



Research Article

Investigation of the usability of modified aSPI and eRDI indexes in Sanliurfa Province and determination of temperature and precipitation trends

Murat BATAN^{1,*}

¹Department of Civil Engineering, Batman University, Batman, 72060, Türkiye

ARTICLE INFO

Article history

Received: 06 August 2024

Revised: 03 October 2024

Accepted: 05 May 2025

Keywords:

Agricultural Drought; aSPI; eRDI; Mann-Kendall; Modified Methods; Sanliurfa Province; RDI; SPI; Trend Analysis

ABSTRACT

The frequency and intensity of drought events have increased due to the increasing impact of global warming for the last 20 years. Drought primarily affects agricultural activities, as approximately 70% of freshwater resources are used in agricultural production. Sanliurfa province, located in the Southeastern Anatolia Region and one of the regions struggling with drought, is known for its intense agricultural production. Therefore, it is important to take measures against drought in Sanliurfa province. The purpose of this research is to investigate the usability of aSPI (Agricultural Standardized Precipitation Index) and eRDI (Effective Reconnaissance Drought Index) methods, which are newly used in the literature and provide more sensitive results in agricultural drought analysis, in Sanliurfa province. In addition, the causes of droughts have been tried to be understood with research on the trends in temperature and precipitation data. Consequently, agricultural drought analyses were conducted with aSPI and eRDI modified methods. Drought analyses were also performed with SPI (Standardized Precipitation Index) and RDI (Reconnaissance Drought Index) methods and compared with modified methods. In this study, 31 years of precipitation and temperature data between 1993 and 2023 of Sanliurfa province were obtained from the Meteorology General Directorate (MGM). The analysis results based on aSPI and eRDI show similarities with the original SPI and RDI analysis results. However, the drought classes of some years were different. While 2017 was severely arid in the original methods, it was extremely arid in the modified methods. In addition, the years 2014, 2015 and 2023, which were mildly arid in most methods, were not mildly arid in some methods. In addition to the main purpose of the research, findings of the Mann-Kendall trend analysis, based on the 0.05 significance level, determined that the annual minimum and maximum temperatures are trending upward. For this reason, it was determined that rising temperatures are increasing drought. For this reason, it is necessary to take action to lower evaporation, especially in the summer months in Sanliurfa province. The use of aSPI and eRDI methods should be expanded in the investigation of agricultural drought.

Cite this article as: Batan M. Investigation of the usability of modified aSPI and eRDI indexes in Sanliurfa Province and determination of temperature and precipitation trends. Sigma J Eng Nat Sci 2026;44(3):1597–1618.

*Corresponding author.

*E-mail address: murat.batan@batman.edu.tr

This paper was recommended for publication in revised form by Editor-in-Chief Ahmet Selim Dalkilic



INTRODUCTION

The agriculture sector is most affected by drought and global warming because it is the sector that uses the most freshwater [1]. Therefore, in addition to combating these negativities, adaptation efforts must also be carried out. Recently, both academics and government officials have been making great efforts to cope with the effects of global warming, and countries are allocating large budgets for this [2-5]. These efforts include; switching from fossil fuels to renewable energy sources to reduce greenhouse gas emissions, switching to irrigation methods such as sprinkler and drip to save water and encouraging the cultivation of crops that consume less water, building underground dams to reduce evaporation, and conveying water through closed pipes. In addition, conducting drought analyses to take precautions against drought is also included in these efforts. [3,6-8].

Any disturbance in the agricultural sector or water resources jeopardizes the provision of basic requirements such as food and water, causing hunger and thirst. Therefore, it is critical that we give this issue more attention. Climate modeling and drought evaluations have been conducted often in recent years to avoid negative impacts on water acquisition, which is critical in the agriculture sector [3,9-12]. Drought can have devastating effects on the agricultural sector. Therefore, it is important to determine

the location, severity and frequency of drought [2,3,13]. Numerous drought studies conducted in recent years have revealed that the frequency and severity of droughts have increased in many regions [9,14,15].

Drought is defined as rainfall that is less than normal or below the long-term average in the literature [10, 16]. In addition, four types of drought are defined in the literature. These drought types are meteorological, hydrological, agricultural, and socioeconomic drought. Meteorological drought is defined as receiving less rainfall than usual for at least 30 years and is the initial stage of drought. Agricultural drought is described as the inability of plants to meet their needs due to low soil moisture levels. It arises as a result of diminishing water supplies. Agricultural drought is the second stage of drought and occurs after meteorological drought. Hydrological drought is characterized by the reduction of underground and surface water resources due to lack of rainfall and is the third stage of drought. It occurs following an agricultural drought. It can continue the effect of hydrological drought for many years. Socio-economic drought examines the effect of drought on socio-economic systems and thus on people’s socio-economic status and behavior [17-19].

The causes of four types of drought and their consequences are summarized in Figure 1. The diagram emphasizes that the main reasons for the onset of drought are lack

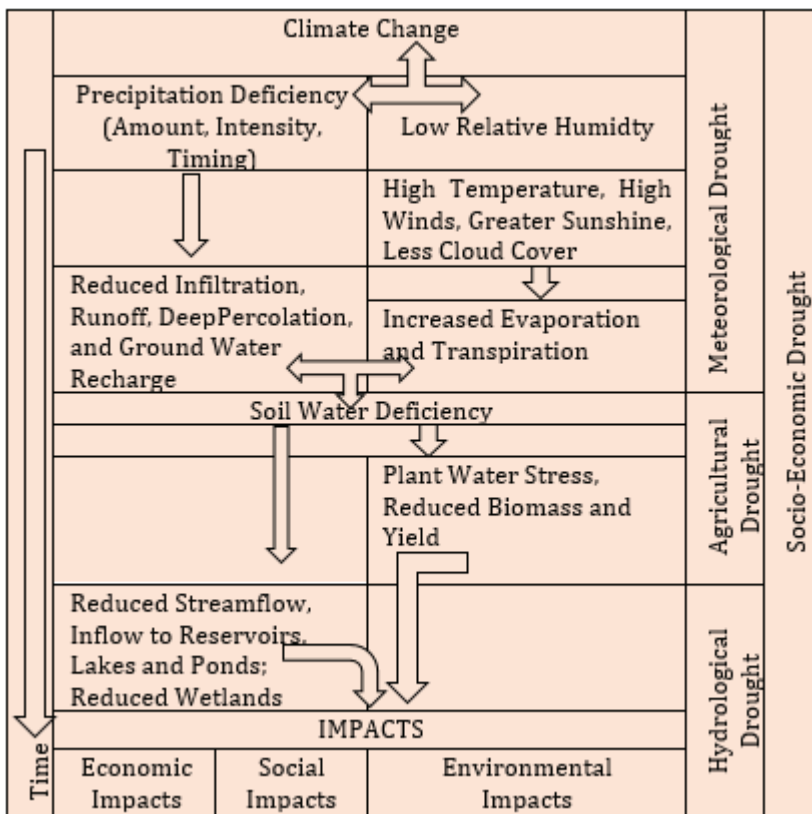


Figure 1. Diagram showing the timing, causes, and effects of four drought types [20,21] [created by author]

of rainfall and increased temperatures and that these effects negatively affect agricultural activities and living things [20,21].

The literature contains a wide variety of drought analysis techniques. Each method may obtain better results for different purposes or for different drought types in different regions. A method can be developed to overcome the shortcomings of another method, or a method can be improved by modification [22].

In literature, there are methods used for different drought indicators, such as the SPI, aSPI, RDI, eRDI, Percentage of Normal Index (PNI), Standardized Precipitation Evapotranspiration Index (SPEI), Aridity Index (AI), Streamflow Drought Index (SDI), Palmer Hydrological Drought Index (PHDI), Precipitation Deciles (PD), Normalized Difference Vegetation Index (NDVI), Erinç Drought Index (EDI), De Martonne-Gotmann Index (DMGI), Relative Soil Moisture (RSM), and Effective Drought Index (EDI), [3,21,23,24].

Some of these methods analyze the drought with only one data type. Some methods require many different data types for drought analysis [23,25]. Methods that require only one or two types of data are simple and practical. In addition, analysis can be performed in regions where sufficient data cannot be obtained with these methods [24]. Methods such as SPI, aSPI, PNI, DI, EDI, and SDI only analyze the drought with precipitation data. RDI, eRDI, DMGI, and AI methods require precipitation and temperature data for drought analysis. Methods such as PHDI, PMDI, and SPEI require more than two data types [13,21,23,26].

The SPI method is the most popular method in the literature and is a simple, useful method that can produce very good results. The RDI method, which has been widely used in scientific research for the last 15 years and has given good results, performs drought analyses using PET values and precipitation data. Meteorological and agricultural drought analyses can be performed with the SPI and the RDI methods [8,27,28]. In the literature, particular approaches have been created for the desired objectives, and new methods have been obtained [29]. For example, the DI method was created to solve the computational problems in the PNI approach [30]. Similarly, aSPI and eRDI methods were developed by using effective precipitation data instead of precipitation data in order to make more effective the SPI and RDI methods in agricultural drought analysis. The aSPI and the eRDI methods have been shown to give more accurate results in predicting agricultural droughts, especially in arid regions [12,29,31-33]. After the aSPI and eRDI methods emerged and their competence was proven, these methods can be used directly in agricultural drought analyses without any further research. In this way, the researcher saves time and labor. In addition, as seen in the results of this study, by determining drought classes more precisely, more accurate measures can be taken. This will also avoid economic loss.

The reason why aSPI and eRDI methods were used in this study in Türkiye is the idea that these methods can also give good results in Türkiye, especially since they give good results in a country under the influence of the Mediterranean climate such as Greece. For this reason, it would be beneficial to try these methods in a province of Turkey where agricultural activities are intensive. Sanliurfa province, which is affected by drought and where crops with high water consumption such as cotton, pistachios and corn are grown, was suitable for applying these methods. In addition, the agricultural sector in Şanlıurfa province is very dependent on irrigation due to drought and high evaporation. Although large dams were built to meet the irrigation needs, this was not enough. Irrigation problems are experienced especially in the summer months. For this reason, it has become necessary to take some precautions.

In this study, drought analyses with SPI, aSPI, RDI, and eRDI methods were performed for Sanliurfa province. The DrinC (Drought index Calculator) program was used for the analyses. The results obtained from the methods used in the study were compared. The objective of this study is to ascertain more sensitive the agricultural drought situation of Sanliurfa province. It was tried to determine whether the aSPI and eRDI methods, which are newly used in the literature can be used in determining agricultural drought in Şanlıurfa province. In addition, long-term temperature and precipitation trends were investigated using the Mann-Kendall trend analysis method to determine the causes of drought in Sanliurfa province. All results were visualized with graphics.

When the studies in the literature are examined, it has been determined that aSPI and eRDI have not yet been used in Turkey. For this reason, this study is important in terms of showing the applicability of this modified methods in the drought-affected Sanliurfa province. This study conducted for Şanlıurfa province aims to eliminate this deficiency in the literature.

Literature Review

In the above paragraph, it was stated that the use of aSPI and eRDI methods in the literature is limited, although they give good results. For this reason, drought analysis studies with these methods should be carried out as soon as possible, especially in regions or provinces where agricultural activities were intensively carried out in Turkey. In the limited number of studies in the literature, traditional methods and modified methods were generally compared. In some studies, drought analyses were conducted with traditional methods to determine the drought status of a region. These studies are given below.

In a study conducted with the SPI method, monthly and annual drought analyses were conducted at Siirt, Gaziantep, and Siverek stations in the Southeastern Anatolia Region of Turkey. According to the annual analysis results, although there were differences between stations, it was determined that severe drought occurred between 12% and 20% [34].

In another study conducted for the Southeastern Anatolia Region in Turkey, drought analyses were conducted for 18 stations using SPI and RDI methods. The results of the two methods were similar. According to the annual SPI analysis results, the driest station was Gölbaşı station with 55.5%, while according to the annual RDI analysis results, Kilis station was determined as the driest station with 53.5% [35]. In the drought analysis study conducted for Batman and Diyarbakır provinces, which are two provinces located in the Southeastern Anatolia Region, meteorological and hydrological drought analyzes were conducted for the period 1990-2020 with four different indexes including the SPI and the RDI. The analysis results showed that both provinces were affected by drought during the analyzed period [36].

