

Drought Dynamics in Antalya Province over the Last 34 Years: Evaluation of SPI Time Series with CHIRPS Data

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ABSTRACT

The province of Antalya is located in the Mediterranean region of Türkiye and faces an increased risk of drought due to climate change. The objective of this study is to analyse the drought dynamics of the province of Antalya for the period 1990–2024. The analyses are based on 3-, 6-, and 12-month Standardized Precipitation Index (SPI) time series calculated using CHIRPS satellite rainfall data on the Google Earth Engine (GEE) cloud platform. The results indicate that the region has undergone distinct dry and wet cycles over the past 34 years. Frequent occurrences of moderate droughts have been documented in the region. It is also noteworthy that no events classified as extremely dry have been observed in the region on a 12-month time scale. The findings of this study indicate that Antalya is subject to moderate to severe drought conditions, thereby validating the efficacy of GEE and CHIRPS data in facilitating reliable drought analysis in regions characterised by incomplete data coverage. The findings provide a contemporary scientific basis for the management of water resources at the regional level, as well as for the development of strategies to mitigate the effects of drought.

Keywords: Drought, Standardized Precipitation Index (SPI), Climate Change, Google Earth Engine (GEE), CHIRPS, Antalya

Son 34 Yılda Antalya İlindeki Kuraklık Dinamikleri: CHIRPS Verileri ile SPI Zaman Serilerinin Değerlendirilmesi

ÖZ

Antalya ili, Türkiye'nin Akdeniz bölgesinde yer almakta olup iklim değişikliğine bağlı olarak artan kuraklık riskiyle karşı karşıyadır. Bu çalışmanın amacı, Antalya ilinin 1990–2024 dönemine ait kuraklık dinamiklerini analiz etmektir. Analizler, Google Earth Engine (GEE) bulut platformunda CHIRPS uydu yağış verileri kullanılarak hesaplanan 3, 6 ve 12 aylık Standartlaştırılmış Yağış İndeksi (SPI) zaman serilerine dayanmaktadır. Elde edilen sonuçlar, bölgenin son 34 yılda belirgin kurak ve nemli döngüler yaşadığını göstermektedir. Bölgede orta şiddette kuraklık olaylarının sıkça meydana geldiği tespit edilmiştir. Ayrıca, 12 aylık zaman ölçeğinde aşırı kurak olarak sınıflandırılan herhangi bir olaya rastlanmamış olması dikkat çekicidir. Bu çalışmanın bulguları, Antalya'nın orta ile şiddetli kuraklık koşullarına maruz kaldığını ortaya koymakta ve GEE ile CHIRPS verilerinin, veri eksikliklerinin bulunduğu bölgelerde güvenilir kuraklık analizleri yapılabilmesi açısından etkili olduğunu doğrulamaktadır. Elde edilen sonuçlar, bölgesel ölçekte su kaynakları yönetimi ile kuraklığın etkilerini azaltmaya yönelik stratejilerin geliştirilmesi için güncel bilimsel bir temel sunmaktadır.

INTRODUCTION

Drought is one of the disasters that has serious negative effects on agriculture and water resources as a result of global warming and climate change (Acar and Gönençgil 2022; Öz, Özelkan, and Tatlı 2024). The Mediterranean Basin, the region most affected by climate change, is considered a significant region in terms of drought and faces a serious drought risk due to irregular rainfall patterns and rising temperatures (Tsesmelis et al. 2023). Recent studies have highlighted an escalating vulnerability of Türkiye to arid conditions. The country's geographical and topographical characteristics render it particularly vulnerable to drought. Research has indicated that temperature is a contributing factor in the occurrence of drought, with studies noting an increase in arid periods since the 2000s (Acar and Gönençgil 2022; Öz, Özelkan, and Tatlı 2024; Poyrazoğlu and Arıman 2022; Tsesmelis et al. 2023). Research has demonstrated that drought trends exhibit geographical variation. In the study conducted by Dinç et al., the drought situation in Antalya province between 1970 and 2014 was examined, and no significant increase was observed (Dinç et al. 2016). In a similar vein, the study conducted by Söylemez and Kızıl revealed no discernible trend towards aridification in Çanakkale province (Söylemez and Kızıl 2025). However, the study conducted by Poyrazoğlu and Arman found an increase in drought periods in Kahramanmaraş after the 2000s (Poyrazoğlu and Arıman 2022). The observed variations across different geographical regions underscore the intricate nature of drought dynamics at the regional scale. This underscores the necessity for spatially-based analyses to facilitate a comprehensive understanding of these dynamics. It is evident that the distribution and number of meteorological measurement stations in the region do not accurately reflect the pervasive drought conditions that prevail. The utilisation of satellite-based precipitation products is imperative in overcoming this limitation. Among these products, the CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data) dataset is a reliable source for drought studies due to its high spatial and temporal (1981-present) resolution (Dubey et al. 2021; Hanh et al. 2024). GEE environment, with its substantial computational capacity, comprehensive data repository, and cloud-based architecture, has recently emerged as a significant solution for analysing, processing, and visualising these extensive datasets. Numerous studies have confirmed that the GEE platform is an effective tool for drought monitoring and analysis in many regions (Erdoğan and Yılmaz 2024; Khan and Gilani 2021; Mehravar et al. 2021; Sazib, Mladenova, and Bolten 2018). GEE facilitates the calculation of various drought indicators (VCI, VHI, SPEI, SPI, TCI, etc.) and the analysis of their spatial-temporal trends (Taheri Qazvini and Carrion

