Reference Evapotranspiration Trends in A Semi-Arid Mediterranean Climate: A Six-Decade Station Record From Adana, Türkiye (1960–2024)

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Abstract. Evapotranspiration is a crucial element of the hydrological cycle, directly affecting the availability of water resources and the sustainability of both irrigated and rain-fed agricultural systems. Understanding its long-term variability is essential for developing effective climate adaptation and water resources management strategies. This study analyzes trends in evapotranspiration time series computed from the monthly records of the Adana meteorological station (1960–2024) in a semi-arid region of Türkiye. The standardized FAO Penman–Monteith method was employed to estimate ETo based on observed meteorological variables. Temporal trends were assessed at monthly, seasonal, and annual scales using the non-parametric Mann–Kendall trend detection test, while Sen's slope estimator was applied to quantify the magnitude of changes. Research results revealed statistically significant increasing trends in ETo during April, July, October, and December, and decreasing trends in January, June, August, September, and November. At the seasonal scale, ETo exhibited declining trend behaviour in winter, summer, and autumn, despite an overall increasing trend on an annual basis. These findings highlight the impact of climate change on evapotranspiration and underscore the importance of long-term monitoring in guiding water resource management and climate-resilient agricultural planning.

Keywords: Reference Evapotranspiration, Climate-Resilient Planning, Trend Analysis, Climate Variability.

1 Introduction

Evapotranspiration, the combined process of water evaporation from land surfaces and transpiration from plants, represents a key component of the terrestrial water cycle (Go-

A. M. Bozdoğan et al. (eds.), *Proceedings of the 5th International Conference on Research of Agricultural and Food Technologies (I-CRAFT 2025)*, Atlantis Highlights in Sustainable Development 8,
https://doi.org/10.2991/978-94-6239-666-1_18

cic & Trajkovic, 2014; Alsenjar et al., 2023a). Among its various forms, reference evapotranspiration (ETo) is particularly significant as it provides a standardized measure of the atmospheric demand for water vapor, serving as a fundamental input for irrigation planning, water budgeting, and hydrological modeling (Cetin et al., 2023a, 2023b). It reflects the potential loss of water from a reference surface, typically a well-watered grass crop, under given climatic conditions, without considering soil moisture or crop-specific characteristics.

In agricultural regions, particularly those with limited water resources or prone to climatic extremes, monitoring ETo is crucial for optimizing water use and maintaining crop yields. It provides a benchmark for calculating actual crop evapotranspiration and determining irrigation requirements. Long-term trends in ETo can reveal how climate change is altering atmospheric demand for water, guiding future water resource allocation and agricultural planning (Onoz & Bayazit, 2003).

The Mediterranean region, including Türkiye's southern provinces, is well known as a climate change hotspot due to its vulnerability to rising temperatures, shifting precipitation patterns, and increasing frequency of droughts. Adana, one of the region's major agricultural hubs, is situated in a semi-arid zone where climatic variability already has a significant impact on water availability and crop yield performance (Alsenjar et al., 2023a). The region is characterised by the cultivation of a diverse range of crops, many of which require substantial amounts of water for their production. These include, but are not limited to, citrus fruits, cotton, and cereals (Cetin et al., 2023a; Alsenjar et al., 2023a, 2023b). This agricultural activity renders the region particularly vulnerable to the effects of climatic stressors. Therefore, understanding how ETo has evolved in this area over time is essential for anticipating future water needs and adapting to changing environmental conditions.

Climate change influences ETo primarily through changes in air temperature, relative humidity, solar radiation, and wind speed. Increases in temperature and solar radiation typically enhance atmospheric water demand, potentially leading to higher ETo values (Allen et al., 1998). However, these effects can be modulated by other factors, such as reduced wind speed or increased humidity, making it necessary to consider multiple climatic variables when assessing trends. As such, quantifying the direction and magnitude of ETo trends provides insight into the region's hydroclimatic dynamics, helping stakeholders make informed decisions regarding irrigation scheduling, drought preparedness, and agricultural sustainability.

Despite the pivotal role of reference evapotranspiration (ETo) in hydroclimatic assessment, the application of long-term trend analyses based on standardised estimation procedures remains comparatively limited in Türkiye. The majority of national studies place a strong emphasis on air temperature and precipitation; however, ETo – which reflects the combined effects of radiation, humidity, wind, and temperature – has received comparatively less focused attention. In this study, we analyse monthly, seasonal, and annual ETo at the Adana meteorological station for the period 1960–2024. We employ the FAO-56 Penman–Monteith formulation and non-parametric trend statistics (Mann–Kendall test with Sen's slope) in our analysis. ***The study has three objectives***: ***(i)*** to compute a consistent ETo record from long-term meteorological observations; ***(ii)*** to detect and quantify monotonic trends across temporal scales; and ***(iii)*** to discuss their implications for irrigation planning and water-resources management in semi-arid Mediterranean settings. By providing a station-based, methodologically standardised six-decade record, this work contributes context-specific evidence to the regional climate literature and supports operational decision-making under a changing climate.

2 Materials and Methods

The present study adopted a stepwise workflow, commencing with data acquisition and quality assurance, progressing to ETo estimation through the utilisation of the FAO-56 Penman–Monteith method, and culminating in trend detection. The overall procedure is summarised in Figure 1; the data utilised in the study and the methodological details are provided in the following subsections.

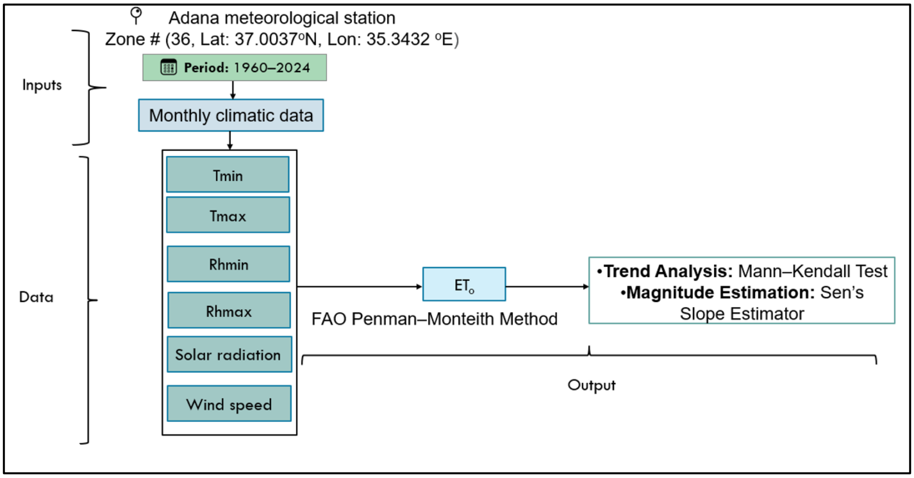


Fig. 1. Workflow for reference evapotranspiration (ETo) trend analysis at the Adana meteorological station (1960–2024): from monthly climatic inputs, through FAO-56 Penman–Monteith ETo computation, to trend detection using the Mann–Kendall test and Sen's slope.

