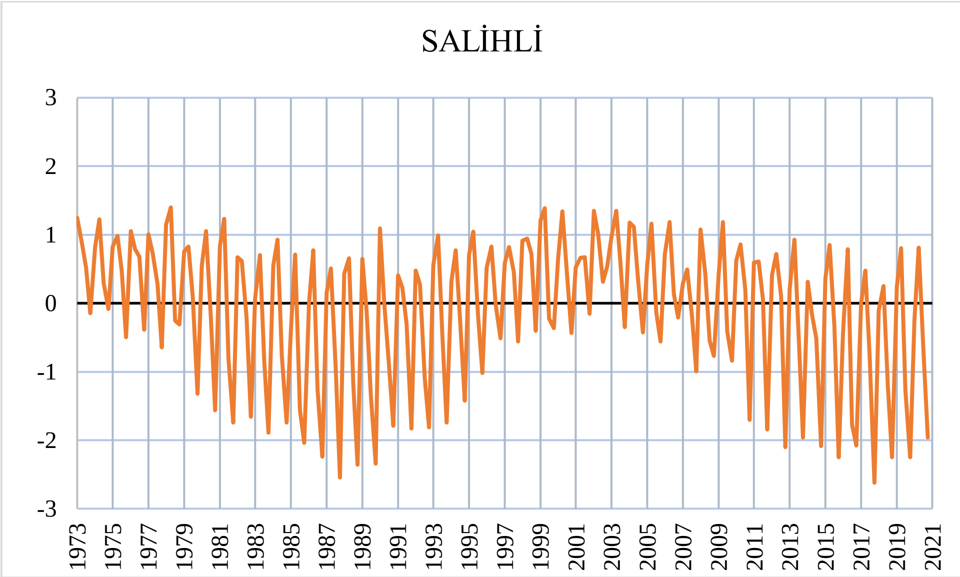

Figure B.2.9: Nazilli SPEI-3 Results

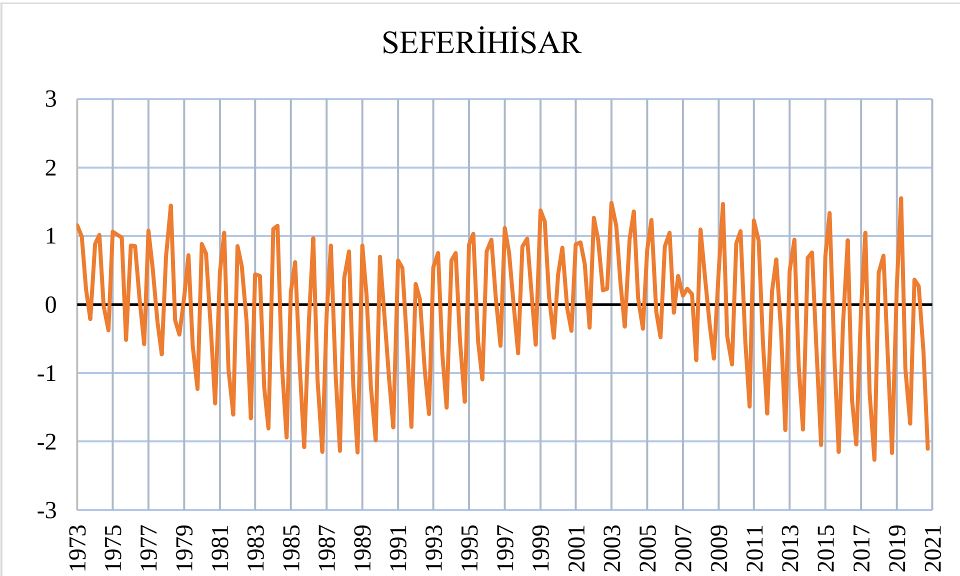

Figure B.2.10: Seferihisar SPEI-3 Results

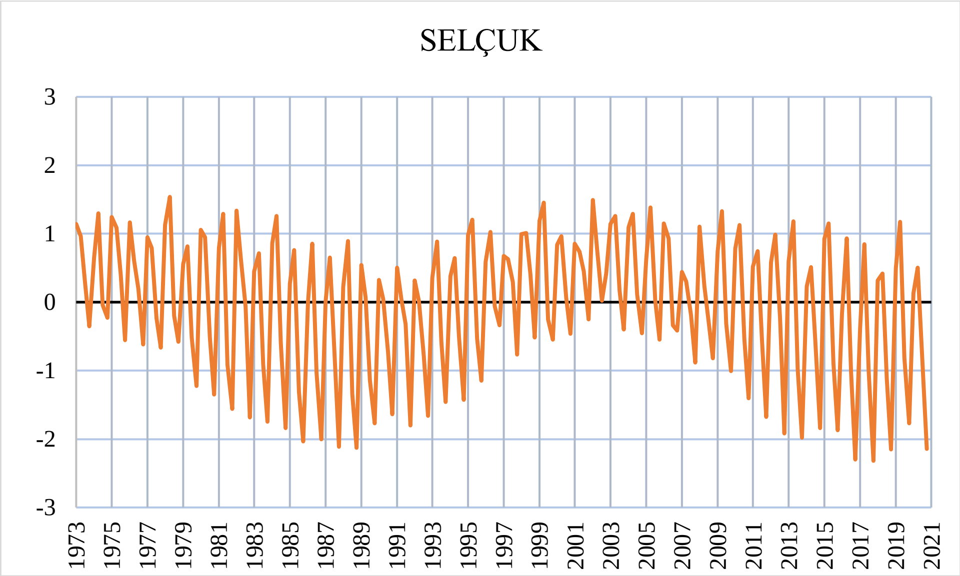

Figure B.2.11: Selçuk SPEI-3 Results

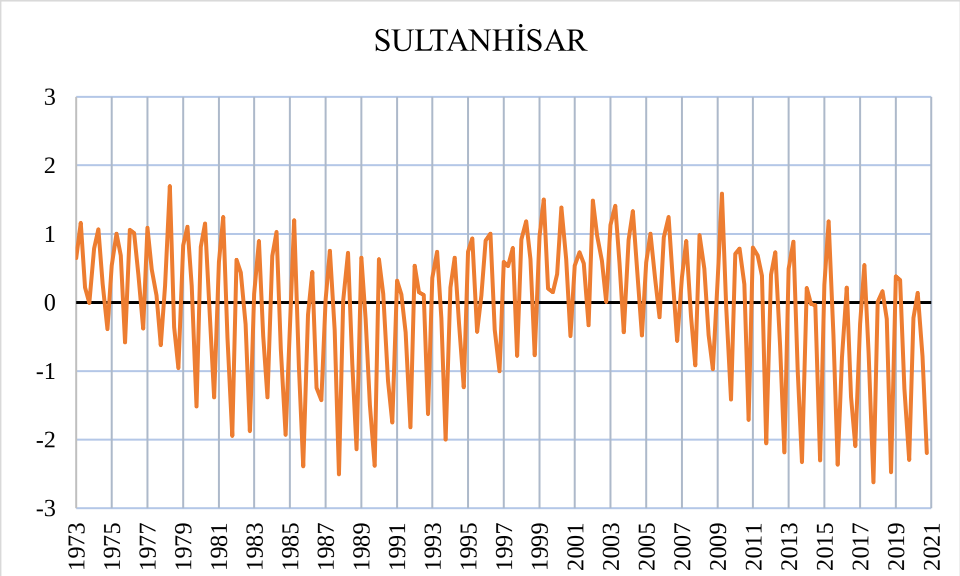

Figure B.2.12: Sultanhisar SPEI-3 Results

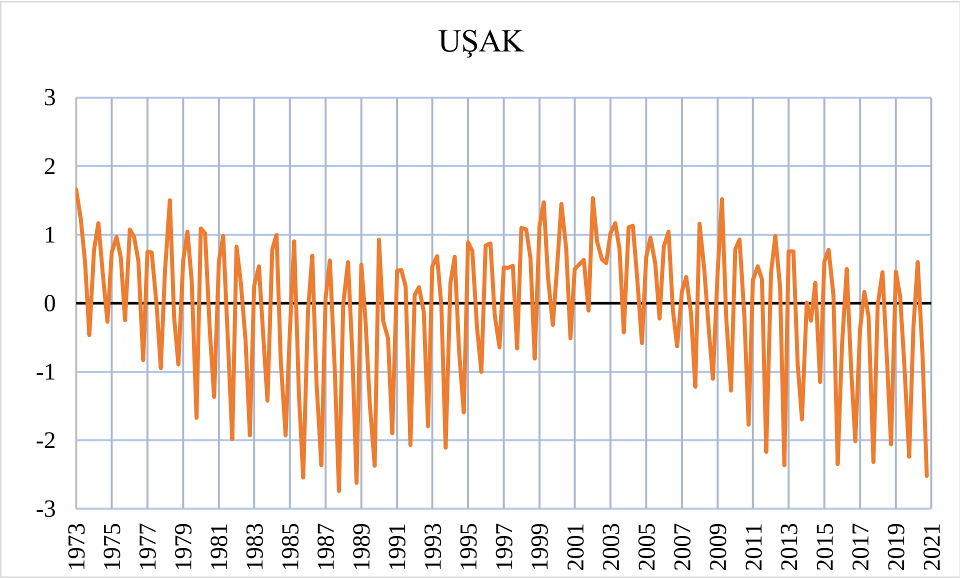

Figure B.2.13: Uşak SPEI-3 Results

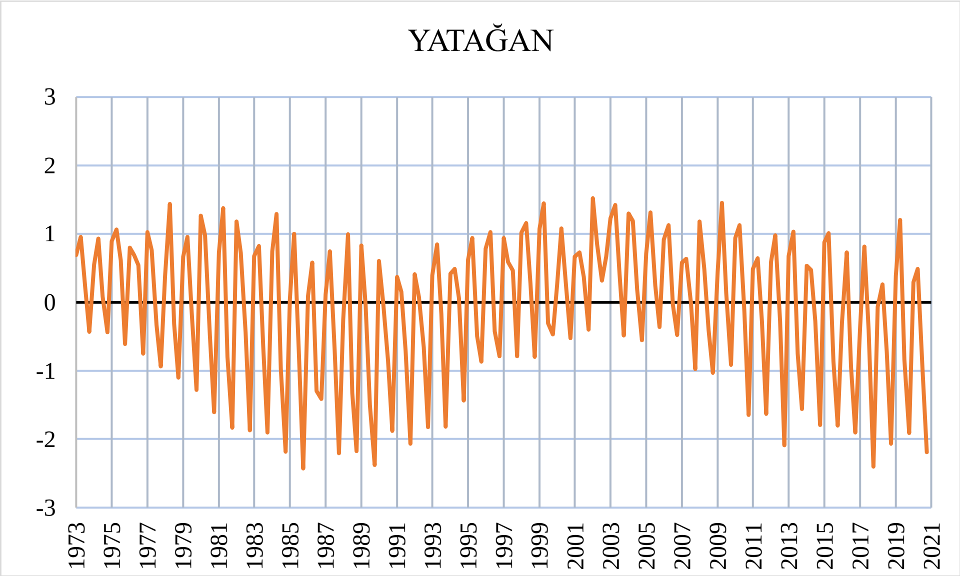

Figure B.2.14: Yatağan SPEI-3 Results