2023; Zhao et al. 2022). This study aims to analyze the spatial and temporal variations of meteorological drought in Antalya from 1990 to 2024 using CHIRPS satellite rainfall data and the advanced statistical capabilities of the GEE platform. By doing so, the research provides a contemporary scientific basis for the development of effective drought mitigation plans and regional water resource management strategies.

MATERIALS AND METHODS

This section provides a comprehensive overview of the Standardized Precipitation Index (SPI), which serves as the foundation for analysing Antalya's geographical characteristics and meteorological drought. Additionally, it outlines the implementation of this method within the GEE platform.

Study Area

The present study encompasses the province of Antalya, situated on the Mediterranean coast in southwestern Turkiye (see Figure 1). The province of Antalya is situated between 36°07' and 37°29' north latitude and 29°20' and 32°35' east longitude. It is an important location for the country's tourism and agriculture sectors. The region is typified by a Mediterranean climate, marked by hot, dry summers and humid winters.



Figure 1. A map of the study area.

Data

The precipitation data utilised in this study are the CHIRPS dataset, which was developed by the Climate Hazards Group at the University of California, Santa Barbara (UCSB). This particular dataset is notable for its integration of satellite and station data, encompassing the period from 1981 to the present day. It is noteworthy for its spatial resolution of approximately 5 km. In the field of drought studies, this method is frequently favoured due to its ability to provide consistent rainfall data in regions characterised by heterogeneous station distribution (Dubey et al. 2021; Hanh et al. 2024). The present study utilised daily CHIRPS data from 1 January 1990 to 31 December 2024 directly via the GEE platform. The CHIRPS v2.0 dataset is available on the Google Earth Engine cloud platform under the ID 'UCSB-CHG/CHIRPS/DAILY'. The precipitation dataset in question combines satellite data with ground station observations, thereby providing data at a resolution of 0.05° (~5.5 km) (Patel, Desai, and Shah 2025).

Methods

The Standardized Precipitation Index (SPI), as developed by McKee et al. (1993) (McKee, Doesken, and Kleist 1993), was utilised to analyse the drought situation in the province of Antalya. This index is used to express the deviation of the precipitation amount in a specific time interval from the regional precipitation average in terms of standard deviation. The SPI is predicated on the assumption that the total precipitation series over a specific time interval (e.g., 3 months) follows a Gamma probability distribution. The cumulative probability value obtained from this distribution is then converted to a standard normal distribution (Z-score) with a mean of 0 and a standard deviation of 1 to obtain the final SPI value (Guttman 1998). Positive values are indicative of wet conditions, whilst negative values are indicative of arid conditions. In this study, SPI time scales reflecting seasonal droughts (SPI-3, 3-month), medium-term trends (SPI-6, 6-month), and long-term hydrological droughts (SPI-12, 12-month) were calculated. The standard SPI ranges provided in Table 1 were utilised to classify drought severity.

