Levantine Journal of Applied Sciences, Volume 5 (1) (2025) 1-8

Levantine Journal of Applied Sciences

journal homepage: https://www.ljoas.com

Assessment of Drought in the Cekerek River Basin with Satellite-Based Palmer Drought Severity Index (PDSI)

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Keywords

Drought, Palmer Drought Severity Index,
Satellite-based Palmer Drought Severity Index,
Inovative Trend Analysis,
Drought Severity,
Cekerek River Basin

ABSTRACT

Drought-related outcomes, such as a decline in agricultural production and crop quality and a shift in diversity, result in significant socio-economic issues. Therefore, drought monitoring is essential to boost agricultural output, safeguard the environment, and minimize financial losses in drought-prone areas. The fact that drought cannot be observed instantly like natural disasters makes it possible to take necessary precautions on a basin basis. In this direction, in this study, the Palmer Drought Severity Index (PDSI) was determined in the Çekerek River Basin with satellite-based data. According to the results obtained, extreme drought events were observed at all stations in May 2021. The highest number of extreme drought events occurred at Çamlıbel station (51 events). The number of extreme humid events varied between 2 and 15, and the highest number of humid events were observed at Çamlıbel (15 events) and Yeşilyurt (15 events) stations. The drought trend status of the basin was evaluated with Innovative Trend Analysis (ITA). According to ITA results, a decreasing trend was detected at Çekerek, Çamlıbel and Yeşilyurt stations. Overall, it was determined that the drought status of the basin tended to exacerbate according to satellite-based PDSI values.

1. Introduction

Drought is an important natural event that threatens both humans and all natural systems. It is a slowly starting and naturally recurring event that affects different environmental systems around the world [1]. Although drought develops slowly, it causes great effects on regional ecology, hydrology and economy. This is because the recovery process can take a long time after the drought ends [2], [3]. The severity of climate-related events such as floods and droughts increases with the effect of global warming on the hydraulic cycle [4], [5]. Drought has wide-ranging effects on surface and groundwater resources, agricultural production, water consumption, energy production and various other socio-economic issues. The effects of drought go beyond environmental dimensions and affect society in many sectors [4], [6]. It is emphasized that the damage caused by drought is approximately eight billion dollars [7], [8]. This situation is especially important in regions with arid and semiarid climates.

Drought is generally defined as precipitation occurring less than the long-term average. It could be of different types: meteorological, agricultural, hydrological and socioeconomic drought [9], [10], [4]. Meteorological drought is caused by a lack of precipitation. This situation leads to water shortages due to the imbalance between precipitation and evaporation. Agricultural drought leads to a lack of water required for plant growth, and the water intake and consumption of plants become unbalanced due to various external factors. Hydrological drought refers to the inadequacy of surface water and groundwater supply. Socioeconomic drought is the undesirable social and economic effects caused by the combination of these three drought types [11], [12], [13], [14].

With the increase in drought, the occurrence of very large water shortages makes the sharing and management of water resources even more difficult [15]. Drought is a natural disaster that is continuous and the dry periods experienced today are of

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http://dx.doi.org/10.56917/ljoas.22

great importance in terms of showing the dimensions of the danger that Türkiye will face in the future [16]. In addition, the fact that Türkiye is under the influence of the Mediterranean climate causes many natural disasters such as drought, floods, forest fires, earthquakes, landslides and erosion due to global climate change [17].

Drought is generally defined by its severity, duration and frequency [18]. With the severity, periodicity and randomness of drought and the increasing frequency and effects of drought in recent decades, research on drought has become increasingly important worldwide [14]. Similarly, it was stated that being aware of the severity, duration, frequency and effects of drought is important for plans to reduce the effects of drought [19]. Therefore, it is important to use various drought indices for timely and accurate monitoring of drought conditions.

It is not possible to prevent the drought events that affect the world with current technologies. Studies show that although it is not possible to eliminate drought, its impact and prevalence can be reduced. Common drought monitoring and assessment methods are based on station-based meteorological data. For example, Palmer Drought Severity Index (PDSI) [11], Standardized Precipitation Index (SPI) [20] and Standardized Precipitation Evapotranspiration Index (SPEI) [1] are widely used to monitor drought. Meteorological data are not sufficient to monitor drought because they are incomplete or incorrect at different stations in the same region. Satellite-based data provide significant convenience in determining the time and severity of drought [21]. It was emphasized that when meteorological data are integrated with remote sensing data, drought monitoring can provide more comprehensive, reliable and accurate results [22], [23], [24]. Specific agricultural drought index (SWDI) was calculated based on soil moisture content and soil water parameters for an agricultural area in Spain using data from SMOS (Soil Moisture and Ocean Salinity) satellite [25]. The indices calculated using soil moisture parameters obtained from satellite data with ground measurements were compared. In another study, scPSDI and SPEI indices, which are widely used to monitor drought in China between 1961-2011, were compared [26]. Similarly, using climate data from 17 meteorological stations in the Aegean Region of Türkiye between 1980-2000, Aydeniz drought model was compared with PDSI index, which is widely used in drought studies [27]. The dominant drought periods, the beginning, end and severity of drought in Konya, Karaman, Aksaray and Karapınar stations in the Konya Region of the Central Anatolia Region was determined using PDSI [28]. Using temperature and precipitation data from 96 meteorological stations in Turkey and useful soil water holding capacity (AWHC) data from the 1-m soil depth dataset of ORNL DAAC in the USA, values for past significant drought years were calculated according to the PDSI index [29]. In a study performed in the Aegean Region of Türkiye, the relationship and frequency between the drought indices (VHI, VCI, TCI) calculated from satellite-derived data and the drought index (SPEI) calculated from meteorological data were determined [30].