As in this study, in a study conducted with the SPI method for the Sanliurfa province, data from 5 stations in Sanliurfa were used, and drought analyses were made for 2 different periods (1975-1997 and 1997-2019). According to the annual analysis results at all stations, there were increases in the severity, frequency, and duration of droughts in the second period compared to the first period [37].

In another study conducted for the Sanliurfa province, drought analyses were conducted using 78 years of precipitation data covering the period 1937-2014 for different time scales using the SPI method. According to the analysis results, it was determined that the number of dry months in the 1986-2014 period was higher than the number of dry months in the 1937-1985 period [38]. When the studies conducted in Turkey are examined, it has been determined that some studies have been conducted with original methods, and drought analysis studies have not been conducted with modified aSPI and eRDI methods. Therefore, it is necessary and important to conduct drought analysis studies with modified methods in Turkey.

Drought assessments were carried out using SPI and RDI methods on 43 years of temperature and precipitation data from the Banas River basin in India. According to the findings of both techniques, drought has grown in several areas in recent years. As a result, it was determined that temperature and precipitation variations have an impact on agricultural indicators [14].

Another study that used SPI and RDI methods was carried out in Ghana's Tano River basin. Drought analyses were performed with the DrinC program on various time scales. The results of the two methods were compared with regression analysis. Based on the findings, the correlation values for time periods of 1, 6, and 12 months were obtained as 0.98, 0.97, and 0.88, respectively. In other words, it was determined that there was a higher correlation between the two methods at shorter time periods [19].

In some drought analysis studies, future drought conditions have been estimated according to future climate scenarios [11]. In one of these studies, drought analyses were conducted with the DrinC program using historical data and future data estimated with the RCP4.5 scenario with

SPI, RDI, and SDI methods. According to the results, while severe and extreme droughts occurred once every 2 years in the past, it was determined that this occurrence frequency will be 5 years in the future [13].

In another a study on estimating future drought conditions, future drought conditions were determined using CMIP5 (Coupled Model Intercomparison Project Phase 5) climate data in the Tana Lake basin in Ethiopia with SPI, RDI, and SDI methods based on scenarios from RCP4.5 and RCP8.5. It was determined that droughts in the future periods will be seen every 2 years according to SPI and RDI methods. Although there are different percentages on various time periods, it was determined that the drought percentage in the future will increase between 17.24% and 20.69% [27].

When the studies on aSPI and eRDI indexes used to determine agricultural drought in the literature are examined, the first studies are on the comparison of modified aSPI and eRDI methods with the original SPI and RDI methods. One of these studies was conducted with RDI and eRDI methods in agricultural areas of Greece with Mediterranean climatic conditions. The connection between drought analysis findings and crop yields for the analyzed period was tried to be understood by determining the correlation coefficients. Based on the findings of the analysis, it was concluded that the eRDI method gave better results than original the RDI method [31].

In another a study conducted for Greece, drought analyses were conducted for four regions of Greece using aSPI and SPI methods. Drought analysis results were compared with annual crop yields and annual crop loss rates. In these comparisons, aSPI results were determined to have a higher correlation than SPI results [32].

In an investigation carried out in the central plateau basin of Iran, drought analyses were conducted using aSPI, eRDI, aSPEI, and TWSDI (Terrestrial Water Storage Deficit Index) methods. Based on the findings of the analysis, it was determined that the findings of the eRDI and aSPI approaches were compatible with a high correlation [39].

In a study conducted in Saudi Arabia, drought analyses were conducted with 6 drought indices, including aSPI and eRDI methods, in its region where 70% of Arabia is known to be affected by drought. With the analyses, dry years and the longest dry period were determined for the period 1985–2020 [40]. In a study conducted for the Balochistan region in Pakistan, drought analyses were conducted for the period 1992-2021 with SPI, SPEI, and aSPI methods. It has been determined that many cities in the Balochistan region have severe and extreme drought years [41]. In a drought analysis study conducted for Sindh region, another region of Pakistan with a significant history of drought, monthly precipitation data between 1961-2004 were used to conduct drought research for different time periods with the SPI index. The analysis results showed that clearer results were obtained for longer time scales of 24 and 48 months. Sindh

region was affected by drought in the early 1960s and late 1970s [42]

In an investigation carried out in Greece on the integration of aSPI and eRDI methods into the DrinC program, it was determined that aSPI and eRDI methods can be used to determine agricultural drought [33]. Again, in a study conducted in Greece, winter wheat yield values were compared with eRDI and RDI drought indices in different periods. It was determined that the eRDI method gave better results over all time periods [24].

In another study comparing yield values with drought indices, yield values of rainfed maize plants in the Sinaloa region of Mexico were compared with indice values of SPI, aSPI, RDI, and eRDI methods using Pearson and Spearman correlation methods. It was determined that modified methods gave better results [43].

Drought analyses were conducted for the period 1982-2018 with aSPI and SVSWI (Standardized Vegetation Supply Water Index) in 4 regions of China. Drought analysis results were compared with the yield values of winter wheat and summer corn crops during this period by the Pearson correlation method. The analysis's findings demonstrated that extreme drought events increased after 2000. This had an impact on the winter wheat growing period of December-May [44].

In some studies, the usability of the aSPI and eRDI methods has been investigated by using tree ring data instead of yield values. In comparisons performed to understand the influence of drought on the development of the Black Pine tree growing in the Mediterranean area, it was determined that the indice values of the aSPI and eRDI methods showed a higher correlation with the ring data [45].

Some studies have also investigated the usability of modified methods in humid and arid areas. In one of these studies, drought analyses were conducted with eRDI and RDI methods at 22 synoptic stations in Iran. Considering the analysis's conclusions, it was concluded that the results of the RDI method and eRDI method were very similar in humid regions, but the eRDI method gave better results in stations with arid and extremely arid conditions [46].

There are other modified methods developed in the literature as an alternative to SPI and RDI methods. One of these methods is the $_{mn}$ SPI modified method. This method employed time-varying parameters to assess the potential threat of drought events. In an investigation carried out in the Jinsha River Basin, it was found that the $_{mn}$ SPI method gave better results [29].

MATERIALS AND METHODS

Information About the Study Area

Sanliurfa is located in the southeast of Turkey, between $37^{\circ} 49' - 40^{\circ} 10'$ east longitude and $36^{\circ} 41' - 37^{\circ} 57'$ north latitude [47]. Sanliurfa province is the 7th largest province in Turkey, with a total area of 18765 km^2 [48]. Sanliurfa has a continental climate with quite hot and dry summers and cold winters [45]. There is a temperature difference, especially between day and night. Since it is far from the sea, the humidity is low compared to the coastal areas. It is shown among the hottest provinces of Türkiye [47]. As seen in Figure 2, Sanliurfa province has 10 districts [49].

The average annual temperature of Sanliurfa province is 18.4°C , and the average precipitation height is 463.6 mm . The annual maximum temperature in the period 1929-2019 is 46.8°C [50]. Figure 3 displays the monthly average



Figure 2. Sanliurfa province and its districts [49] [created by author].

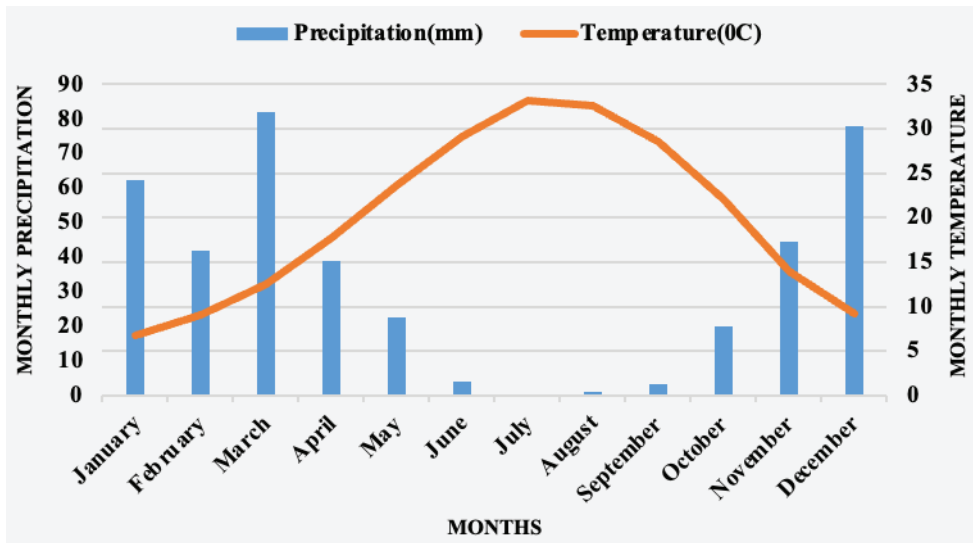


Figure 3. Average of monthly precipitation and temperature data of Sanliurfa province for the period 2014–2023 (Source: Author).

temperature and total precipitation statistics for Sanliurfa during the last decade (2014–2023).

Sanliurfa has a high level of agricultural activity. The agricultural area in the province corresponds to approximately 5% of the total agricultural area of Turkey and 36% of the agricultural area of the GAP region. Sanliurfa province's agricultural area of approximately 12,200,000 decares constitutes 59.3% of its total land area. Sanliurfa's agricultural area is the third largest in Turkey, after Konya and Ankara [51,52]. For this reason, agriculture has an important place in the economy of Sanliurfa. The production of crops such as cotton, red pepper, pistachio and corn in Sanliurfa province has an important share in Turkey's production. The shares of these crops in Turkey's production are 41.95%, 38.76%, 34% and 11.82%, respectively [53]. Most of these crops have high water consumption and high economic value. On the other hand, water losses are high in Sanliurfa province. In periods when summer rainfall is insufficient, irrigation is inevitable to prevent a decrease in crop yield.

Data Utilized in the Research

In this investigation, SPI, aSPI, RDI, and eRDI methods were used for drought analyses in Sanliurfa province. Drought study requires at least 30 years of data. For this reason, drought analysis was based on 31 years of monthly total precipitation, monthly maximum temperature, and monthly minimum temperature data obtained from the MGM from 1993 to 2023. The data and methods used are described in Table 1 below. Annual maximum and minimum temperature values, annual average temperature

values, and annual average total precipitation values were used as trend analysis data.

There is no deficiency in temperature data from the data used. In the precipitation data, it was seen that in some months the precipitation was zero, that is, there was no precipitation. When these months were examined, it was seen that there was generally no precipitation in the summer months, so this was thought to be normal. In a drought-affected province like Sanliurfa, it is normal to be no precipitation in the summer months. If there was a lack of data due to a measurement deficiency in other months, these missing data could be completed by taking the arithmetic average of the data of the three neighboring provinces in those months. Neighboring provinces are adjacent to Şanlıurfa province and have similar climate characteristics. Therefore, it is not thought that spatial change problems will be very effective in completing the missing data. In addition, the arithmetic method used in completing the missing data is a widely used method in the literature. Since PET data are calculated using temperature and precipitation data in the DrinC program, there is no missing data in the PET data. Of course, there may also be a possibility of measurement error in the data used. However, MGM has been making meteorological measurements with automatic precision devices for the last 15–20 years. This minimizes measurement errors.

When conducting drought analyses with the DrinC program, long-term data should be arranged according to the hydrological year. For this reason, in all methods, the data were organized so that the data began in October, which is the first month of the hydrological year, and concluded in September, which is the last month [54].

Table 1. Methods used in drought analysis, data types used, periods analyzed, and drought types determined by the methods

Method	Data type used	Period	Drought type
SPI	Monthly total precipitation data	1993-2023	Meteorological and Agricultural
RDI	Monthly total precipitation data and monthly minimum and maximum temperature data for PET calculation	1993-2023	Meteorological and Agricultural
AI _{UNEP}	Total annual precipitation and total annual evapotranspiration	1993-2023	Meteorological and Agricultural
aSPI	Monthly total effective precipitation data	1993-2023	Agricultural
eRDI	Monthly total effective precipitation data and monthly minimum and maximum temperature data for PET calculation	1993-2023	Agricultural

METHODS USED IN ANALYSIS

Standardized Precipitation Index (SPI)

The SPI method created by McKee, Doesken, and Kleist in 1993 is among the most widely used methods [37]. Its use has become very widespread due to its simple structure, low data requirement, and good results. It is used in the assessment of meteorological and agricultural drought.