Table 1. Drought Classification Based on SPI Values (McKee, Doesken, and Kleist 1993)

SPI Value	Drought Class
0.0 to -0.99	Near-Normal
-1.0 to -1.49	Moderate Drought
-1.5 to -1.99	Severe Drought
≤ -2.0	Extreme Drought

The workflow of the study is presented in Figure 2. The data processing and analyses were performed using the GEE platform, which facilitates the processing of large-scale geographic datasets (Gorelick et al. 2017). Initially, precipitation data from the CHIRPS database were filtered for the 1990-2024 time period within the GEE framework. The daily data were converted into cumulative precipitation data for each month to obtain monthly total precipitation data. Subsequently, employing the functions available in GEE, SPI values were calculated for each pixel at 3-, 6-, and 12-month time scales. The computational processes in the study were performed on GEE using customized algorithms via a code editor. The daily CHIRPS data were aggregated for each month using the `.sum()` function to obtain monthly total precipitation series. The moving window technique was employed to calculate SPI-3, SPI-6, and SPI-12 values, with the cumulative totals being utilized for this calculation. The index values were obtained by subtracting the mean from the cumulative precipitation series and dividing by the standard deviation (Z-score standardization). The `ee.Reducer.mean()` and `ee.Reducer.stdDev()` functions were utilized at a resolution of 5,000 meters (scale: 5,000) to extract regional statistics. Moreover, the decadal analysis and frequency distributions of drought events were calculated using automated functions based on the thresholds determined by McKee et al. (Table 1). Finally, the mean of the pixels containing the SPI value within the boundaries of Antalya province was taken to create a time series characterising the region for each time scale. Temporal trends were identified, and drought periods were analysed on the obtained series. To assess the magnitude and statistical significance of drought trends, the Mann-Kendall (MK) trend test and Sen's slope estimation method were used. The MK test is a statistical method used to evaluate the presence of a continuous increase or decrease trend in time series data (Mann 1945). In contrast, Sen's slope calculates the quantitative rate of change over time (Sen 1968). All analyses were conducted at a 95% confidence level ($\alpha = 0.05$), employing the 'pyMannKendall' library within the Python programming language (Hussain and Mahmud 2019).

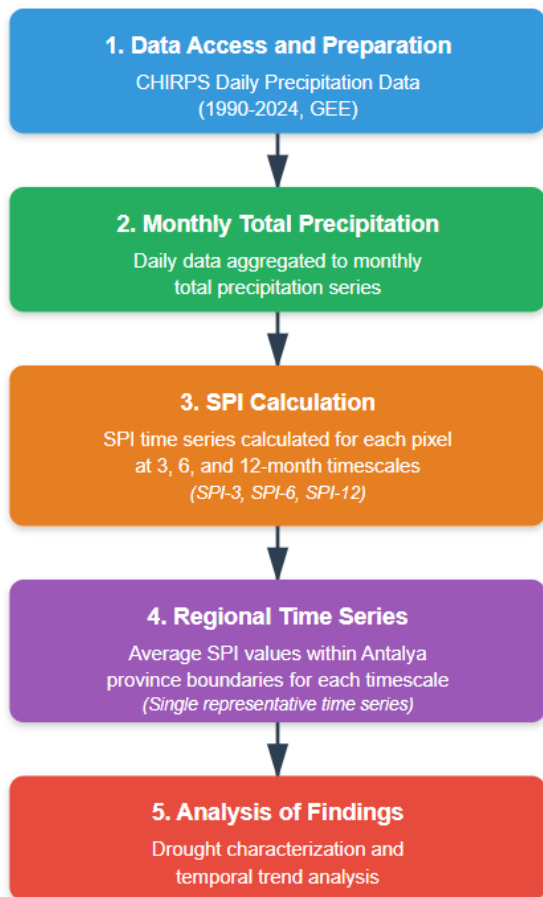


Figure 2. Flowchart

RESULTS AND DISCUSSION

In this section, the temporal characteristics of meteorological drought in the region encompassing the province of Antalya between 1990 and 2024 were examined using the CHIRPS precipitation dataset and SPI values calculated on the GEE platform. The findings are based on the analysis of SPI values at 3-, 6-, and 12-month time scales.