B.3. SPEI-12

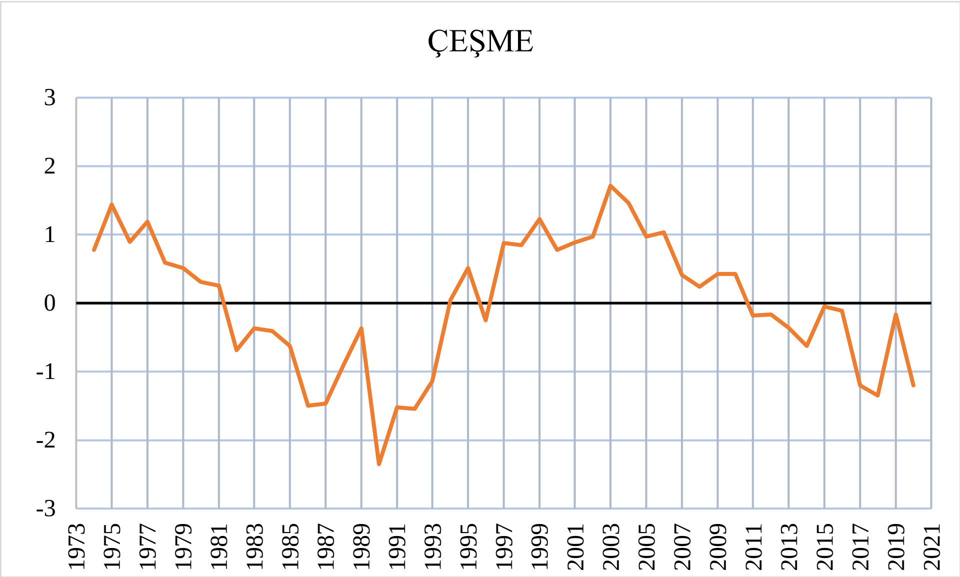

Figure B.3.1: Çeşme SPEI-12 Results

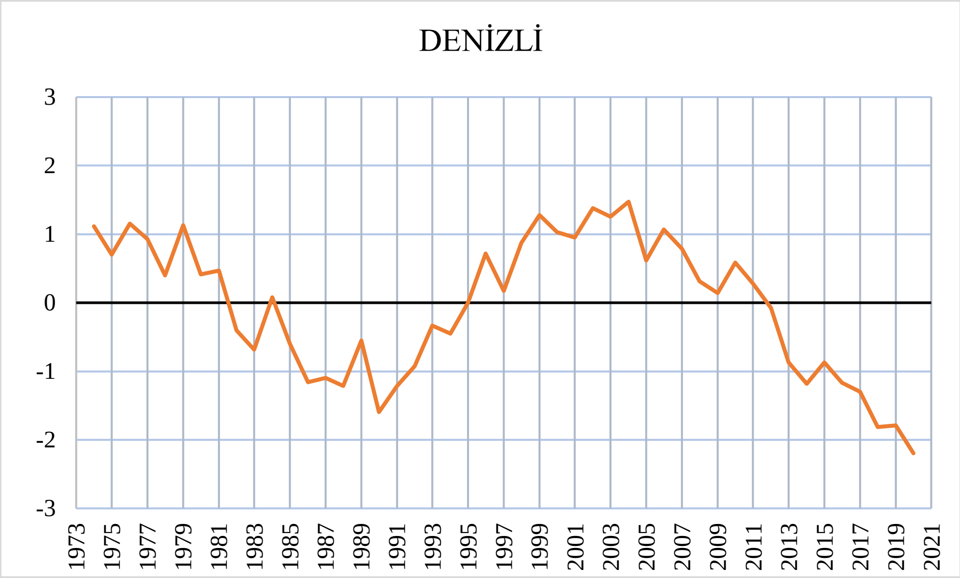

Figure B.3.2: Denizli SPEI-12 Results

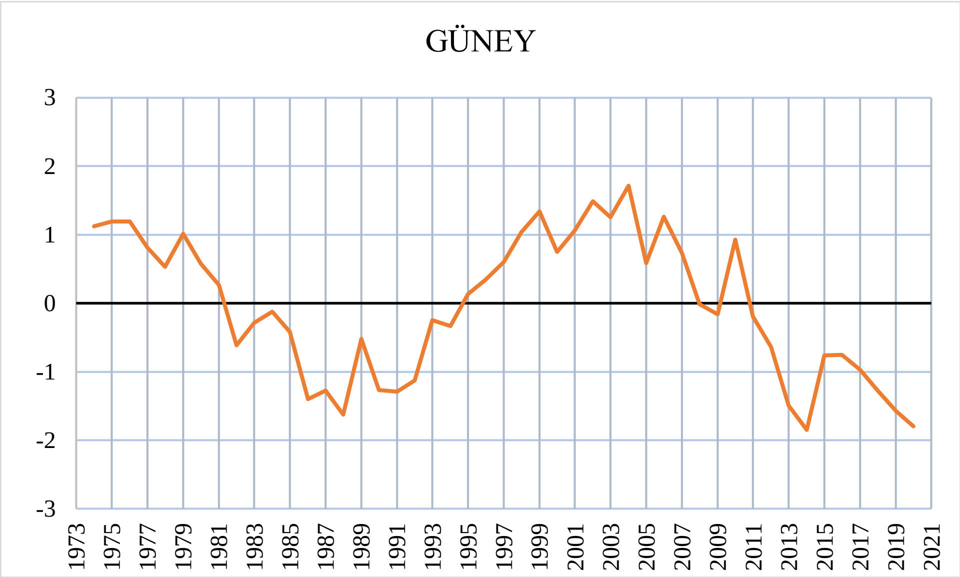

Figure B.3.3: Güney SPEI-12 Results

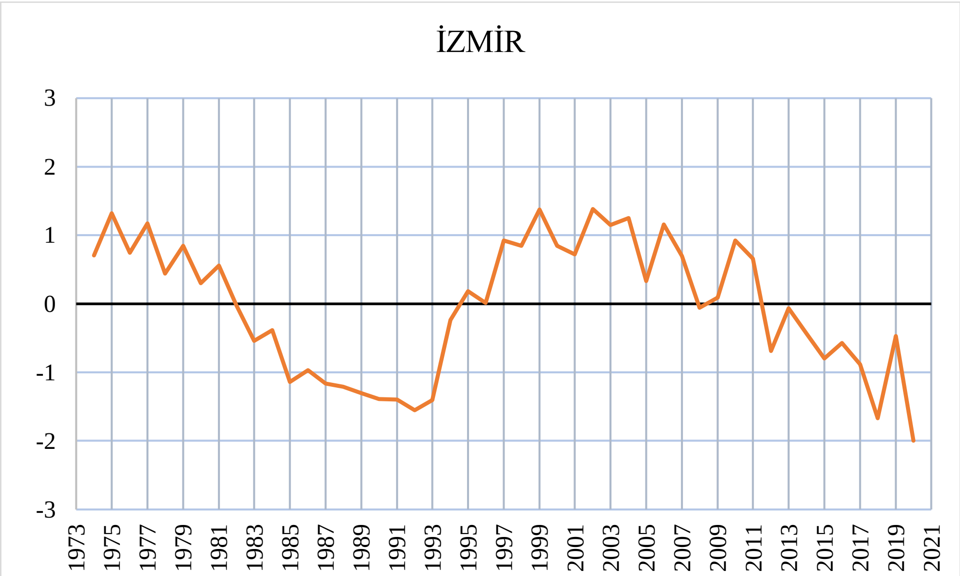

Figure B.3.4: Izmir SPEI-12 Results

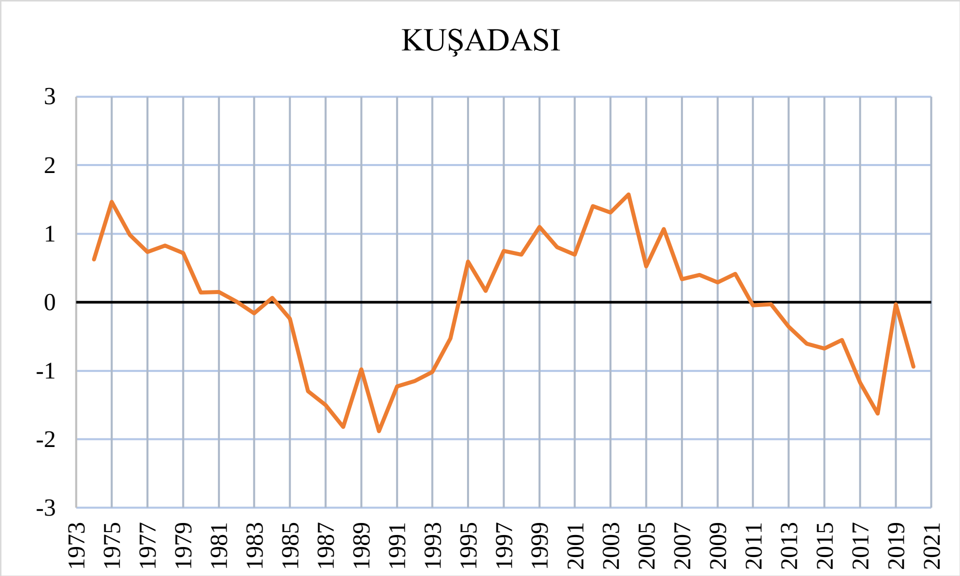

Figure B.3.5: Kuşadası SPEI-12 Results

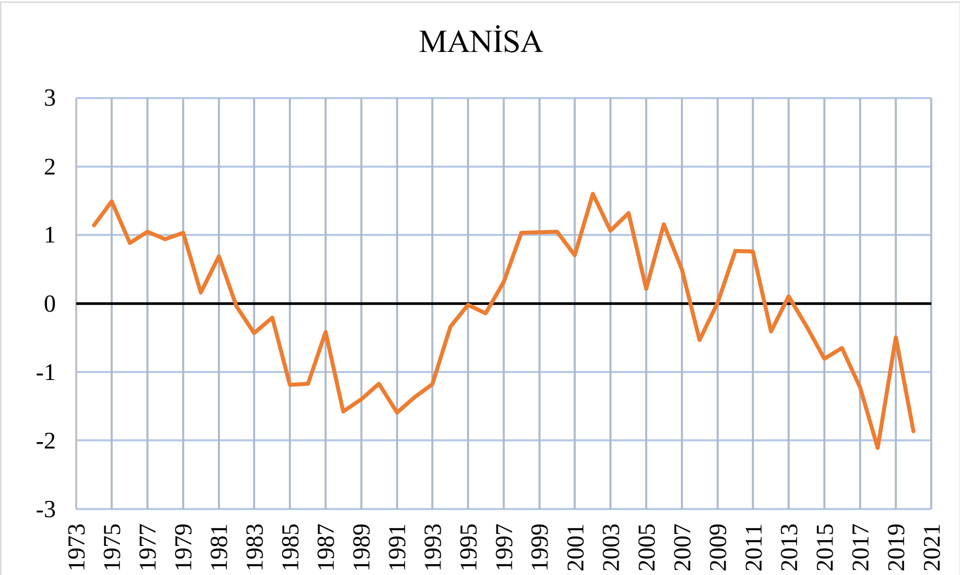

Figure B.3.6: Manisa SPEI-12 Results

