Black Sea Journal of Environmental Sciences

Doi: 10.5281/zenodo.18226782

Open Access Journal
e-ISSN: 3108 - 4273

Research Article
Volume 1 - Issue 2: 60-67 / December 2025

ASSESSMENT OF CLIMATE CHANGE TRENDS IN ADIYAMAN PROVINCE, TÜRKİYE

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Abstract: Factors affecting climate formation are examined in two main categories: natural and anthropogenic factors. Natural factors include atmospheric composition, solar radiation, topographic structure, and ocean circulation, while anthropogenic factors encompass industrial activities, energy production, agricultural practices, deforestation, and urban expansion. In this study, climate trend analyses were conducted for Adıyaman province located in the Southeastern Anatolia Region. In this context, trend analyses were performed on annual extreme temperature data obtained from meteorological stations in Adıyaman center, Kahta, and Gölbaşı for the period 1993-2022. Non-parametric statistical methods (Mann-Kendall test and Sen's slope estimator) were used for trend analyses. Research findings revealed statistically significant increases in maximum and minimum temperature values in the Adıyaman region. Trend analyses demonstrated that temperature values in the region showed an upward trend and the frequency of extreme temperature events increased. In conclusion, this research has revealed the sensitivity of the Adıyaman region to climate change and the effects of temperature increases with scientific data. The results constitute an important scientific resource for understanding regional climate variability, predicting future climate trends, and developing climate change mitigation strategies.

Keywords: Climate change, Trend analysis, Mann-Kendall, Sen's slope, Extreme temperature, Adıyaman

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Received: November 14, 2025
Accepted: December 15, 2025
Published: December 15, 2025

Cite as: Arıman, S., & Özbek, M. Ş. (2025). Assessment of climate change trends in Adıyaman province, Türkiye. *Black Sea Journal of Environmental Sciences*, *1*(2), 60–67.

1. Introduction

Climate change represents one of the most critical contemporary challenges, generating profound environmental, economic, and social consequences on a global scale. The climate system is governed by both natural forcings (atmospheric composition, solar radiation, topography, and ocean circulation patterns) and anthropogenic drivers (industrial processes, energy production, agricultural practices, deforestation, and urbanization). Over the past century, the intensification of anthropogenic influences has led to significant increases in mean global temperatures, resulting in substantial alterations to regional climate patterns and increased frequency of extreme weather events.

Türkiye exhibits enhanced vulnerability to climate change impacts due to its geographical location at the intersection of multiple climate zones and its complex topographic features. The Southeastern Anatolia Region is particularly susceptible, characterized by semi-arid climate conditions, rapid urbanization, and intensive agricultural land use. Recent research demonstrates that this region is experiencing pronounced warming trends and increasing drought severity. Erlat and Güler (2018) analyzed temporal variations in extreme temperature events across Turkey during 1950-2017, identifying the most significant reduction in cold period duration within the Southeastern Anatolia Region. Acar-Deniz and Gönençgil (2017) documented statistically significant increases in extreme hot day frequencies nationwide, while Turgu and Kömüşcü (2011) detected accelerating drought trends in Southeastern Anatolia using Mann-Kendall trend analysis. In the Southeastern Anatolia region, Kartal et al. (2024) analyzed long-term meteorological data from three stations (1981-2022) using the Mann-Kendall test, Sen's slope estimator, and innovative trend analysis, identifying a declining precipitation trend coupled with increasing drought severity since 1996. Their findings using multiple drought indices (SPI, SPEI, CZI, and EDI) demonstrated that the region's water resources and agricultural activities face growing pressure from climate change.

Temperature trend variations in Adıyaman province have generated considerable impacts on critical sectors, particularly agriculture and water resource management.