2.1 Study Area

This study was conducted using data acquired from the Adana meteorological station (37.0° N, 35.3° E) in southern Türkiye, which lies in a semi-arid Mediterranean climate; its location is shown in Figure 2. Based on the Köppen–Geiger climate classification, Adana falls within the Csa category, characterized as a hot-summer Mediterranean climate. The region experiences hot, dry summers and mild, wet winters. Adana is a key agricultural hub, particularly for crops including, but are not limited to as cotton, citrus, and maize (Alsenjar et al., 2023a, 2023b), where efficient water use is vital. In the Adana Plain, most agricultural lands are irrigated, as inadequate precipitation amounts and their uneven distribution during the growing season make irrigation essential for crop production (Cetin et al., 2023a; Alsenjar et al., 2023a). Understanding reference evapotranspiration (ETo) patterns is therefore crucial for sustainable agricultural planning and water management in the area.

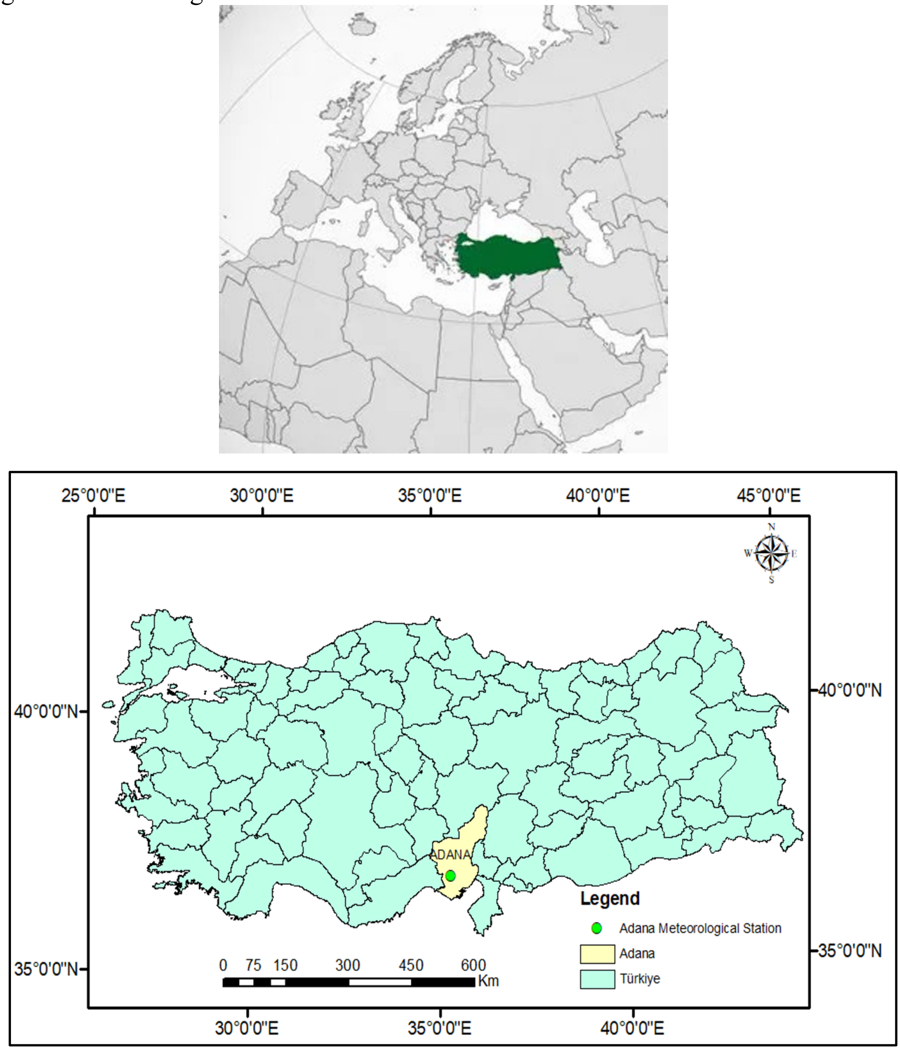


Fig. 2. Location map of the study area showing Adana city (yellow) and the geographical location of Adana meteorological station (green dot).

2.2 Meteorological Data Acquisition, Gap Filling, and Quality Assurance/Quality Control (QA/QC)

The present study obtained daily and monthly meteorological data from 1960 to 2024 from the Adana Meteorological Station (**station ID**: 17351). The following parameters were utilised: minimum and maximum air temperature (Tmin, Tmax), minimum and maximum relative humidity (RHmin, RHmax), solar radiation, wind speed, and atmospheric pressure. To ensure data quality and provide assurance, the daily time series were subjected to visual and statistical examinations for record continuity, abrupt (step) changes, missing observations, and other data-quality anomalies. Preliminary analyses were conducted to determine the number of missing records in the 65-year daily dataset (January 1, 1960 – December 31, 2024) from the Adana meteorological station (see Table 1).

Table 1. Number and percentage of missing daily climate observations at the Adana meteorological station, 1960–2024.

Meteorological parameters	Number of missing data	Percentage of missing data (%)
Solar radiation (Cal/cm²)	4729	19.91
Minimum temperature (°C)	6	0.03
Maximum temperature (°C)	6	0.03
Mean temperature (°C)	7	0.03
Minimum relative humidity (%)	10	0.04
Maximum relative humidity (%)	10	0.04
Mean relative humidity (%)	39	0.16
Mean wind speed (m/s)	294	1.24
Sunshine duration (hours)	1338	5.64

After quantifying the number and percentage of missing observations for each variable (Table 1), gaps were imputed using two complementary procedures. For variables with isolated missing days, we imputed the missing value by simple temporal averaging, defined as the arithmetic mean of the immediately preceding and following days (Jerez et al., 2010; Hırca and Eryılmaz-Türkkan, 2024). In contrast, the daily global solar radiation series contained extended gaps in some years, including intervals of one month or longer; because such gaps violate the assumptions of simple averaging, we imputed these values from an empirical regression between daily global solar radiation and daily sunshine duration fitted on overlapping observations, and then used the fitted coefficients to predict the missing values (Jerez et al., 2010; Keskiner and Çetin, 2022), thereby obtaining a continuous series. The most considerable amounts of missing data occurred in global solar radiation (4,729 values, 19.91%) and sunshine duration (1,338 values, 5.64%). The mean wind speed had 294 missing values (1.24%). Relative humidity showed 39 missing values (0.16 percent) for the mean and 10 missing values (0.04 percent) each for the minimum and the maximum. Temperature data exhibited relatively few gaps, with six missing values (0.03 percent) for both the minimum and maximum, and seven missing values (0.03 percent) for the mean. These imputation procedures ensured continuity of the daily series for subsequent calculations of reference evapotranspiration and for trend analysis.