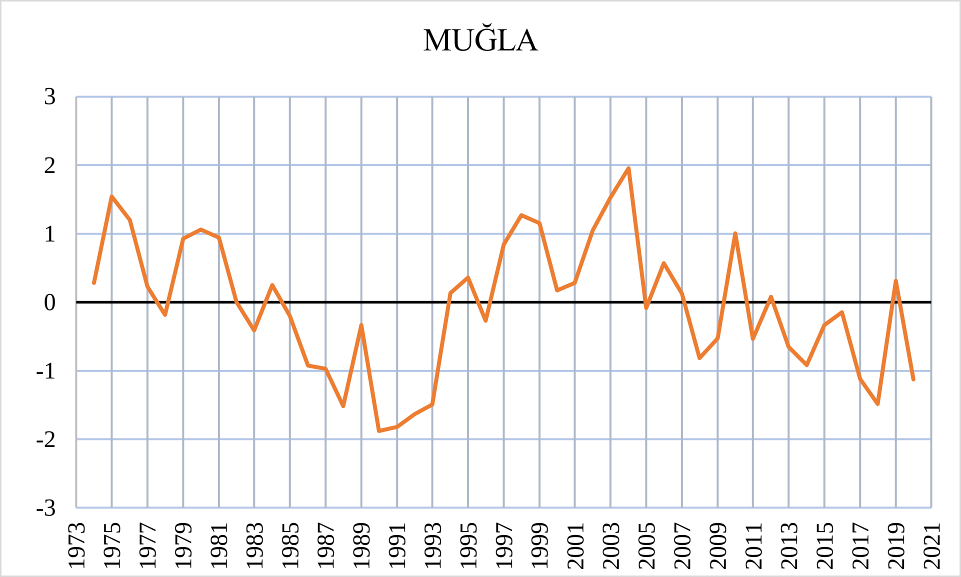

Figure B.3.7: Muğla SPEI-12 Results

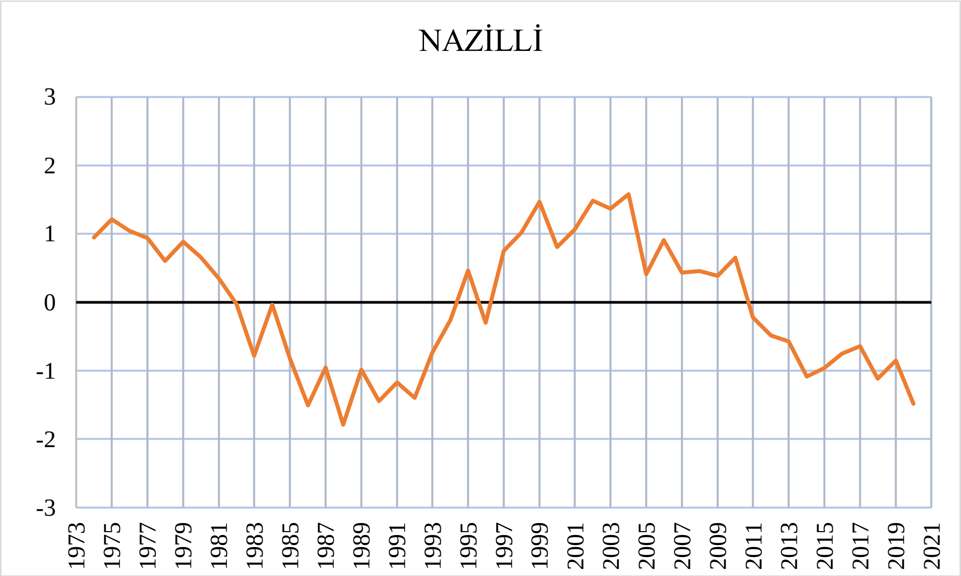

Figure B.3.8: Nazilli SPEI-12 Results

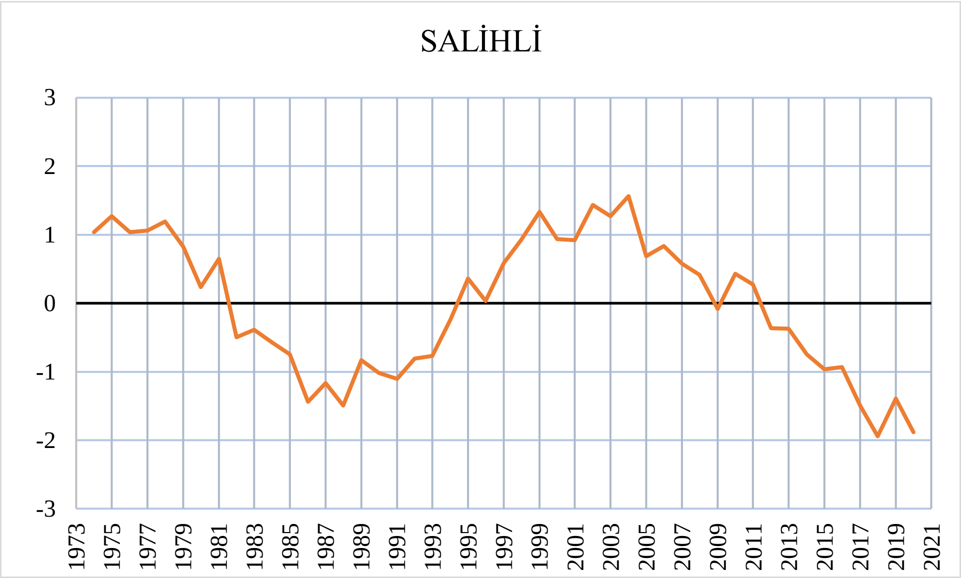

Figure B.3.9: Salihli SPEI-12 Results

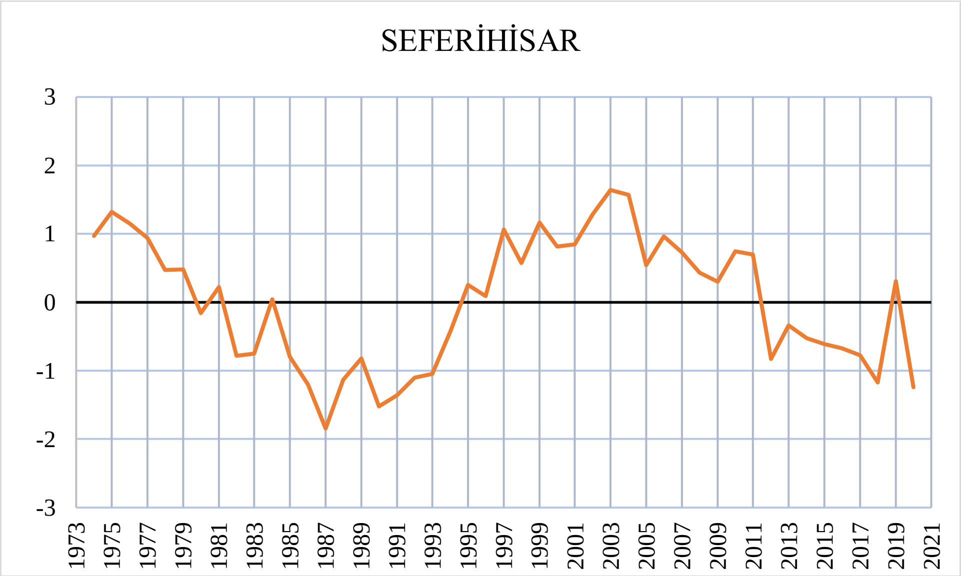

Figure B.3.10: Seferihisar SPEI-12 Results

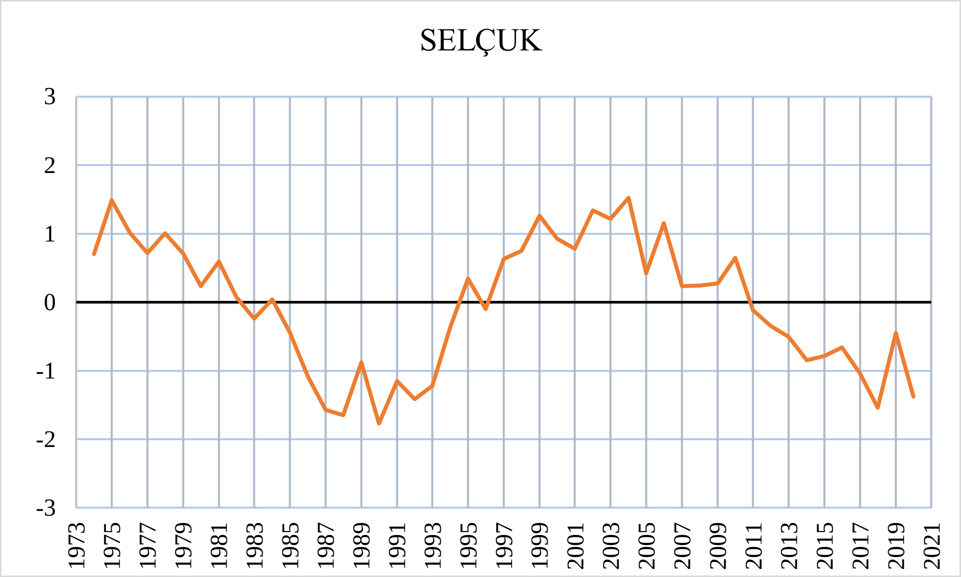

Figure B.3.11: Selçuk SPEI-12 Results

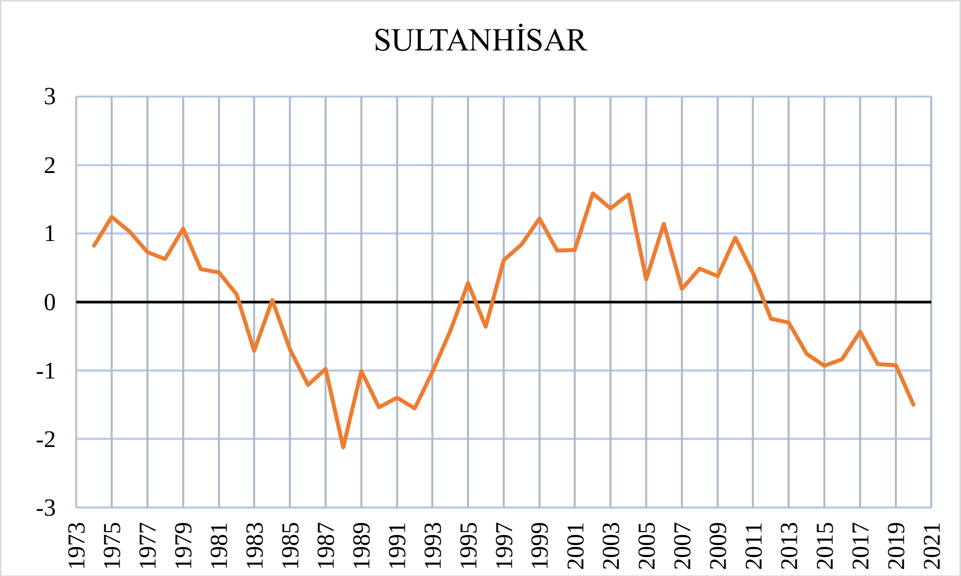

Figure B.3.12: Sultanhisar SPEI-12 Results