Summer maximum temperatures have exhibited marked increases in recent decades, frequently exceeding 40°C. These extreme thermal conditions pose substantial risks to agricultural productivity, water availability, and public health. Beyond agricultural and hydrological implications, rising temperatures adversely affect urban environmental quality and livability (Çiflik, 2012). Regional studies, specifically focusing on Adıyaman province, have revealed significant vulnerability to climate change. Yeşilata et al. (2004) investigated the influence of Atatürk Dam Lake on regional microclimate, observing post-construction increases in both temperature and relative humidity. Tufaner and Dabanlı (2018) employed the Standardized Precipitation Index (SPI) to assess meteorological drought conditions, documenting declining precipitation totals and persistent severe drought risk. These findings underscore the necessity for comprehensive climate trend assessments in the region. Heat waves constitute a critical indicator of anthropogenic climate change impacts. Güneş and Efe (2022) conducted a temporal analysis of heat wave characteristics for Samsun province for the period 1990-2019, determining that heat wave frequency has increased substantially in recent years, with event duration extending across all seasons. Similarly, Kaya et al. (2024) conducted comprehensive trend analyses of temperature and precipitation data for Siirt Province (1980-2023) using the Mann-Kendall test, Sen's slope estimator, Innovative Trend Analysis (ITA), and Innovative Polygon Trend Analysis (IPTA). Their analyses consistently identified decreasing precipitation and increasing temperature trends, with more pronounced changes observed at monthly and seasonal scales, underscoring the growing need for enhanced drought risk management and water resource planning in the region. The objective of this study is to characterize climate change indicators in Adıyaman province through a comprehensive analysis of extreme temperature trends and heat wave patterns during the 1993-2022 period. Regional climate trends were evaluated using robust non-parametric statistical methods, the Mann-Kendall trend test and Sen's slope estimator, applied to both precipitation and temperature meteorological variables. This investigation provides essential baseline information for understanding regional climate variability, projecting future climate scenarios, and developing evidence-based climate adaptation and mitigation strategies.

2. Materials and Methods

2.1. Study Area

Adıyaman is located between 37° 25' and 38° 11' north latitude and 37° and 39° east longitude. The northern part of the province is surrounded by the Taurus Mountains. Much of the land in the districts of Çelikhan, Gerger, and Tut is mountainous. Generally, it exhibits the climatic characteristics of the Mediterranean, Eastern, and Southeastern Anatolian regions. Therefore, its vegetation also reflects the characteristics of these three regions. Furthermore, the Euphrates River is the most important in the province (Adıyamanlılar Vakfı, 2023) (Figure 1).

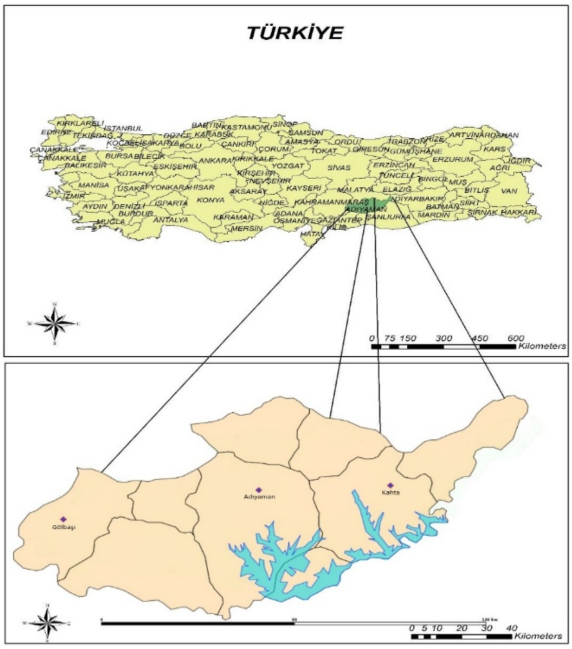


Figure 1. Study Area.

2.2. Data

This study utilized three meteorological stations in Adıyaman city. Minimum, maximum, and average daily temperature data for the period 1993-2022 were obtained from the Turkish State Meteorological Service (TSMS). Other stations in the province were not used due to reasons such as their recent installation and the large amount of missing or discontinuous data. Information for the stations used in the study is given in Table 1.