In the SPI method, the gamma density function is applied to the total monthly precipitation data. As seen in Equation (1), SPI index values are found by deducted the long-term precipitation averages from the total monthly precipitation data and dividing by the standard deviation [38]. There is no drought if the SPI indices are positive; on the other hand, a drought exists if they are negative. In the classification table given in Table 4, drought categories are given according to the indice values.

$$SPI = \frac{X_{ij} - X_{im}}{\sigma} \quad (1)$$

In the formula, X_{ij} is the monthly total precipitation at the j_{th} observation at the i_{th} precipitation station, X_{im} is the long-term average precipitation, and σ represents the standard deviation.

United Nations Environment Programme Aridity Index (UNEP-AI)

This index was applied to select the method using for calculating the effective rainfall data to be used in the modified aSPI and eRDI methods. In the analysis made with

Table 2. UNEP aridity index drought classes [55] [created by author]

UNEP Aridity Index	
AI _{UNEP} < 0.05	Hyper-arid
0,05 ≤ AI _{UNEP} < 0.20	Arid
0,2 ≤ AI _{UNEP} < 0.5	Semi-arid
0,5 ≤ AI _{UNEP} < 0.65	Dry sub-humid
AI _{UNEP} ≥ 0.65	Humid

this method, Sanliurfa province was found to be semi-arid with an aridity index value of 0.22. The UNEP aridity index value (AI_{UNEP}) is calculated as given in Equation (2) [55]:

$$AI_{UNEP} = \frac{P}{PET} \quad (2)$$

P represents the annual total precipitation (mm), and PET represents annual total potential evapotranspiration (mm). Drought categories of the UNEP aridity index are given in five classes in Table 2.

Agricultural Standardized Precipitation Index (aSPI)

A modified version of the SPI method is called as the aSPI method and is accepted to be a more effective method for determining agricultural drought [32,33]. It is clear from the investigations in the literature that the aSPI method is more suitable for use in regions where drought is effective, data acquisition is limited, and comprehensive drought indexes cannot be used [32,39,44].

In the aSPI method, effective precipitation (Pe), which is the amount of precipitation utilized by plants, is used instead of the monthly total precipitation. Pe is characterized as the proportion of precipitation entering the plant root zone. There are four different methods to calculate Pe in the literature. These methods are the USBR (United States Bureau of Reclamation) method, which is an empirical method, the USDA-SCS (United State Department of Agriculture-Soil Conservation Services) method, the shortened form of the USDA-SCS method and the empirical method proposed by FAO (Food and Agriculture Organization). Among these methods, USBR and USDA-SCS methods are suitable for use in semi arid and arid areas [31,43]. Therefore, firstly the drought situation of Sanliurfa province was determined with the UNEP aridity index. According to the results of this analysis, Sanliurfa province was found to be semi-arid with a indice value of 0.22. For this reason, the USBR method, an empirical method that gives more good results from USDA-SCS method in semi-arid and arid areas, was chosen for calculating Pe [32,56]. In the USBR method, total precipitation (P), actual evapotranspiration (ET_c), and soil water storage factor (SF) are used in the calculations as shown in Equation (3) and Equation (4), [32].

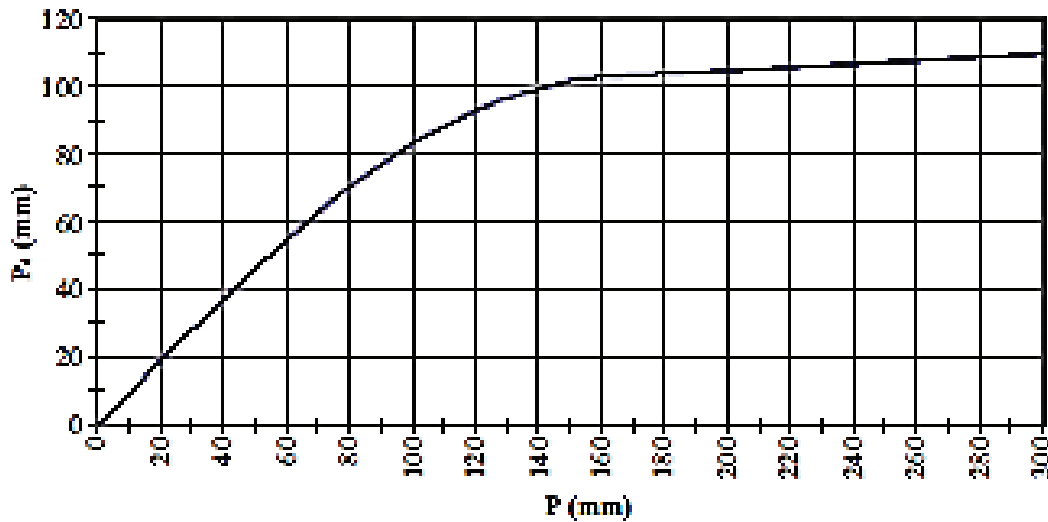


Figure 4. Change with monthly effective precipitation (P_e) of monthly total precipitation (P) according to the USBR method [31] [created by author]

Table 3. Percentages corresponding to monthly precipitation to estimate effective precipitation according to the USBR method [45] [created by author]

Monthly precipitation (mm)	Effective precipitation (mm) (percentage of montly precipitation)
0.0-25.4	90%-100%
25.4-50.8	85%- 95%
50.8-76.2	75%-90%
76.2-101.6	50%-80%
101.6-127.0	30%-60%
127.0-152.4	10%-40%
>152.4	0%-10%

$$P_e = 25.4 \times SF \times (0.04931 \times P^{0.82416} - 0.11565) \times 10^{0.000955 \times ET_c} \quad (3)$$

$$SF = 0.531747 + 0.011621 \times D - 8.943 \times 10^{-5} \times D^2 \quad (4)$$

Here, D represents the usable soil water storage. It makes up 40%-60% of the available soil moisture in the plant root zone. The unit of the parameters in the equation is mm. Figure 4 shows the variation of P and P_e based on the USBR technique.

According to the USBR method, Table 3 shows the determination of effective precipitation with percentages determined according to the amount of monthly total precipitation values.

Reconnaissance Drought Index (RDI)

Tsakiris and Vangelis developed the RDI method for observing the meteorological and agricultural drought.

[58]. The RDI method is frequently applied in semiarid and arid areas. The basic data required for the calculation of RDI are monthly total precipitation (P) and potential evapotranspiration (PET). PET is defined as the maximum amount of water lost through evaporation and transpiration when water is sufficient. For the PET computation, maximum, minimum, average temperature, and amount of space radiation data are used as shown in Equation (8).

To find the RDI indice values, after calculating the initial value α_k^i , RDI_{nor} (normalized) and RDI_{std} (standardized) values are calculated [58,59]. The equations used to calculate the α_k^i , RDI_{nor} and RDI_{std} are given with Equation (5), Equation (6), and Equation (7).

$$\alpha_k^i = \frac{\sum_{j=1}^k P_{ij}}{\sum_{j=1}^k PET_{ij}}, \quad i = 1, 2, \dots, N, \quad j = 1, 2, \dots, k \quad (5)$$

Here, P_{ij} represents total precipitation for the j_{th} month of the i_{th} year, PET_{ij} is the PET value of the same period.

The hydrological year between October and September serves as the basis for the analysis (k=1 for October, k=12 for September), and N is the total number of years.

$$RDI_{nor} = \frac{\alpha_k^i}{\mu_k} - 1 \tag{6}$$

Here, μ_k is the arithmetic mean of a_k values.

$$RDI_{std} = \frac{y_k^i - \mu_k}{\sigma} - 1 \tag{7}$$

Where, y_k^i is the natural logarithm of a_k , $\ln(a_k(i))$, μ_k is the arithmetic mean of a_k , σ is the standard deviation of a_k .

PET values used to calculate RDI indice values can be calculated by four methods. These methods are the Hargreaves, Thornthwaite, Blaney-Criddle, and Penman-Monteith methods [22]. Among these methods, the Thornthwaite method, which uses the average temperature in analyses, is frequently used. However, when the temperature is zero or lower, the PET value is zero and the findings may be incorrect. In this research, the Hargreaves-Samani method was employed for PET calculation since there are temperature values of zero and lower. PET values were calculated using Equation (8) with the Hargreaves-Samani method [57-60].

$$PET = 0.0023 * 0.408 * Ra(T_{ort} + 17.8) * (T_{max} - T_{min})^{0.5} \tag{8}$$

Here, PET is the calculated potential evapotranspiration (mm); the 0.408 is the coefficient used to convert to equivalent evaporation in mm/day the radiation expressed in MJ/m²/day. Ra is the amount of space radiation (MJ/m²/day); T_{ort} is the monthly mean temperature (°C); T_{max} is the monthly maximum temperature (°C); T_{min} is the monthly minimum temperature (°C).

Effective Reconnaissance Drought Index (eRDI)

In order to determine more accurately the agricultural drought, the eRDI technique is a modified form of the RDI method that takes into consideration parameters related to evapotranspiration and precipitation. In the eRDI method, the total effective precipitation parameter is taken into account instead of total precipitation as in the aSPI method. This method retains the simple structure and low data requirement as in the original RDI method [31,33].

To find the eRDI indice values in the this method, the initial value (α_{ek}^i) is calculated with Equation(9) [24].

$$\alpha_{ek}^i = \frac{\sum_{j=1}^k P_{ej}}{\sum_{j=1}^k PET_{ij}}, \quad i = 1,2, \dots, N, \quad j = 1,2, \dots, k \tag{9}$$

Where P_{ej} is the effective precipitation of j_{th} month, PET_{ij} is the potential evapotranspiration of j_{th} month.

In the eRDI method, $eRDI_{nor}$ and $eRDI_{std}$ are calculated with the same equations as in the original RDI method. Only α_{ek}^i has to be written instead of α_k^i . Therefore, these equations were not given here again [31].

Table 4. Common drought classification table used for SPI, aSPI, RDI, and eRDI methods

Index value	Category
≥ 2.00	Extremely wet
1.5 to 1.99	Severely wet
1.0 to 1.49	Moderately wet
0.0 to 0.99	Mildly wet
0.0 to -0.99	Mildly drought
-1.00 to -1.49	Moderately drought
-1.50 to -1.99	Severely drought
≤ -2.00	Extremely drought

Although there are similar and separate drought classification tables for each method in the literature for the methods used in this study, many studies have used the same classification table for the SPI, aSPI, RDI, and eRDI methods. In this research, the common classification table presented for the four methods in Table 4 was used to evaluate the results of the analyses [43,45,61].

Mann-Kendall Trend Analysis Method

The Mann-Kendal method can be applied to find the magnitude and direction of a link between variables, without considering whether they are dependent or independent [61,63]. This method, which allows to missing data, also does not require conformity to a specific data distribution. The pairs X_i, X_j in the time series X_1, X_2, X_n are split into two groups. P represents the number of pairs $X_i < X_j$ for $i < j$ and M represents the number of pairs $X_i > X_j$ for $i > j$, Equation (10) is used to calculate the Mann-Kendall Method statistic (S), [64,65]:

$$S = P - M \tag{10}$$

After the S value is found, the Kendall correlation coefficient (τ) is calculated by Equation (11):

$$\tau = \frac{S}{[N(N - 1)/2]} \tag{11}$$

Where, N is the total number of data. For $N \geq 10$, the standard deviation (σ_s) of S is calculated by Equation (12).

$$\sigma_s = \sqrt{[N(N - 1)(2N + 5)/18]} \tag{12}$$

The Z test statistic value with a standard normal distribution is found by Equation (13). The null hypothesis is agreed upon and it is determined that there is no trend in the studied data if the absolute value of the calculated Z is smaller than the $Z_{\alpha/2}$ value of the normal distribution corresponding to the selected significance level α . A trend is identified if the Z value determined from the examined data is larger than $Z_{\alpha/2}$. Furthermore, a trend in an increasing direction is understood if the S value is positive (+), and

a trend in a decreasing direction is understood if the S value is negative (-). The critical value for $Z_{\alpha/2}$ at the 85% significance level is ± 1.44 , at the 90% significance level is ± 1.65 , and at the 95% significance level, the $Z_{\alpha/2}$ value is ± 1.96 . In this study, significance level $\alpha = 0.05$ was chosen. According to the standard normal distribution, $Z_{\alpha/2} = \pm 1.96$. In other words, a trend is present if the computed $|Z|$ value is larger than 1.96 [66,67].

$$Z = \begin{cases} \frac{S - 1}{\sigma_s} & \text{If } S > 0 \\ 0 & \text{If } S = 0 \\ \frac{S + 1}{\sigma_s} & \text{If } S < 0 \end{cases} \quad (13)$$

Software for Drought Analysis (DrinC)

DrinC (drought indices calculator) is a tool that provides an easy-to-use but feature-rich interface for determining drought indicators. This application now includes modules for drought analysis methodologies such as SPI, RDI, DI, and SDI. Later, agricultural drought analysis modules were added to the application, utilizing aSPI and eRDI methodologies. The program also includes a module that calculates PET for RDI and eRDI methods that need PET values for drought analysis. PET calculations in the program can be done using three different methods: Hargreaves, Thornthwaite, and Blaney-Criddle [58].