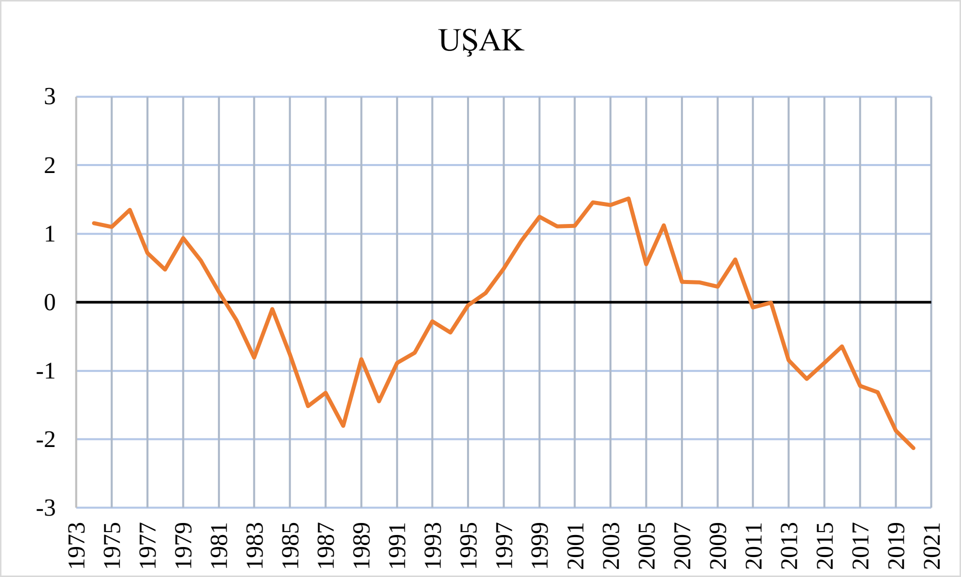

Figure B.3.13: Uşak SPEI-12 Results

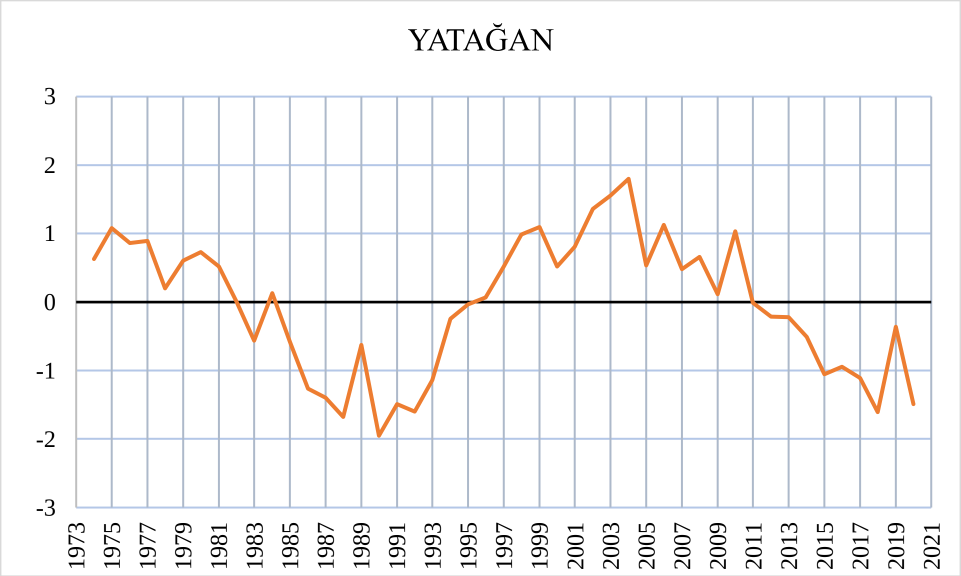

Figure B.3.14: Yatağan SPEI-12 Results

APPENDIX C. DPI RESULTS

C.1. DPI-3

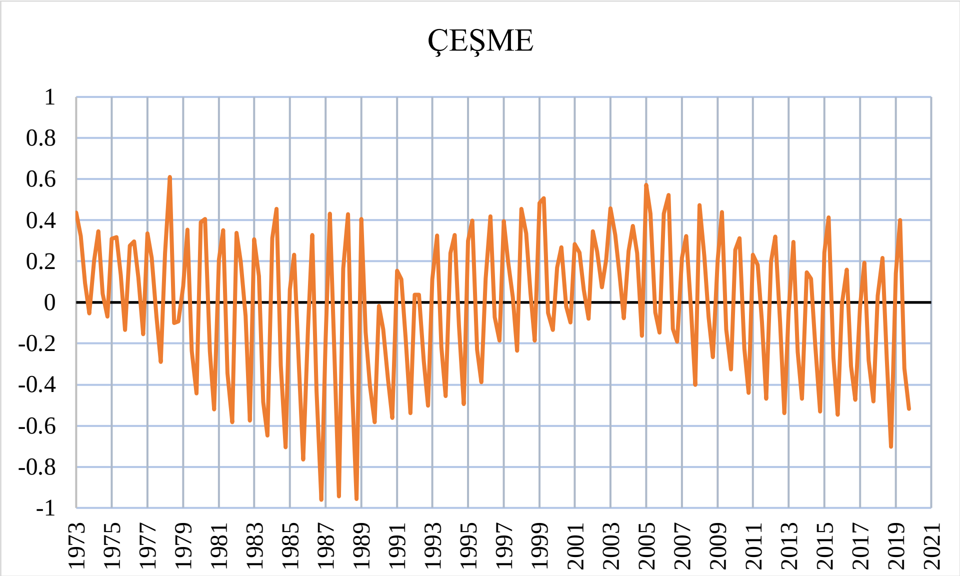

Figure C.1.1: Çeşme DPI-3 Results

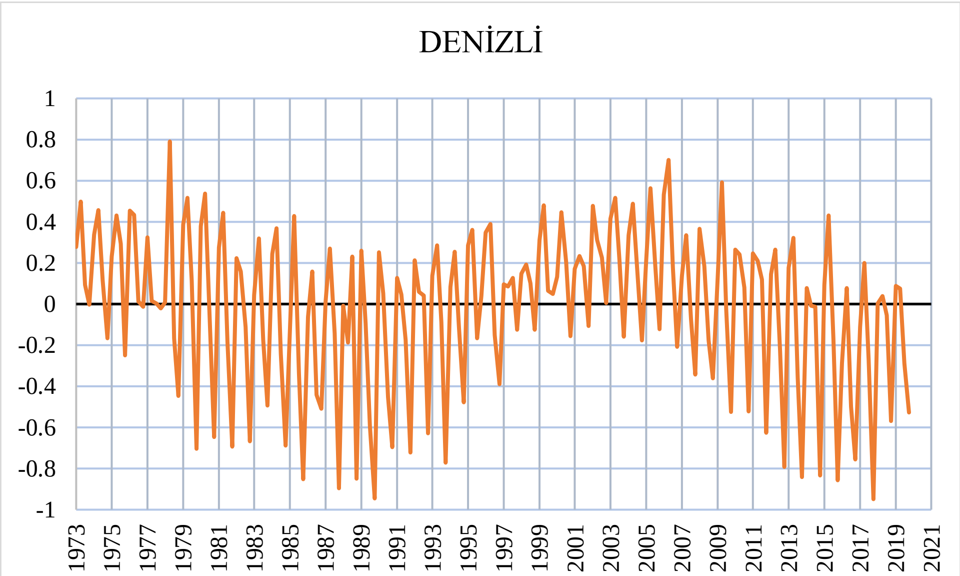

Figure C.1.2: Denizli DPI-3 Results

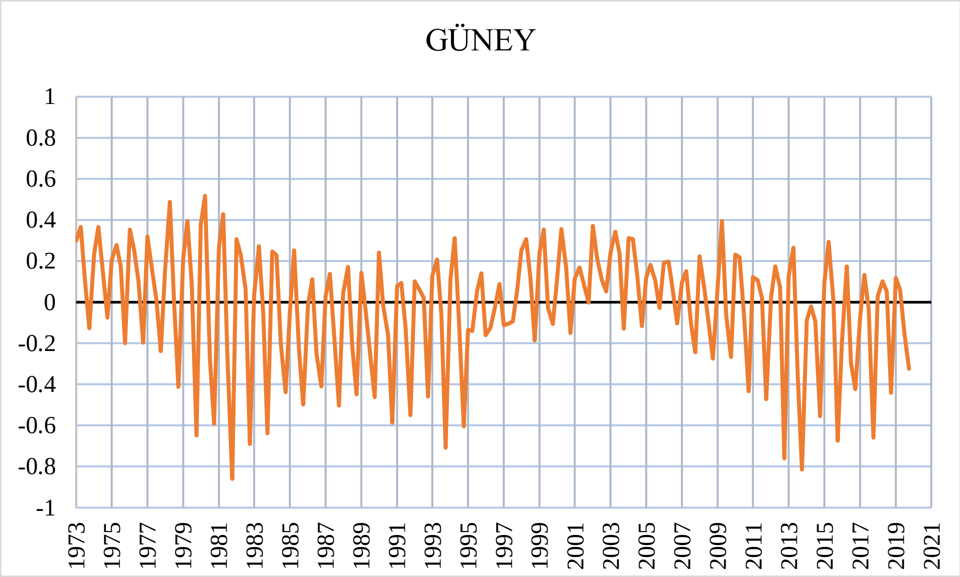

Figure C.1.3: Güney DPI-3 Results

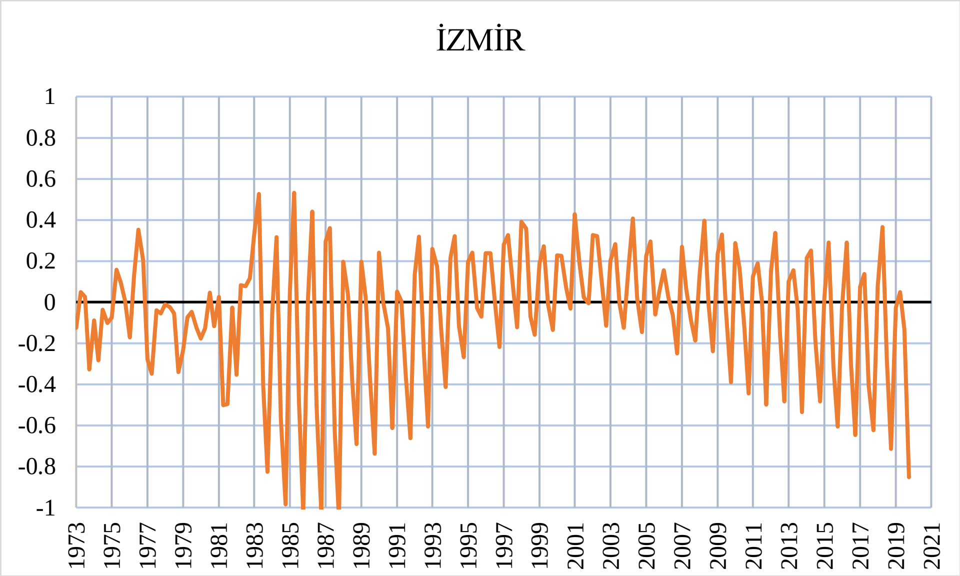