The main purpose of the present study was to evaluate the agricultural drought of Çekerek Basin, which is located in Yeşilırmak basin and has a high probability of drought due to its location, with the satellite-based PDSI index. PDSI is preferred by many researchers to evaluate different drought types. Researchers such as [13] and [31] used PDSI as an agricultural drought index in their studies. The procedures performed to achieve the main objective of the study were as follows: a) downloading satellite-based monthly PDSI maps and determining drought index values in the ARCMAP program, and b) determining the trend of the obtained PDSI values with Innovative Trend Analysis (ITA).

2. Material and Method / Experiment

The Çekerek River Basin is located between latitudes 39° 30' and 40° 45' N and longitudes 35° 15' and 36° 15' E. This area is approximately 1,165,440 hectares and constitutes approximately 1.5% of the total area of Türkiye. The Çekerek River Basin, located in the central part of Turkey, is an important sub-basin of the Yeşilırmak Basin, one of the country's largest water collection basins. The Çekerek Basin covers parts of the provinces of Tokat, Amasya, Sivas, Çorum and Yozgat. Therefore, it is located in a transition zone between the Central Anatolia and Black Sea regions.

In this study, PDSI maps of the relevant stations from the Terra Cilimate database were used as material in determining satellite-based PDSI values (Table 1). The geographical map of the study area and the locations of the stations on the basin are given in Figure 1.

Table 1. Some features of the stations used in the study

Stations	Longitude (East)	Latitude (North)	Year of record
Cekerek	40.08975	35.51139	1990-2023
Camlibel	40.04514	36.39951	1990-2023
Sulusaray	39.97968	36.0888	1990-2023
Yesilyurt	40.03515	36.21929	1990-2023
Zile	40.2976	35.86523	1990-2023

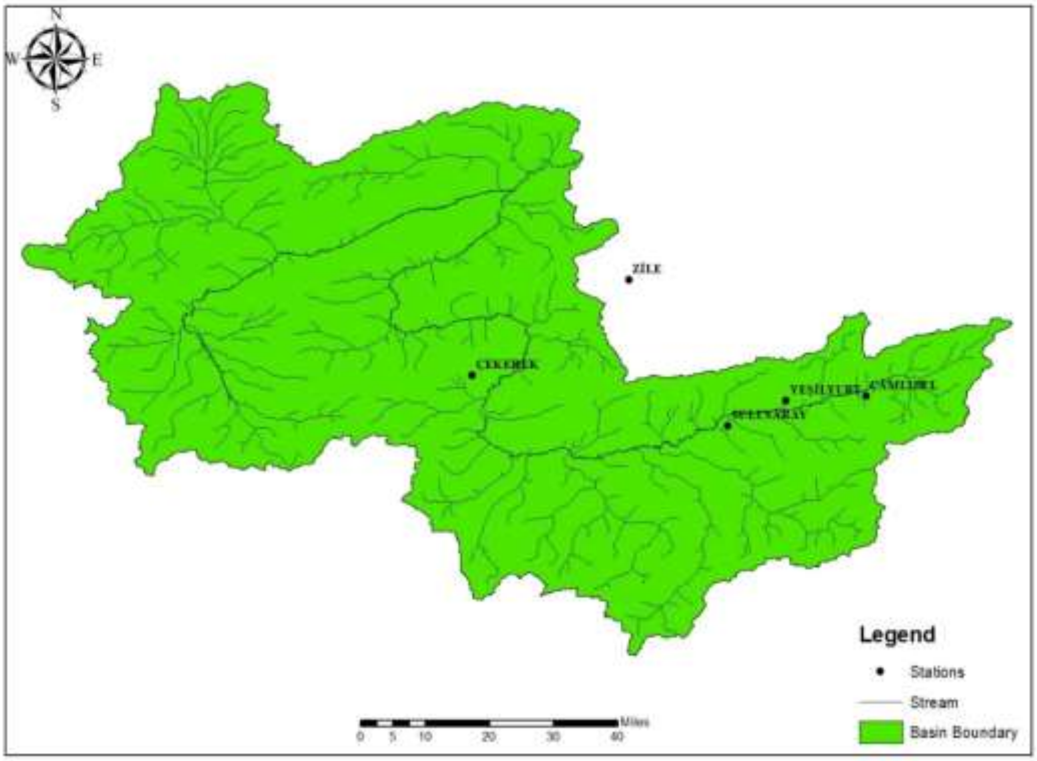


Figure 1. Study basin and locations of stations on the basin

2.1. Palmer Drought Severity Index (PDSI)

This index, developed by Palmer [11], uses monthly climate data to determine drought severity and focuses on regional water balance calculations. Palmer developed this index to statistically standardize anomalies between drought and humidity.