2.3 Estimation of Reference Evapotranspiration (ETo)

Reference evapotranspiration was computed using the FAO Penman–Monteith equation, which is considered the global standard due to its physical basis and robustness across various climatic regions. The equation integrates multiple climatic inputs and is expressed as:

$$ET_o = \frac{0.408\times \Delta\times (R_n - G) + \gamma\times\frac{900}{T+273}\times u_2\times (e_s - e_a)}{\Delta + \gamma\times (1 + 0.34\times u_2)} \quad (1)$$

where
ETo is the reference evapotranspiration (mm day^{-1}),
R_n is the net radiation at the crop surface (MJ m^{-2} day^{-1}),
G is the soil heat flux density (MJ m^{-2} day^{-1}),
T is the mean daily air temperature at 2 m height (°C)
u_2 is the wind speed at 2 m height (m s^{-1}),
e_s is the saturation vapour pressure (kPa),
e_a is the actual vapour pressure (kPa),
$e_s - e_a$ is the saturation vapour pressure deficit (kPa),
Δ and γ are the slope (kPa°C^{-1}) of the vapour pressure curve and the psychrometric constant (kPa°C^{-1}), respectively.
Monthly ETo values were derived from daily estimates to capture seasonal dynamics and support trend analysis.

2.4 Trend Detection and Statistical Analysis

Temporal trends in reference evapotranspiration (ETo) were evaluated with non-parametric procedures selected to accommodate non-normal distributions and limit the influence of outliers and serial dependence. Monotonic trends at monthly, seasonal, and annual scales were tested using the Mann–Kendall test (Mann, 1945; Kendall, 1948), which does not assume linearity (Libiseller and Grimvall, 2002; Birsan et al., 2005; Aksu et al., 2022). Trend magnitude was quantified with Sen's slope and reported as the median change per unit time (Sen, 1968). Serial correlation was diagnosed; where present, tests were run after trend-free prewhitening to reduce bias in the test statistic. Statistical significance was assessed using two-sided tests at α levels of 0.10, 0.05, and 0.01 (90%, 95%, and 99% confidence). The seasons were defined as follows: winter (December–February), spring (March–May), summer (June–August), and autumn (September–November). All analyses and graphics were produced in R and Python (for example, pyMannKendall, NumPy, Pandas, and Matplotlib), while spreadsheets were used only for tabulation and figure layout.

3 Results and Discussion

3.1 Long-Term Monthly Variability and Trends of ETo

Figure 3 and Table 2a present the monthly distribution of reference evapotranspiration (ETo) for 1960–2024 at the Adana meteorological station. Mean monthly ETo ranges from 41.30 mm in December to 178.64 mm in July, reflecting the dominant controls of air temperature and solar radiation on atmospheric evaporative demand in this semi-arid Mediterranean climate. The pronounced seasonal contrast is a direct consequence of the region's climatic regime: summer months (June–August) are characterized by prolonged sunshine duration, high maximum temperatures, and minimal cloud cover, which together produce the highest ETo values. In contrast, winter months (December–February) exhibit markedly lower ETo due to reduced solar radiation, shorter photo-period, and cooler air masses advected from mid-latitude systems.

The elevated standard deviations observed during the summer months are indicative of significant interannual climatic variability, a factor that is particularly salient for agricultural planning, as the fluctuations in summer ETo directly translate into variable irrigation requirements. This variability is frequently associated with large-scale circulation patterns, such as the North Atlantic Oscillation (NAO) and the Eastern Mediterranean Pattern (EMP), which have the capacity to modulate the annual regional balance of temperature, humidity, and wind speed (Hurrell, 1995). Anomalously high values of summer ETo are typically observed in years which also exhibit protracted heatwaves and suppressed humidity. Conversely, years with lower summer ETo may be indicative of intrusions of humid air from the Mediterranean Sea or increased cloud cover during the growing season.

The marked seasonal and interannual variations underscore the notion that the dynamics of ETo in Adana are not exclusively temperature-driven. Rather, they are the consequence of a multifaceted interaction among various climatic elements, including, but not limited to, radiation, vapour pressure deficit, wind speed, and relative humidity. Collectively, these factors determine the extent of atmospheric water demand. It is imperative to comprehend these patterns in order to formulate effective adaptive water management strategies, particularly in the context of the Adana Plain, where agricultural productivity is contingent on irrigation to counterbalance the seasonal fluctuations in rainfall.

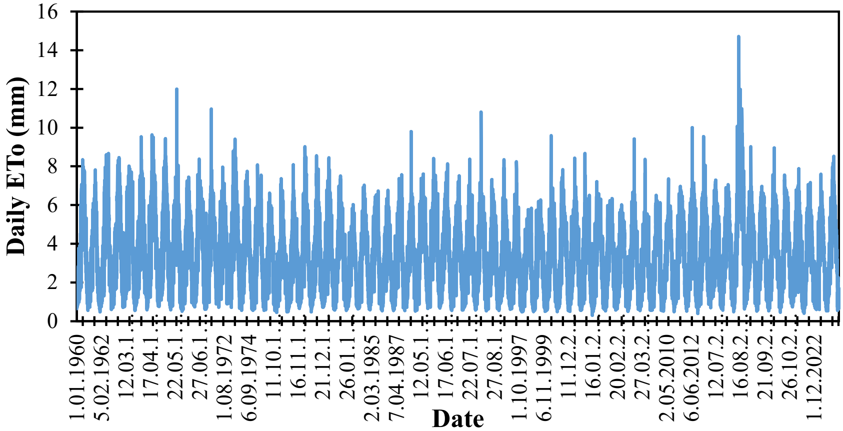


Fig. 3. Time series of daily reference evapotranspiration (ETo) at the Adana meteorological station (1960–2024), computed with the FAO-56 Penman–Monteith method.

Table 2. a. Descriptive statistics for monthly reference evapotranspiration (ETo, mm) at the Adana meteorological station (1960–2024).