Figure C.1.4: Izmir DPI-3 Results

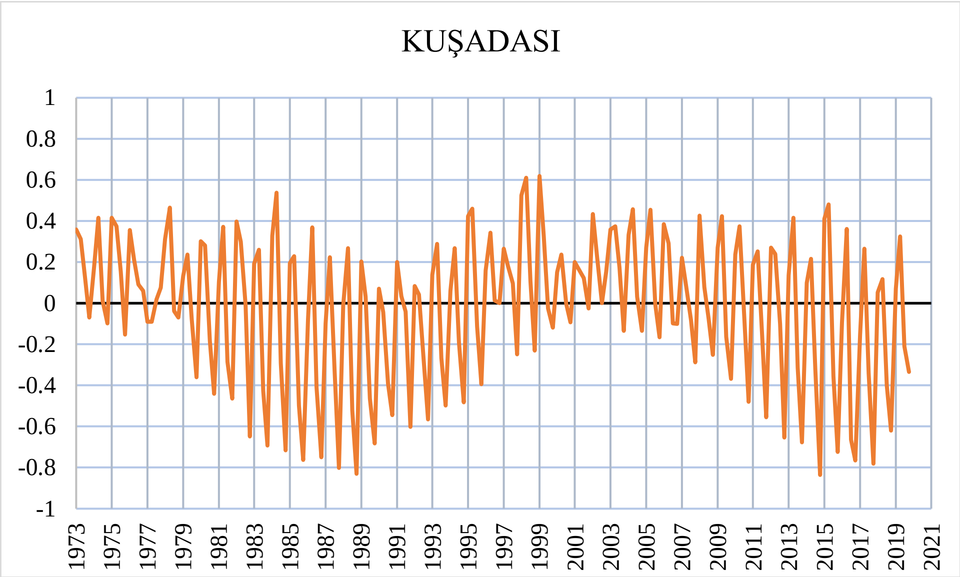

Figure C.1.5: Kuşadası DPI-3 Results

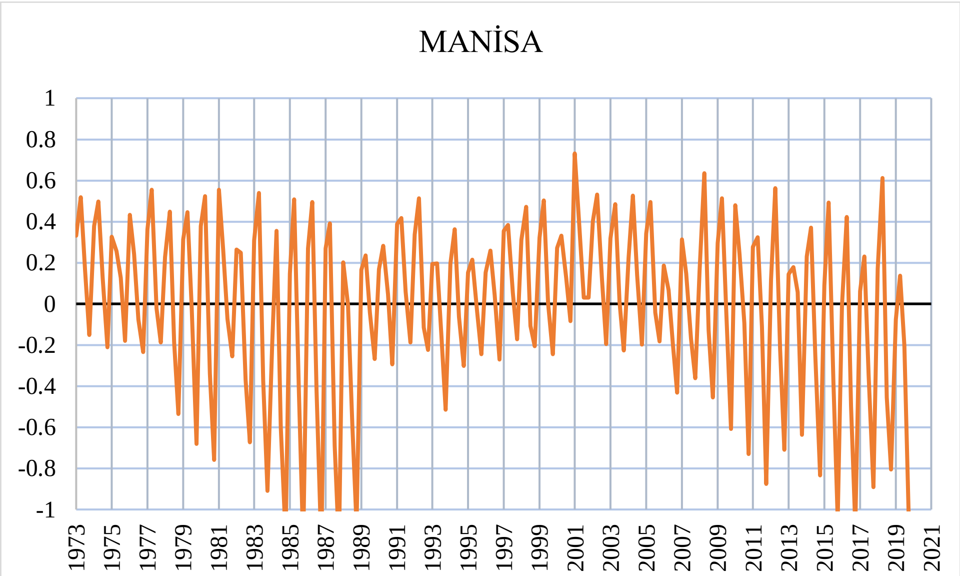

Figure C.1.6: Manisa DPI-3 Results

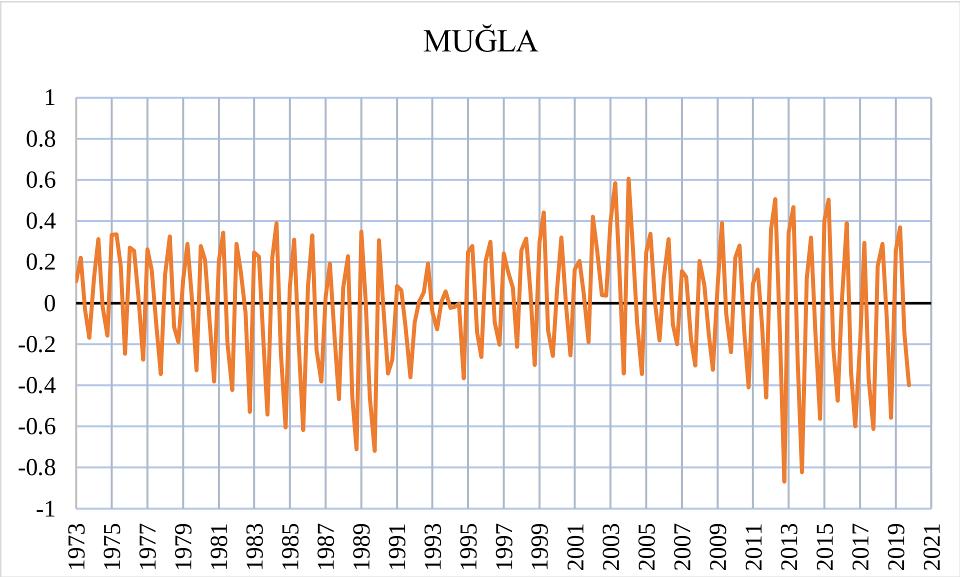

Figure C.1.7: Muğla DPI-3 Results

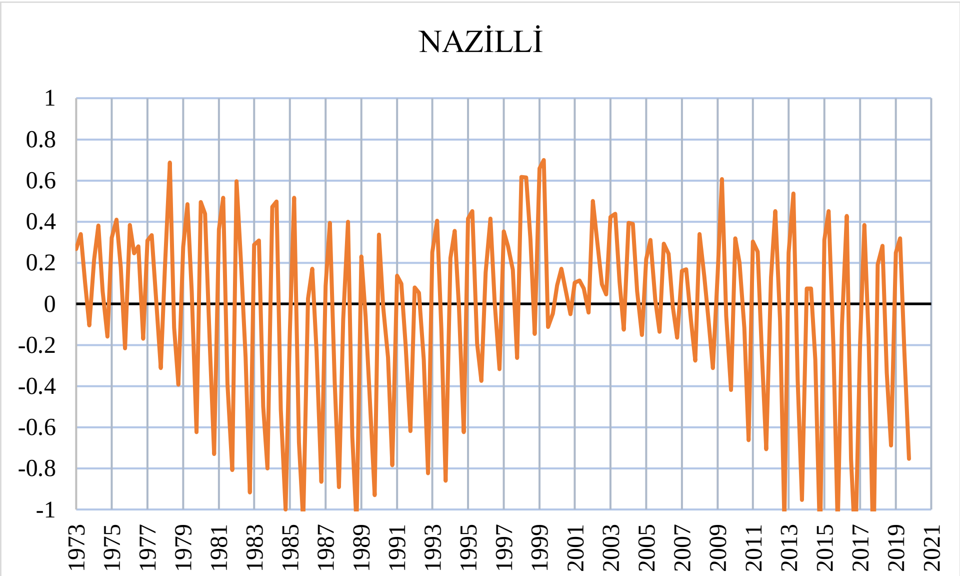

Figure C.1.8: Nazilli DPI-3 Results

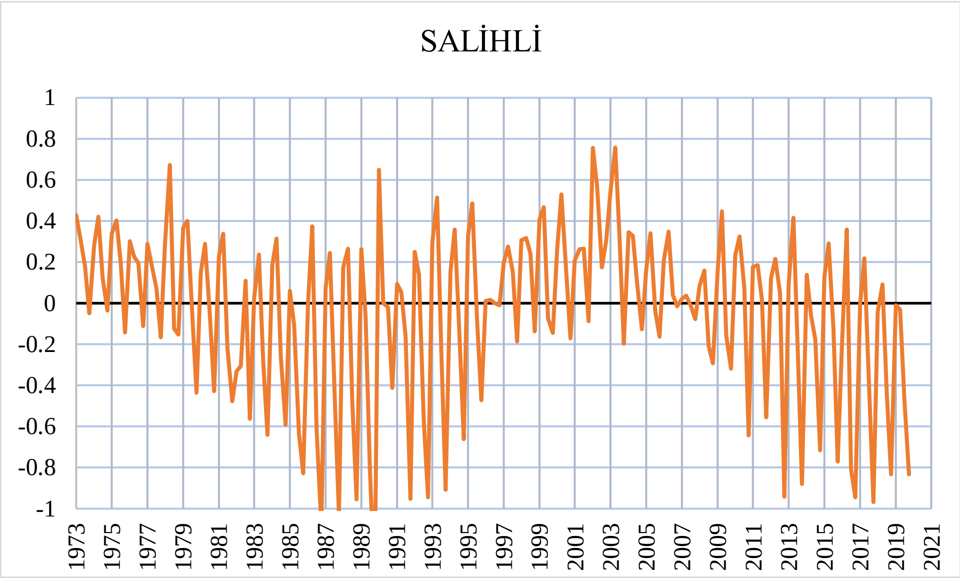

Figure C.1.9: Salihli DPI-3 Results

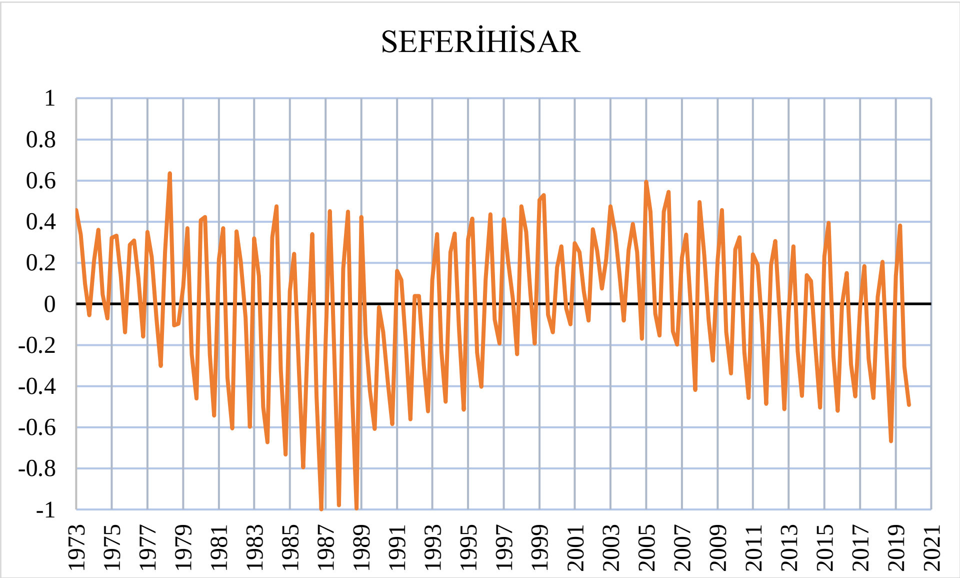

Figure C.1.10: Seferihisar DPI-3 Results