2.3. Homogeneity Test

A homogeneity test is a statistical test used to determine whether the variances of one or more sample groups are equal. Homogeneity tests play an important role in statistical analyses. These tests facilitate the correct interpretation of data and enhance the reliability of results. In this study, the Kolmogorov-Smirnov Test was applied to the data to test whether the data conformed to a normal distribution. Following this test, Levene's homogeneity test was applied to assess the homogeneity of data that did not conform to a normal distribution. This test is used for data that does not exhibit a normal distribution.

This test is based on the application of one-way analysis of variance using the absolute values of deviations from the mean, defined as , $z_{ij} = |x_{ij} - \bar{x}_j|$ where $\bar{x}_j$ represents the value of the i-th unit in the j-th group and x_{ij} represents the mean of the j-th group (Gamgam and Altunkaynak, 2008).

2.4. Variance Test

When considering a hypothesis test regarding population variance, the sample variance can be used as the test statistic. Assuming that the sample is drawn from a population with a normal distribution, the sampling distribution of the test statistic follows a chi-square distribution with n − 1 degrees of freedom, where n denotes the sample size (Walpole et al., 2012).

For a two-tailed test, critical values are obtained from the chi-square distribution table and compared with the calculated test statistic. If the test statistic falls within the acceptance region, the null hypothesis (H_0) is accepted; otherwise, it is rejected. For one-tailed tests, the acceptance region is determined based on whether the alternative hypothesis specifies that the population variance is less than or greater than the hypothesized value. A left-tailed test is applied when testing whether the variance is less than the specified value, whereas a right-tailed test is used when testing whether the variance is greater than the specified value (Montgomery and Runger, 2014).

Table 1. Information on the stations.

	Station name	Station No	Altitude (m)	Latitude (North)	Longitude (East)	Measurement Range
1.	Adıyaman	17265	672	37° 45' 00.0"	38° 17' 00.0"	1993-2022
2.	Kahta	17910	675	37° 47' 00.0"	38° 37' 00.0"	1993-2022
3.	Gölbaşı	17871	900	37° 47' 00.0"	37° 38' 00.0"	1993-2002

2.5. Mann-Kendall Test

The Mann-Kendall test is a statistical test used to determine the presence and direction of trends in a data set. This test is employed to identify whether the values in a data set exhibit an increasing or decreasing trend and is a non-parametric test; therefore, it does not require the assumption of normal distribution. The Mann-Kendall test is a frequently utilized analysis for detecting trends in hydro-meteorological time series (Hirsch, et al., 1982; Yue et al., 2002).

The Mann-Kendall S test statistic is calculated as shown in equation (1) below.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_i) \quad (1)$$

where n is the total number of data points, x_i and x_j are the data points at times i and j, respectively, and j > i. Sgn is the sign function and is calculated as shown in equation (2).

$$\operatorname{gn}(x_j - x_i) = \begin{cases} +1 \text{ If } (x_j - x_i) > 0 \\ 0 \text{ If } (x_j - x_i) = 0 \\ -1 \text{ If } (x_j - x_i) < 0 \end{cases} \quad (2)$$

The variance of S is determined by the following equation.

$$\operatorname{Var}(S) = \frac{[n(n-1)(2n+5) - \sum_{i=1}^{m} t(t-1)(2t+5)]}{18} \quad (3)$$

In equation (3), m represents the total number of equal numbers, and t represents the number of equal data points. Using the test statistic Z value, S from equation 1 and Var(S) from equation (3), equation (4) is obtained:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\operatorname{Var}(S)}} \text{ If } S > 0 \\ 0 \quad \text{If } S = 0 \\ \frac{S+1}{\sqrt{\operatorname{Var}(S)}} \text{ If } S < 0 \end{cases} \quad (4)$$

A positive Z value indicates an increasing trend, while a negative value indicates a decreasing trend (Gilbert, 1987; Helsel and Hirsch, 2002).