Month	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Yearly**
Mean	43.79	53.05	81.84	107.14	142.43	165.00	178.64	164.55	130.67	92.49	55.13	41.30	1256.03
Standard Error	0.93	0.94	1.13	1.73	1.98	2.00	2.00	2.36	1.88	1.60	1.05	0.97	13.62
Median	43.27	52.48	81.02	106.30	142.82	164.95	177.20	164.64	131.53	92.11	56.05	40.67	1267.41
Standard Deviation	7.47	7.48	9.08	13.86	15.87	15.97	16.03	18.87	15.01	12.81	8.39	7.79	108.94
Sample Variance	55.84	55.97	82.44	192.19	251.89	255.06	256.91	356.16	225.37	164.17	70.36	60.61	11868.85
Kurtosis	0.78	0.39	-0.48	-0.78	0.03	0.75	0.23	-0.01	-0.21	-0.57	-0.17	1.39	-0.60
Skewness	0.37	0.46	-0.09	0.21	-0.03	0.45	0.32	0.31	-0.14	0.16	0.02	0.60	-0.14

Range	41.37	37.57	37.47	55.65	73.27	83.26	81.15	88.17	72.36	56.87	38.36	41.58	522.70
Minimum	23.71	36.98	60.77	82.81	105.60	133.90	139.28	125.78	89.62	62.88	37.89	25.49	991.34
Maximum	65.09	74.56	98.23	138.46	178.86	217.16	220.43	213.95	161.98	119.75	76.25	67.06	1514.05
Confidence Level (95.0%)	1.87	1.87	2.27	3.46	3.96	3.99	4.00	4.71	3.75	3.20	2.10	1.94	27.21

Table 3. b. Descriptive statistics of seasonal reference evapotranspiration (ETo, mm) at the Adana meteorological station (1960–2024).

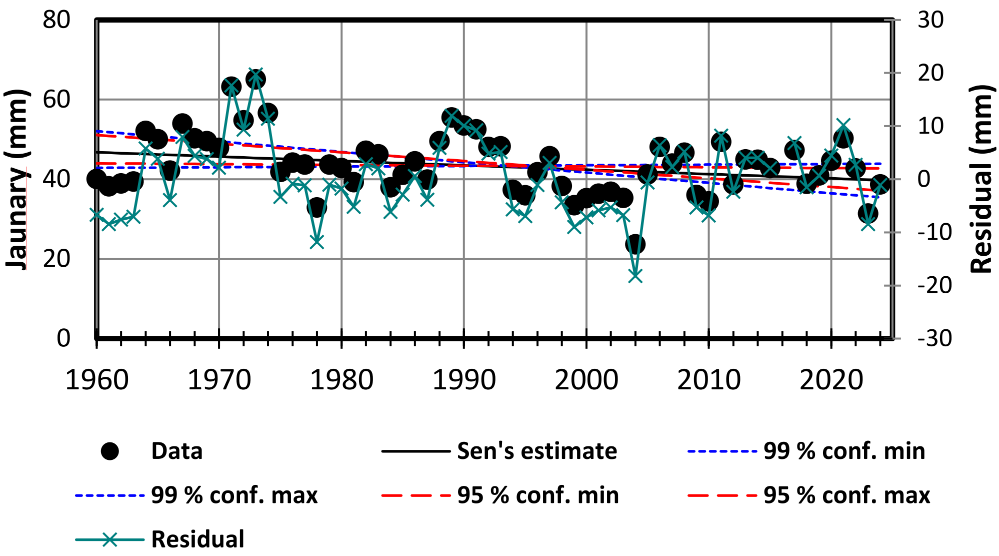
Season	**Winter**	**Spring**	**Summer**	**Autumn**
Mean	**136.63**	**331.41**	**508.19**	**278.29**
Standard Error	**2.45**	**3.90**	**5.77**	**4.09**
Median	**134.00**	**327.32**	**509.98**	**278.12**
Standard Deviation	**19.59**	**31.17**	**46.15**	**32.69**
Sample Variance	**383.69**	**971.52**	**2129.58**	**1068.94**
Kurtosis	**1.79**	**-0.73**	**0.26**	**-0.57**
Skewness	**0.76**	**0.03**	**0.29**	**-0.04**
Range	**111.28**	**133.41**	**232.23**	**144.10**
Minimum	**95.43**	**270.53**	**398.97**	**204.69**
Maximum	**206.71**	**403.94**	**631.20**	**348.79**
Confidence Level (95.0%)	**4.89**	**7.79**	**11.53**	**8.17**

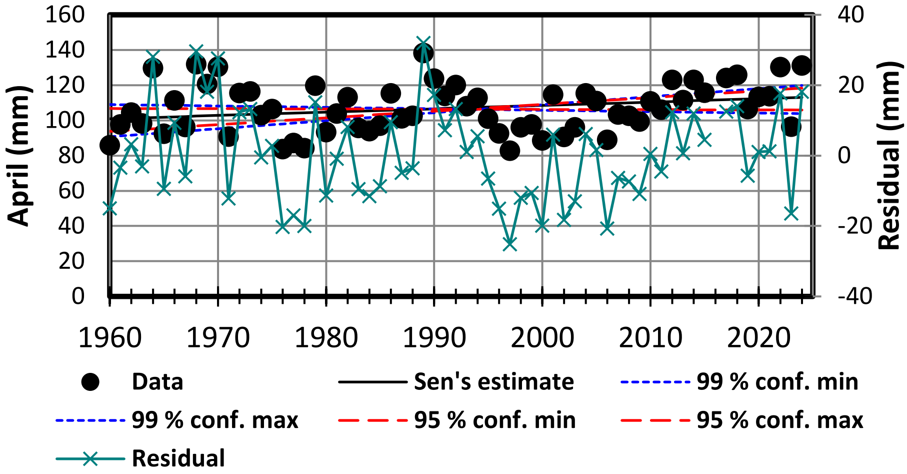
Using the Mann–Kendall test (Figure 4; Table 3), statistically significant positive monotonic trends were detected in April, July, October, and December, with July exhibiting the largest magnitude (Sen's slope = +0.21 mm $month^{-1}$ yr^{-1}). These increases are consistent with documented warming in the Eastern Mediterranean (IPCC, 2021), which elevates atmospheric evaporative demand during key periods of crop growth. Comparable summer increases have been reported for Southeastern Anatolia (Keskiner and Çetin, 2022), where higher air temperatures and declining relative humidity were identified as primary drivers. In Adana, such trends are particularly consequential for summer-irrigated crops—cotton, maize, and citrus—implying higher seasonal irrigation requirements to offset increased ETo.