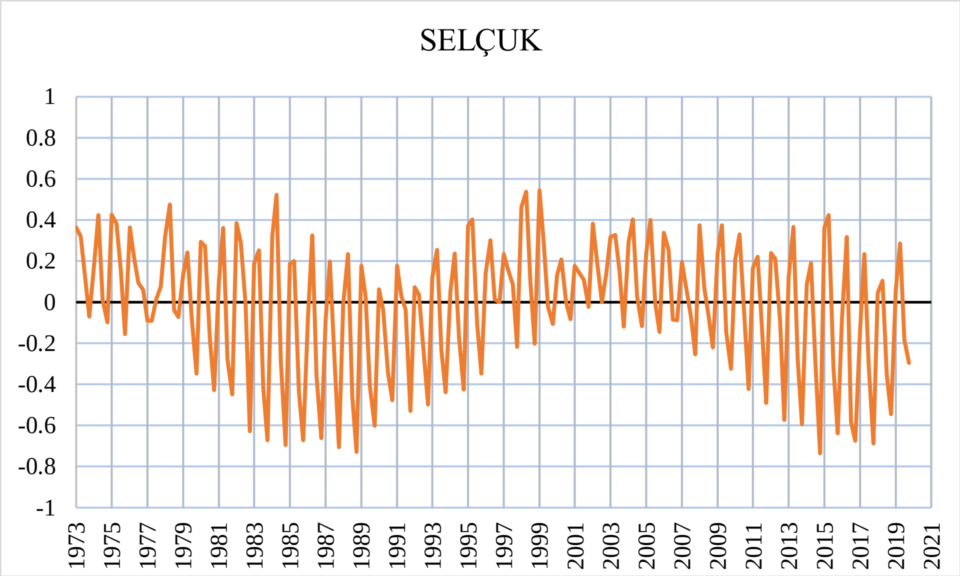

Figure C.1.11: Selçuk DPI-3 Results

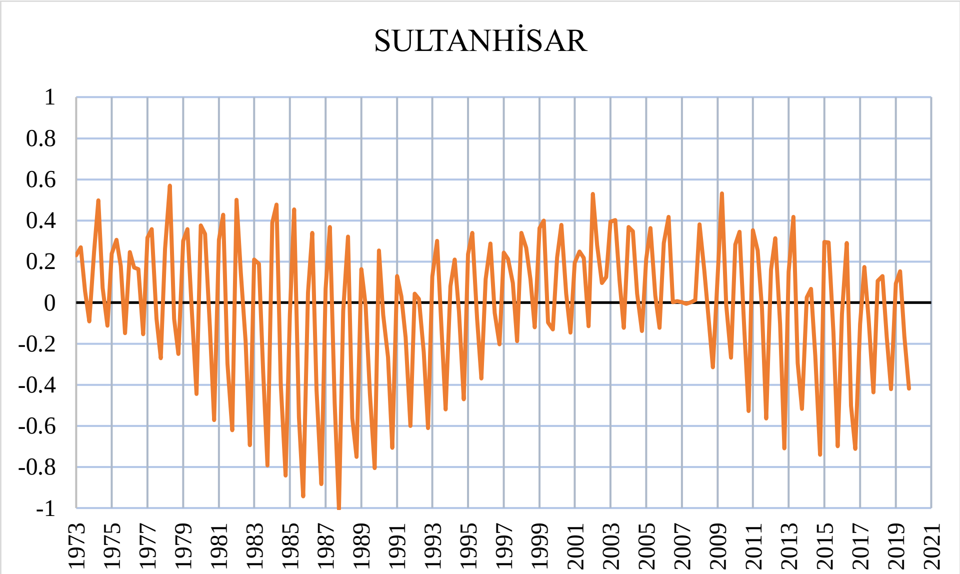

Figure C.1.12: Sultanhisar DPI-3 Results

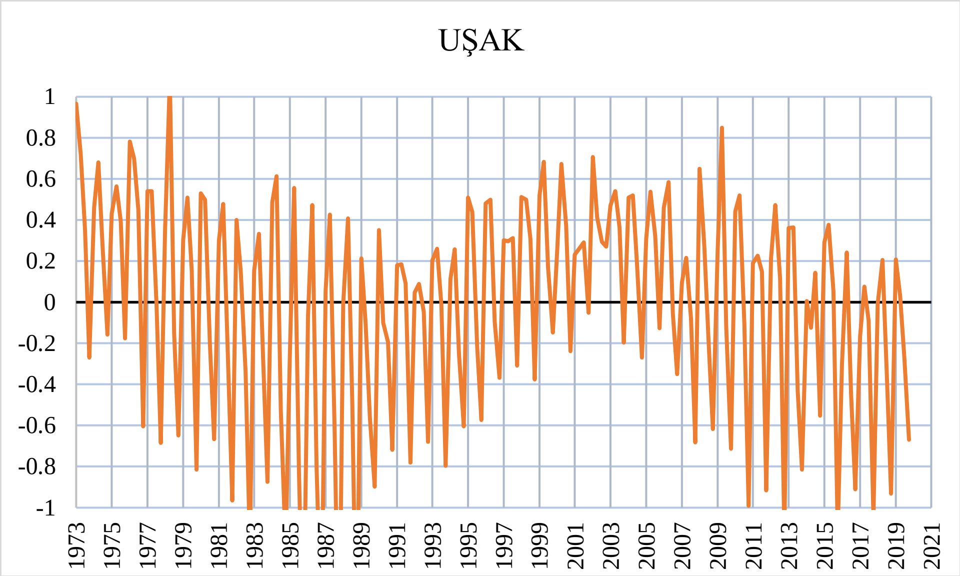

Figure C.1.13: Uşak DPI-3 Results

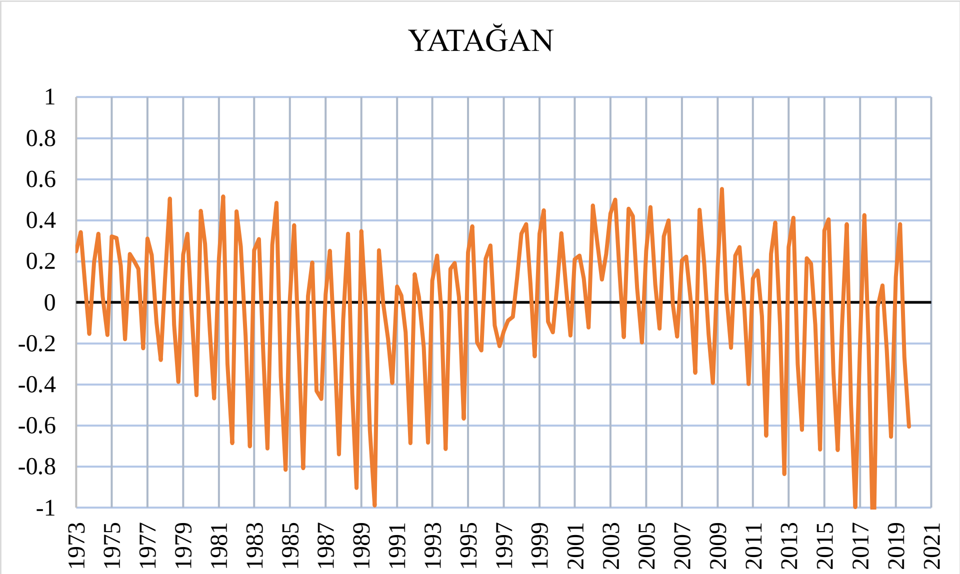

Figure C.1.14: Yatağan DPI-3 Results

C.2. DPI-12

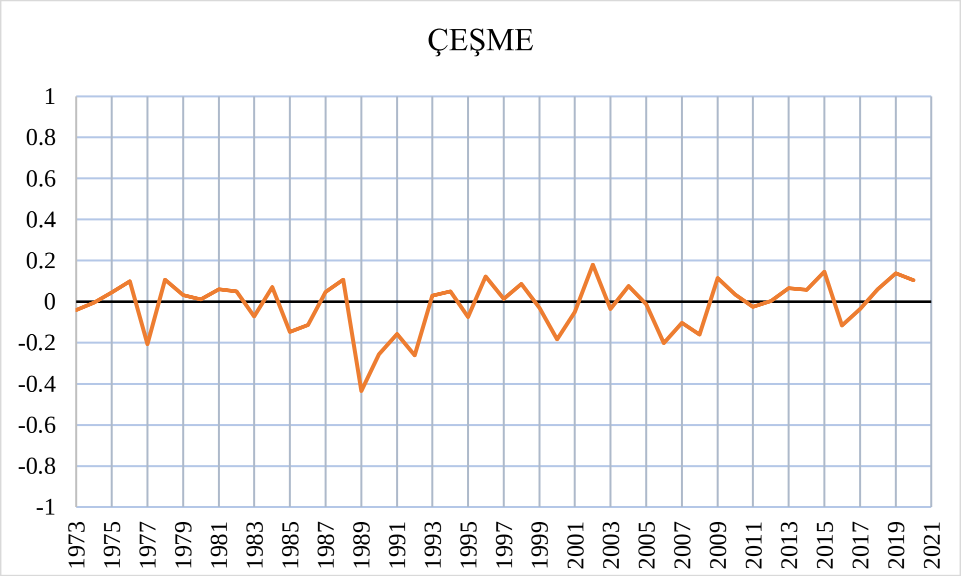

Figure C.2.1: Çeşme DPI-12 Results

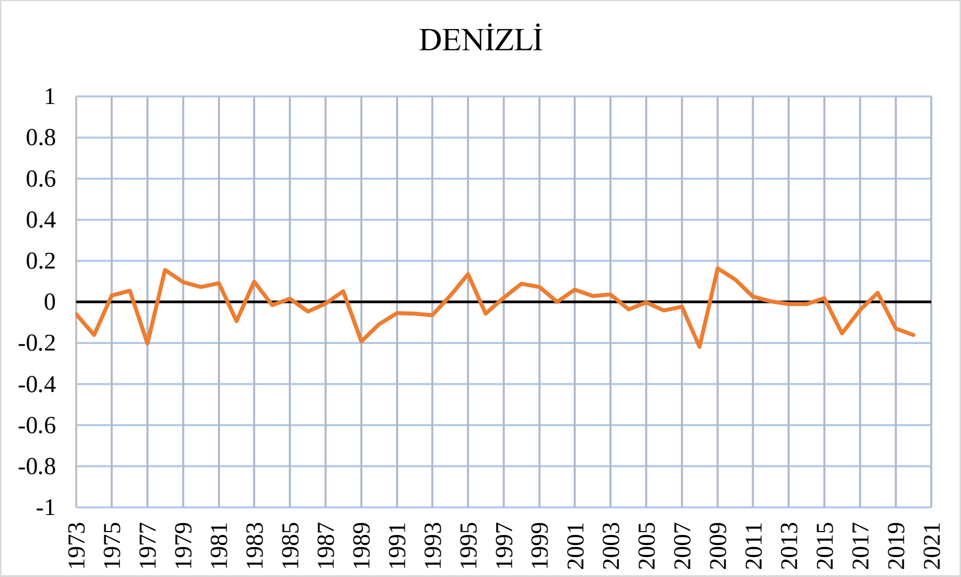

Figure C.2.2: Denizli DPI-12 Results