2.6. Sen’s Slope Estimator

When a linear trend exists within a time series, Sen's slope estimator is used to estimate the actual trend. It is a non-parametric method and can be applied in cases where the trend can be assumed to be linear (Salmi et al., 2002). This method calculates the slope for all pairs of ordered data values and uses the median of these slopes to determine the trend line. This line represents the magnitude and direction of the trend in the data set. The linear model $f(t) = Q_t + B$ is expressed as:

where x_j and x_k are the data at times j and k (provided j > k).

$$N = \frac{n(n-1)}{2} \quad (5)$$

n: represents time periods. The value of Q_i (i = 1,2, ..., n) is expressed by the equation in (6).

$$Q_i = \frac{(x_j - x_k)}{j - k} (j = 1,2, \ldots, N) \quad (6)$$

The obtained Q_i values are sorted from smallest to largest. The median of N Q_i values estimates Şen's linear slope parameter. If the number N is odd, (7) is used; if it is even, (8) is used:

$$Q = Q_{\frac{N+1}{2}} \quad (7)$$

$$Q = \left\{\frac{1}{2}\left[Q_{\frac{N}{2}} + Q_{\frac{N+2}{2}}\right]\right\} \quad (8)$$

3. Results and Discussions

3.1. Evaluation of Temperature

Upon examination of the temporal graphs illustrating the monthly and annual maximum, minimum, and mean temperature values for the Adıyaman station, it is evident that temperature values exhibit clear variability across both months and years (Figures 2–4). At the Adıyaman station, maximum mean temperature values reach their highest levels during May and July, approaching 40 °C. In contrast, temperatures decrease during the autumn and winter seasons, with the lowest maximum values observed in December and January. Minimum mean temperature values attain their lowest levels in January and February and gradually increase toward the summer months. Mean temperature values peak during the summer season, with June, July, and August representing the warmest period of the year. Conversely, the mean temperatures decline during the winter months.

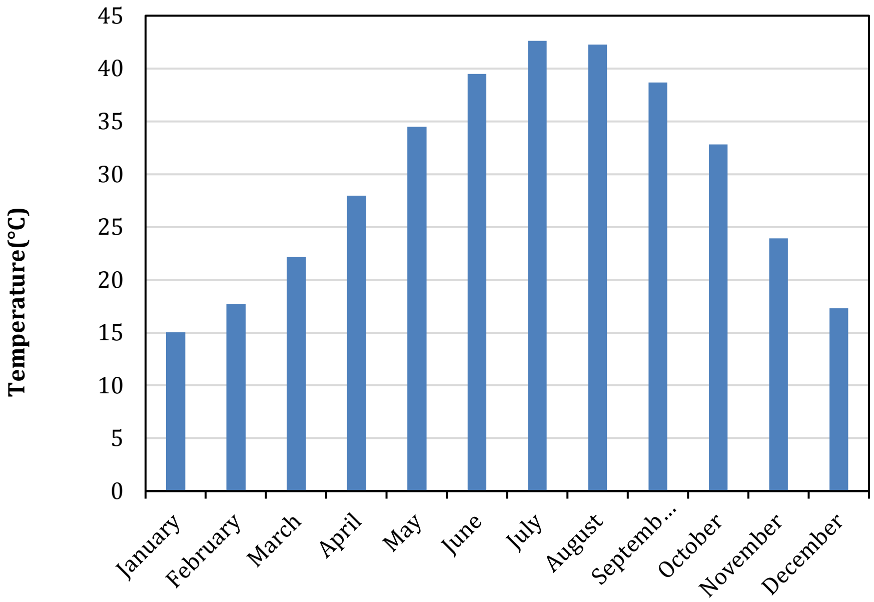


Figure 2. Monthly mean maximum temperature distribution at Adıyaman station.