General Trends and Time Series Analysis (SPI-3, SPI-6, and SPI-12)

The SPI-3, SPI-6, and SPI-12 time series calculated within the scope of this study revealed that there are seasonal fluctuations in Antalya's rainfall regime and that dry/wet conditions vary according to time scales (Figure 3). The SPI values calculated at all scales exhibited regular oscillation in both positive and negative directions. The MK test results confirmed that there is no statistically significant trend toward aridification or humidification in Antalya province ($p > 0.05$) (Table 2). For the SPI-12 series, which demonstrates the impact of prolonged hydrological conditions, the Z-value was

determined to be -0.0923 , the p-value was 0.9264 , and Sen's slope was -0.000028 . Analogous outcomes were noted for SPI-3 ($Z = 0.0456$, $p = 0.9637$) and SPI-6 ($Z = -0.0694$, $p = 0.9447$). This finding suggests that, despite the fluctuations between dry and wet periods observed during the 34-year study period, there is no discernible long-term or permanent change trend in Antalya's precipitation regime. The SPI-12 curve is indicative of prolonged drought conditions, with precipitation anomalies in the region being clearly evident. The recent drought is a noteworthy drought event in terms of its intensity and duration within the time period examined. Conversely, the periods 1998–1999 and 2010–2013 are noteworthy as discrete wet periods, with the SPI-12 persisting in the positive range.

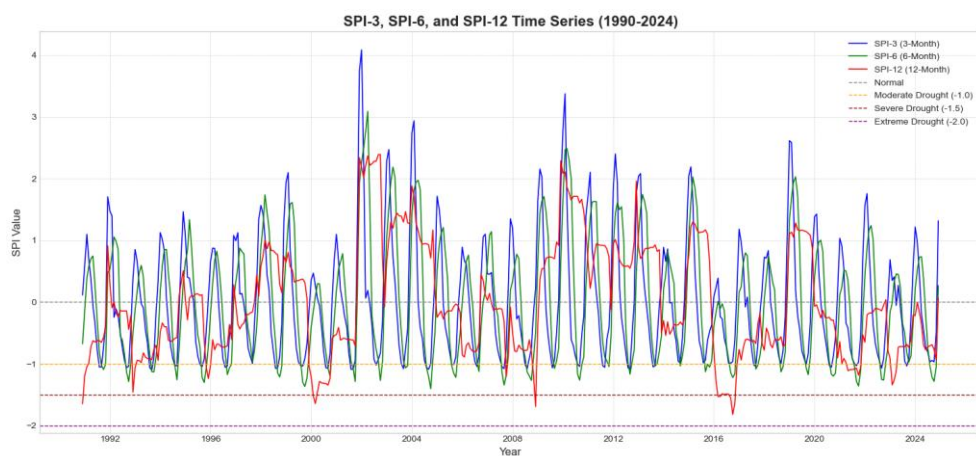


Figure 3. Three-month (SPI-3), six-month (SPI-6), and twelve-month (SPI-12) SPI time series for Antalya for the period 1990–2024.

When these time scales are compared, a significant differentiation is observed:

- SPI-3 demonstrates sensitivity to short-term rainfall changes, reflecting sudden rainfall anomalies. Upon examination of the graph, it becomes evident that it fluctuates in both positive and negative directions.
- SPI-6 has been demonstrated to characterise both short- and medium-term drought effects with greater efficacy than SPI-3, offering a smoother transition. However, it remains sensitive to sudden rainfall deficits.
- The SPI-12 index has been demonstrated to be a reliable indicator of long-term hydrological drought trends within the region, with the ability to filter out short-term fluctuations.

In this context, a comprehensive assessment of the three time scales reveals both the long-term and short-term meteorological effects of drought in the Antalya region.

Table 2. Mann-Kendall Trend Test and Sen’s Slope Results for SPI Series (1990–2024)

SPI Scale	Z-value	p-value	Sen’s Slope	Trend
SPI-3	0.0456	0.9637	0.000010	No Trend
SPI-6	-0.0694	0.9447	-0.000021	No Trend
SPI-12	-0.0923	0.9264	-0.000028	No Trend

Seasonal Distribution of Drought (SPI-12 Analysis)

In order to analyse the frequency and severity of prolonged droughts in the province of Antalya, drought classification was performed over a 408-month time series spanning 1990–2024 (see Figure 4). The analysis yielded results that indicated the presence of moderate drought conditions over a period of 34 months. This finding suggests that this is the most frequently observed intensity level of long-term drought events in the region. A comprehensive analysis of severe drought events revealed that these conditions persisted for a duration of nine months. It was ultimately determined that no month was designated as extreme drought ($SPI \leq -2.0$) during the period under review (1990-2024). This finding suggests that the province of Antalya has not experienced a protracted and exceptionally severe drought in the last 34 years.