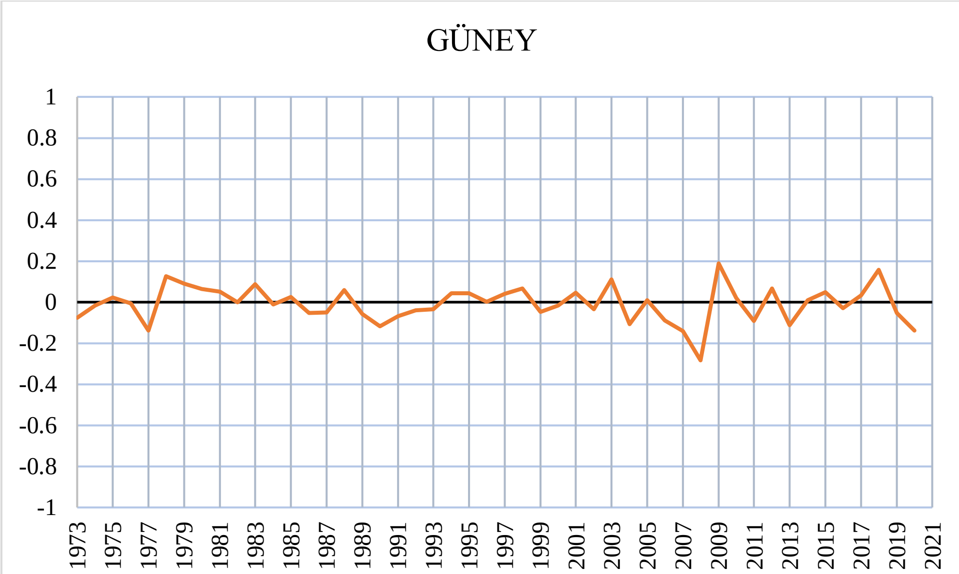

Figure C.2.3: Güney DPI-12 Results

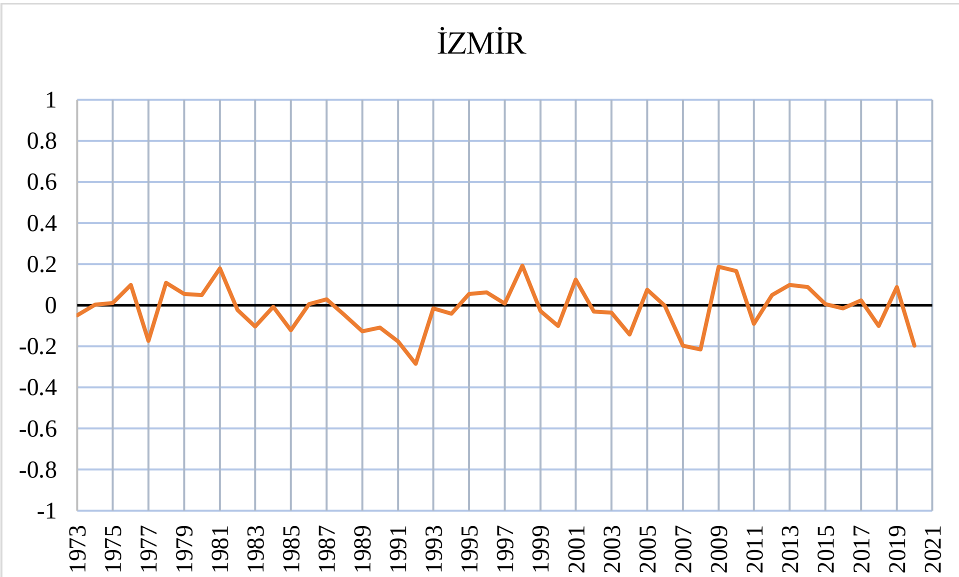

Figure C.2.4: Izmir DPI-12 Results

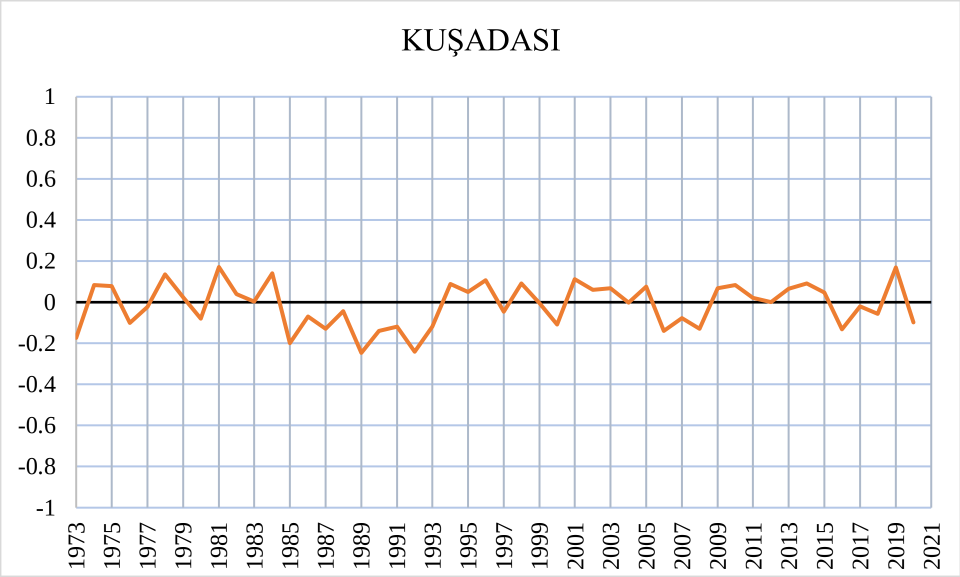

Figure C.2.5: Kuşadası DPI-12 Results

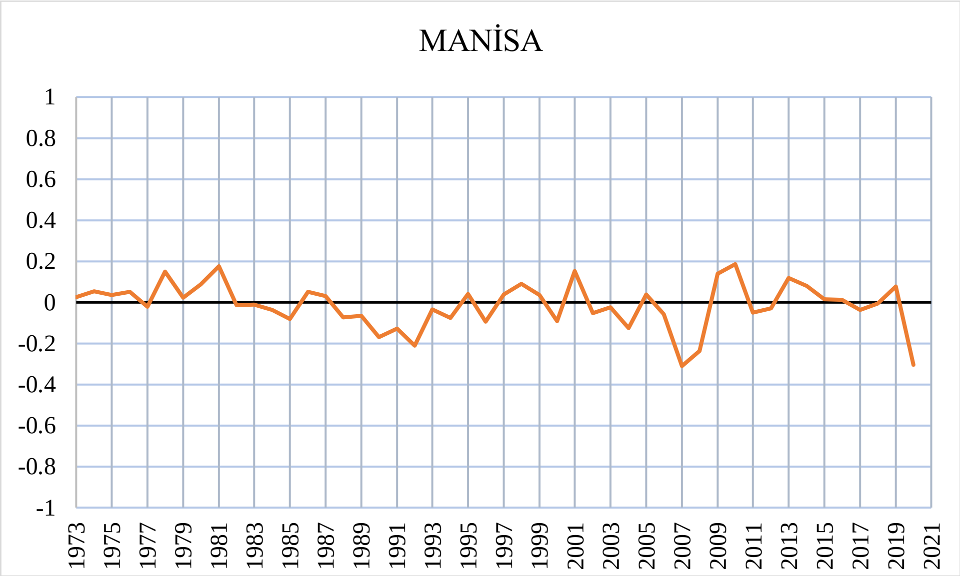

Figure C.2.6: Manisa DPI-12 Results

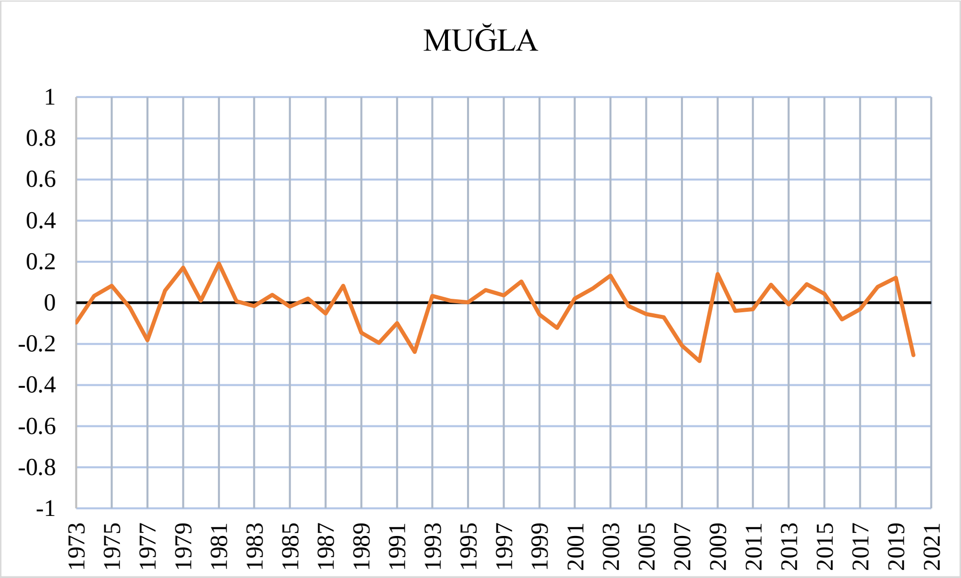

Figure C.2.7: Muğla DPI-12 Results

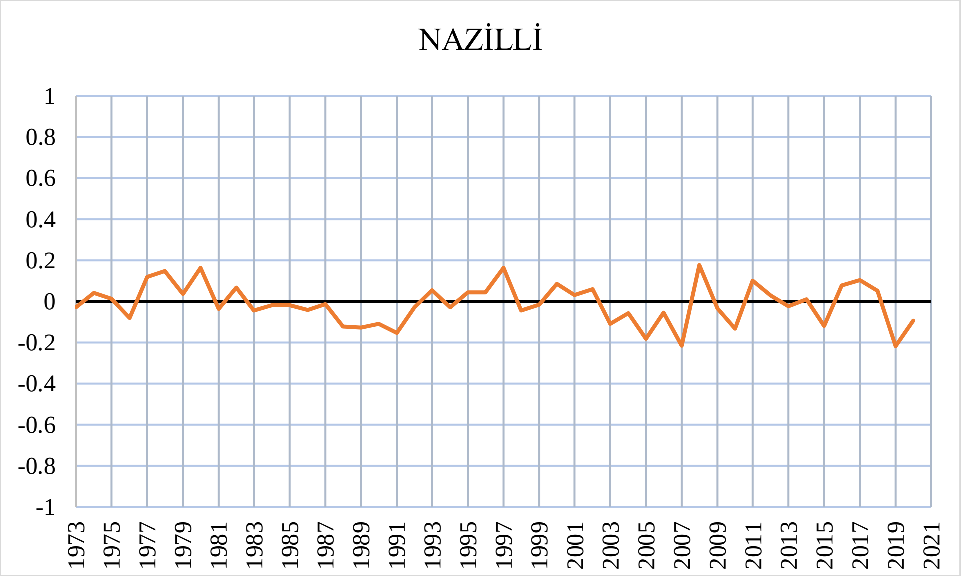

Figure C.2.8: Nazilli DPI-12 Results