With DrinC software, drought analysis can be performed, and the severity, time, and frequency of drought can be determined for any region. In addition to determining the past and present status of drought, this software

can also make future drought predictions using data from climate change future projections. The DrinC program can provide accurate drought analysis results, especially in semiarid or arid areas [58].

Drought analysis for different periods (1, 3, 6, 9, and 12 months) can be done in the program. When entering data into the program, the data should be organized according to the hydrological year. In other words, data in Excel format should be structured beginning in October and ending in September. While performing the PET calculation, the latitude value of the area where drought analysis is conducted should be input. In addition, the gamma distribution should be selected in the program to fit the data to the normal distribution for the methods used in this study. When analyzing with aSPI and eRDI methods in the program, unlike the original methods, USBR or USDA-SCS (Cropwat version) modules should be selected for Pe calculation in semiarid and arid areas.

RESULTS AND DISCUSSION

SPI Index Results

For the Sanliurfa province, 12-monthly drought analysis was conducted with the SPI method using the monthly total precipitation data obtained from MGM for the period between 1993 and 2023. The reason of performing 12-monthly analyses is that there is a wide variety of crops in Sanliurfa province and the growing periods of many crops are different. Agricultural drought is related to the growth season of the crop rather than the hydrological year period. Since many crops are grown in Sanliurfa, instead of determining a crop-based drought analysis period, the

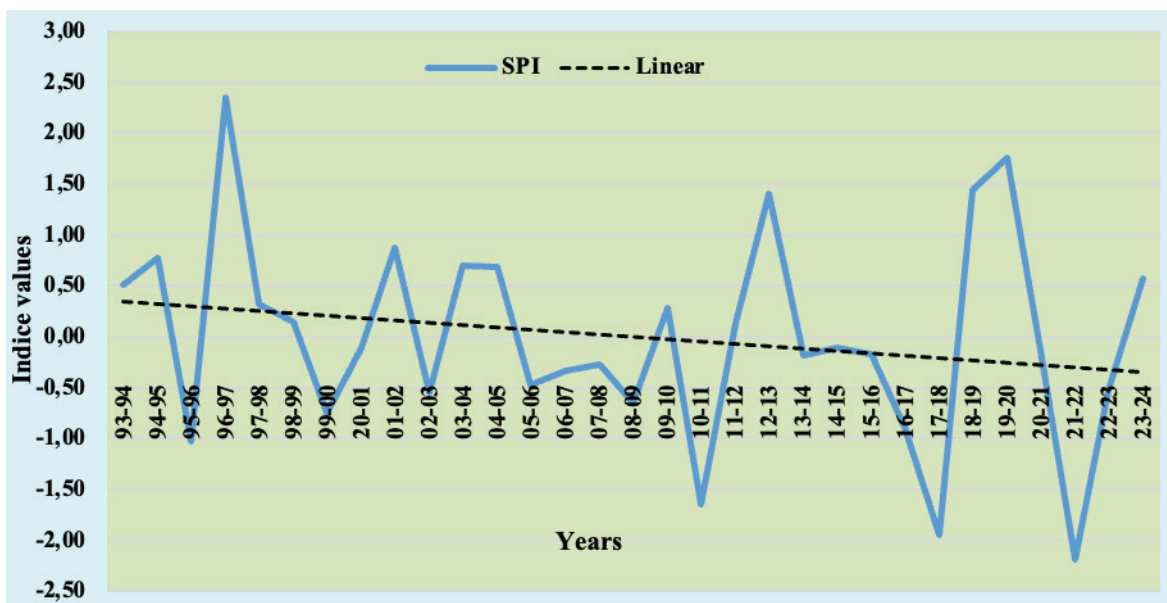


Figure 5. SPI method drought analysis results for Sanliurfa province in the period 1993-2023 (Source: Author).

analysis was made for a 12-monthly period based on the entire hydrological year [31]. The SPI method is mostly used to determine meteorological and agricultural drought. For agricultural drought, aSPI and eRDI methods that are determined to provide better results in the literature have been developed [31,43]. In this research, the analysis with the SPI method was conducted in order to compare with aSPI and eRDI results.

According to the common classification table in Table 4, the results of the SPI method analyses for Sanliurfa province are as follows: 1 year is extremely arid, 2 years are severely arid, 1 year is moderately arid, 13 years are mildly arid, 2 years are extremely humid, 2 years are moderately humid, and 10 years are mildly humid. As seen in Figure 5, in Sanliurfa province, drought effect was observed in 17 years, while precipitation effect was observed in 14 years in the analyzed period. It was found that the extremely arid year was 2021 with an indice value of -2.19, while the severely arid years were 2010 and 2017 with indices of -1.65 and -1.95, respectively. 1995 was a moderately arid year, with an indice value of -1.03. The linear trend line, which shows the SPI drought indice values is given in Figure 5. It is seen that the linear trend line is moving downwards in the direction of drought.

aSPI Index Results

For the Sanliurfa province, 12-monthly drought analysis was conducted with the aSPI method using the monthly total precipitation data obtained from MGM for the period between 1993 and 2023. The USBR method was selected in the program for effective precipitation calculation in the

analyses with the aSPI method. However, the USDA-SCS method, which produces accurate results in the computation of effective precipitation in semiarid and arid locations, is also included for comparison in this study. For the reasons explained in Section 3.1, the analysis was conducted for a 12-monthly period based on the entire hydrological year [31].

The results of the aSPI method analyses for Sanliurfa province are largely similar with the original SPI method results. However, there are differences in some years. It is understood from many studies in the literature that they give largely similar results. According to the common classification table in Table 4, the results of the aSPI (USBR) method analysis for Sanliurfa province are as follows: 2 years are extremely arid, 1 year is severely arid, 1 year is moderately arid, 12 years are mildly arid, 1 year is extremely humid, 3 years are moderately humid, and 11 years is mildly humid. As seen in Figure 6, in Sanliurfa province, drought effect was observed in 16 years, while precipitation effect was observed in 15 years in the analysed period. It was found that the extremely arid years were 2017 and 2021 with indice values of -2.26 and -2.56, respectively, and the severely arid year was 2010 with an indice value of -1.83. 1995 was a moderately arid year, with an indice value of -1.02. When the original SPI results are compared with the aSPI (USBR) results, it is seen that the drought class of five years are different. When the USDA-SCS method was taken into account in the calculation of effective precipitation, it was determined that the drought classes of three years are different. The aSPI (USDA-SCS) method was found to be more compatible with the original SPI method. According

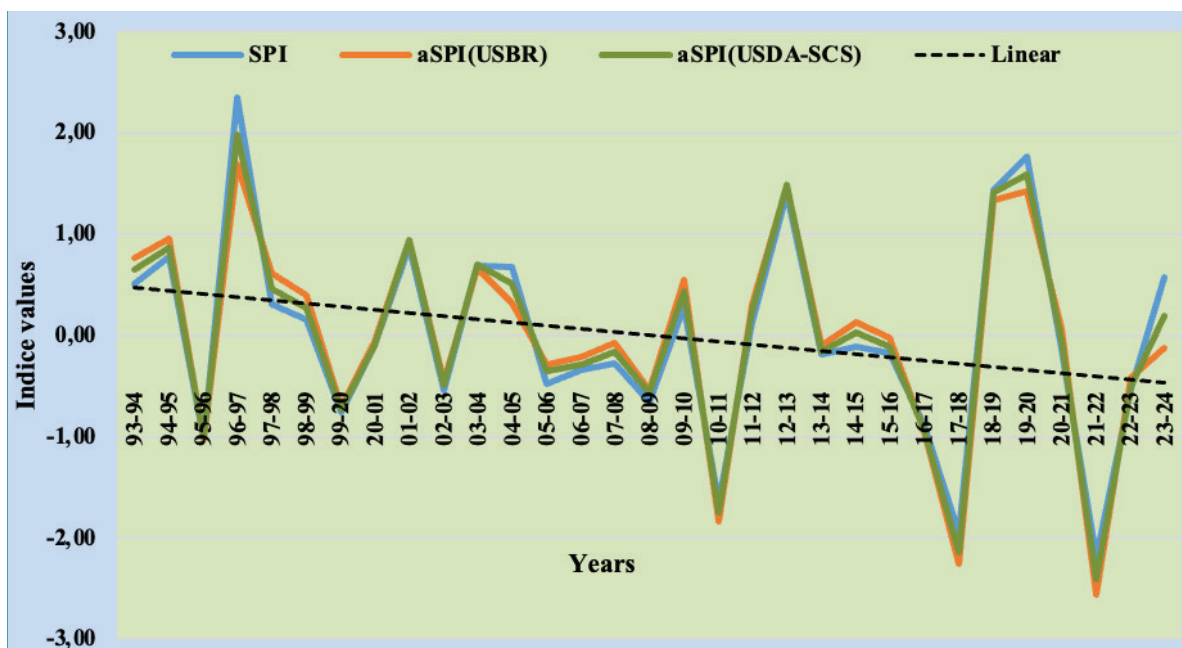


Figure 6. Comparison of drought analysis results of SPI-aSPI(USBR)-aSPI(USDA-SCS) methods in the period 1993-2023 for Sanliurfa province (Source: Author).

to the correlation analysis, a correlation of 0.99 was identified between the original SPI drought indice values and the aSPI(USDA-SCS) drought indice values, while a correlation of 0.96 was found between the original SPI drought indice values and the aSPI (USBR) drought indice values. The fact that the aSPI (USDA-SCS) method results are more compatible with the original SPI results shows that aSPI(USDA-SCS) does not provide very sensitive results in agricultural drought analyses. In fact, it has been stated in the literature that the aSPI (USBR) method results are more different from the original SPI method results and are more effective in determining agricultural drought. As seen in Figure 6, the linear trend line shows a downward trend in the drought direction for all of the SPI and aSPI methods.

RDI Index Results

For the Sanliurfa province, 12-monthly (annually) drought analysis was conducted with the RDI method using the monthly total precipitation data obtained from MGM for the period between 1993 and 2023. For the reasons explained in Section 3.1, the analysis was conducted for a 12-month period based on the entire hydrological year [32]. The RDI approach is applied to ascertain meteorological and agricultural drought. In this study, the analyses with the SPI and RDI method was applied for comparison with aSPI and eRDI results.

According to the common classification table in Table 4, the results of the RDI method analysis for Sanliurfa province are as follows: 1 year is extremely arid, 2 years are severely arid, 1 year is moderately arid, 13 years are mildly arid, 2 years are extremely humid, 2 years are moderately humid, 10 years are mildly humid. As seen in Figure 7, in Sanliurfa province, drought effect was observed in 17 years,

while precipitation effect was observed in 14 years in the analyzed period. It was found that the extremely arid year was 2021 with an indice value of -2.19, while the severely arid years were 2010 and 2017 with indices of -1.69 and -1.93, respectively. 1995 was a moderately arid year, with an indice value of -1.02. When the original RDI results were compared with the original SPI results, it was observed that the drought classes were completely the same in all years, with only minor differences in the indice values. It is known from studies in the literature that the drought analysis results of the SPI and RDI methods are very compatible [14,19]. As seen in Figure 7, the linear trend line of the RDI results shows a downward trend in the direction of drought.

eRDI Index Results

For the Sanliurfa province, 12-monthly (annually) drought analysis was conducted with the eRDI method using the monthly total precipitation data obtained from MGM for the period between 1993 and 2023. The USBR method was selected in the program for effective precipitation calculation in the analysis with the eRDI method. However, the results of the USDA-SCS method, another method that gives correct results in the calculation of effective precipitation in semiarid and arid areas, are also given in this study for comparison. For the reasons explained in Section 3.1, the analysis was conducted for a 12-monthly period based on the entire hydrological year [32]. The eRDI method is a newly developed method for determining agricultural drought, like the aSPI method. eRDI results are compared with RDI results in Figure 8. Also in Figure 8, the drought analysis results in which effective precipitation is determined by the USBR method and the USDA-SCS method are shown separately.