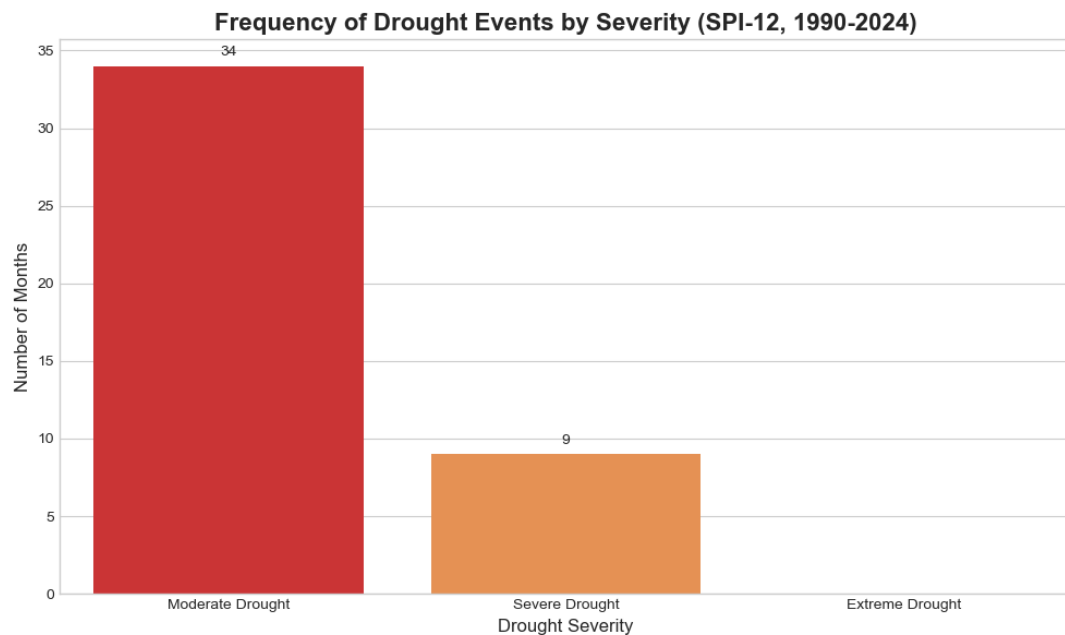


Figure 4. Monthly frequency distribution of drought events occurring in Antalya according to their severity levels based on the SPI-12 index during the period 1990–2024.

Seasonal Distribution of Drought (SPI-12 Analysis)

In order to comprehend the seasonal characteristics of drought and wet conditions, an examination was conducted of the distribution of SPI-12 values by month (see Figure 5). The monthly median SPI-12 values remained close to the zero line throughout the year, indicating that no particular month was drier or wetter than the others. However, the slight shift of the median values into the slightly negative region in September, October, and November indicates that the drought trend increases somewhat at the beginning of autumn. A salient feature of the monthly distributions is the wide range of values observed in January, February, and March. The presence of both higher and lower extreme values during these months indicates that winter represents the most variable period of the year in terms of aridity and wet conditions. This phenomenon underscores the heightened probability of precipitation anomalies in these months, giving rise to both severe droughts and excessively wet conditions. Conversely, the distribution appears marginally more balanced in the middle of the year (particularly in the May-August period), and it can be posited that the variability of hydrological conditions during these periods is more constrained within the year.