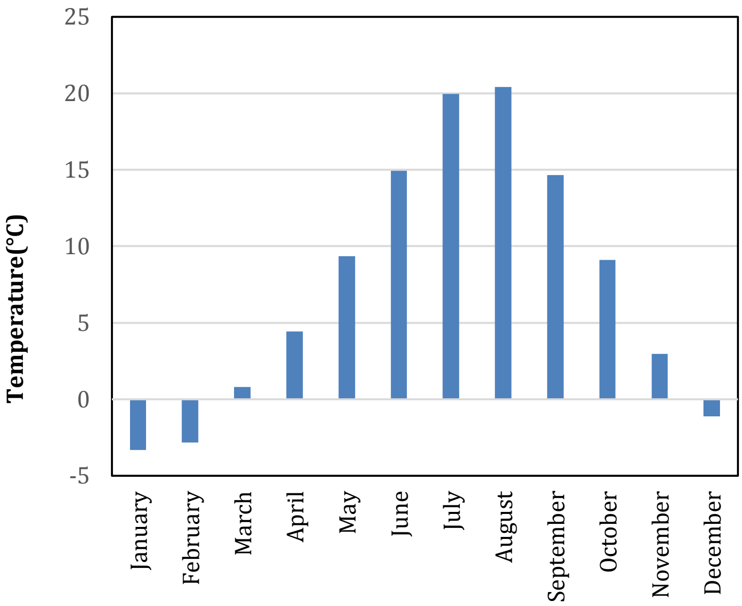


Figure 3. Monthly mean minimum temperature distribution at Adıyaman station.

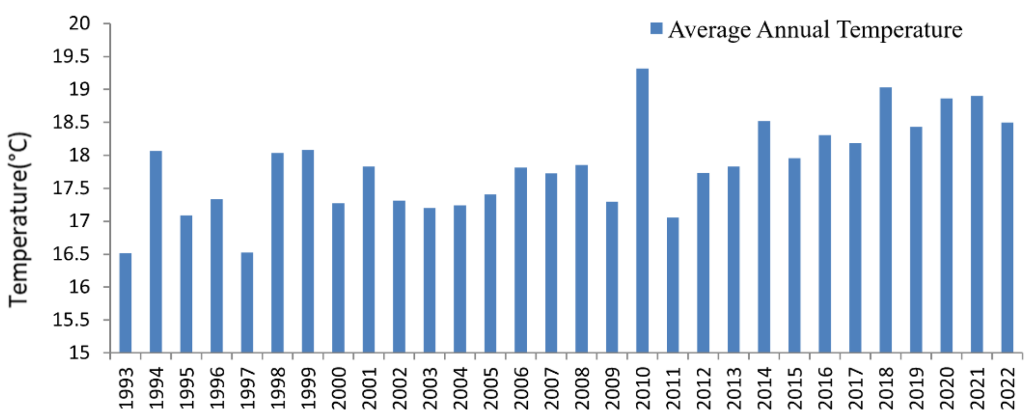


Figure 4. Mean annual temperature distribution at Adıyaman station

3.2. Homogeneity Test Results for Temperature

According to the homogeneity test results for mean temperatures at the Adıyaman station, the analysis was conducted monthly and subsequently on an annual basis. Data with a p-value equal to or greater than 0.05 were considered homogeneous, indicating that no statistically significant change was detected. In contrast, data with a p-value below 0.05 were classified as non-homogeneous, suggesting the presence of a statistically significant change. Overall, the results indicate that the mean temperature data at the Adıyaman station are not homogeneous (Figure 5).