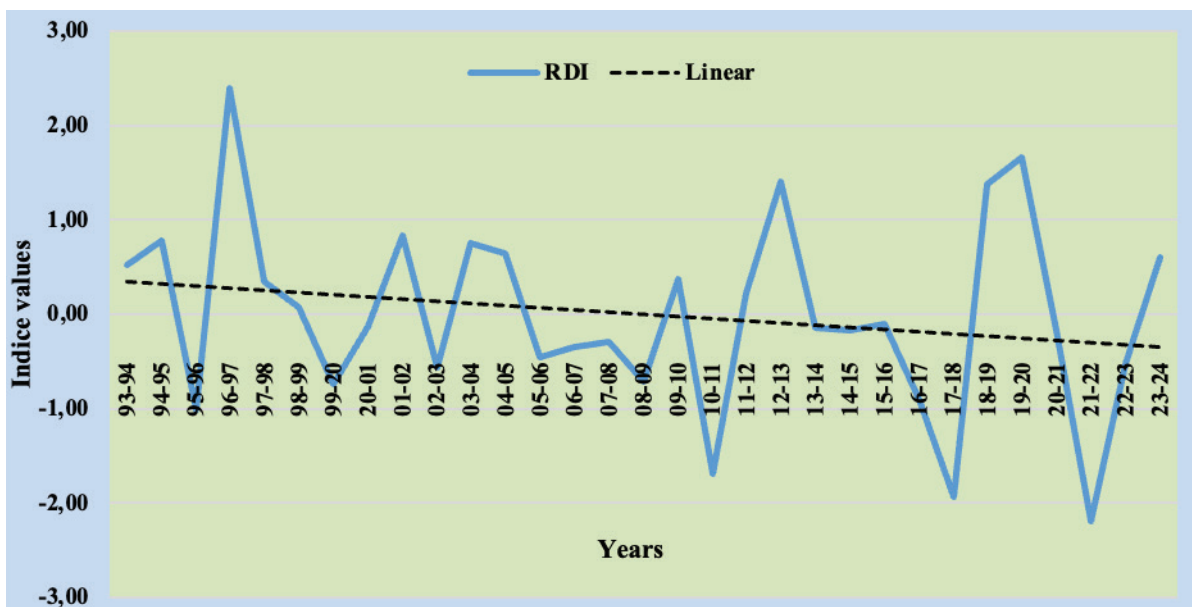


Figure 7. RDI method drought analysis results for Sanliurfa province in the period 1993-2023 (Source: Author).

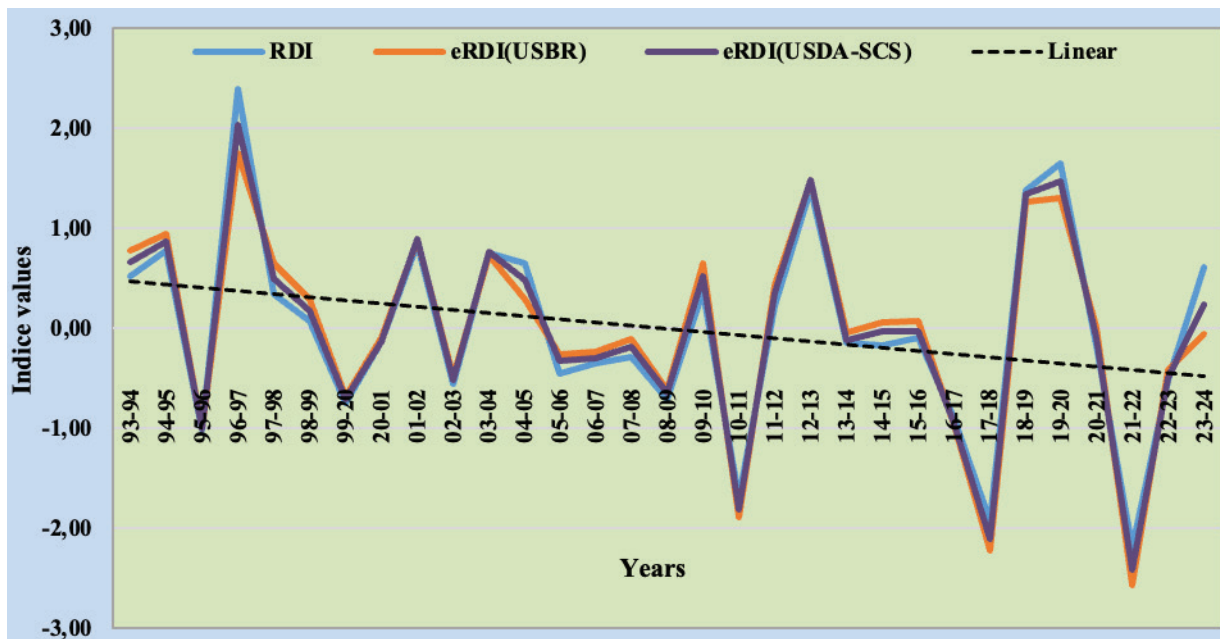


Figure 8. Comparison of drought analysis results of RDI-eRDI (USBR)-eRDI (USDA-SCS) methods in the period 1993-2023 for Sanliurfa province (Source: Author).

The results of the eRDI method analyses for Sanliurfa province are largely similar with the RDI method results. However, there are differences in some years. It is understood from many studies in the literature that they give largely similar results. According to the common classification table in Table 4, the results of the eRDI method analysis for Sanliurfa province are as follows: 2 years are extremely arid, 1 year is severely arid, 1 year is moderately arid, 11 years are mildly arid, 1 year is extremely humid, 3 years are moderately humid, and 12 years are mildly humid. As seen in Figure 8, in Sanliurfa province, drought effect was observed in 15 years, while precipitation effect was observed in 16 years in the analyzed period.

It was found that the extremely arid years were 2017 and 2021, with indice values of -2.22 and -2.56, respectively, and the severely arid year was 2010 with an indice value of -1.89. It was concluded that 1995 was moderately arid, with an indice value of -1.00. When the original RDI results are compared with the eRDI(USBR) results it is seen that the drought class of six years are different. When the original RDI results are compared with the eRDI (USDA-SCS) method results, it is seen that the drought class of two years are different. The eRDI (USDA-SCS) method was found to be more compatible with the original RDI method. According to the correlation analysis, a correlation of 0.99 was identified between the original RDI and eRDI (USDA-SCS) drought indice values, while a correlation of 0.96 was found between the original RDI and eRDI (USBR) drought indice values. The fact that the eRDI (USDA-SCS) method results are more compatible with the original RDI results shows that eRDI(USDA-SCS) does not provide very

sensitive results in agricultural drought analyses. In fact, it has been stated in the literature that the eRDI (USBR) method results are more different from the original RDI method results and are more effective in determining agricultural drought. As seen in Figure 8, the linear trend line shows a downward trend in the drought direction for all of the RDI and eRDI methods. According to all original and modified methods used in this study, a downward trend in drought direction was determined. In other words, it is obvious that there is an increasing trend towards drought in Sanliurfa province which is known to have been affected by drought in recent years. According to the Aridity Index used by the UNEP, Sanliurfa province was determined to be semi-arid.

Comparison of the Results of All Methods

Drought analyzes of Sanliurfa province were performed in the period 1993-2023 with SPI, aSPI (USBR), aSPI (USDA-SCS), RDI, eRDI (USBR), and eRDI (USDA-SCS) methods. In general, drought indices were found to be close to each other, but drought classes were different in some years. Table 5 shows the results of all methods. Since the analysis with the UNEP-AI method was conducted only to determine the method used to calculate the effective precipitation in the aSPI and eRDI methods, this method is not included in the table. When the analysis results are evaluated, it is proved that the drought classes of the original SPI and original RDI methods are completely the same in all years. At the same time, the modified methods were found to be compatible with each other. In all four modified methods, moderately arid, severely arid, and extremely

arid years were completely the same. It was determined that there were differences only in some mildly arid years. In all six methods, 1995 was found to be a moderately arid year. According to outcomes of the original and modified methods, while 2010 was the same as the severely arid year, 2017 was extremely arid instead of severely arid in the modified methods. In all methods, 2021 was an extremely arid year. It was determined that mildly arid years were dominant in all methods. It was determined that the mildly arid years were exactly the same in the original methods, and there were differences only in the last few years in the modified methods. As seen in Table 5, while the number of dry years was the same in the original methods, it was very close but different in the modified methods.

In addition, it was determined that results of modified methods in which effective precipitation is determined with the USDA-SCS method are more compatible with results of the original methods. Studies in the literature indicate that drought analyses in which effective precipitation is determined with the USBR method give more accurate results in determining agricultural drought [31,43]. For this reason, the results of aSPI (USBR) and eRDI (USBR) analyses

are compared with the results of the original methods in Figure 9. aSPI (USBR) and eRDI (USBR) results were found to have significant differences from the original methods (see Table 5 and Figure 10). The results of the aSPI (USDA-SCS) and eRDI (USDA-SCS) methods are not very different from the original methods, especially in determining drought classes. In other words, the aSPI(USDA-SCS) and eRDI(USDA-SCS) methods could not obtain very sensitive results in determining agricultural drought, showing similarity to the results of the original methods. Because of this, the use of modified methods, in which effective precipitation is determined by the USBR method instead of the original methods, should be widespread in agricultural drought analyses.

The drought classes determined by the methods used in this study for the Sanliurfa province are given as a column chart in Figure 10 below. Figure 10 shows the percentage of dry classes and the percentage of wet classes. As seen in the column graph, mildly dry and mildly wet classes are dominant in all methods. Furthermore, there is an increase in the percentage of extremely arid years in the modified methods in contrast to the original methods. Additionally,

Table 5. Dry years and drought classes according to the analysis results of all methods for Sanliurfa province

Method used in analysis	Period	Total number of dry years	Mildly arid years	Moderately arid years	Severely arid years	Extremely arid years
SPI	1993-2023	17	1999, 2000, 2002, 2005, 2006, 2007, 2008, 2013, 2014, 2015, 2016, 2020, 2022	1995	2010, 2017	2021
RDI	1993-2023	17	1999, 2000, 2002, 2005, 2006, 2007, 2008, 2013, 2014, 2015, 2016, 2020, 2022	1995	2010, 2017	2021
aSPI(USBR)	1993-2023	16	1999, 2000, 2002, 2005, 2006, 2007, 2008, 2013, 2015, 2016, 2022, 2023	1995	2010	2017, 2021
aSPI(USDA-SCS)	1993-2023	16	1999, 2000, 2002, 2005, 2006, 2007, 2008, 2013, 2015, 2016, 2020, 2022	1995	2010	2017, 2021
eRDI(USBR)	1993-2023	15	1999, 2000, 2002, 2005, 2006, 2007, 2008, 2013, 2016, 2022, 2023	1995	2010	2017, 2021
eRDI(USDA-SCS)	1993-2023	17	1999, 2000, 2002, 2005, 2006, 2007, 2008, 2013, 2014, 2015, 2016, 2020, 2022	1995	2010	2017, 2021

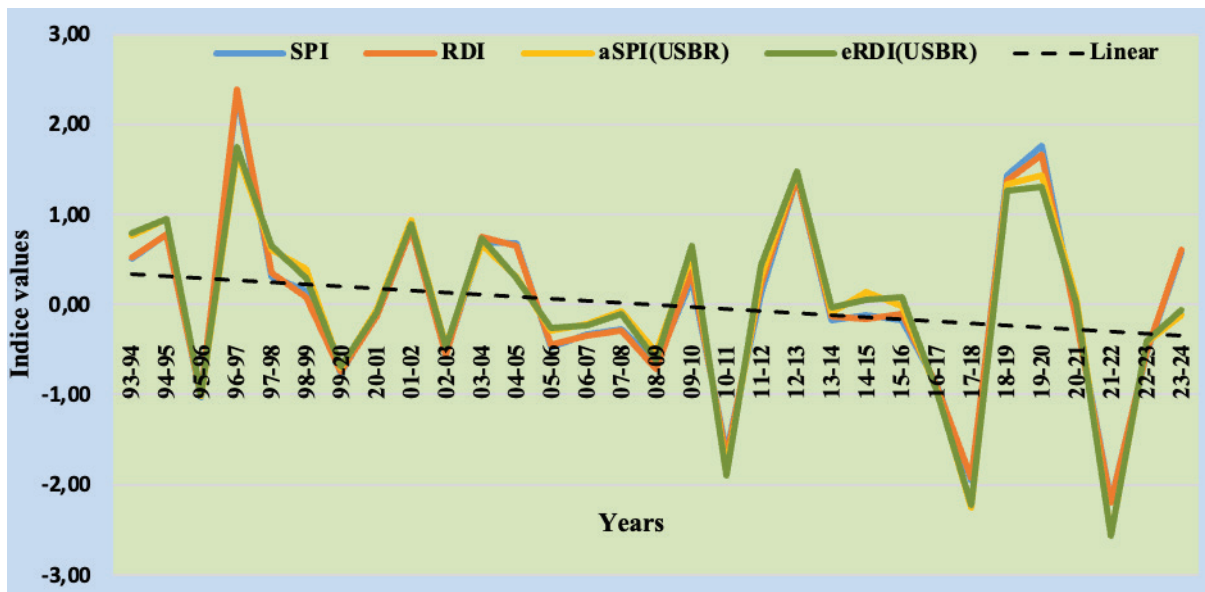


Figure 9. Comparison of drought analysis results of original SPI, original RDI, aSPI (USBR) and eRDI (USBR) methods in the period 1993-2023 for Sanliurfa province (Source: Author).