In contrast, **significant decreasing trends** were observed in January, June, August, September, and November, with **August showing the steepest decline** (−0.18 mm/month/year). Similar reductions in late summer ETo have been documented in the

Cukurova Plain (Cetin et al., 2020), where increased relative humidity, reduced wind speeds, and sporadic cloud cover in the late summer months moderated evaporative demand despite rising air temperatures. These decreases may also be linked to changes in large-scale atmospheric circulation patterns that periodically enhance moist air advection from the Mediterranean Sea into southern Türkiye, thereby reducing the vapour pressure deficit.

The coexistence of months with opposite trends underscores the complex, non-linear interplay of climatic drivers that regulate reference evapotranspiration (ETo) in this transitional climate zone. While air temperature is frequently the predominant factor, variations in relative humidity, wind speed, and net radiation can offset or amplify its influence (Allen et al., 1998). Findings of thgis study indicate that rising temperatures are not the sole driver of ETo dynamics; concurrent changes in atmospheric humidity, wind speed, and cloud cover are also consequential. These patterns highlight the need for water-management strategies tailored to monthly conditions—for example, augmenting irrigation efficiency during months characterised by increasing ETo, while capitalising on reduced atmospheric demand in months exhibiting declining trends.




April (mm)
Residual (mm)
160
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2020
Data
Sen's estimate
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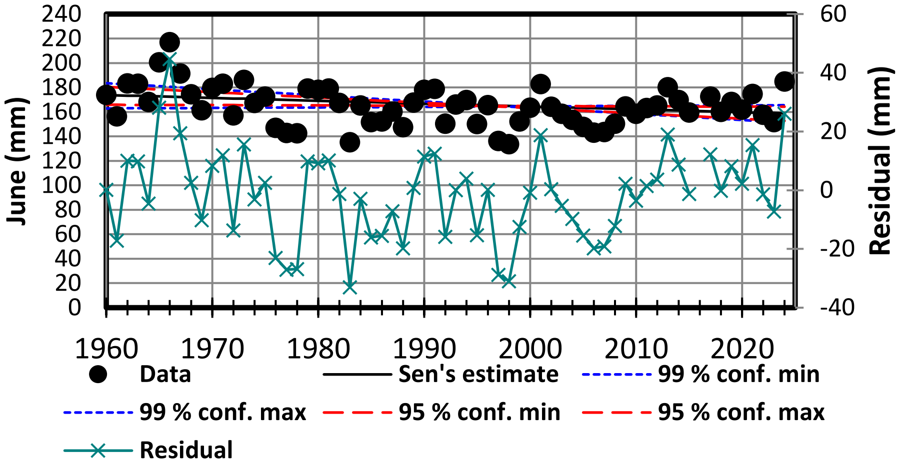
Residual


June (mm)
Residual (mm)
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Sen's estimate
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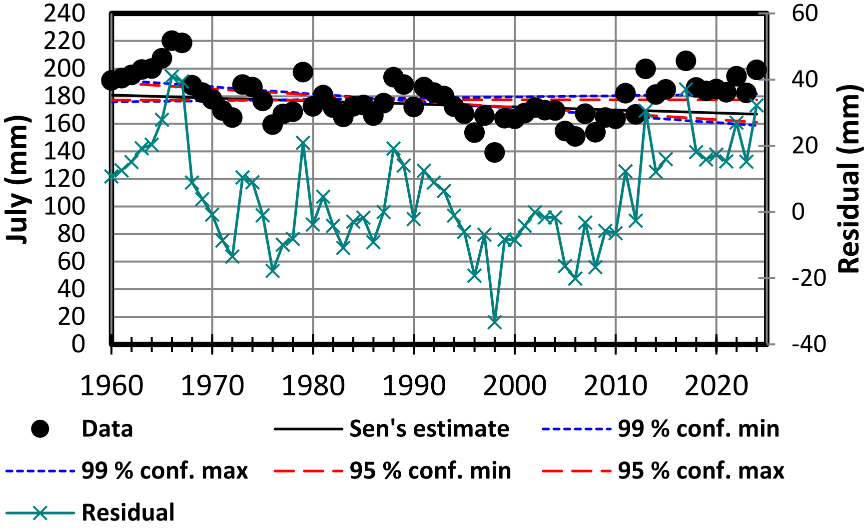
July (mm)
Residual (mm)
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Sen's estimate
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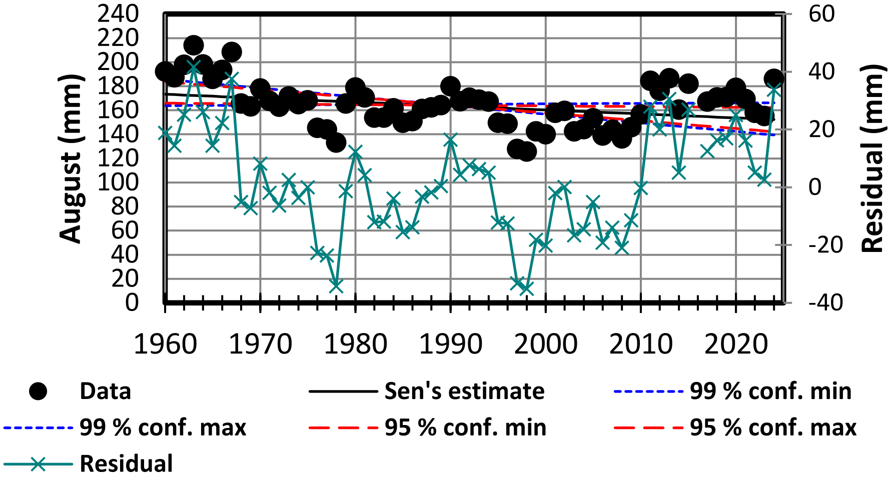
Residual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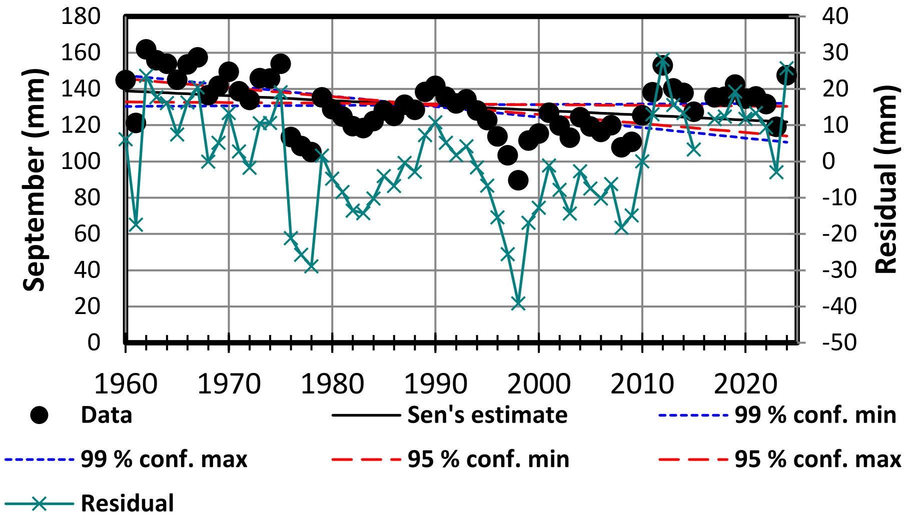
95 % conf. max
Residual