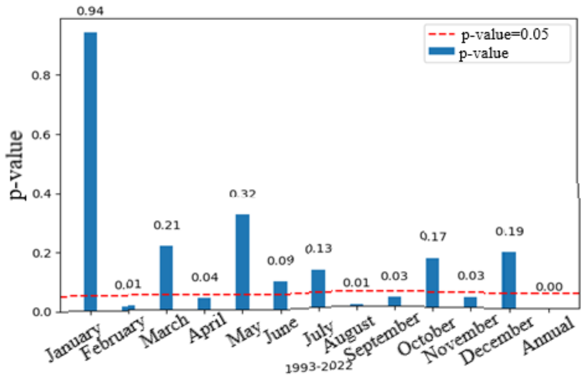


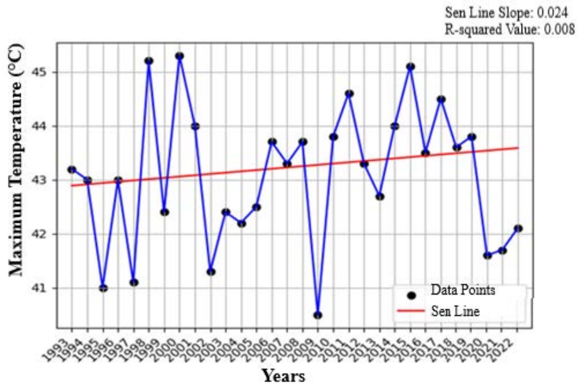
Figure 5. Homogeneity test results for the mean temperature values at the Adıyaman station.

3.3. Sen's Slope–Based Trend Analysis Results

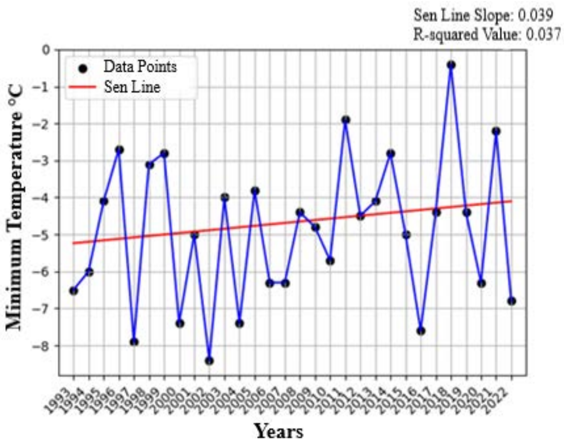
An examination of the trend graphs representing annual maximum, minimum, and mean temperature values for Adıyaman Province indicates a continuous increase in temperature on an annual basis. At the Adıyaman station, temperature values clearly exhibit interannual variability. The trend graphs illustrate seasonal variations, the direction and magnitude of temperature changes, and differences between years (Figure 6).

Sen's slope trend analysis conducted for the Adıyaman station reveals a positive trend in annual temperature records. The slope value for annual maximum temperature was calculated as 0.024, while the slope for annual minimum temperature was 0.039. For the annual mean temperature, the Sen's slope value was determined to be 0.059, indicating a pronounced increasing temperature trend over the study period.

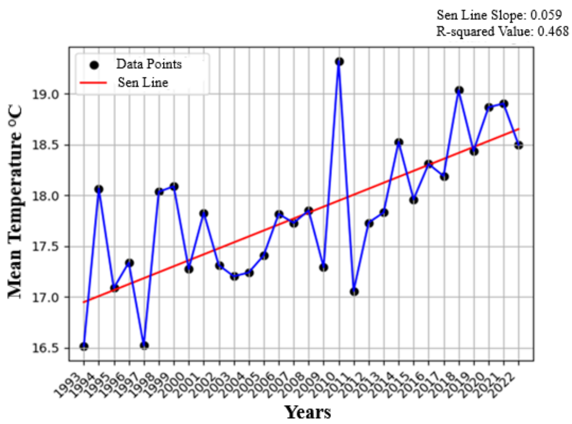
The climatological analysis of temperature parameters at Adıyaman Station over the 1993-2022 period reveals distinct thermal characteristics. Annual maximum temperature extremes exhibit a range of 4.8°C, with values spanning from 40.5°C to 45.3°C and a mean temperature of 43.07°C. The relatively low standard deviation (σ = 1.276) indicates minimal interannual variability in extreme maximum temperatures, while the slightly negative skewness coefficient (-0.150) suggests a near-normal distribution with a marginal left-tail tendency (Table 2).