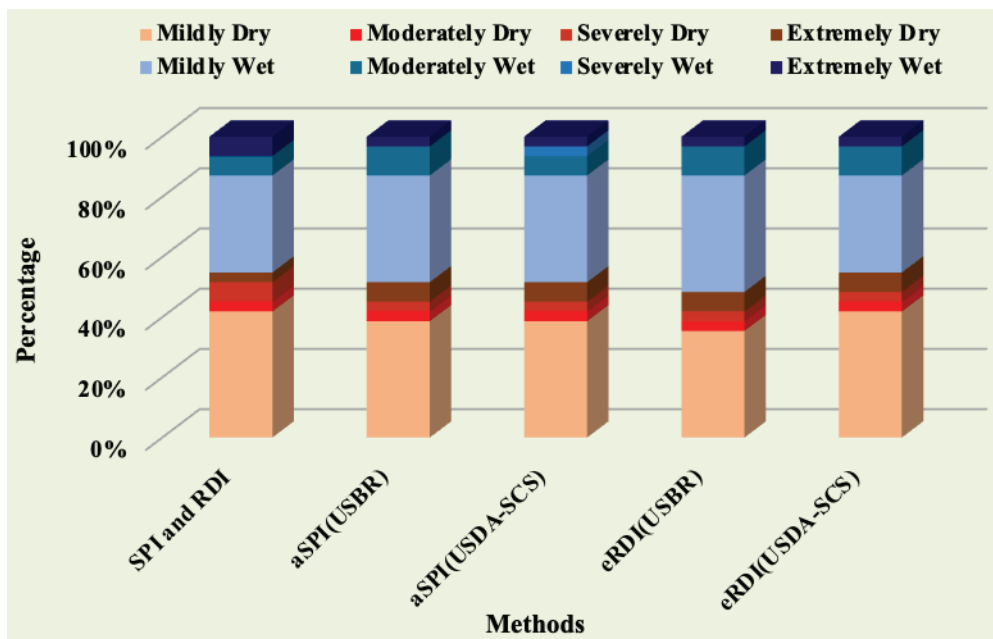


Figure 10. Comparison with a column graph of drought analysis percentages of original methods and modified methods for Sanliurfa province (Source: Author).

the percentage of the extremely wet years is lower in the modified methods.

Trend Analysis of Precipitation and Temperature Data

The Mann-Kendall trend analysis method was implemented on the annual average temperature, annual total precipitation values, annual maximum temperature, and

annual minimum temperature values for the 31-year period 1993-2023 in order to understand the cause of droughts in Sanliurfa province. Mann-Kendall trend analysis tests were performed with XLSTAT statistical software integrated with Excel. Based on the findings of trend analysis, although there is an increase in annual average temperatures, no trend was found at the 0.05 significance level.

Similarly, although there is a decrease in the annual total precipitation data, no trend was found at the 0.05 significance level. However, it was found that there's an increasing trend in the annual minimum temperature and annual maximum temperature data according to the 0.05 significance level. The p-values for the minimum and maximum temperature trends are 0.00 and 0.007, respectively. In other words, the p-value is lower than $\alpha=0.05$ in both cases. The Z values for minimum and maximum temperature trends are 247 and 210, respectively. In both cases, Z is higher than the limit value of 1.96. In other words, there is a significant increasing trend with 95% confidence in the annual minimum temperature and annual maximum temperature data. Trend graphs of minimum and maximum temperatures are given in Figure 11 and Figure 12. When looking at the trend graphs below, there is an upward trend, that is, an increase in both maximum and minimum temperatures.

As it is understood from these results, although the lack of precipitation is partially effective in the droughts experienced in Sanliurfa province, the rise in minimum and maximum temperatures is the primary cause. With rising temperatures, evaporation increases, and water resources are depleted. This study also shows the importance of methods that take into account temperature data as well as precipitation data in drought analysis, such as RDI and eRDI, which are utilized in this study.

Comparison with Studies in the Literature of Analysis Results

In lots of research in the literature, drought analyses were conducted with the original SPI and RDI methods.

In these studies, it was determined that the drought indice values calculated with historical data using SPI and RDI methods were very compatible with each other. In a study in the literature, it was determined that 12 monthly drought indice values in drought analyses performed with historical data using SPI and RDI methods were compatible with a correlation value of 0.88. In this study, it was observed that the results of the drought analyses performed using historical data for Sanliurfa province with SPI and RDI methods were very compatible as the studies in the literature. In this study, a very good correlation of 0.99 was obtained between the drought indices obtained with both methods. Based on the findings of the drought analysis conducted with SPI and RDI methods in the literature, drought years generally occurred every 2 years. In this study, dry years were observed every 2 or 3 years, and sometimes consecutive droughts occurred. This is due to the fact that the regions examined are different and the analyses is made for different periods. [13,14,19,27].

Additionally, there are studies comparing the aSPI and eRDI modified methods with the original SPI and RDI methods. In most of these studies, the correlation between drought analysis results and crop yields was utilized to compare the original and modified methods. According to the correlation results, it was found that the modified methods, aSPI and eRDI, gave better results than the original methods. In this study, when the aSPI and eRDI modified methods were compared with the original SPI and RDI methods, it was determined that there were some differences in drought classes in Sanliurfa province. In the modified methods, extremely dry years were more common,

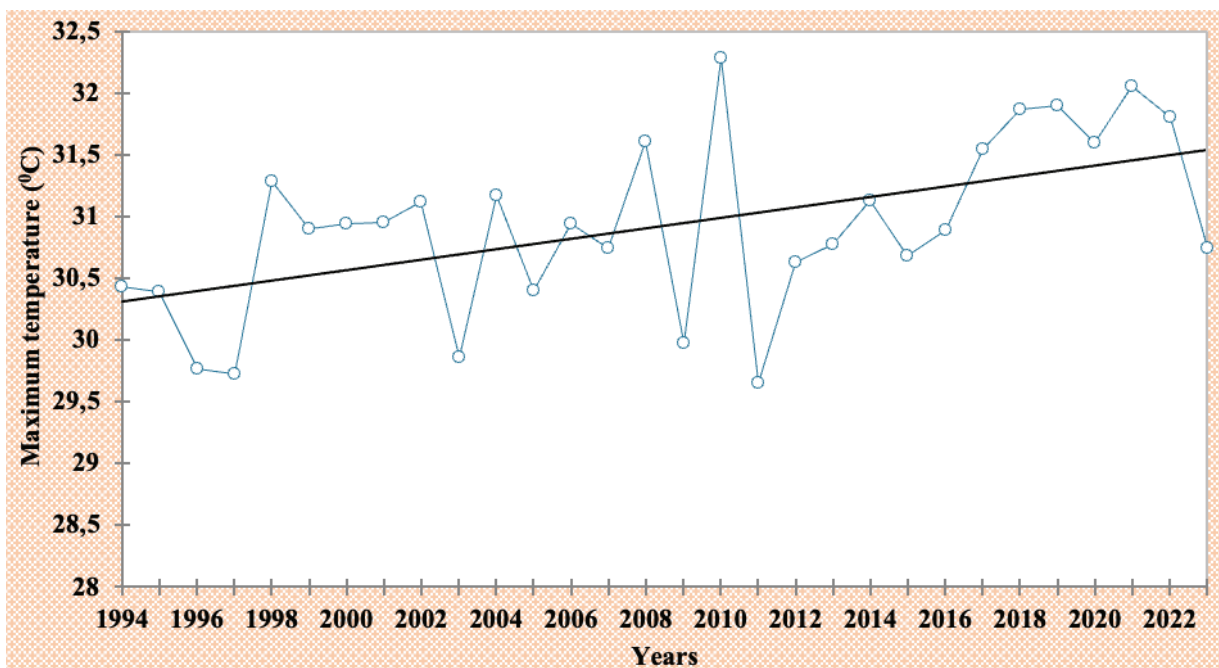


Figure 11. Trend analysis of annual maximum temperatures in the period 1993–2023 for Sanliurfa province (Source: Author)

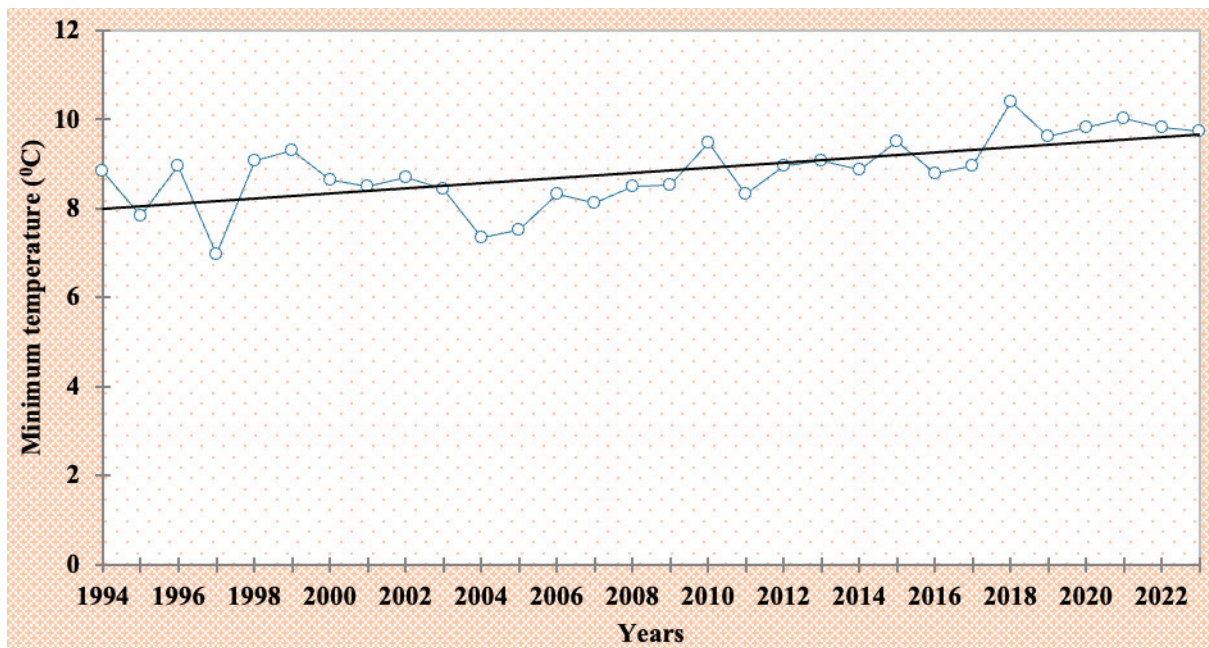


Figure 12. Trend analysis of annual minimum temperatures in the period 1993-2023 for Sanliurfa province (Source: Author).

while extremely wet years were less common. It can be said that these results are realistic for the province of Sanliurfa, which is affected by droughts, and agricultural activities are intensive. In this study, a climate diagram graphic was created using the temperature and precipitation data of the last 10 years for Sanliurfa province. According to this graphic, it was determined that there was a water shortage in Sanliurfa province in June, July, August, and September. When the drought classes of the last 10 years for Sanliurfa province are examined, drought was observed in 6 years according to the aSPI (USBR) method, while drought was observed in 5 years according to the eRDI (USBR) method. Therefore, it can be said that the droughts experienced in Sanliurfa province are caused by the change in climate parameters. According to the Mann-Kendall trend analyses conducted in this study, the increasing trend in minimum and maximum temperatures also confirms this.