September (mm)
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Sen's estimate
99 % conf. min
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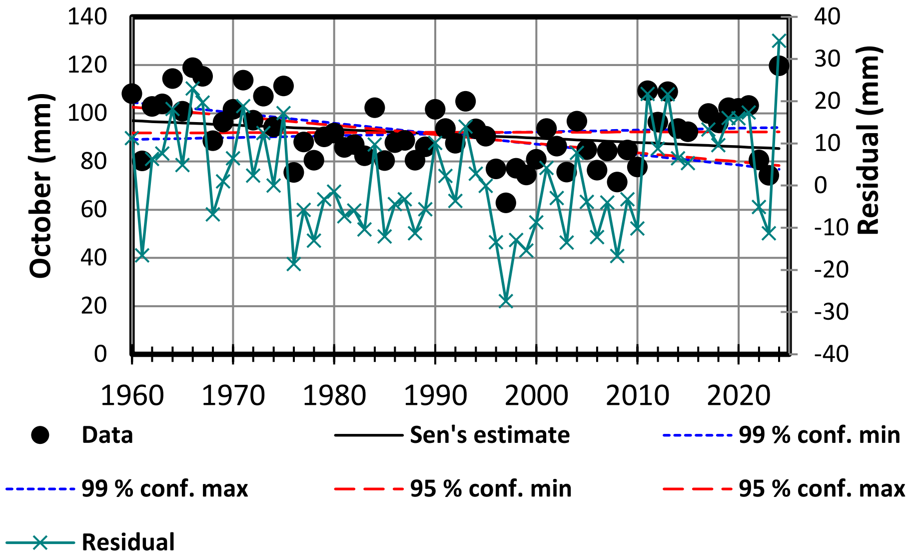
95 % conf. max
Residual


October (mm)
Residual (mm)
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Sen's estimate
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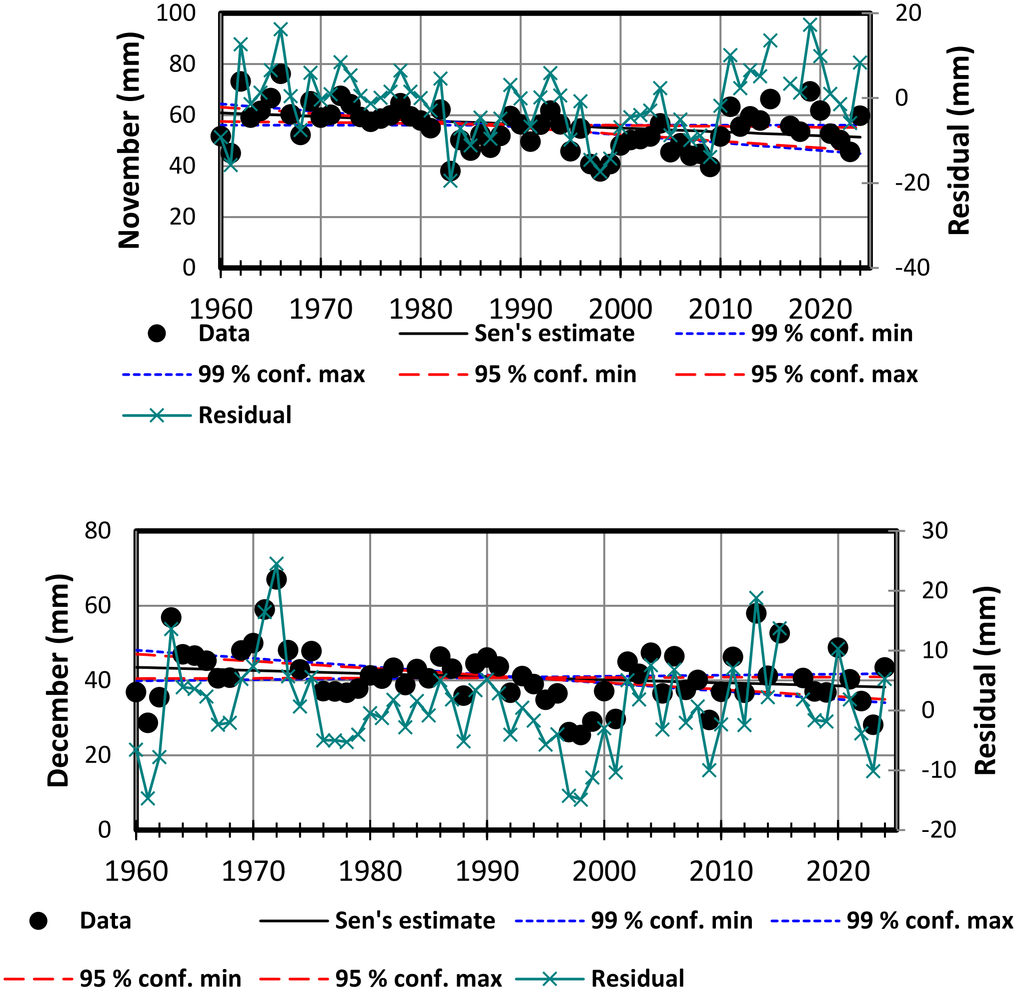


Fig. 4. Monthly reference evapotranspiration (ETo) trends at the Adana meteorological station, 1960–2024: Sen's slope estimates are presented along with 95% and 99% confidence intervals. Asterisks (*) denote trends statistically significant at the 5% level ($p < 0.05$), while plus signs (+) indicate significance at the 10% level ($p < 0.10$). Residuals are also displayed.