In the study, the climatic water balance is modeled using basic inputs such as monthly mean temperature, monthly total precipitation and soil water content. In the calculation process, an empirical approach is used to define the moisture accumulation structure by dividing the soil layer vertically into two parts. The upper layer is assumed to hold approximately 25 mm of the field capacity's available water. Rainfall and evaporation take place in this stratum. The plant's effective root depth and the properties of the soil determine how much water is available in the lower layer of the soil. In order to meet the water requirement, PET must first occur, then the soil must become saturated and then surface flow must occur.

Moisture loss in the upper soil layer (L_S) or (PET-P) and moisture loss from the lower layer (L_U) are calculated with the formulas given in Equations 1 and 2.

$$L_S = min[\, S_S,\ (PET - P)] \tag{1}$$

$$L_U = [(PET - P) - L_S]\frac{S_U}{AWHC}, \qquad L_U \leq S_U \tag{2}$$

Here, S_S is the initially available water amount in the upper layer; PET is the potential evapotranspiration calculated according to the Thornthwaite method for that month; P is the monthly total precipitation amount for the same month; S_U is the available water amount stored in the lower soil layer at the beginning of the month and AWC is the total available water amount in both layers.

In the Palmer approach, several parameters are required for the water balance. These are; potential recharge (PR); potential loss (PL) and potential surface runoff (PRO). Potential recharge is the amount of water required to bring the soil to field capacity and is calculated by Equation 3.

$$PR = AWHC - S \tag{3}$$

Here, S is the available water amount in both layers of the soil at the beginning of the month.

Potential loss (PL) is the amount of water that could be lost from the soil if there is no precipitation and is calculated based on Equation 4.

$$PL = PL_S + PL_U \tag{4}$$

Here, PL_S is the potential loss in the upper layer of the soil while PL_U is the potential loss in the lower layer and is calculated as shown in Equations 5-6.

$$PL_S = min[PET, S_S] \tag{5}$$

$$PL_U = (PET - PL_S)\frac{S_U}{AWHC}, \qquad PL_U \leq S_U \tag{6}$$

Palmer (1965) defined potential surface runoff as a function of the amount of available water in the soil. This function is simply given by Equation 7.

$$PRO = AWHC - PR = S \quad (7)$$

Using the four potential values obtained (PET, PR, PL and PRO), four coefficients required for climatic calculations are determined. These are evapotranspiration coefficient (α), recharge coefficient (β), surface runoff coefficient (γ) and moisture loss coefficient (δ). The coefficients are calculated separately for each of the 12 months. The coefficients are used to calculate the difference (d) between the total precipitation (P) for each month and the suitable precipitation ($\hat{P}$) created by the climatological conditions in the relevant month.

$$d = P - \hat{P} \quad (8)$$

$\hat{P}$ expression given in Equation 8 is calculated by Equation 9:

$$\hat{P} = \alpha PET + \beta PR + \gamma PRO + \delta PL \quad (9)$$

Coefficients given in Equation 9 is calculated by Equation 10:

$$\alpha = \frac{\overline{ET}}{\overline{PET}},\ \beta = \frac{\bar{R}}{\overline{PR}}, \gamma = \frac{\overline{RO}}{\overline{PRO}}, \delta = \frac{L}{PL} \quad (10)$$

Here ET; evapotranspiration, PET; potential evapotranspiration, R; soil water recharge, PR; potential soil water recharge, RO; flow, PRO; potential flow, L; loss water, PL; potential loss water.

After calculating the value given in Equation 8, the Palmer Moisture Anomaly Index given in Equation 11 is calculated.

$$Z = K \times d \quad (11)$$

Here, K is the weight factor of the relevant month. The weight factor is calculated with Equation 12. It represents the regional climate correction coefficient K' given in the equation.

$$K = 17.67 \frac{K'}{\sum_{i=1}^{12} \bar{D} \times K'} \quad (12)$$

$$K' = 1.5 \times \log_{10}\left[\left(\frac{M' + 2.8}{\bar{D}}\right)\right] + 0.5 \quad (13)$$

$$M' = \left(\frac{\overline{PE} + \bar{R} + \overline{RO}}{\bar{p} + \bar{L}}\right) \quad (14)$$

Finally, the PDSI value is calculated with the help of Equation 15.

$$X_i = 0.897 X_{i-1} + \frac{Z_i}{3} \quad (15)$$

Table 2 shows the classification of drought values according to PDSI. Although the values vary between -4 and 4, values smaller than -4 and larger than 4 can also be calculated.

Table 2. The drought classes by PDSI drought indices

PDSI Value	Drought Classifications
≥ 4	Extremely wet
3.00 – 3.99	Very wet
2.00 – 2.99	Moderate wet
1.00 – 1.99	Slightly wet
0.50 – 0.99	Incipient wet spell
0.49 – (-0.49)	Normal
-0.50 – (-0.99)	Incipient drought spell
-1.00 – (-1.99)	Mild drought
-2.00 – (-2.99)	Moderate drought
-3.00 – (-3.99)	Very drought
≤ -4	Extreme drought

2.2. Satellite image data

Satellite-based PDSI data were obtained from http://www.climatologylab.org/terraclimate.html database. TerraClimate is a dataset of monthly climate and climatic water balance for global terrestrial surfaces for the years 1958-2019. These climate data are generated by merging CRU (Climate Research Unit TS 4.0) and JRA-55 (Japanese 55-year Reanalysis) data. In addition, it has been validated with Global Historical Climatology Network (GHCN) station data and converted into a 4 km high-resolution spatial data. These high-resolution data provide a reliable source for detailed climate analysis and water balance calculations. The data covers the period 1958-2023. The data is updated periodically.