In Şanlıurfa province, conducting drought analyses with modified methods that have just begun to be used in the literature is important both for the agricultural activities of the province and because it will contribute to the literature. In the future, the drought analysis results for Sanliurfa province can be compared with the yield values of rainfed agricultural products to determine the accuracy of the modified methods more realistically [32,33,44,46].

In some studies in the literature, the modified methods aSPI and eRDI were compared with some methods other than the original SPI and RDI methods to verify the usability of the modified methods. In these studies, it was determined that modified methods gave accurate results [39]. In this study, modified methods were compared with original

methods, and it was determined that they gave accurate results. In addition, it has been stated in the literature that drought conditions may change in a region due to climate change and that drought analyses should be carried out at regular intervals with up-to-date data [3]. In this study, drought analyses were conducted for the first time with modified methods in the Sanliurfa province using current data.

In previous studies, drought analysis results of aSPI and eRDI modified methods were compared, and it was determined that they were compatible with a high correlation percentage [39]. In this study, it was found that the aSPI results were compatible with the eRDI results with a correlation percentage of 0.99. In this research, the compatibility of the results of the original method with the results of the modified methods was also examined. According to these results, when the effective precipitation values were calculated with the USBR method, the correlation was 0.96, while when calculated with the USDA-SCS method, the correlation was 0.99. Since it is stated in the literature that the USBR method gives more accurate results in determining effective precipitation, the results of the USBR method were taken into consideration in this study [32,57].

In addition, future drought predictions have been made in some regions using future climate data obtained according to climate scenarios in the literature [13,27,68]. Drought analyses can be conducted for Sanliurfa province with future climate data to investigate how successful modified methods are in predicting future agricultural drought.

Many studies in the literature have determined that droughts have increased in recent years [14,27,44]. When

we look at the graphs of the drought analysis results obtained in this study, it is seen that the trend line tends downwards, in the direction of drought. Likewise, in this research, analogous to research in the literature, it was determined that there has been an increase in droughts in recent years.

Limitations

Although the data used in the article are obtained reliably from measurement stations established by national institutions, measurement errors may occur on some days due to environmental factors. PET values were not obtained by on-site measurements, but were calculated using an equation that is frequently used in the literature and provides reliable results. There may be small errors in such calculations. In this study, these errors were ignored and analyses were conducted by relying on the data.

CONCLUSION

In this study, drought analyses were conducted in the drought-affected Sanliurfa province using the aSPI and eRDI methods, which will be applied for the first time in Turkey, and the original SPI and RDI methods. Monthly total precipitation data, and maximum and minimum temperature data obtained from the Regional Directorate of Meteorology for the period 1993-2023 were used for the analyses. The average temperature data used for PET calculation in RDI and eRDI methods were calculated using the observational maximum and minimum temperature data entered into the DrinC program. The effective precipitation data used in the aSPI and eRDI methods were calculated by using the monthly total precipitation data entered into the DrinC program. USBR and USDA-SCS modules were selected for effective precipitation calculation in the program. In this research, the USBR method was used to calculate effective precipitation. However, in order to make a comparison, effective precipitation was also calculated by the USDA-SCS method, and drought analyzes were made.

According to the analysis results, the aSPI and eRDI drought analysis results for Sanliurfa province are analogous to the original SPI and RDI analysis results as similar to the research in the literature. However, the drought classes of some years were different. According to the aSPI results; it was determined that 2 years were extremely arid, 1 year was severely arid, 1 year was moderately arid and 12 years were mildly arid. According to the eRDI results; it was determined that 2 years were extremely arid, 1 year was severely arid, 1 year was moderately arid, and 11 years were mildly arid. When the original SPI and RDI results of Sanliurfa were compared, although there are some differences in the drought indice values, the drought classes are completely the same. In both methods, it was determined that 1 year was extremely arid, 2 years were severely arid, 1 year was moderately arid, and 13 years were mildly arid. As can be seen, the original methods and the modified methods gave similar results among themselves. However, there were

noticeable differences between the outcomes of the original methods and the modified methods. Some years' drought classes turned out to be different. While 2017 was severely arid in the original methods, it was extremely arid in the modified methods. In the last few years (2014, 2015, and 2023), mildly arid years have changed. Similar differences have been found in previous studies in the literature. For this reason, agricultural drought analyses in semiarid and arid areas should be carried out with modified methods, and measures should be taken according to these results.

As can be seen, the original methods could not detect an extremely dry year, and differences from modified methods were observed in the drought classes of some years. If this change in drought classes of these years is not taken into account, the necessary precautions cannot be taken fully. As a result, agricultural activities will be disrupted, and economic losses may be experienced. For example, if more water is not stored in water reservoirs in 2017, which is determined as an extremely dry year by modified methods, there will be a water shortage in the summer, and agricultural activities will be negatively affected. Some crops will experience yield loss or will be completely destroyed. As a result of these negativities, farmers will suffer economic losses and some socio-economic problems will arise. From this perspective, the importance of performing drought analyses with modified methods that provide more precise results can be better understood.

In addition, SPI and RDI analysis results were compared, and it was determined that they were compatible with a correlation percentage of 0.99. In this study, it was determined that the outcomes of the original methods were also compatible with the results of the modified methods. According to these results, when the effective precipitation values were calculated with the USBR method, the modified methods were compatible with the original methods with a correlation percentage of 0.96, while when calculated with the USDA-SCS method, they were compatible with a correlation percentage of 0.99. In other words, when effective precipitation values are calculated with the USBR method, modified methods can better determine the details that the original methods could not determine.

These results showed that aSPI and eRDI modified methods can be utilized in agricultural drought analysis in arid and semiarid regions. Because, in order to take measures in agricultural activities in semiarid and arid areas, it is important to conduct agricultural drought analyzes with modified methods such as aSPI and eRDI instead of original methods in order to get more precise outcomes.

In regions where drought analysis has been done previously, drought analyses should be done with current data and methods due to climate change. In regions where drought analysis has never been done previously, agricultural drought analyses should be done with modified methods. In addition, it would be useful to obtain future climate data by conducting climate modeling with climate scenarios widely used in the literature in these regions and

to make future drought predictions with modified methods. In future studies, the efficiency of modified methods can be better understood by comparing the yield values of rainfed crops in drought-affected regions of Turkey with the drought indices obtained with modified and original methods. As stated in the limitations section of the study, although PET values are calculated with high accuracy, there may be some errors. After all, they are not data obtained by measurement. In future studies, evapotranspiration values can be determined as a result of measurement and more reliable results can be achieved. There may be errors in the past data obtained from the measurement stations used in the study due to environmental conditions. However, the measurements of MGM stations, which make more precise measurements compared to the past, should be trusted.

According to the results of the trend analysis, although precipitation data, which show a slightly decreasing trend, partially affect the droughts in Sanliurfa province, the primary cause is the rise in minimum and maximum annual temperatures according to the 0.05 significance level. The p-values for the minimum and maximum temperature trends are 0.00 and 0.007, respectively. In other words, the p-value is less than $\alpha=0.05$ in both cases. The Z values for minimum and maximum temperature trends are 247 and 210, respectively. In both cases, Z is higher than the limit value of 1.96. In other words, there is a noticeable increasing trend with 95% confidence in the annual minimum and maximum temperature data. This change in climate parameters requires the carrying out of agricultural drought analyses at regular intervals with updated data and modified methods in arid and semi-arid regions. In this study, according to the drought assessment made according to the Aridity Index, it was determined that Sanliurfa province is semi-arid. This research is the first drought analysis study conducted in Sanliurfa province and Turkey with updated data using modified aSPI and eRDI methods. These features show that the study is new and original. The idea of determining the cause of drought by looking at the trend in climate parameters also partially differs from the studies in the literature.

The increasing trend in temperatures increases the evaporation especially in summer months, and causes drought. For this reason, irrigation should be carried out with water-saving systems like drip and sprinkler irrigation. Irrigation water must be transmitted through closed pipes to reduce evaporation, and underground dams should be built. Water reservoirs should be covered with shade covers. Crops that consume less water should be preferred. Plant adaptation strategies should be developed and crops that can easily adapt to drought should be grown. Additionally, people should be made aware of water saving.

NOMENCLATURE

D	Usable soil water storage
ET _c	Actual evapotranspiration, mm
M	Number of pairs

N	Number of years
P	Annual total precipitation, mm
PET	Annual total potential evapotranspiration, mm
Pe	Effective precipitation, mm
Ra	Amount of space radiation, MJ/m ² /day
S	Mann-Kendall method statistic
SF	Soil water storage factor
T _{max}	Monthly maximum temperature, °C
T _{min}	Monthly minimum temperature, °C
T _{ort}	Monthly mean temperature, °C
X _{ij}	Monthly total precipitation, mm
X _{im}	Long-term average precipitation, mm
y _k ⁱ	Natural logarithm
Z	Standart normal variable
Z α /2	Standart normal critical variable

Greek symbols

σ	Standard deviation
α_k^i	Initial value
μ_k	Arithmetic mean
τ	Kendall correlation coefficient

Subscripts

k	Number of hydrological year
---	-----------------------------

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The data supporting this study's findings are available on request from the corresponding author.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

REFERENCES

- [1] Nzovoa V, Ahumada-Rudolph R, Rojas O, Munizaga J, Sáez K, Arumí JL. Sustainability assessment of the agricultural water footprint in the Cachapoal River basin, Chile. *Ecol Indic* 2019;98:19–28. [CrossRef]