(a)



(b)



(c)

Figure 6. Annual temperature trends at the Adıyaman station based on Sen's slope analysis: (a) maximum temperature, (b) minimum temperature, and (c) mean temperature.

Annual minimum temperature extremes demonstrate substantially greater variability, with a thermal range of 8.0°C extending from -8.4°C to -0.4°C and a climatological mean of -4.84°C. The higher standard deviation (σ = 1.956) relative to maximum temperatures indicates enhanced interannual fluctuations in cold extremes. The positive skewness coefficient (0.293) reveals a right-skewed distribution, indicating a tendency toward milder winter minimum temperatures during the study period.

Mean annual temperature values range from 16.5°C to 19.3°C, with a 30-year climatological normal of 17.84°C.

This parameter exhibits the lowest temporal variability, as evidenced by the minimal standard deviation (σ = 0.703) and variance (σ^2 = 0.494). The weakly positive skewness coefficient (0.153) indicates an approximately symmetrical distribution with a slight bias toward warmer years (Table 2).

Table 2. Temperature parameters and statistical values obtained from annual data for the 1993-2022 period at Adıyaman station

Parameter	Minimum Value	Maximum Value	Mean (μ)	Variance (σ^2)	Standard Deviation (σ)	Skewness Coefficient
Max. Temperature	40.5	45.3	43.07	1.628	1.276	-0.150
Min. Temperature	-8.4	-0.4	-4.84	3.828	1.956	0.293
Mean Temperature	16.5	19.3	17.84	0.494	0.703	0.153

3.5. Mann-Kendall Trend Analysis Results

The Mann-Kendall trend analysis conducted for Adıyaman Station over the 1993-2022 period reveals statistically significant positive trends in all temperature parameters (Table 3.2.). The null hypothesis (H_0) of no trend was evaluated at two significance levels (α = 0.10 and α = 0.05). For maximum temperature, the Mann-Kendall test statistic (S = 41) yielded a standardized Z value of 0.71 (Table 3.2.). While this value does not exceed the critical threshold at either the 90% (Z = ±1.645) or 95% (Z = ±1.96) confidence levels, the positive S statistic indicates an upward tendency in annual maximum temperature extremes, though the trend is not statistically significant at significance levels.

Minimum temperature exhibited a similar pattern, with a test statistic of S = 45 and a calculated Z value of 0.79. This value also falls below the critical thresholds, indicating a positive but statistically non-significant trend in annual minimum temperature extremes at the α = 0.05 and α = 0.10 levels. Mean annual temperature demonstrated the strongest and most statistically significant trend, with a Mann-Kendall statistic of S = 215 and a highly significant Z value of 3.82. This value substantially exceeds both critical thresholds (α = 0.10 and α = 0.05), leading to the acceptance of the alternative hypothesis (H_1) and confirming the presence of a statistically significant increasing trend in mean annual temperature at the 95% confidence level ($p < 0.05$). The magnitude of the Z statistic (3.82) indicates a robust and persistent warming trend in the baseline climatic conditions at Adıyaman Station during the 30-year study period (Table 3). All three temperature parameters exhibit upward trends (▲), consistent with regional warming patterns associated with anthropogenic climate change in the Eastern Mediterranean region. The findings of this study are in agreement with Kartal (2024), who identified a statistically significant increasing trend in mean annual temperature at Adıyaman Station, reflecting a clear regional warming signal. Consistent with this warming trend, our results indicate a general decrease in precipitation and an increase in drought frequency and severity across Southeastern Anatolia since the mid-1990s. Together, these results confirm that rising temperatures, coupled with changing precipitation patterns, are intensifying drought risk and increasing pressure on regional water resources and agricultural activities, in line with the conclusions of Kartal (2024).