2.3. Innovative Trend Analysis

According to this approach proposed in [32], the existing data is divided into two parts without considering which distribution the data fits and their increasing alignment is made. Two data groups with increasing alignment are positioned against each other in a coordinate system perpendicular to each other, according to a line with a slope of 1:1 or 45°. Thus, the change in the data is interpreted according to whether the positioned data is above, below and above the 1:1 line. If the positioned data is on the line, it is decided that there is no change in the data, if it falls below the line, it is concluded that there is a decreasing change in the data, if it falls above the line, it is concluded that there is an increasing trend in the data. [33] also presented the statistical significance test of this test. The decision of whether this test is statistically significant or not is based on the comparison of the means of the sub-series. For this purpose, the calculated slope value (S_{cal}) of the considered data is compared with the critical slope (S_{crit}) values and it is concluded whether the change in the data is statistically significant or not. The calculated slope value is calculated with Equation 16.

$$S_{cal} = \frac{2(\bar{y}_2 - \bar{y}_1)}{n} \quad (16)$$

In the equation, $\bar{y}_1$ and $\bar{y}_2$ are the averages of the two series of the original data while "n" is number of observations. Standard deviation of the calculated slope (σ_S) is obtained by Equation 17.

$$\sigma_S = \frac{2\sqrt{2}}{n\sqrt{n}} \sigma \sqrt{1 - \rho_{\bar{y}_1, \bar{y}_2}} \quad (17)$$

The terms "$\rho_{\bar{y}_1, \bar{y}_2}$" and "$\sigma$" in the equation represents correlation coefficient and standard deviation of the original data. The confidence interval of the calculated slope at the 5% significance level is obtained with Equation 18.

$$CI_{(1-\alpha)} = 0 \pm S_{crit} \sigma_S \quad (18)$$

In the equations above, the ''S_{crit}'' value is equal to the ±1.96 value obtained from the standard normal distribution table for a 5% significance level.

3. Results and Discussion

3.1. Satellite-based PDSI results

One-year PSDI maps between 1990-2023 were downloaded from the TerraClimate database. The downloaded maps have the extension '.nc'. First, these maps were converted to raster format maps. The converted maps were loaded into the ARCMAP software to obtain monthly PDSI data. The temporal graphs of the satellite-based PDSI results are given in Figures 2-6.