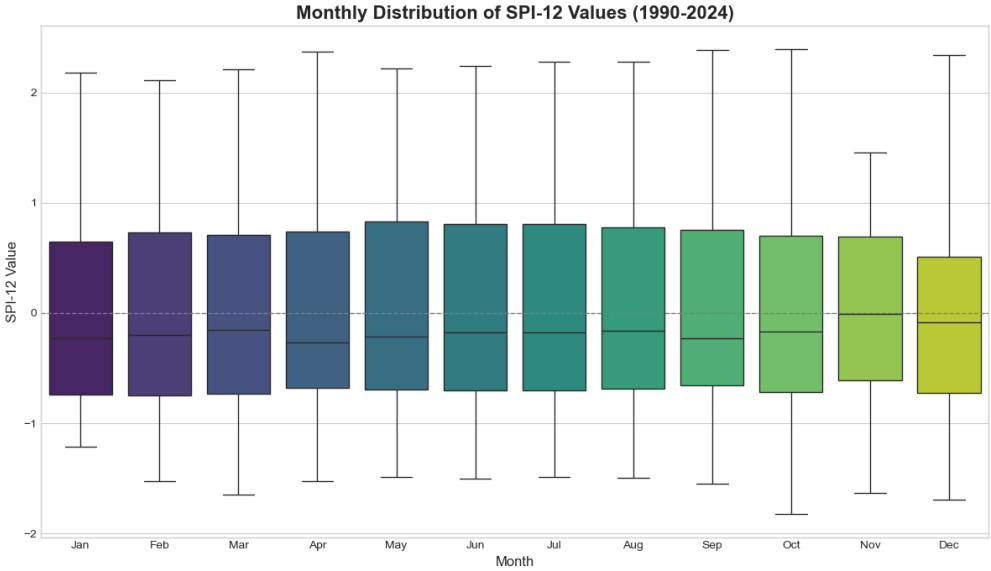


Figure 5. Distribution of SPI-12 values by month for the period 1990–2024.

Discussion

The present study analysed the meteorological drought dynamics in Antalya between 1990 and 2024 using CHIRPS satellite-based rainfall data and the GEE platform with SPI. The results indicate that Antalya has experienced both prolonged drought and distinct wet periods over the last 34 years. Of particular note are the periods following 2017 and 2021–2024, during which SPI-12 values remained continuously in the negative range, constituting the most severe and persistent drought periods of the study period. The results obtained in this study are consistent with those reported in the extant literature. Dinç et al. (2016) did not detect a statistically significant drought trend in the period 1970–2014, which is consistent with the findings of our study up to 2014 (Dinç et al. 2016). However, as the current study covers more recent data, it provides a complementary contribution to the existing literature, as the marked increase in drought after 2017 indicates that regional climate dynamics may have changed over the last decade. Despite the absence of statistically significant trends in SPI series over a 35-year period, extant literature indicates that seasonal variations can impact the outcomes. Mahnamfar and Nigusie's (2023) analysis revealed substantial drought trends across the majority of stations, particularly on the SPI-12 scale, during the period spanning from 1970 to 2007 (Mahnamfar 2023). A similar observation was reported in the study by Ercan et al. (2026), which covered a broader time frame (Ercan, Abu, and Şişman 2025). The "no trend" result in our study may be due to the wet years at the beginning of the analysis period balancing out the recent dry years; however, the negative SPI values observed after 2017 are consistent with the aridification signals indicated by Ercan et al. (2025). As demonstrated in the studies conducted by Öz et al. (2024) and Tsesmelis et al. (2023), there is an increasing trend of drought in Türkiye and the Eastern Mediterranean region (Öz, Özelkan, and Tatlı 2024; Tsesmelis et al. 2023). The original contribution of this study lies in its presentation of the temporal characteristics of drought in areas with a heterogeneous station network using satellite-based CHIRPS precipitation data. This approach has been shown to reduce the representativeness issues encountered in traditional analyses based on station data, providing a more reliable assessment for the region. The reliability of CHIRPS data has been confirmed in related studies, thereby validating the method. The absence of any month falling into the extreme drought category ($SPI \leq -2.0$) is a noteworthy result, suggesting that the region has been relatively protected thus far. However, the persistence of moderate and severe droughts indicates the region's vulnerability from a hydroclimatological perspective. As with any study, this one also has certain limitations. Despite the fact that CHIRPS data is station-supported, no validation process has been carried out with existing stations in the region. Moreover, it should be noted that the drought analysis is solely rainfall-based; consequently, it fails to consider the impact of rising temperatures on drought. The utilisation of

indices such as the SPEI, encompassing temperature and evapotranspiration, will ensure more precise and comprehensive results in forthcoming studies. In a similar manner, the evaluation of vegetation cover (VCI, VHI), soil moisture, and evaporation data will also contribute to a more detailed analysis of the ecosystem and agricultural impacts of drought.

CONCLUSION(S)

The present study has revealed the meteorological drought cycles in the province of Antalya between 1990 and 2024 using SPI values calculated from CHIRPS rainfall data. The results indicate that moderate and severe droughts are persistent in the region and that no event has been classified as extreme drought. However, the findings indicate the presence of a distinct drought peak, particularly between 2021 and 2024. The findings indicate that the SPI is a reliable method for evaluating drought trends; however, the incorporation of SPEI and analogous temperature-sensitive indices will be essential to account for projected temperature increases. This study provides contemporary scientific information for the management of water resources and drought adaptation strategies in Antalya.

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Declaration of interests

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions

1st İsmail Yılmaz : Conceptualization; data curation; formal analysis; investigation; methodology; software; writing—original draft; writing—review and editing...

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