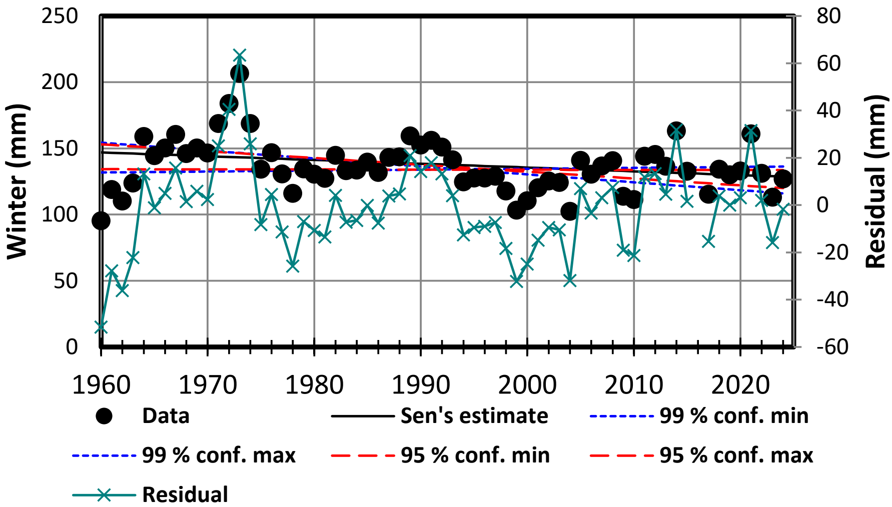
3.2 Seasonal-Scale Analysis of Reference Evapotranspiration Trends

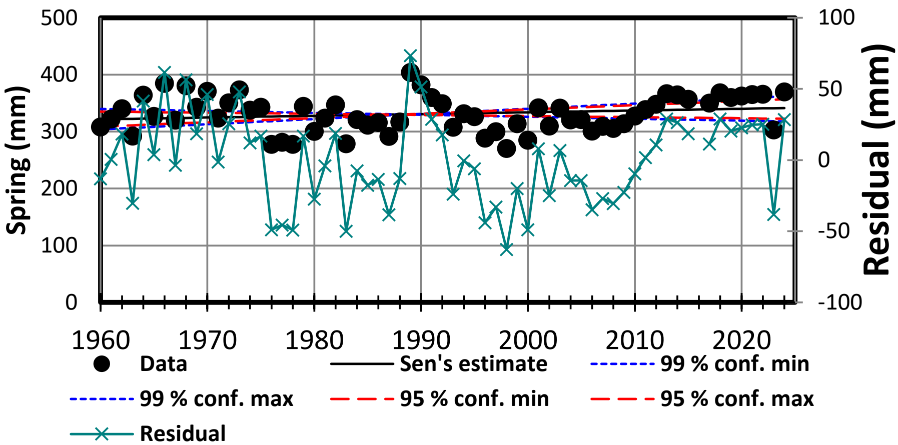
Seasonal analysis (Table 3; Figure 5) indicated statistically significant declines in winter, summer, and autumn reference evapotranspiration (ETo), whereas spring showed no significant long-term change. The decreases in summer and autumn are notable given the a priori expectation of increasing evaporative demand in a warming climate. The summer decrease—despite a pronounced increase in July—points to marked intra-

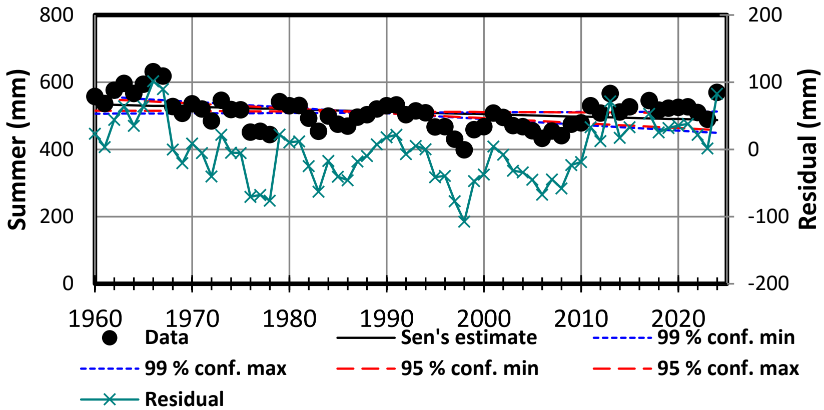
seasonal variability that may reflect month-to-month shifts in relative humidity, episodic cloud cover, and changes in prevailing wind regimes. Episodic advection of humid maritime air from the Mediterranean can temporarily lower the vapour-pressure deficit, suppressing ETo even during otherwise hot periods.
Comparable seasonal declines have been reported elsewhere in the Eastern Mediterranean, indicating that temperature alone does not govern changes in evapotranspiration. Regional-scale atmospheric dynamics—including variability in humidity, wind patterns, and cloudiness—play a critical role in shaping seasonal ETo behaviour. From an agricultural perspective, such seasonal decreases could suggest lower aggregate irrigation demand; however, this can be misleading because short-lived peaks in ETo during phenologically sensitive stages—particularly in July for maize and cotton—can still drive high water requirements. These findings support irrigation planning based on monthly (or sub-monthly) variability rather than seasonal averages, which can mask short-term extremes relevant for operational management.

Table 4. Summary of the trend results of the Mann-Kendall (MK) test and Sen's slope method at the 5% and 10% significance levels for monthly, seasonal, and annual ETo. * indicates significance at $p < 0.05$, and + indicates significance at $p < 0.10$

Time series	First year	Last Year	Mann-Kendall Z	Signific.	Q (Sen's Slope)
Jaunary	1960	2024	-2.30	*	-0.109
February	1960	2024	-0.25		-0.015
March	1960	2024	0.27		0.017
April	1960	2024	1.78	+	0.190
May	1960	2024	-0.16		-0.021
June	1960	2024	-2.15	*	-0.235
July	1960	2024	-1.93	+	-0.215
August	1960	2024	-2.38	*	-0.327
September	1960	2024	-2.36	*	-0.267
October	1960	2024	-1.86	+	-0.181
November	1960	2024	-2.57	*	-0.149
December	1960	2024	-1.76	+	-0.083
Winter	1960	2024	-2.05	*	-0.286
Spring	1960	2024	1.18		0.308
Summer	1960	2024	-2.25	*	-0.734
Autumn	1960	2024	-2.40	*	-0.611
Yearly	1960	2024	-1.91	+	-1.613


Winter (mm)
Residual (mm)
Data
Sen's estimate
99 % conf. min
99 % conf. max
95 % conf. min
95 % conf. max
Residual


Spring (mm)
Residual (mm)
Data
Sen's estimate
99 % conf. min
99 % conf. max
95 % conf. min
95 % conf. max
Residual