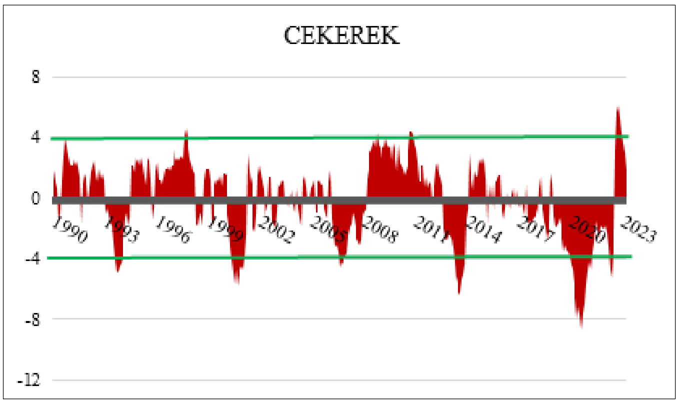


Figure 2. Temporal graph of satellite-based PDSI values for Çekerek

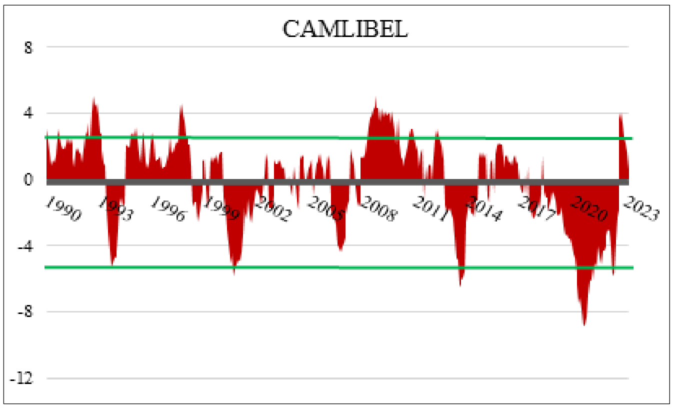


Figure 3. Temporal graph of satellite-based PDSI values for Çamlıbel

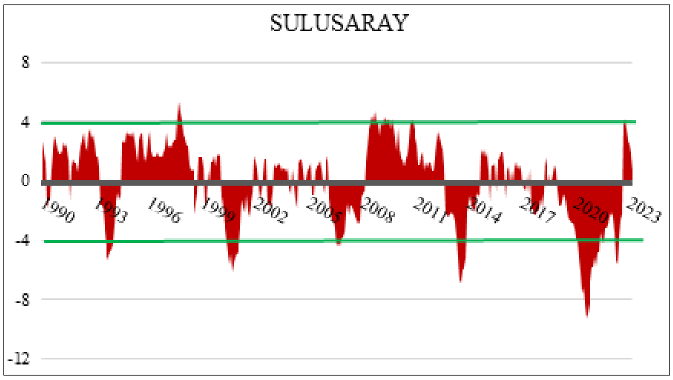


Figure 4. Temporal graph of satellite-based PDSI values for Sulusaray

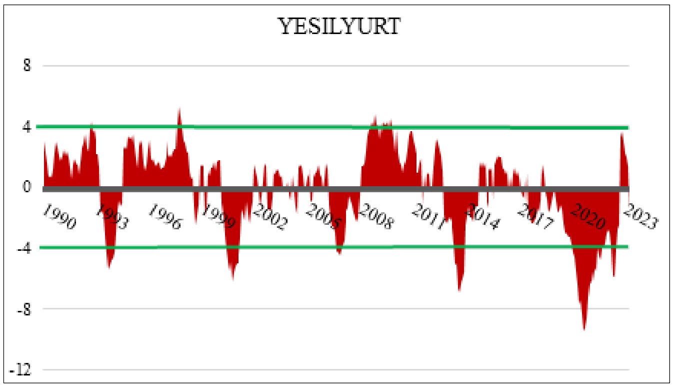


Figure 5. Temporal graph of satellite-based PDSI values for Yeşilyurt

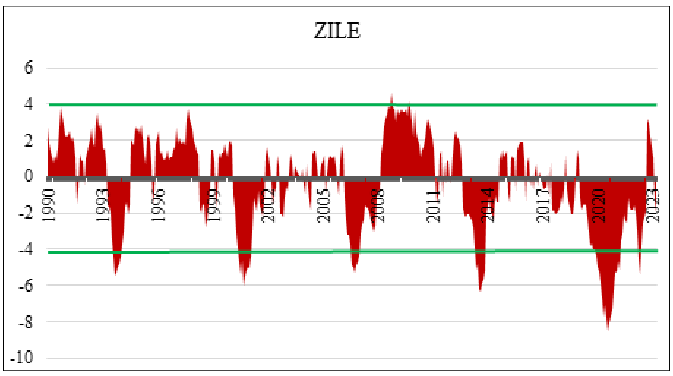


Figure 6. Temporal graph of satellite-based PDSI values for Zile

When satellite-based PDSI graphs are examined, the driest event at Çekerek station occurred in May 2021 (PDSI: -8.64). Forty-two extremely dry events were detected. The driest year at Çamlıbel station was determined as 2021, and all months of that year were extremely dry. The driest event was observed in May with a PDSI data of -8.9. Fifty-one extremely dry events occurred at Çamlıbel station. When Sulusaray station is examined, while all months of 2021 were extremely dry, the driest month was May with a PDSI value of -9.31. Forty-six extremely dry events were observed at this station. All months of 2021 were extremely dry at Yeşilyurt station. The driest month was May with a PDSI value of -9.81. Forty-nine extremely dry events occurred at this station. Finally, 2021 was extremely dry at Zile station. The driest event occurred in May with a PDSI value of -8.54. Forty-six extremely dry events were detected at Zile station. These results are given in Table 3.

Table 3. Comparison of PDSI calculated with meteorological data and satellite-based PDSI values

Satellite-based PDSI	Extremely dry year	Extremely dry month	Extreme drought value	Number of extremely dry events (<-4)	Number of extremely wet events (>4)
Cekerek	2021	May	-8.64	42	10
Camlıbel	2021	May	-8.9	51	15
Yesilyurt	2021	May	-9.31	49	15
Sulusaray	2021	May	-9.81	46	12
Zile	2021	May	-8.54	46	2

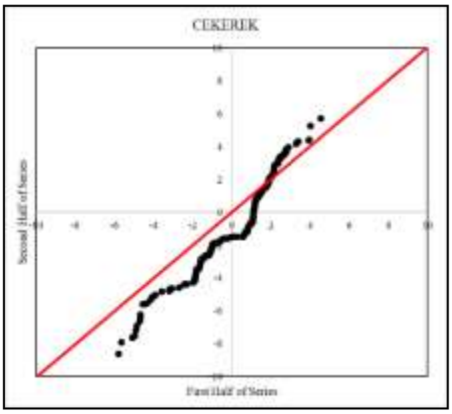
3.2. Results of Innovative Trend Analysis (ITA)

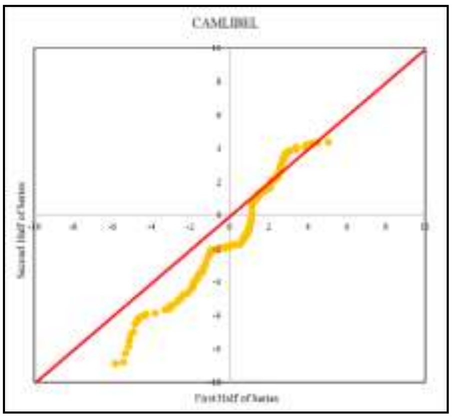
Both statistical and graphical analysis were done for ITA in the study. ITA graphs of five stations in the study area are given in Figure 7.

The monthly PDSI data were subjected to a statistical ITA test, which yielded the upper and lower critical limit values at a 95% confidence level. Based on the test results, it is accepted that there is no trend when the trend slope is between the confidence levels, that there is a trend that is decreasing when it is below the lower confidence level, and that there is an increasing trend when it is higher than the upper confidence level. The ITA test findings for the monthly PDSI drought severity values at the 95% significant level are displayed in Table 4. It is evident from the table that Çekerek, Çamlıbel and Yeşilyurt stations have a statistically significant decreasing trend. This finding indicates that drought tends to increase at these stations. No significant trend was detected at Sulusaray and Zile stations.