Table 3. Mann-Kendall test results and trend analysis based on annual data for the 1993-2022 period at Adıyaman station

Parameter	MK Test Statistic (S)	Calculated Z Values	Critical Z Value (α=0.10)	Critical Z Value (α=0.05)	H_0 Hypothesis	Trend Present/Absent	Trend
Max. Temperature	41	0.71	±1.645	±1.96	Rejected	Present	▲
Min. Temperature	45	0.79	±1.645	±1.96	Rejected	Present	▲
Mean Temperature	215	3.82	±1.645	±1.96	Accepted	Present	▲

4. Conclusion

This study assessed climate change trends in Adıyaman Province, Turkey, through a comprehensive statistical analysis of temperature data spanning the 1993-2022 period. The Mann-Kendall trend test and Sen's slope estimator were employed to detect and quantify temporal trends in annual maximum, minimum, and mean temperature parameters. The climatological analysis of Adıyaman Station revealed distinct thermal characteristics across different temperature metrics. Maximum temperature values exhibited a range from 40.5°C to 45.3°C with a climatological mean of 43.07°C, while minimum temperatures ranged from -8.4°C to -0.4°C with a mean of -4.84°C. Mean annual temperatures varied between 16.5°C and 19.3°C, with an overall climatological normal of 17.84°C. The relatively low standard deviation (σ = 0.703) in mean temperature suggests baseline climatic stability during the study period.

The Mann-Kendall trend analysis demonstrated statistically significant evidence of warming trends across all temperature parameters at Adıyaman Station. While maximum temperature (S = 41, Z = 0.71) and minimum temperature (S = 45, Z = 0.79) exhibited positive trends that did not reach statistical significance at confidence levels (α = 0.05 or α = 0.10), mean annual temperature showed a highly significant increasing trend (S = 215, Z = 3.82, $p < 0.05$). The calculated Z value of 3.82 substantially exceeded both critical thresholds, confirming a warming trend at the 95% confidence level. Sen's slope analysis quantified the magnitude of the temperature trend, revealing an increasing rate of 0.059°C per year for mean annual temperature. This warming rate translates to an approximate temperature increase of 1.77°C over the 30-year study period, demonstrating substantial climatic change in the region. The significant upward trend in mean annual temperature, coupled with positive tendencies in both maximum and minimum extremes, suggests that Adıyaman Province is experiencing measurable impacts of climate change.

The implications of these warming trends are considerable for the region. Rising temperatures may influence agricultural productivity, water resource availability, energy demand patterns, and ecosystem dynamics. The increase in temperature extremes could exacerbate heat stress conditions during summer months, potentially affecting human health and socioeconomic activities. Additionally, changes in thermal regimes may alter hydrological processes, including evapotranspiration rates and soil moisture dynamics, with cascading effects on regional water security.

These findings underscore the necessity for climate adaptation strategies tailored to Adıyaman Province. Local authorities should integrate these trends into long-term planning for water management, agriculture, urban development, and public health. Further research on precipitation patterns, extreme events, and drought indices is recommended for a comprehensive understanding of regional climate impacts. The methodological approach employed in this study, combining non-parametric statistical tests with trend magnitude estimation, proved effective for detecting and quantifying climate trends in the absence of normally distributed data. This framework can be applied to other meteorological stations across Turkey to develop a comprehensive assessment of regional climate change patterns and inform evidence-based climate policy and adaptation measures.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	S.A	M.Ş.Ö	B.E.
C	40	30	30
D	40	30	30
S	40	30	30
DCP	40	30	30
DAI	40	30	30
L	40	30	30
W	40	30	30
CR	40	30	30
SR	40	30	30
PM	40	30	30
FA	40	30	30

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

Acknowledgements

We would like to thank the Turkish State Meteorological Service for providing the meteorological data used in the study.

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