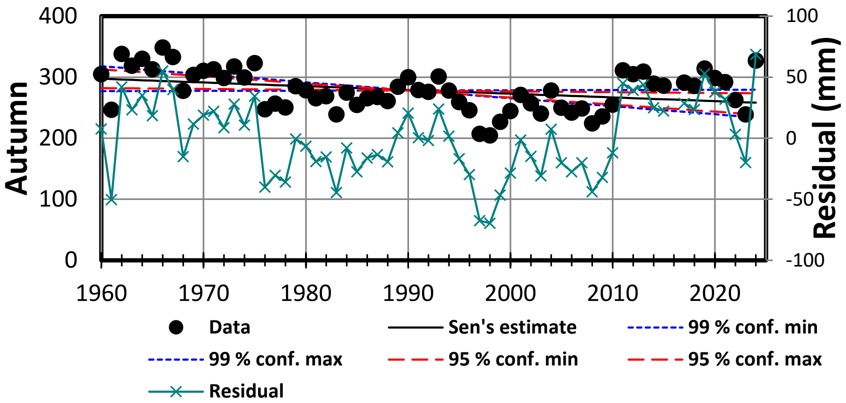


Fig. 5. Seasonal Trend of ETo 1960-2024 at Adana Meteorological Station. Sen's slope estimates are presented along with 95% and 99% confidence intervals. Asterisks (*) denote trends statistically significant at the 5% level ($p < 0.05$), while plus signs (+) indicate significance at the 10% level ($p < 0.10$). Residuals are displayed.

On an annual scale (Figure 6), reference evapotranspiration (ETo) exhibits an upward trend of approximately +0.8 mm yr^{-1}, indicating a steady rise in atmospheric evaporative demand. In the Cukurova region—primarily within the Seyhan and Ceyhan river basins, with contributions from the Berdan/Tarsus sub-basin—this implies a gradual

yet persistent increase in baseline irrigation requirements, thereby intensifying pressure on already limited water resources. The direction and magnitude of this trend are consistent with warming-driven increases in evaporative demand and have immediate operational relevance. Elevated ETo during phenologically sensitive stages is expected to raise irrigation needs for citrus, cotton, and maize, potentially straining existing conveyance and on-farm delivery systems. In water-scarce settings, heightened evaporative demand may exacerbate competition among agricultural, municipal, and environmental uses, particularly during prolonged droughts. Addressing these pressures will require wider adoption of high-efficiency irrigation technologies, carefully optimised deficit-irrigation practices, mulching to reduce non-productive evaporation, and climate-resilient cultivars, alongside improved ETo-based scheduling and allocation.
Overall, while some intra-seasonal declines in ETo may provide temporary relief, the long-term trajectory points to a persistent increase in atmospheric evaporative demand. These results underscore the need for adaptive, data-driven water-management strategies that account for short-term variability as well as long-term climatic change.

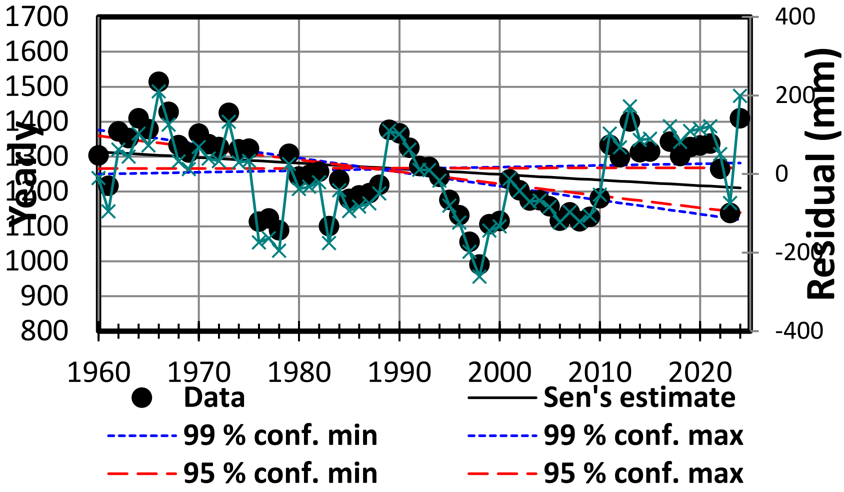


Fig. 6. Yearly trend of ETo (1960-2024) at Adana Meteorological Station. Meteorological Station. Sen's slope estimates are presented along with 95% and 99% confidence intervals. Asterisks (*) denote trends statistically significant at the 5% level ($p < 0.05$), while plus signs (+) indicate significance at the 10% level ($p < 0.10$). Residuals are also displayed.

4 Conclusions and Recommendations

This study evaluated long-term variability in reference evapotranspiration (ETo) at the Adana meteorological station in the Cukurova region (Türkiye) using a continuous daily record for 1960–2024. ETo was estimated with the FAO-56 Penman–Monteith formulation, and monotonic trends were tested at monthly, seasonal, and annual scales with the Mann–Kendall test and quantified by Sen's slope.

Statistically significant monthly increases were detected in April, July, October, and December, while January, June, August, September, and November exhibited significant decreases; other months showed no trend. Seasonally, winter, summer, and autumn displayed significant declining trends, whereas spring showed no significant change. Despite these seasonal decreases, the annual ETo series increased at +0.8 mm yr^{-1} (Sen's slope), indicating a persistent rise in atmospheric evaporative demand.

The pattern of mixed monthly trends is consistent with the principal controls on ETo in semi-arid Mediterranean climates: air temperature, humidity, wind speed, and radiation/cloudiness. Thus, ETo dynamics in the Cukurovba region reflect not only warming but also concurrent variability in atmospheric humidity, wind, and cloud cover. From an agricultural perspective, the upward annual trend implies greater irrigation requirements during phenologically sensitive stages (e.g., midsummer for maize and cotton), increasing pressure on limited water resources. These results support adaptive, ETo-informed water-management strategies—such as higher-efficiency irrigation systems, optimised scheduling, and the use of climate-resilient cultivars—while detailed design and evaluation lie beyond the scope of this study.

In conclusion, analysis of the 1960–2024 record from the Adana meteorological station reveals a persistent annual increase in reference evapotranspiration, i.e., ETo, of +0.8 mm yr^{-1} and pronounced midsummer (July) peaks despite mixed monthly trends. These results warrant adoption of station-based, daily/weekly ETo-driven irrigation rules with crop-specific thresholds, early-warning triggers for July peaks, and staged curtailment protocols in the Cukurova region. We further recommend wide-scale deployment of high-efficiency pressurized irrigation, optimized deficit irrigation, and evaporation-suppressing practices (e.g., mulching) to offset rising evaporative demand.

Acknowledgements. This study was financially supported by the Scientific and Technological Research Council of Türkiye (TÜBİTAK) under project number 223O514.

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