Table 4. ITA test results of the stations

Station	Slope	Correlations	Slope of SD	Lower CL	Upper CL	Conclusion
Cekerek	**-0.0084**	-0.1421	0.0029	-0.0056	0.0056	Decreasing
Camlıbel	**-0.0114**	0.0358	0.0028	-0.0055	0.0055	Decreasing
Yesilyurt	**-0.0127**	-0.0204	0.0029	-0.0057	0.00572	Decreasing
Sulusaray	-0.0110	-0.0572	0.0029	-0.0057	0.0057	No Trend
Zile	-0.0107	-0.1278	0.0028	-0.0055	0.0055	No Trend





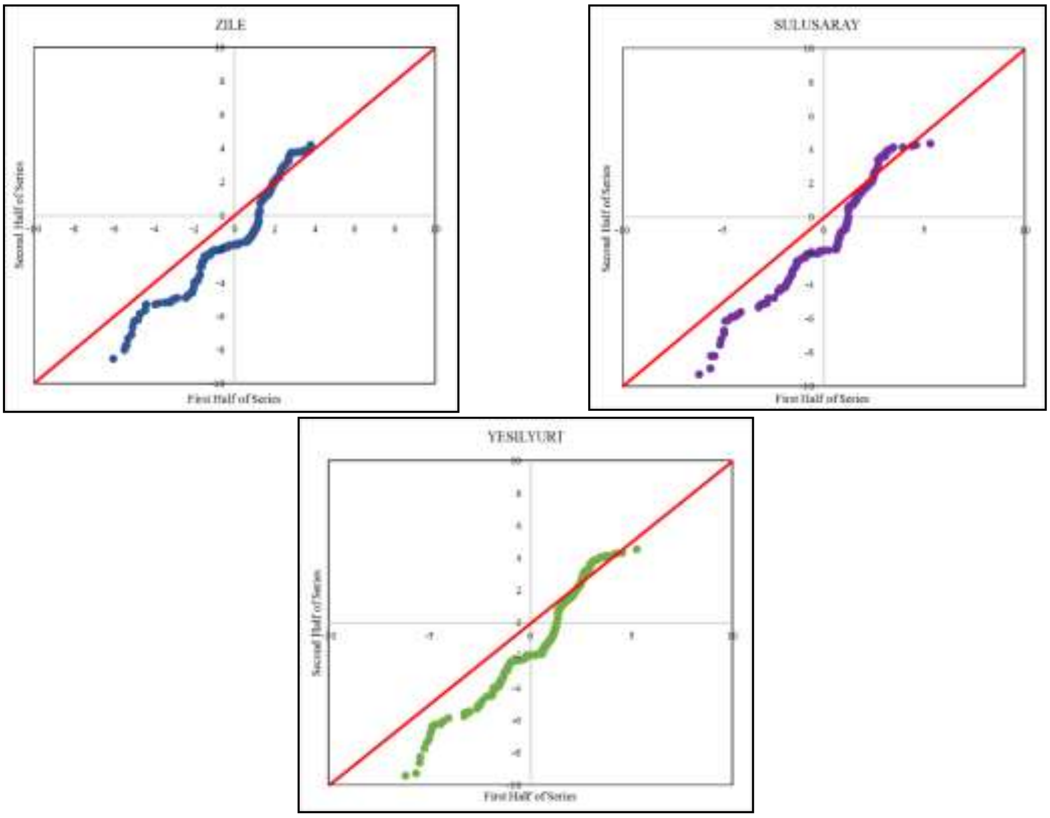


Figure 7. ITA graphics of PDSI drought severity values

Meteorological data is generally preferred in drought monitoring and assessment studies. However, drought monitoring studies are negatively affected in cases where meteorological data is missing or insufficient. Satellite-based drought indices are preferred to eliminate this deficiency. The SPI drought index in South Korea was compared using satellite-based precipitation data and station-based precipitation data [34]. According to the results obtained, satellite-based precipitation estimates offered significant advantages in terms of spatial coverage, timely information provision and cost effectiveness compared to meteorological data in drought assessments. Erdem et al. [35] stated in their study that the analysis results obtained from satellite images and the SPI values obtained from precipitation data were highly compatible with each other. As a result of the study, they emphasized that satellite images can be used successfully in drought analysis. Türkyılmaz et al. [36] compared thermal satellite images and air temperature measured from meteorological stations. They stated that the air temperature value obtained from satellite images showed a high accuracy relationship with meteorological stations under homogeneous land cover conditions. Çelik and Karabulut [24] stated in their drought analysis study in the Antalya region that satellite-based vegetation index models provide significant convenience in understanding and predicting the drought phenomenon.

4. Conclusion

Turkey is located in the Mediterranean basin, so the risk of drought is quite high. With the increasing impact of climate change, drought severity is also increasing. Drought risk analysis requires a comprehensive understanding and analysis of the frequency of drought characteristics associated with drought severity and duration. In this study, the drought status of the Çekerek basin was evaluated using satellite-based PDSI values in the River Basin and the drought trend was examined. The main findings are as follows:

• Extreme drought events occurred in May 2021 at all stations.
• It was determined that extreme drought events occurred the most at Çamlıbel station (51 dry events) and the least at Çekerek station (42 dry events).
• It was determined that the number of extreme wet events was less than extreme dry events, and extreme wet events were observed most at Çamlıbel and Yeşilyurt stations.
• When the drought trend was examined, it was determined that drought tended to increase at Çekerek, Çamlıbel and Yeşilyurt stations according to ITA results.