- [2] Batan M. Küresel iklim değişikliği ve beklenen sonuçları [dissertation]. Diyarbakır, Türkiye: Dicle Üniversitesi; 2014.
- [3] Batan M. Çeşitli kuraklık indisleri ile Batman ilinin kuraklık analizi ve kontur haritalarının çıkarılması. *Doğal Afetler ve Çevre Derg* 2021;7:252–265. [\[CrossRef\]](#)
- [4] Batan M, Toprak ZF. Küresel iklim değişikliğinin olumlu etkileri ve bu etkilerin iklim değişikliğine uyum kapsamında değerlendirilmesi. *Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Derg* 2015;6:93–102.
- [5] Karacaoğlu B, Akbaba MF. Leaders of change: Children and the climate change movement. *Sigma J Eng Nat Sci* 2024;42:957–964. [\[CrossRef\]](#)
- [6] Inan M, Atayılmaz ŞÖ. Experimental investigation of evaporation from a horizontal free water surface. *Sigma J Eng Nat Sci* 2017;35:118–131.
- [7] Özyonar F, Gökkuş Ö. Change in highway transportation-induced carbon footprint of Kayseri province. *Sigma J Eng Nat Sci* 2022;40:868–876. [\[CrossRef\]](#)
- [8] Mohamed MAEH, Moursy FI, Darrag MH, El-Mahdy MES. Assessment of long-term trends and mapping of drought events in Tunisia. *Sci Afr* 2023;21:e01766. [\[CrossRef\]](#)
- [9] Yaltı S, Aksu H. Drought analysis of Iğdır, Turkey. *Turk J Agric Food Sci Technol* 2019;7:2227–2232. [\[CrossRef\]](#)
- [10] Kapluhan E. Türkiye’de kuraklık ve kuraklığın tarıma etkisi. *Marmara Coğrafya Derg* 2013;27:487–510.
- [11] Öztürk T, Turp MT, Türkeş M, Kurnaz ML. Future projections of temperature and precipitation climatology for CORDEX-MENA domain using RegCM4.4. *Atmos Res* 2018;206:87–107. [\[CrossRef\]](#)
- [12] Rezaei M, Moghaddam MA, Azizyan G, Shamsipour AA. Prediction of agricultural drought index in a hot and dry climate using advanced hybrid machine learning. *Ain Shams Eng J* 2024;15:102686. [\[CrossRef\]](#)
- [13] Alemu GT, Desta SA, Tareke KA. Characterize and analysis of meteorological and hydrological drought trends under future climate change conditions in South Wollo, North Wollo, and Oromia Zones, in Ethiopia. *Heliyon* 2024;10:e29694. [\[CrossRef\]](#)
- [14] Rani A, Sharma D, Babel MS, Sharma A. Spatio-temporal assessment of agroclimatic indices and the monsoon pattern in the Banas River Basin, India. *Environ Chall* 2022;7:100483. [\[CrossRef\]](#)
- [15] Guardiola-Claramonte M, Troch PA, Breshears DD, Huxman TE, Switanek MB, Durcik M, Cobb NS. Decreased streamflow semi-arid basins following drought-induced tree die-off: A counterintuitive and indirect climate impact on hydrology. *J Hydrol* 2011;406:225–233. [\[CrossRef\]](#)
- [16] Güngen Y. Standart yağış indisi(SPI) ile güneydoğu anadolu bölgesinde kuraklık analizi [master’s thesis]. Manisa, Türkiye: Manisa Celal Bayar Üniversitesi; 2019.
- [17] Ilgar R. Çanakkale’de kuraklık durumu ve eğilimlerinin standartlaştırılmış yağış indisi ile belirlenmesi. *Marmara Coğrafya Derg* 2010;22:183–204.
- [18] Nabaei S, Sharafati A, Yaseen ZM, Shahid S. Copula based assessment of meteorological drought characteristics: Regional investigation of Iran. *Agric For Meteorol* 2019;276:107611. [\[CrossRef\]](#)
- [19] Nasirudeen AF, Kobo-bah AT, Amo-Boateng M, Karthikeyan B. Analysis of drought patterns in the Tano river basin of Ghana. *Sci Afr* 2021;13:e00883. [\[CrossRef\]](#)
- [20] Sarıcan Y. Avrupa birliği ve türkiyede kuraklık yönetimi uygulamalarının değerlendirilmesi. Ankara, Türkiye: Orman ve Su İşleri Bakanlığı, Su Yönetimi Genel Müdürlüğü Yayını; 2015.
- [21] Zargar A, Sadiq R, Naser B, Khan FI. A review of drought indices. *Environ Rev* 2011;19:333–349. [\[CrossRef\]](#)
- [22] Topçu E. Doğu akdeniz, seyhan, ceyhan ve asi havzalarında farklı yöntemler kullanılarak kuraklık analizi [dissertation]. Adana, Türkiye: Çukurova Üniversitesi; 2018.
- [23] Vergni L, Vinci A, Todisco F. Effectiveness of the new standardized deficit distance index and other meteorological indices in the assessment of agricultural drought impacts in central Italy. *J Hydrol* 2021;603:126986. [\[CrossRef\]](#)
- [24] Tigkas D, Vangelis H, Tsakiris G. Introducing a modified reconnaissance drought index (eRDI) incorporating effective precipitation. *Procedia Eng* 2016;162:332–339. [\[CrossRef\]](#)
- [25] Gümüş V, El Moçayd N, Seker M, Seaid M. Future projection of droughts in Morocco and potential impact on agriculture. *J Environ Manage* 2024;367:122019. [\[CrossRef\]](#)
- [27] Wubneh MA, Alemu MG, Fekadie FT, Worku TA, Demamu MT, Aman TF. Meteorological and hydrological drought monitoring and trend analysis for selected gauged watersheds in the Lake Tana basin, Ethiopia: Under future climate change impact scenario. *Sci Afr* 2023;20:e01738. [\[CrossRef\]](#)
- [28] Mohammed R, Scholz M. Impact of evapotranspiration formulations at various elevations on the reconnaissance drought index. *Water Resour Manage* 2017;31:531–548. [\[CrossRef\]](#)
- [29] Özmen F. Batman ve diyarbakır illerinin uzun yıllar iklim verileri kullanılarak çeşitli kuraklık indisleriyle kuraklık analizinin yapılması ve literatürle karşılaştırılması [master’s thesis]. Batman, Türkiye: Batman Üniversitesi; 2022.
- [30] Ju X, Wang Y, Wang D, Singh VP, Xu P, Wu J, Zhang J. A time-varying drought identification and frequency analyzation method: A case study of Jinsha River Basin. *J Hydrol* 2021;603:126864. [\[CrossRef\]](#)
- [31] Gibbs WJ, Maher JV. Rainfall deciles as drought indicators (Kuraklık göstergesi olarak yağış ondalık oranları). Bureau of Meteorology Bulletin, No. 48. Melbourne: Bureau of Meteorology; 1967.

- [32] Tigkas D, Vangelis H, Tsakiris G. An enhanced effective reconnaissance drought index for the characterisation of agricultural drought. *Environ Processes* 2017;4:137–148. [CrossRef]
- [33] Tigkas D, Vangelis H, Tsakiris G. Drough characterisation based on an agriculture-oriented standardised precipitation index. *Theor Appl Climatol* 2019;135:1435–1447. [CrossRef]
- [34] Tigkas D, Vangelis H, Proutsos N, Tsakiris G. Incorporating aSPI and eRDI in drought indices calculator(DrinC) software for agricultural drought characterisation and monitoring. *Hydrology* 2022;9:100. [CrossRef]
- [35] Ozfidaner M, Topaloğlu F. Standart yağış indeksi yöntemi ile güneydoğu anadolu bölgesinde kuraklık analizi. *Toprak Su Derg* 2020;9:130–136. [CrossRef]
- [36] Taşkolü İ. Güneydoğu Anadolu Bölgesi için kuraklık analizi [master's thesis]. Denizli: Pamukkale Üniversitesi; 2023.
- [37] Ozmen F, Batan M. Drought analysis of Batman and Diyarbakır provinces in Türkiye with various drought indices. *Pamukkale Üniversitesi Mühendislik Bilimleri Derg* 2025;31:1036–1048. [Turkish]
- [38] Ircan MR, Duman N. Standartlaştırılmış yağış indeksi (SYİ) yöntemi ile Şanlıurfa ili kuraklık analizi. *Coğrafya Derg* 2021;2021:1–18. [CrossRef]
- [39] Gümüş V, Başak A, Oruç N. Standartlaştırılmış yağış indeksi (SYİ) yöntemi ile Şanlıurfa istasyonunun kuraklık analizi. *Harran Üniversitesi Mühendislik Derg* 2016;1:36–44.
- [40] Nemati A, Najafabadi SHG, Joodaki G, Nadoushani SSM. Spatiotemporal drought characterization using gravity recovery and climate experiment (GRACE) in the Central Plateau Catchment of Iran. *Environ Processes* 2020;7:135–157. [CrossRef]
- [41] Syed FS, Adnan S, Zamreeq A, Ghulam A. Identification of droughts over Saudi Arabia and global teleconnections. *Nat Hazards* 2022;112:2717–2737. [CrossRef]
- [42] Ahmad MB, Muavia A, Iqbal M, Arshed AB, Ahmad MM. Spatio-temporal drought assessment and comparison of drought indices under climatic variations in drought-prone areas of Pakistan. *J Water Clim Change* 2023;14:3726–3752. [CrossRef]
- [43] Sadiq N, Abbasi AA, Qureshi MS. Drought analysis of Sindh using Standardized Precipitation Index (SPI). *MAUSAM* 2014;65:433–437. [CrossRef]
- [44] Omar LC, Mariano NC, Alberto G, Ernestina PG, Jorge MM, Enrique TD. Sensitivity of four indices of meteorological drought for rainfed maize yield prediction in the state of Sinaloa, Mexico. *Agriculture* 2022;12:525. [CrossRef]
- [45] Javed T, Zhang J, Bhattarai N, Sha Z, Rashid S, Yun B, Kamran M. Drought characterization across agricultural regions of China using standardized precipitation and vegetation water supply indices. *J Cleaner Prod* 2021;313:127866. [CrossRef]
- [46] Proutsos N, Tigkas D. Growth response of endemic black pine trees to meteorological variations and drought episodes in a Mediterranean region. *Atmosphere* 2022;11:554. [CrossRef]
- [47] Zarei AR, Moghimi MM, Bahrami M. Comparison of reconnaissance drought index (RDI) and effective reconnaissance drought index (eRDI) to evaluate drought severity. *Sustainable Water Resour Manag* 2019;5:1345–1356. [CrossRef]
- [48] MoS (Municipality of Sanliurfa). Climate. Sanliurfa: MoS; 2020 Available at: <https://www.sanliurfa.bel.tr/icerik/22/2/iklim> Accessed on Jun 15, 2020.
- [49] GoS (Governorship of Sanliurfa). General information. Sanliurfa: GoS; 2020. Available at: <http://www.sanliurfa.gov.tr/genel-bilgiler> Accessed on Jun 22, 2020.
- [50] Wikipedi. Şanlıurfa districts file. 2021. Available at: https://tr.m.wikipedia.org/wiki/Dosya:%C5%9Eanl%C4%B1urfa_districts.png#file Accessed on Jul 16, 2021.
- [51] MGM (Turkish Directorate General of Meteorological). Meteorological Service, analyses. Ankara: MGM; 2020. Available at: <https://www.mgm.gov.tr/> Accessed on Jun 28, 2020.
- [52] Benek S. Agricultural structure, problems of province of Sanliurfa and recommendations. *Turkish J Geogr Sci* 2006;4:67–91.
- [53] MoEU (Turkish Ministry of Environment and Urbanisation). Sanliurfa province 2017 environmental status report. Sanliurfa: Directorate Environment and Urbanism of Sanliurfa province; 2018.
- [54] MoAF (Ministry of Agriculture and Forestry). Sanliurfa agricultural investment guide. Ankara: Directorate General of Agricultural Reform; 2024.
- [55] Topçu E, Seçkin N. Doğu Akdeniz, Seyhan, Ceyhan ve Asi havzalarında farklı yöntemler kullanılarak kuraklık analizi. *Çukurova Üniv Fen Müh Bil Derg* 2020;39.
- [56] Ullah S, You Q, Sachindra DA, Nowosad M, Ullah W, Bhatti AS, Ali A. Spatiotemporal changes in global aridity in terms of multiple aridity indices: An assessment based on the CRU data. *Atmos Res* 2022;268:105998. [CrossRef]
- [57] Stamm GG. Problems and procedures in determining water supply requirements for irrigation projects. In: Hagan et al, editors. *Irrigation of agricultural lands. Agronomy Monograph 11*. Madison: American Society of Agronomy; 1967. p. 771–784. [CrossRef]
- [58] Tsakiris G, Vangelis H. Establishing a drought index incorporating evapotranspiration. *Eur Water Publ* 2005;9:3–11.
- [59] Tigkas D, Vangelis H, Tsakiris G. DrinC: A software for drought analysis based on drought indices. *Earth Sci Inf* 2015;8:697–709. [CrossRef]
- [60] Yürekli K, Ünlükara A, Yıldırım M. Farklı yaklaşımlarla Karaman ilinin kuraklık analizi. *Tarım Bilimleri Araştırma Derg* 2010;1:19–23.

- [61] Hargreaves GH, Samani ZA. Estimating potential evapotranspiration. *J Irrigation Drainage Div* 1982;108:225–230. [\[CrossRef\]](#)
- [62] Tsakiris G, Loukas A, Pangalou D, Vangelis H, Tigkas D, Rossi G, Cancelliere A. Drought characterization. *Drought Management Guidelines Technical Annex* 2007;58:85–102.
- [63] Mann HB. Non-parametric tests against trend. *Econometrica* 1945;13:245–259. [\[CrossRef\]](#)
- [64] Kendall MG. Rank correlation methods. 2nd ed. New York: Hafner; 1970.
- [65] Çeribaşı G, Doğan E. Trend analysis of average annual precipitation for Black Sea and Sakarya Basins. *Süleyman Demirel Univ Int Technol Sci* 2015;7:1–7.
- [66] Terzioğlu ZÖ, Kankal M, Yüksek Ö, Nemli MÖ, Akcay F. Analysis of the precipitation intensity values of various durations in Trabzon province of Turkey by Şen's innovative trend method. *Sigma J Eng Nat Sci* 2019;37:241–250.
- [67] Mondal A, Kundu S, Mukhopadhyay A. Rainfall trend analysis by Mann Kendall test: A case study of North Eastern part of Cuttack District, Orissa. *Int J Geol* 2012;2:70–78.
- [68] Vishwakarma A, Choudhary MK, Chauhan MS. Non-parametric trend and the validity of a newly developed drought indicator for agricultural application over the central India region. *Arab J Geosci* 2022;15:365. [\[CrossRef\]](#)
- [69] Amognegn AE, Nigussie AB, Adamu AY, Mulu GF. Analysis of future meteorological, hydrological, and agricultural drought characterization under climate change in Kessie watershed, Ethiopia. *Geocarto Int* 2023;38:2247377. [\[CrossRef\]](#)