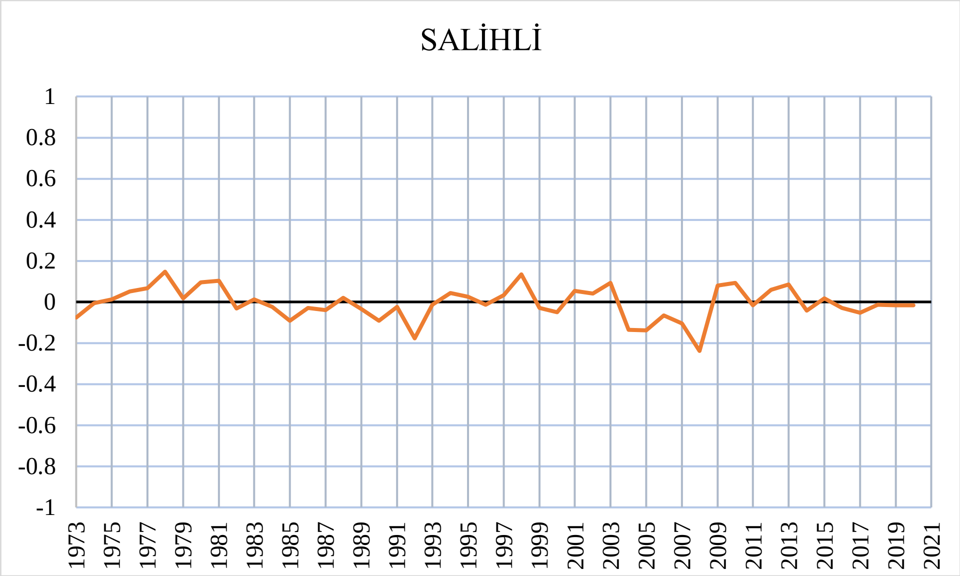

Figure C.2.9: Salihli DPI-12 Results

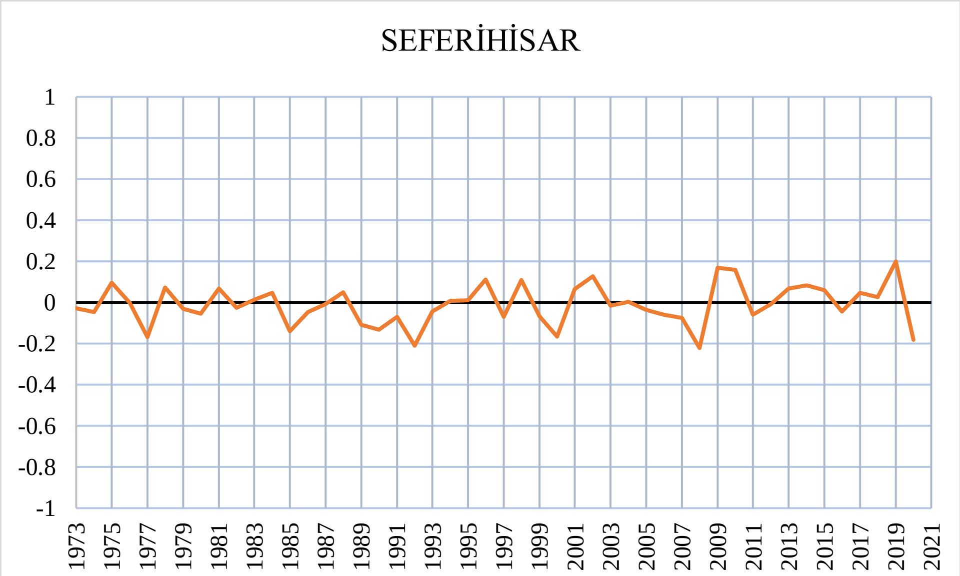

Figure C.2.10: Seferihisar DPI-12 Results

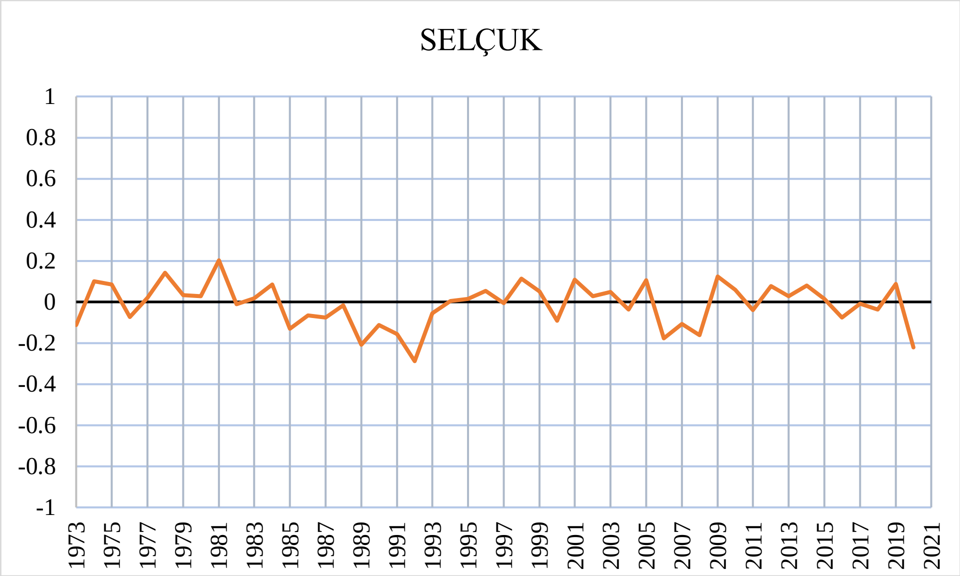

Figure C.2.11: Selçuk DPI-12 Results

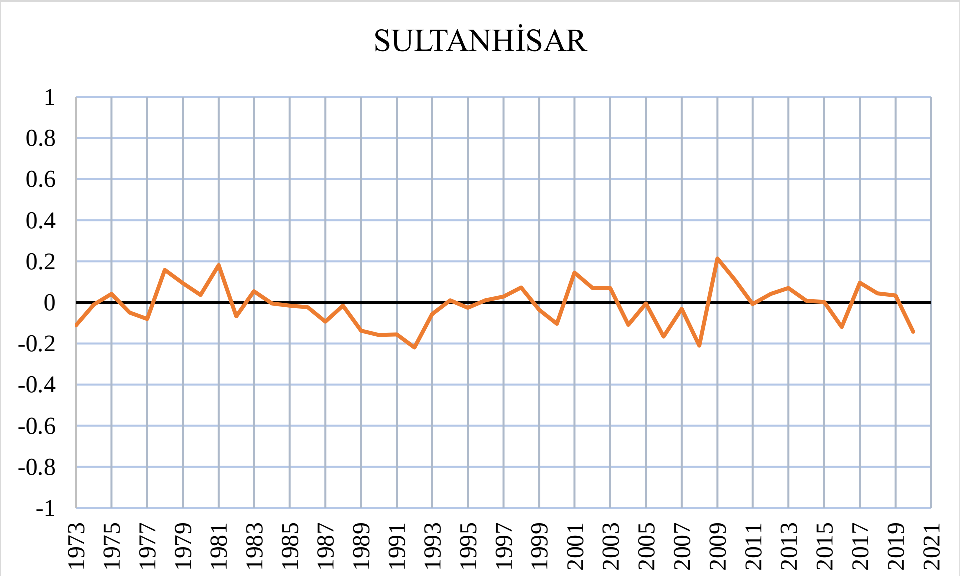

Figure C.2.12: Sultanhisar DPI-12 Results

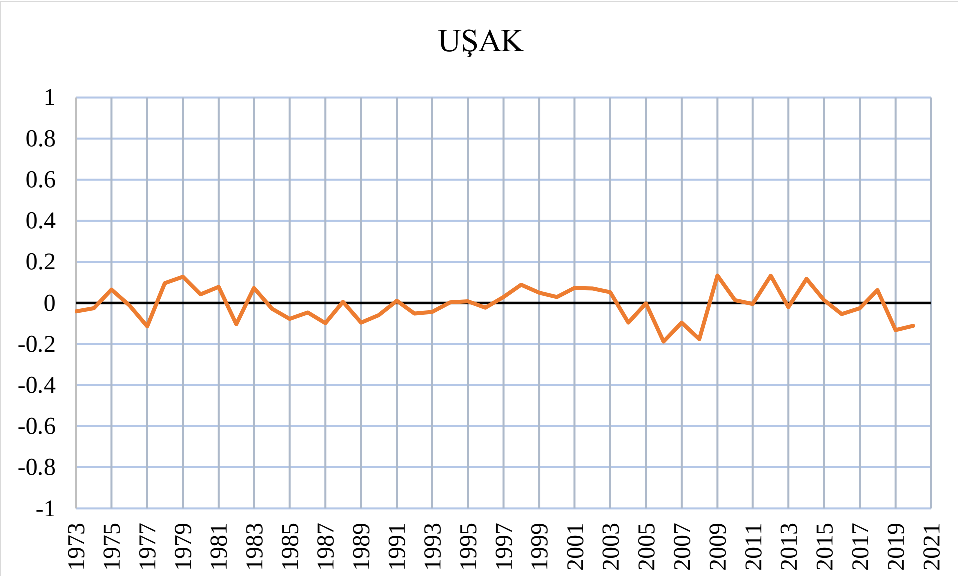

Figure C.2.13: Uşak DPI-12 Results

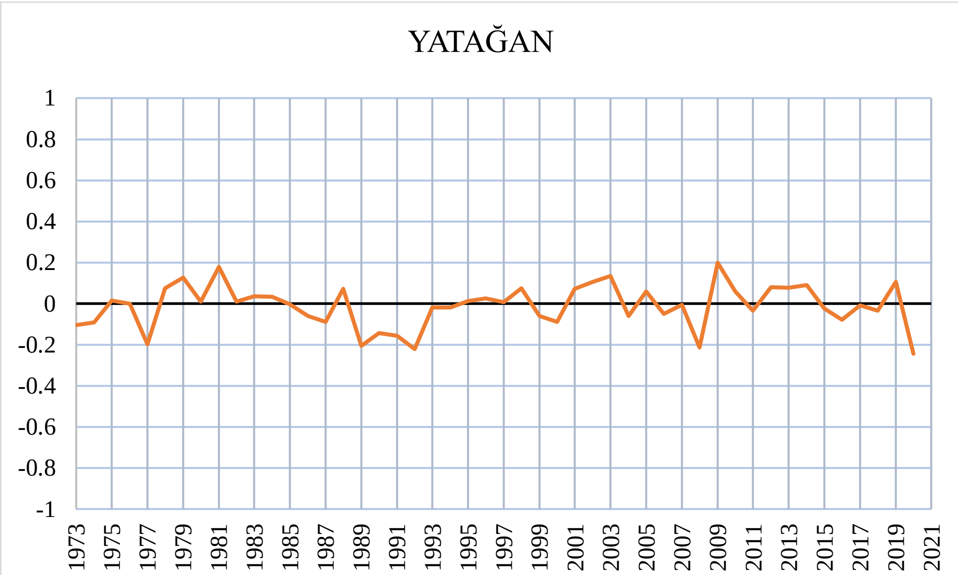

Figure C.2.14: Yatağan DPI-12 Results