In conclusion, the drought is increasing at the Çekerek River Basin according to the satellite-based PDSI index. Determining the drought characteristics of the region and analyzing their temporal changes contribute to the drought management and drought action plans of the region. Therefore, in future studies, it is recommended to conduct a more detailed analysis of the drought using different drought indices and trend analysis methods.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Cite this article: *Erdogan Karaağaçlı, M. and Yurekli, K., 2025. Assessment of Drought in the Cekerek River Basin with Satellite-Based Palmer Drought Severity Index (PDSI). Levantine Journal of Applied Sciences, Volume 5 (1), 1-8.* http://dx.doi.org/10.56917/ljoas.22

References

[1] Vicente-Serrano, S., Quiring, S., Pe˜na-Gallardo, M., Yuan, S. and Domínguez-Castro, F., 2020. A review of environmental droughts: Increased risk under global warming? Earth Sci. Rev. 201, 102953 https://doi.org/10.1016/j.earscirev.2019.102953

[2] Jasechko, S. and Perrone, D., 2020. California's central valley groundwater wells run dry during recent drought. Earth's Future 8 (4). https://doi.org/10.1029/2019EF001339

[3] Wang, L., Yu, H., Yang, M., Yang, R., Gao, R. and Wang, Y., 2019. A drought index: the standardized precipitation evapotranspiration runoff index. J. Hydrol. 571, 651–668. https://doi.org/10.1016/j.jhidrol.2019.02.023

[4] Mishra, A.K. and Singh, V.P., 2010. A review of drought concepts. Journal of Hydrology, 391(1-2): 204-216. https://doi.org/10.1016/j.jhidrol.2010.07.012

[5] Yao, N., Li, Y., Lei, T. and Peng, L., 2018. Drought evolution, severity and trends in mainland China over 1961-2013. Sci. Total Environ. 616–617, 73–89. https://doi.org/10.1016/j.scitotenv.2017.10.327

[6] Nasseri, M. and Koucheki, A., 2024. Does snow storage affect the Palmer drought severity index? Revisiting PDSI drought indicator via conceptual model and large-scale information. Physics and Chemistry of the Earth, Parts A/B/C, 135, 103608. https://doi.org/10.1016/j.pce.2024.103608

[7] Wilhite, D.A., 2000. Chapter Drought as a Natural. Concepts and Definitions, Hazard.

[8] Yang, H., Gao, X., Sun, M., Wang, A., Sang, Y., Wang, J., ... & Ariyasena, H. H. S. (2024). Spatial and temporal patterns of drought based on RW-PDSI index on Loess Plateau in the past three decades. *Ecological Indicators*, *166*, 112409. https://doi.org/10.1016/j.ecolind.2024.112409

[9] Dracup, J.A., Lee, K.S. and Paulson, E.G., 1980. On the statistical characteristics of drought events. Water Resour Res 16:289–296. https://doi.org/10.1029/WR016i002p00289

[10] Orville H., 1990. AMS statement on meteorological drought. Amer Meteorological Soc, Boston, pp 02108–03693.

[11] Palmer, W.C., 1965. Meteorological Drought, U.S. Department of Commerce, Research Paper No.45, Washington D.C

[12] Agnew, C.T. ve Warren, A., 1996. A framework for tackling drought and land degradation. Journal of Arid Environments, 33, 309-320. https://doi.org/10.1006/jare.1996.0067

[13] Sheffıeld, J., Gotetı, G., Wen, F. ve Wood, E.F., 2012 A Simulated Soil Moisture Based Drought Analysis for the United States. Journal of Geophysical Research: Atmospheres, 109(D24). https://doi.org/10.1029/2004JD005182

[14] Wei, W., Zhang, J., Zhou, L., Xie, B., Zhou, J. and Li, C., 2021. Comparative evaluation of drought indices for monitoring drought based on remote sensing data. *Environmental Science and Pollution Research*, *28*, 20408-20425. https://doi.org/10.1007/s11356-020-12120-0

[15] Mengü, G.P., Anaç, S. and Özçakal, E., 2011. Kuraklık Yönetim Stratejileri. Ege Üniv. Ziraat Fak. Derg. , 48 (2): 175-181

[16] Çakmak, B. and Gökalp, Z., 2013. Kuraklık ve tarımsal su yönetimi. Gaziosmanpaşa Bilimsel Araştırma Dergisi, (4), 1-11.

[17] Turan, E.S., 2018. Türkiye'nin iklim değişikliğine bağlı kuraklık durumu. Doğal Afetler ve Çevre Dergisi, 4(1), 63-69.

[18] Bandyopadhyay N, Bhuiyan C. and Saha AK., 2020. Drought mitigation: critical analysis and proposal for a new drought policy with special reference to Gujarat (India). Progress Disaster Sci. 5:100049. https://doi.org/10.1016/j.pdisas.2019.100049

[19] Mullapudi, A., Patil, C. H., Vibhute, A. D. and Mali, S., 2024. Comparison of Agricultural Drought Indices for Ahmednagar Region for a Period of 1990–2023. SN Computer Science, 5(8), 1-13. https://doi.org/10.1007/s42979-024-03497-7

[20] Mckee T.B., Doesken N.J. and Kleıst J., 1993. The Relationship of Drought Frequency and Duration to Time Scales, 8th Conference on Applied Climatology, Anaheim, California, pp.179-184

[21] Schultz, G.A. and Engman, E.T., 2012. Remote Sensing in Hydrology and Water Management. Springer-Verlag Berlin Heidelberg, Berlin, Almanya, p. 483.

[22] Bhuıyan, C., Sıngh, R.P. and Kogan, F.N., 2006. "Monitoring drought dynamics in the Aravalli region (India) using different indices based on ground and remote sensing data" International Journal of Applied Earth Observation and Geoinformation 8, 289-302. http://dx.doi.org/10.1016/j.jag.2006.03.002

[23] Anderson, M. C., Hain, C., Wardlow, B., Pimstein, A., Mecikalski, J. R. and Kustas, W. P., 2011. Evaluation of drought indices based on thermal remote sensing of evapotranspiration over the continental United States. Journal of Climate, 24(8), 2025-2044. https://doi.org/10.1175/2010JCLI3812.1

[24] Çelik, M. A. and Karabulut, M., 2017. Uydu Ve İstasyon Tabanli Kuraklik İndeksleri Kullanilarak Akdeniz Bölgesinde Kuraklik Analizi. Akademik Sosyal Araştırmalar Dergisi, 5:44, 341-370

[25] Martínez-Fernández, J., González-Zamora, A., Sánchez, N., Gumuzzio, A. and Herrero-Jiménez, C.M., 2016. Satellite Soil Moisture for Agricultural Drought Monitoring: Assessment of the SMOS Derived Soil Water Deficit Index. Remote Sensing of Environment, 177, 277–286. https://doi.org/10.1016/j.rse.2016.02.064

[26] Zhao, H., Gao, G., An, W., Zou, X., Li, H. and Hou, M., 2017. Timescale Differences between sc-PDSI and SPEI for Drought Monitoring in China. Physics and Chemistry of the Earth, 102, 48–58. https://doi.org/10.1016/j.pce.2015.10.022

[27] Özgürel, M., Pamuk, G. and Topçuoğlu, K., 2003. Ege Bölgesi Koşullarında Farklı İki Kuraklık İndisinin Karşılaştırılması. Ege Üniv. Ziraat Fak. Derg., 40(1), 95–102.

[28] Türkeş, M., Akgündüz, A.S. and Demirörs, Z., 2009. Palmer Kuraklık İndisi'ne
Göre İç Anadolu Bölgesi'nin Konya Bölümü'ndeki Kurak Dönemler ve Kuraklık Şiddeti. Coğrafi Bilimler Dergisi, CBD 7 (2), 129-144. https://doi.org/10.1501/Cogbil_0000000102

[29] Akbaş, A. and Tatlı, H., 2013. Türkiye Üzerindeki Belli Kuraklık Yılların Palmer Kuraklık Şiddeti İndisi İle Analizi. 6th Atmospheric Science Symposium, 24-16 April 2013, İstanbul Technical University, Turkey

[30] Kaeamzadeh Kocaaslan, S., 2022. Uzaktan algılama verileri kullanılarak kuraklık olaylarının alansal, zamansal ve frekans analizleri: Ege bölgesi örneği (Doctoral dissertation, Lisansüstü Eğitim Enstitüsü).

[31] Wang, W., Ertsen, M., Svoboda, M. ve Hafeez, M., 2016. Propagation of Drought: From Meteorological Drought to Agricultural and Hydrological Drought. Advances in Meteorology. 2016. 1-5. http://dx.doi.org/10.1155/2016/6547209

[32] Sen Z., 2012. Innovative trend analysis methodology. Journal of Hydrologic Engineering, 17(9), 1042-1046. https://doi.org/10.1061/(ASCE)HE.1943-5584.0000556

[33] Sen Z., 2017. Innovative trend significance test and applications. *Theoretical and applied climatology*, *127*(3), 939-947. https://doi.org/10.1007/s00704-015-1681-x

[34] Mun, Y. S., Nam, W. H., Kim, T., Hong, E. M. and Sur, C., 2020. Evaluation and comparison of meteorological drought index using multi-satellite based precipitation products in East Asia. *Journal of the Korean Society of Agricultural Engineers*, *62*(1), 83-93. https://doi.org/10.5389/KSAE.2020.62.1.083

[35] Erdem, F., Atun, R., Avdan, Z. Y., Atila, I. and Avdan, U., 2021. Drought analysis of Van Lake Basin with remote sensing and GIS technologies. *The Egyptian Journal of Remote Sensing and Space Science*, *24*(3), 1093-1102. https://doi.org/10.1016/j.ejrs.2021.10.006

[36] Türkyılmaz, M., Özelkan, E. and Karaman, M., 2020. Termal uydu görüntülerinden üretilen yer yüzeyi sıcaklığı ile hava sıcaklığı ilişkisinin değerlendirilmesi. *Avrupa Bilim ve Teknoloji Dergisi*, (20), 932-948. https://doi.org/10.31590/ejosat.799722